ALTERNATIVE METALS STUDY

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FINAL REPORT

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EXECUTIVE SUMMARY

Pursuant to Public Law 111-302 (the Coin Modernization, Oversight, and Continuity Act of 2010), the Secretary of the Treasury was given "authority to conduct research and development on all circulating coins." Furthermore, this law authorized the Secretary of the Treasury to "solicit input from or otherwise work in conjunction with entities within or outside of the Federal Government." To achieve an unbiased, independent assessment of potential and currently available metallic materials and processing methods for production of United States (US) circulating coins, the United States Mint, working on behalf of the Secretary of the Treasury, awarded a competitively bid contract (Number TM-HQ-11-C-0049 entitled "Alternative Materials Study"; referred to here as "the study") to Concurrent Technologies Corporation (CTC) headquartered in Johnstown, Pennsylvania. The objectives of this study were to:

- Reduce the costs to produce circulating coins
- Consider key stakeholders and, to the greatest extent possible, minimize conversion costs that would be necessary to accommodate significant changes to all circulating coins simultaneously
- Address critical performance attributes including physical, electromagnetic, mechanical and chemical properties.

To accomplish the goals of this Act and the requirements of subchapter II of chapter 51 of title 31, United States Code elements of this study or factors to be considered included the following:

- Research and development (R&D) of metallic materials appropriate for coinage
- Perform appropriate testing of appropriate coinage metallic materials within or outside the Department of the Treasury
- Fraud prevention
- Ease of use and ability to co-circulate new coinage materials[1]
- Analysis of production costs for each circulation coin and alternative material candidates, cost trends for such production
- Improved production efficiency
- Impacts on current and potential suppliers
- Environmental assessment
- Detailed recommendations for any appropriate changes to metallic content of circulating coins
- Recommendations for improved production efficiencies, changes in the methods of producing coins, that would further reduce the costs to produce circulating coins.

This report summarizes the findings of the study from which important conclusions and recommendations are presented that are related to each of these objectives.

To meet the schedule required by the study, CTC chose to leverage the research and development of current material suppliers of coinage materials to the United States Mint. These suppliers were selected as a result of their preexisting familiarity with US circulating coin

[1] Seamless – Differences and abilities to recognize or process incumbent coins and coins produced from alternative material candidates cannot be distinguished through normal coin processing.
Co-circulate – Differences between incumbent coins and coins produced from alternative material candidates can be accommodated, however, upgrades are required for coin-processing equipment.

specifications. In addition, these suppliers have proven ability to "develop and evaluate the use of alternative metallic materials" and the "potential impact of any revisions to the composition of the materials used in coin production," as required by Public Law 111-302 section 2(a) and section 2(b)(1), respectively. Each of these suppliers produces materials for other mints throughout the world and was thereby familiar with and/or had previously developed potential low-cost alternative materials for use in US circulating coins. In addition, other metallic material suppliers were consulted and asked to recommend materials that would meet the current specifications and demanding requirements of US circulating coins. A search was made of novel methods to produce stock materials (including sheet, blanks [i.e., cylindrical disks] or planchets [i.e., blanks that have been further processed and are ready for striking into a finished coin]). Finally, the Royal Canadian Mint and the Royal Mint (in the United Kingdom) were consulted relative to plated-steel coinage materials. In all cases, suppliers were asked to provide material samples that were subsequently tested according to standard ASTM International and/or United States Mint material tests that included wear, steam corrosion, color shift after steam corrosion, hardness, determination of critical metallurgical features, electromagnetic properties and coinability (i.e., the ability to be formed into a visually aesthetic coin).

There are two types of alternative material candidates presented for each denomination: 1) potentially seamless candidates having approximately the same EMS and weight as the incumbent coin and 2) non-seamless (co-circulate) alternative candidates having a different, albeit unique, EMS and/or a different weight from the incumbent coin. The seamless alternative material candidates provide for a modest cost savings, whereas the non-seamless alternative material candidates result in larger cost savings to the United States Mint. Use of non-seamless alternative material candidates may result in significant conversion costs to upgrade coin-processing equipment.

Supporting the selection of potential material candidates, detailed production cost analyses were completed. These analyses included the cost of materials (both raw material and vendor fabrication costs), production costs at the United States Mint, transportation costs to the Federal Reserve Bank and United States Mint indirect costs. The projected costs to manufacture production quantities of these coins were then compared to known production costs for incumbent US circulating coins to assess the economic viability of each potential alternative material. Using the metals prices defined on the London Metal Exchange, CTC identified iron (and steels), zinc and aluminum alloys as the leading alternative candidates to potentially reduce the cost of coinage by replacing copper and nickel to varying degrees.

Two sets of striking trials were conducted on separate sets of alternative candidate materials. These trials, which were conducted in an isolated room with controlled access in the United States Mint facility located in Philadelphia, consisted of progressive striking trials followed by a small test-production run of up to a few hundred nonsense test pieces.[2] The first striking trial included 15 material-denomination combinations; the second striking trial included nine down selected materials from the first striking trial that were found to have desirable coin characteristics or properties; eight additional material-denomination combinations were also evaluated in the second striking trial. Therefore, a total of 25 unique material-denomination combinations were tested among the two striking trials; see table below. In addition, four

[2] Nonsense pieces included an image of Martha Washington on the obverse, a scene on the reverse and letters that were scrambled. These features were designed to replicate the detailed images common to circulating coins.

materials were corrosion tested for alternative materials for the dollar coin. The nonsense test pieces produced from these striking trials represented potential alternative material candidates for the one-cent, 5-cent, dime, quarter dollar and half dollar coins. Consistent with incumbent US coinage, the project team assumed that the dime, quarter dollar and half dollar coins would continue to be constructed of like materials in the same relative weight proportions as their assigned monetary value. Of these three denominations, only quarter dollar nonsense pieces were struck.

Candidates	Alternative Materials	Denomination
1	Aluminized Steel (Ryerson)	One Cent
2	Aluminized Steel (Atlas)	One Cent
3	5052-H32 Aluminum	One Cent
4	Copper-Plated Steel (JZP)	One Cent
5	Copper Plated Steel (RM)	One Cent
6	430 Stainless Steel	One Cent
7	302 Stainless Steel	One Cent
8	Dura-White-Plated Zinc 3µ Sn	5-Cent
9	Multi-Ply-Plated Steel (Lot #137)	5-Cent
10	Multi-Ply-Plated Steel (Lot #170)	5-Cent
11	302 Stainless Steel	5-Cent
12	430 Stainless Steel	5-Cent
13	G6 Mod	5-Cent
14	669z	5-Cent
15	Plated 31157	5-Cent
16	Unplated 31157	5-Cent
17	Nickel-Plated Steel (RM)	5-Cent
18	669z-Clad C110	Quarter Dollar
19	Multi-Ply-Plated Steel (Lot #140)	Quarter Dollar
20	Dura-White-Plated Zinc 5µ Sn	Quarter Dollar
21	Dura-White-Plated Zinc 8µ Sn	Quarter Dollar
22	Dura-White-Plated Zinc 10µ Sn	Quarter Dollar
23	Nickel-Plated Steel (RM)	Quarter Dollar
24	302 Stainless Steel	Quarter Dollar
25	302 Stainless Steel (Radical Anneal)	Quarter Dollar
	88Cu-12Sn-Plated Zinc	Dollar
	C69250-Clad C110	Dollar
	K474-Clad C110	Dollar
	Y42	Dollar

Stakeholders[3] dependent on coins to conduct commerce were considered. Conversion costs,[4] ease of use and ability of new coins to co-circulate with incumbent coins were considered.

[3] Stakeholders included "vending machine and other coin acceptor equipment manufacturers, vending machine owners and operators, transit officials, municipal parking officials, depository institution, coin and currency

Factors evaluated in this analysis included changes to coin dimensions (diameter and/or thickness), weight and electromagnetic properties. Nonsense test pieces from the two striking trials were tested by three coin-acceptance equipment manufacturers (two manufacturers, MEI and Coinco, are American owned) to determine which of the material/denomination combinations could be introduced into circulation without significant modifications to existing coin-processing equipment. Coin fraud prevention was evaluated during both stakeholder conversations and testing of nonsense test pieces. Each denomination and alternative material was evaluated relative to actions that would "facilitate or allow the use of a coin with a lesser value produced, minted, or issued by another country, or the use of any token or other easily or regularly produced metal device of minimal value, in the place of a circulating coin produced by the Secretary" [section 3(e) of Public Law 111-302].

An environmental assessment was made for each of the candidate materials. This assessment included the effects of air and water pollution, worker health hazards, toxicological effects and recycling. Local permitting issues at the United States Mint production sites were also considered in these environmental assessments. All alternative material candidates were found to have lower environmental impacts relative to incumbent coinage materials.

Based upon the information gathered from each of the above alternative material selection factors, CTC offers the following detailed recommendations for consideration and implementation by the United States Mint. The most salient recommendations are offered here; additional recommendations, along with detailed descriptions of the study's findings and conclusions can be found in the body of the report.

- Maintain existing coin dimensions (i.e., thickness and diameter) for all future coins regardless of their materials of construction. The conversion costs to coin-processing equipment are too large to justify changes to coin dimensions.
- Maintain the incumbent materials of construction for the one-cent coin. When metal and production costs are accounted for, copper-plated steel one-cent coins (which would have the look and feel of incumbent one-cent coins) offer no cost savings from incumbent copper-plated zinc one-cent coins. Other potentially low-cost metal alloys lacked the ability to meet one or more provisions of the Coin Modernization, Oversight, and Continuity Act of 2010: aluminum alloys jam or destroy some types of coin-acceptance or coin-handling equipment, which would require costly upgrades to enable this equipment to process aluminum-based coins; the surface-modifying technologies (to reduce tarnish and/or corrosion of single-alloy coins) evaluated in this study lacked application maturity; other alternatives did not offer sufficient corrosion and/or wear resistance. Copper-plated zinc remains the most viable material option for the one-cent coin.
- Further develop the copper-based alloys, unplated 31157, G6 and 669z, as future 5-cent coin materials of construction. Although, it was not shown that these alloys would bring the costs to parity, these alloys would produce material cost savings and decrease the furnace annealing temperature resulting in decreased energy costs and prolonging furnace

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handlers, armored-car operators, car wash operators and manufacturers of commercial coin processing equipment," as defined in Public Law 111-302 section 2(b)(3).

[4] Conversion costs are those required for machine alterations and/or changes to coin processing methods to enable continued use of existing infrastructure.

life. The G6 and 669z have a yellow cast color while the unplated 31157 has a golden hue color. From the Outreach surveys, it is CTC's opinion that the general public would readily accept the 5-cent coin color change. Reductions in the number of individuals suffering from nickel allergies would also provide a cost benefit. However, each of these alloys is less dense than the incumbent 5-cent coin material, which would result in reduced coin weight if the 5-cent coin remained of the same size as the incumbent 5-cent coin. Weight-based coin-acceptance equipment, which comprises far less than 5 percent (%) of the total number of fielded units in the United States, would require one-time conversion costs to the coin-acceptance equipment of approximately $11.3 million (M) for an unplated 31157. Other candidate alloys G6 mod and 669z alloys as tested in the current study, however, would require $56.4M to convert existing coin-processing equipment resident in the US. These materials offer annual cost savings to the United States Mint of up to $16.7M, using March 2012 metal pricing and 2011 production rates of 5-cent coins from the United States Mint. Also note that bulk coin handlers would be impacted by change to the weight of 5-cent coins since additional coin handling would be required to separate incumbent coins from those made of alternative materials of construction. The annual costs for handling 5-cent coins of a different weight than the incumbent 5-cent coins were estimated to be $3.75M.

- Consider copper-based alloy, 669z clad to C110 copper alloy for use in dime, quarter dollar and half dollar coins. Based upon validation testing completed in this study, quarter dollar nonsense test pieces of this construction showed evidence of being a seamless alternative to the incumbent quarter dollar coin. Potential reduced expenses to the United States Mint for dime and quarter dollar coins of 669z-clad C110 were estimated to be approximately $2.2M annually, using March 2012 metal pricing and 2011 production rates of quarter dollar coins. In addition, the annual potential reduced expenses to the United States Mint for dime coins was estimated to be $3.9M; however, these savings need to be validated in future efforts since 669z clad C110 copper dime nonsense pieces were not tested in this study. Also note that bulk coin handlers would be impacted by change to the weight of quarter-dollar coins since additional coin handling would be required to separate incumbent coins from those made of alternative materials of construction. The annual costs for handling quarter-dollar coins of a different weight than the incumbent quarter-dollar coins was estimated to be $9.20M; similar costs for the dime coins are $6.92M and for the half dollar the value was estimated to be $0.04M. It should be noted that 669z-clad C110 has a slight yellow cast and may cause confusion with the golden dollar coin, although it is CTC's opinion that the dollar coin is not widely used in transactions.
- Maintain current dollar coin alloy composition. None of the dollar coin alternative material candidates improved upon the incumbent materials' steam corrosion characteristics and did not show any improvement in cost. As it was deemed that revising the incumbent dollar coin material would have minimal impact to overall United States Mint costs, the dollar coin received a lower priority than the other denominations. Alternative material candidates for the dollar coin were tested for steam corrosion only.
- Provide future generations of nonsense test pieces to appropriate organizations for testing and evaluation as potential replacement alloys are further developed beyond that of the current study. Comments and additional recommendations related to potential changes in properties and/or performance from these evaluators should be considered by the United

States Mint to increase the likelihood of a smooth introduction and transition of alternative coins into circulation. Each of these nonsense pieces need to be well controlled since such nonsense pieces would be highly prized by numismatists.

- Provide manufacturers of automated coin-processing equipment samples of the final coins (made from the new materials of construction) at least 18 months in advance of the expected release date for introducing these coins into circulation, enabling the coin-process industry time to respond to changes in the construction of coins. These samples are expected to be used to design the necessary changes to the manufacturer's equipment and to get their clients prepared for the release of these coins into circulation.
- All denominations of alternative construction should be introduced into circulation on or approximately on the same date. Doing so will minimize the conversion costs to stakeholders.
- Continue long-range research on surface engineering of zinc or low-carbon steel for the one-cent coin may be a useful technology to obviate the copper plating and its associated costs. For example, inexpensive paints or colored particles on bare zinc covered with a wear resistant coating could considerably reduce costs to produce one-cent coins.
- Continue research and development (R&D) efforts on stainless steels as a potential alternative material for lower-denomination coins. Also development of stainless steel alloys clad to C110 alloy for higher denomination coinage to be able to mimic the current electromagnetic signature (EMS) of the incumbent dime, quarter dollar and half dollar coins to avoid the need for upgrading coin-processing equipment, increase cost effectiveness and have the same appearance of the incumbent coins.
- Plated coins for medium- and high-value coins (approximately those greater than 25 cents), is not recommended. Coins whose construction is based upon plating of low-cost alloys were found to potentially reduce United States Mint's material costs approximately 50%. However, for medium- and high-value coins (approximately those greater than 25 cents), plated coins pose security and fraud issues because plating is a common and inexpensive process used by counterfeiters. Plated-steel coins require substantially broader acceptance limits in automated coin-processing equipment, with significant impacts to coin sorting and counting, and would lead to less secure coin identification standards.
- Establish methods for the level-loading of production rates. Complicating the management of coin production, orders from the Cash Product Office of the Federal Reserve are estimated one month in advance, but the actual quantity of coins ordered can still vary by as much as 30%. The actual number of coins required is not defined by the Federal Reserve Banks until the finalization of the order as production actually begins. These shifting, short-term changes in coin demand impact the required installed machine capacity in addition to having an effect on staffing and the supply chain. Operational inefficiencies can be traced to the current and frequently changing production demands placed on the weekly production rate of circulating coins. These inefficiencies include overall circulating coin production capacity, which is approximately twice that required if production rates were level-loaded (i.e., consistent) throughout the year.
- Maintain current processing for producing circulating coins. No best practices and proven methods for forming metal were identified that could economically replace the highly evolved conventional processes used to produce high volumes of circulating coins. Current production techniques used by the United States Mint are quite efficient. The

process for producing metal coins is substantially the same as it has been for years, but has undergone continuous improvement.

- Maintain supplier base for materials used to produce circulating coins. Current suppliers of coinage materials to the United States Mint have proven ability to develop alternative metallic materials and are able to assist in defining chemistry and/or processing changes to current alloys to achieve desired characteristics in coins. Alternative material candidates offered by these material suppliers were useful to the current study. Several were recommended for further assessment and validation as viable alternative materials. When considering the materials recommended, the current fabrication process and quantities sourced between suppliers may change for the copper-based materials. The alternative candidate materials recommended for each denomination are produced by the current suppliers and are well within the capabilities of these suppliers to manufacture. Use of steel, stainless steel and/or aluminum in coinage would likely necessitate the introduction of one or more new material suppliers to the United States Mint. If these alternative materials are chosen for future coins, then the supplier base may have to be expanded.
- Continue to monitor and develop advanced security features into circulated coins; including taggants.
- Continue the Environmental Assessment through completion of the FONSI or Federal Register Notice for public comment. There are no significant negative environmental impacts anticipated from the actions proposed in this study.

The current study identified several potential alternative materials of construction for US circulating coins. More development, testing and evaluation must be completed prior to finalizing a detailed specification for future coinage materials that would include “appropriate changes to the metallic content of circulating coins in such a form that the recommendations could be enacted into law as appropriate” [section 3(b) of Public Law 111-302].

Validation testing must be completed for proposed changes to the materials of construction for circulating coins to quantify 1) the variability of material properties from multiple lots of proposed coin materials and 2) the variability in finished coins through completion of simulated coin production runs each of at least 1,000,000 test pieces. Coins of any given denomination should be made at different times and under a variety of common production conditions. Samples of coins from each of these test conditions should then be tested to establish more robust standard deviations in the characteristics to be expected from volume production of these coins. These tests must also assess the impact of temperature and humidity; coin scratches, gouges, tarnish, corrosion, wear and slight bends; and other stakeholder-defined test conditions.

Finally, an assessment was made of each of the steps required to produce coins at the United States Mint. Production data were obtained; interviews with production personnel from both the United State Mint at Philadelphia and the United States Mint at Denver were completed; and tours of the production facilities at the United Stated Mint at Philadelphia production site were taken. The objective of these efforts was to define improved production efficiency, alternative operating strategies and/or equipment to lower the production costs of all circulating coins. Current production techniques used by the United States Mint were found to be quite efficient. The production steps for producing metal coins is substantially the same as it has been for years, but the processes at the United States Mint have undergone continuous improvement.

This executive summary highlights the significant findings of this study. For in-depth details and complete observations and conclusions; reference the recommendations and conclusions for each chapter and also the recommendations and conclusions sections of this report.

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1.0 INTRODUCTION, OBJECTIVES, ALLOY DESIGN AND SELECTION

1.1 INTRODUCTION AND BACKGROUND

The United States Mint has a long tradition of manufacturing high quality, durable and visually attractive circulating coins that are effective in supporting United States (US) commerce. The current circulating coin denominations are: one-cent, 5-cent, dime, quarter dollar, half dollar and dollar. Until 1964, the four higher denominations contained silver; the one-cent coin was made of a copper-zinc (Cu-5%Zn) alloy[5] through 1982. The 5-cent coin has been monolithic Cu-25%Ni cupronickel (i.e., copper-nickel) alloy (C713) since 1866 [1]. As the price of silver increased and projections suggested that the supply of silver might be inadequate for coinage, in the early 1960s the United States Mint funded the development of new alloys for the higher denominations. Beginning in 1964, the material developed to replace silver in coinage was cupronickel surface alloy C713 that was roll clad to a commercially pure copper core (alloy C110). These two alloys and their relative thicknesses in the cupronickel clad formulation (Cu-25%Ni/Cu/Cu-25%Ni) were developed to have an electromagnetic signature[6] (EMS) close to that of the silver-copper (Ag-10%Cu) alloy used in previous coins including the quarter dollar coin [2, 3]. The clad formulation was necessary to provide an EMS match to enable a seamless transition for acceptance by the vending and coin-acceptance industries and to reduce the probability of fraud by using slugs. Leading up to the alloy change made in the one-cent coin in 1982, copper prices were high enough that the intrinsic value[7] of copper in a one-cent coin exceeded its face value of 1.0 cents. In response, the United States Mint developed and began to produce one-cent coins with a zinc alloy core (Zn alloy A190; composition Zn-0.8%Cu) that was electroplated with a nominal 8 microns of copper. As of May 2012, the intrinsic value of the copper-plated zinc one-cent coin remains below its face value.[8] To keep individuals from melting large stocks of coins (including, but not limited to, pre-1983 one-cent coins) and selling the scrap, typically at a profit, the United States Mint implemented regulations to limit the melting of one-cent and 5-cent coins [4].

As of March 2012, the cost to produce the one-cent and 5-cent coins is greater than face value in part because of the high price of nickel and copper superimposed on the fabrication costs and United States Mint indirect costs. Excluding indirect cost allocation (overhead, sales, general and administrative [G&A], and distribution to the Federal Reserve Banks [FRBs]), the fiscal year (FY) 2011 one-cent coin costs 0.0134 dollars per coin ($/coin) and the 5-cent coin costs

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[5] Here and throughout the report chemical element percentages are in weight percent; balance of composition is the first element listed.

[6] Electromagnetic signature is understood in the industry to mean the electrical signal strength of a nearby electromagnetic sensor as a coin passes in close proximity to the sensor. The magnetic field in the vicinity of the emitting sensor, and therefore the electrical current in the EMS receiving sensor, changes as the coin passes by. The change in electrical signal strength is influenced by the materials of construction along with the thickness and distribution of materials within the coin. The signal strength and/or its decay rate are then used by software to validate the coin and determine its denomination. One key determiner of EMS is electrical conductivity, typically measured by the percent of the conductivity of the International Annealed Copper Standard (%IACS).

[7] The intrinsic value of a coin is its worth as metal.

[8] Other, sometimes larger, elements of cost beyond intrinsic value must also be included to determine the total unit cost of producing coins.

$0.0796/coin. The United States Mint sells coins to the FRBs at face value, so the United States Mint lost $0.0034 for each one-cent coin sold and $0.0296 for each 5-cent coin sold—before indirect costs were allocated. These losses resulted in part from the $0.0069 of metal costs[9] for each copper-plated zinc one-cent coin and the $0.0674 of metal costs for each Cu-25%Ni 5-cent coin. Because the intrinsic value of five-cent coins is above their face value, the possibility of illegal melting of the coins (for redemption as scrap metal) exists.

The FY2011 United States Mint Annual Report [5] was recently issued and the FY2011 burdened (i.e., total unit) costs, summarized in Table 1-1, are $0.0241 for the one-cent coin and $0.1118 for the 5-cent coin. This underscores the need to reduce the costs of these two denominations. The unit cost for any given denomination for any given year is dependent upon metal costs, the allocation of United States Mint overheard and other costs, and the volume of coins produced in that year. The impact of some of the unit cost elements is independent of volume; these cost elements include metal price and distribution of finished coins. On the other hand, the per unit costs for other cost elements are highly dependent upon production volumes; for example general and administrative costs are nearly independent of production volumes; distributing these costs to all coins produced necessarily impacts the per unit costs as production levels vary.

Table 1-1. FY2011 Unit Cost of Producing and Distributing Coins by Denomination [6]

Cost Element	**One-Cent**	**5-Cent**	**Dime**	**Quarter Dollar**	**Half Dollar***	**$1**
Cost of Goods Sold	$0.0197	$0.0938	$0.0474	$0.0923	$--	$0.1531
Sales, General and Administrative	$0.0041	$0.0176	$0.0087	$0.0176	$--	$0.0251
Distribution to FRBs	$0.0003	$0.0004	$0.0004	$0.0015	$--	$0.0021
Total Unit Cost	$0.0241	$0.1118	$0.0565	$0.1114	$--	$0.1803

* Half-dollar coins were not minted for circulation in FY2011.

Due to the increasing cost of metals used in present-day US circulating coins, coupled with the other costs of producing the country's coinage, the US Congress passed Public Law 111-302 entitled "Coin Modernization, Oversight, and Continuity Act of 2010," a copy of which can be found in Appendix 1-A. The goal of this law is "to provide research and development authority for alternative metallic coinage materials." To achieve an unbiased, independent assessment of potential and currently available metallic materials and processing methods for production of US circulating coins, the United States Mint awarded a competitively bid contract (Number TM-HQ-11-C-0049 entitled "Alternative Metals Study"; referred to here as "the study") to Concurrent Technologies Corporation (CTC) headquartered in Johnstown, Pennsylvania. The objectives of this study, in direct fulfillment of Public Law 111-302, were to:

- Reduce the costs to produce circulating coins
- Consider key stakeholders and, to the greatest extent possible, minimize conversion costs that would be necessary to accommodate significant changes to all circulating coins simultaneously

[9] Coin metal costs represent average values for 2011; actual values varied daily with world metal market prices.

- Address critical performance attributes including physical, electromagnetic, mechanical and chemical properties.

This report summarizes the findings of the study from which important conclusions and recommendations are presented later in this report that are related to each of these objectives.

CTC explored metals and coinage concepts to lower the cost of finished coins, while ensuring the most-seamless[10] materials of construction practicable. There are two types of alternative material candidates presented for each denomination: 1) potentially seamless candidates having approximately the same EMS and weight as the incumbent coin and 2) non-seamless (co-circulate) alternative candidates having a different, albeit unique, EMS and/or a different weight from the incumbent coin. The seamless alternative material candidates provide for a modest cost savings, whereas the non-seamless alternative material candidates result in larger cost savings to the United States Mint. Use of non-seamless alternative material candidates may result in significant conversion costs to upgrade coin-processing equipment. In order for a material change to be seamless, many characteristics and properties of the replacement material need to closely mimic those of the incumbent materials. For example, modern coin-acceptor and coin-handling technology, including that used in vending machines, has become increasingly sophisticated and few cost-effective alternative metallic materials exist that would be validated (i.e., accepted) without alterations to the equipment and/or software in which this technology is used. Low-cost metallic materials having properties that differ from those used to validate incumbent coins would require that the associated validation equipment be upgraded at cost to the owner.

To meet the schedule required by the study, CTC choose to leverage the research and development (R&D) of current suppliers of coinage materials to the United States Mint. Materials and technology from other organizations, as discussed below, were also evaluated. CTC endeavored to work closely with proven alloy producers and to select metals and fabrication concepts for which the manufacturing readiness level[11] (MRL) was greater than approximately 5.

1.2 INCUMBENT US COINS

The United States Mint makes high quality, deep relief coins for circulation, bullion for investment and numismatic[12] coins and items for collectors. The circulating coins at the date of this writing are described in a compilation of composition and dimensions in Table 1-2.[13] Among US circulating coins, only the one-cent coin is plated and only the 5-cent coin is monolithic. All other circulating coins are of roll clad construction. It has been generally

[10] Seamless refers to public acceptance and ease of use with minimal disruptions to coin-acceptance and coin-processing equipment.

[11] Manufacturing readiness levels are used to assess the maturity of technology relative to its ability to be introduced into the manufacture of products. The system is defined around a 10-point scale, with a value of 1 being fundamental R&D and 10 indicating that the processes are in place for full-rate production. The system is used by several departments within the US Government and is being adapted by commercial industry. Level 5 defines the stage of manufacturing maturity where required manufacturing technology development has been initiated [7].

[12] Numismatic refers to high quality coins minted for collectors.

[13] Throughout this document quantities are given in the units most commonly used for measurement in the US. When English units are the common unit system, a metric equivalent is noted.

accepted by United States Mint engineers [8] and in the coinage literature [9, 10] that a clad coin has greater security than plated or monolithic coins; the clad layer is more consistent in EMS than a plated layer and the allowable acceptance values (for automated coin validation) can therefore be more tightly defined for a clad coin. In addition, it is difficult for counterfeiters to perform roll-cladding because a large capital expense is required for a roll-cladding facility whereas an inexpensive plating system can be readily assembled. Furthermore, it is relatively easy to make the clad surface layers thick for a desired EMS.[14] Because a given amount of surface wear represents a smaller percentage of a clad layer than that of a plated layer, normal coin wear does not impact the EMS of clad coins to the degree that it does plated coins. More consistent EMS responses and greater coin security are therefore found in clad coins during circulation. Clad coins are therefore used in high-denomination coinage.[15] Plating has been used for the one-cent coin because its face value is considered too low to provide sufficient incentive to counterfeit.

[14] In contrast, making thick electroplated areas results in significant thickness variations in different regions of the coin.

[15] The point at which a coin can be designated as high denomination (as opposed to low or medium denomination) is subject to individual interpretation; however, the threshold between low-denomination and high-denomination coins is approximately at the US quarter dollar coin.

Table 1-2. Compositions and Dimensions of US Circulating Coins

Denomination	One-Cent	5-Cent	Dime	Quarter Dollar	Half Dollar	Presidential $1	Native American $1
Bulk Composition^ (weight percent [%])	Copper-Plated Zinc (97.5% Zn-2.5% Cu)	Monolithic Cupronickel (75% Cu-25% Ni)	Cupronickel-Clad Copper (91.67% Cu-8.33% Ni)	Cupronickel-Clad Copper (91.67% Cu-8.33% Ni)	Cupronickel-Clad Copper (91.67% Cu-8.33% Ni)	Clad Manganese-Brass (88.5% Cu-6% Zn-3.5% Mn-2% Ni)	Clad Manganese-Brass (88.5% Cu-6% Zn-3.5% Mn-2% Ni)
Core	A190 Zn	N/A*	C110 Cu	C110 Cu	C110 Cu	C110 Cu	C110 Cu
Surface*	8 micron plated Cu	N/A	0.175 mm 75Cu-25Ni	0.226 mm 75Cu-25Ni	0.289 mm 75Cu-25Ni	0.413 mm Cu-12Zn-7Mn-4Ni	0.413 mm Cu-12Zn-7Mn-4Ni
Weight* (g)	2.500	5.000	2.268	5.670	11.340	8.1	8.1
Diameter (mm)	19.05	21.21	17.91	24.26	30.61	26.49	26.49
Thickness (mm)	1.55	1.95	1.35	1.75	2.15	2.00	2.00
Edge Design	Plain	Plain	Reeds	Reeds	Reeds	Edge Lettering	Edge Lettering
Number of Reeds*	N/A	N/A	118	119	150	N/A	N/A
Total FY2011 Cost ($/coin)	0.0241	0.1118	0.0565	0.1114	N/A	0.1803	N/A

^ Cu = copper; Mn = manganese; Ni = nickel; Zn = zinc

* g = gram; mm = millimeter; N/A = not applicable

When designing or selecting a new coinage alloy, numerous factors must be considered including:

- Ability of the US industrial base to supply needed materials
- Material availability; now and in the future
- Process consistency at mints and metal producers
- Process capabilities and current capitalization at existing United States Mint facilities
- Price of needed materials
- Price trends of needed materials
- Cost of fabrication
- Coin striking die life
- Available fabrication methods
- EMS
- Wear resistance
- Corrosion resistance
- Color and color change during circulation
- Coinability (i.e., low flow stress,[16] adequate ductility)
- Work hardening[17]
- Density
- Environmental impact
- Toxicity
- Worker health and safety
- Recyclability
- Plating versus cladding versus monolithic
- Security/counterfeiting resistance
- Coin-processing equipment hardware and software
- Recognition and acceptance from the blind and visually-impaired
- Public acceptance and perception
- Co-circulation of incumbent and new coins.

Consideration of all of these issues makes the design and selection of a coinage alloy and the associated production methods a complex, challenging task.

From the Periodic Table of Elements one can observe that most elements are metallic. However, all metals except gold and copper are silver-white in appearance. Therefore to make affordable gold or red-yellow colored coins, one must use copper judiciously, or perform surface engineering to use colored oxides or other non-metallic compounds to modify the surface appearance. This can be illustrated by the red-yellow hue associated with titanium oxide, which can have a variety of shades depending upon impurities and thickness, despite the fact that elemental titanium is inherently silver-white in color.

[16] Flow stress is a measure of the force per unit area required to permanently deform a metal during forming operations.
[17] Work hardening is a material response whereby the strength of metallic materials increases due to plastic (i.e., permanent) deformation.

The public has grown accustomed to coins having sizes and weights similar to incumbent coins. Copper with a density of 8.96 grams per cubic centimeter (g/cm^3) and cupronickel[18] with a density of 8.945 g/cm^3 are relatively dense metals and the public might think a higher denomination coin of the same size made from a significantly lighter metal would feel cheap (see comments in the section entitled "Public" in the Outreach Chapter). The public accepted the lower density of zinc in the copper-plated, zinc-based alloy one-cent coin introduced in 1983, even though it represented a reduction in weight of 20% over the previous materials of construction.

The densities of candidate metallic elements are listed in Table 1-3 where elements that are too reactive, too rare or not affordable for circulating coinage are excluded. Traditional bullion coinage metals, silver and gold, were added for comparison. Several expensive elements are included because they might be considered for surfacing or alloying. A few impractical elements such as uranium and tungsten are included to illustrate the limited options for high-density elements.

[18] Cupronickel is an alloy consisting of 75% copper and 25% nickel.

Table 1-3. Candidate Metallic Elements and Alloys for Coinage[19]

Element(s)	Density (g/cm^3)	Approximate Price ($/pound [lb])	Advantages	Disadvantages
Magnesium (Mg)	1.74	1.56	Lightweight, high number coins/lb	Lightweight, reduced press speed corrosion issue
Beryllium (Be)	1.85	420		Carcinogenic oxide to 3% population; expensive
Aluminum (Al)	2.70	1.04	Lightweight, high number coins/lb	Lightweight, reduced press speed corrosion issue
Titanium (Ti)	4.54	12.00	Durable; colored oxide or nitride	Expensive
Vanadium (V)	6.11	200		Expensive
Zirconium (Zr)	6.51	10.00	Recrystallization inhibitor in Al	Expensive
Zinc (Zn)	7.13	0.96	Affordable	Needs surface protection
Chromium (Cr)^	7.19	~1.20*	Affordable plating	Carcinogenic Cr^{+6}; Cr^{+3} is not carcinogenic
Tin (Sn)	7.31	10.83	Alloying for Cu; affordable plating if thin	Expensive if monolithic; must be alloyed to avoid brittle phase below 13.2 degrees Celsius (°C)
Manganese (Mn)	7.44	1.54	Alloying makes Cu whiter; present in some stainless steels	Corrosion issues
Iron (Fe)	7.87	0.30	Very affordable	EMS and die fatigue issues
0.006% Carbon (C) steel	7.87	0.56	Very low C reduces die fatigue	Double the price of 1005 steel
Stainless steels	~7.7–8.1	1.06–1.67	Affordable; durable	EMS and die fatigue issues
Niobium (Nb)	8.57	68.00		Expensive; used in commemorative coins
Cobalt (Co)	8.90	14.50		Expensive; mostly foreign sources
Nickel (Ni)	8.90	9.03	Good for surfacing	Expensive; volatile price; die wear issues
Cu-25%Ni	8.945	5.16		Too expensive given Ni price and volatility
Copper (Cu)	8.96	3.87	High conductivity	Becoming too expensive
Bismuth (Bi)	9.75	10.70	High density	Expensive
Molybdenum (Mo)	10.22	22.00	High density	Expensive
Silver (Ag)	10.50	~470		Expensive; for bullion and commemorative coins
Lead (Pb)	11.35	0.90	High density	Toxicity issues; not practical
Uranium (U)	18.95	N/A	High density	Radiation & toxicity issues; controlled
Gold (Au)	19.3	~24,000		Expensive; for bullion and commemorative coins
Tungsten (W)	19.3	30.00	High density, ferrotungsten lowers cost	Expensive

*When added as ferrochrome; ^Cr^{+6} = hexavalent chromium; Cr^{+3} = trivalent chromium.

[19] December 2011 prices. Coiled sheet prices used when available. Some prices are for ingot from the London Metal Exchange.

1.3 DISCUSSION OF CANDIDATE ALLOY SYSTEMS

Coins made of low-density metals such as magnesium and aluminum alloys may be perceived by the public to be too light to properly represent the face value of these coins. However, the United States Mint could get about 4 times the number of coins/lb for magnesium and about 2.7 times the number of coins/lb for aluminum compared with the copper-plated, zinc-alloy one-cent coin. In addition, lighter weight coins would be easier to carry and be less expensive to transport in large quantities.

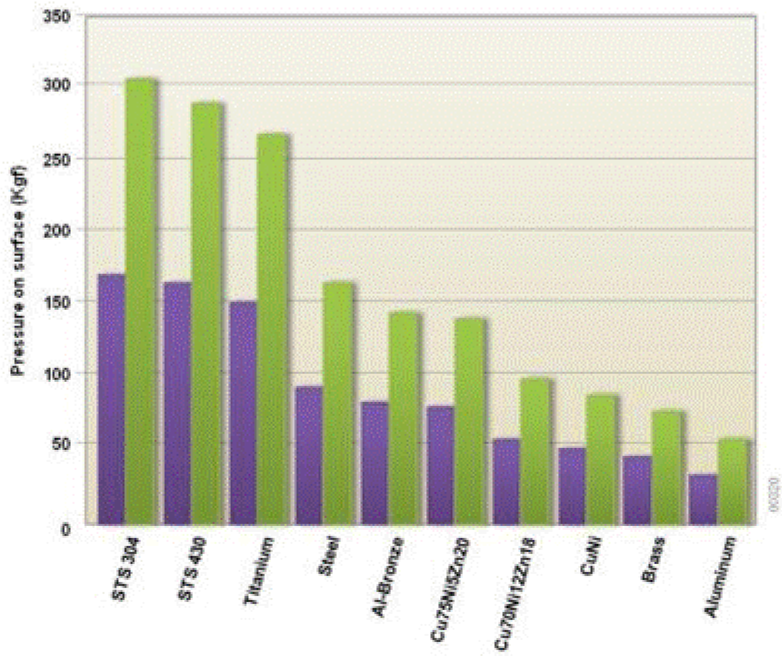
Magnesium produces a large amount of coins per pound. However, it is recognized that magnesium corrodes too rapidly to be used as a coinage material.

Aluminum has many advantages for coinage including having excellent corrosion resistance, relatively low flow stress and an electrical conductivity that among metals is only exceeded by silver, copper and gold. The electrical conductivity of 99.99% pure aluminum is 64.94% IACS[20] [11]. Thus, aluminum provides flexibility in designing a coin with high conductivity. As with nearly all metals, alloying additions decrease electrical conductivity from that of the pure metal.

A United States Mint study recommended an aluminum alloy for the one-cent coin in the 1970s, but vigorous opposition was heard from the vending and coin-processing industries. As a result, Coinco®, SCAN COIN, MEI® and other leading coin-processing equipment manufacturers were contacted in this study to learn of issues associated with the use of aluminum (and other materials) in coins. Representatives from these organizations unanimously recommended avoiding the use of aluminum as a material of construction in circulating coins. The low mass of aluminum coins causes jamming in coin-acceptance mechanisms, which often triggers costly service calls. Furthermore, these vendors point out that the electrical and magnetic properties of aluminum alloys are significantly more sensitive to temperature than cupronickel; aluminum is also more prone to property variations due to acceptable variations in alloy chemistry and production processes.

Titanium has several potentially positive attributes for monolithic coinage including: exceptional corrosion resistance, good wear resistance, two times the number of coins/lb relative to Cu-25%Ni and an oxide that can be tailored for unusual color. However, titanium and its alloys would require high coining forces and would cause significant die wear and fatigue. The high coining pressure of titanium was shown by Kim [12], see Figure 1-1. As well, titanium prices, as of December 2011, are relatively high and volatile in today's market place (> $26/kg [$12/lb]) so titanium is not a preferred candidate for circulating coinage at this time.

[20] The %IACS is a measure of a material's electrical conductivity. The value of commercially pure copper at 20 °C is assigned the value of 100%. All other materials are assigned a value that is proportional to that of commercially pure copper at 20 °C. Extremely high purity copper can exceed 100% IACS.



Note: Which colored bar is measured or predicted is unclear from the paper. However, the relative trend in striking load of different materials is clear.

STS = stainless steel; kgf = kilogram force

Figure 1-1. Predicted and measured coining pressure (Kim [12]).

Zinc has demonstrated its utility, serving as the primary component of the US one-cent coin since 1983. Zinc is relatively inexpensive, readily plated by copper, formable and has a density that is sufficiently similar to the traditional copper one-cent coin. Even with these attributes, the United States Mint is not able to make a copper-plated one-cent coin for face value or less. Nevertheless, zinc is a strong candidate for use in higher denomination coins. Zinc alloys have a relatively high electrical conductivity of about 28% IACS thereby providing the potential to contribute to coinage concepts with tailored EMS. This electrical conductivity is higher than iron and steels where conductivity is 15.6% IACS for 99.9% pure iron.

A bare zinc alloy was considered for the one-cent coin if an attractive oxide film could be formed that would maintain its appearance in service. CTC was not able to develop a visually attractive oxide (or other) film during the limited experimental trials completed under the present study. One-cent and experimental 5-cent size A190 planchets[21] were supplied by Jarden Zinc Products (JZP), the present provider of one-cent planchets to the United States Mint. The planchets were subjected to atmospheric exposure in a semi-rural area of Maryland during a particularly rainy period. They were placed in plastic containers to avoid any galvanic effects. The relatively shiny silver-white planchets (top two in Figure 1-2) quickly became corroded from the rainwater as can be seen after a two-day atmospheric exposure (bottom two planchets in Figure 1-2). Although their appearance was a bit worse after 30 days of exposure (Figure 1-3), the corrosion products largely blocked further corrosion and the zinc did not deteriorate

[21] A planchet is the precursor of a coin. A planchet is a blank that has been "upset", i.e., rimmed and otherwise prepared for striking.

significantly, as is generally known in the zinc industry. Zinc should be plated or otherwise protected if used in coinage. Considering its low cost, zinc and its alloys are clearly affordable candidates for coinage. Continued research on surface engineering of zinc to include attractive oxide films is recommended for the one-cent coin.

Note: A 5-cent planchet (upper left) and one-cent planchet (upper right) are shown above before exposure. The bottom two 5-cent planchets show extensive discoloration after two-day exposure to rainwater.

Figure 1-2. Two-day atmospheric exposure of bare A190 planchets to rainwater.

Figure 1-3. A190 planchets after 30-day atmospheric exposure during a rainy period.

Tin is an appealing element in that it has an attractive silver-white color and is relatively corrosion resistant. Unfortunately, the price of tin as of December 2011 was higher than both copper and nickel; therefore, it is not cost-effective as a main coinage alloy. However, tin is an important alloying element for copper-based alloys and in fact is the major alloying element in bronze alloys. Tin also has potential as a surface plating for coinage as will be discussed below. Because tin is the major alloying element in bronze and a useful element in surface plating or alloy cladding, tin has potential for coinage alloy design.

Manganese is well known as an alloying addition to steels. It is an affordable, albeit weak, austenite[22] stabilizer in stainless steels. Less well known is that manganese, at relatively high alloying levels in copper-based alloys, changes the color of these alloys in the silver-white direction. Kim [12] developed a Cu-20%Mn-20%Zn-0.1%Sb[23] alloy that is silver-white in color by virtue of the high manganese content; this alloy was claimed at the time of its invention to be 50% of the cost of Cu-25%Ni. However, this alloy was not readily available for evaluation during this project. Given the success claimed by Kim [12], further development of a similar alloy may yield benefits for the United States Mint if a US domestic supplier can be found to produce this alloy. For this reason, CTC recommends that the United States Mint initiate research and development of similar alloys for potential use in future US circulating coins. This approach was not undertaken in this study due to the limited duration of the project and the inability of the project team to obtain any of this material. Pursuing such an alloy development effort may require a minimum of 3–5 years to complete. Commercial alloy Cu-24.5%Zn-12%Mn is a "white brass"—a color that results from its high manganese content. Thus, manganese is a useful alloy design ingredient to alter the natural color of copper-based alloys in the silver-white direction. Note that manganese can exist in six states, each of which can alter color when present on the surface bonded to oxygen or other electro-negative elements.

Iron and steels are the most commonly used metals by mankind and iron-based alloys are relatively inexpensive compared to most other metals. Steels, which are alloys of iron with small amounts of carbon, have not traditionally been used for US circulating coins because of their ferromagnetism. The ferromagnetic (i.e., strong attraction to a magnet) nature of iron and steels limits the ability of some coin acceptors to distinguish between steel-based coins and steel-based slugs as discussed in the Outreach Chapter. In addition, the electrical conductivity of steel alloys varies by greater amounts than do the materials used in incumbent coins. Therefore, increased inspection (with associated increases in rejection rates) must be completed during the production of coins or the range of acceptable values measured by coin-processing equipment must be wider, which would decrease the security of coins in these devices. In addition, steels are readily available in the open market allowing for a ready supply of material for making steel slugs. Nevertheless, steels have seen increasing use in coinage throughout the world, primarily for low-denomination coins. Upon additional investigation, CTC learned that to achieve consistent properties for coinage applications, low-carbon steel is used by other mints throughout the world. Therefore CTC began an investigation into the possibility of using low-carbon steel in coins.

The low cost of steel is being exploited as the main alloy for coins using a plating technology called "Multi-Ply technology," which is used to provide corrosion protection and control EMS, presumably making the coins more difficult to counterfeit. Multi-Ply coins typically have three surface layers—nickel/copper/nickel—electroplated on the steel surface. The relative thicknesses of the layers control the coin's EMS.

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[22] Austenite is a non-magnetic phase in steels.
[23] Sb is the atomic symbol for antimony.

The Royal Canadian Mint (RCM) has converted to steel-based coins for all new Canadian coinage.[24] At first glance, given the metal prices shown in Table 1-3, the steel one-cent coin might appear to be clearly less expensive to produce than the zinc one-cent coin. However, steel typically requires a higher coining force than zinc and very-low-carbon steels are preferred for coinage to decrease flow stress and reduce die fatigue. Such ultra-low-carbon steels such as Fe-0.006%C are typically twice as expensive as common low-carbon steels. Furthermore, to copper plate steels requires either a flash nickel electroplate before copper plating or a cyanide solution that complicates environmental health and safety (EH&S) procedures. Moreover, the steel must be annealed before copper plating at a temperature high enough to soften the steel; it must be annealed again after plating at a lower temperature to reduce residual plating stresses in the copper. This increases fabrication costs relative to copper-plated zinc. The Royal Mint (RM) in the United Kingdom (UK) is also increasingly minting low-denomination, plated-steel coins for circulation in the UK and other parts of the world. The RM plates a single layer of relatively thick nickel (25 microns) on low-carbon steel and trademarked this technology under the name aRMour™. For lower denominations such as the one-penny coin, the RM plates copper on 0.008%C steel. The RM plates a thicker layer of copper (25 microns) on steel than the 8 microns of copper plated on the zinc substrate used in the US one-cent coin. The thicker layer of copper on the UK one-penny coin is designed to reduce corrosion susceptibility. This thicker copper layer also increases costs. Cost details discussed in the Cost Trends Analysis Chapter indicate that copper-plated zinc and copper-plated steel one-cent coins have similar total unit cost. However, fluctuations in the costs of metals may at any given time result in a temporary cost advantage to either of these metallic constructions. It is for this reason that the RCM has historically been permitted to produce one-cent coins with either of these metals. At any given time, the RCM was able to choose the metal that yielded the lowest total production cost. At the metal prices as of March 2012, copper-plated zinc was the low-cost option. In summary, steels, in particular low-carbon steel, appeared to be potential candidates for selected coins based upon metal costs and availability, EMS issues and minting considerations notwithstanding. Iron and steels have potential for higher denominations, but EMS and security must be carefully addressed.

A major limitation of iron and steel is that they rust in ambient moist air. Stainless steels have been developed that contain chromium, sometimes nickel, and various other alloying additions. These steels are corrosion resistant because the surface oxide film is modified by the alloying additions. The oxides that form in moist air and many aqueous environments do not have dramatically different lattice parameters[25] with the substrate alloy as do iron oxides, which flake off due to lattice mismatch stresses and thereby expose fresh material to the corrosive environment, which perpetuates the formation of new products of corrosion. In general, the surface oxide film becomes protective above about 12%Cr. The most widely used stainless steel is 304, with the nominal composition Fe-19Cr-9.6Ni-2.0Mn-0.08C max. As shown by Kim [12] (Figure 1-1), 304 requires high coinage force, which increases die fatigue, can shorten die life and thereby increase fabrication costs. Alloy 304 is also very common, which increases the

[24] An exception is sometime made with production of the Canadian one-cent coin. The RCM is legally permitted to produce one-cent coins out of either copper-plated zinc or copper-plated steel depending upon which product form allows for the lowest price of raw metals at any given time. During the final proofing of this document, Canada announced that it would no longer be minting the Canadian one-cent coin.

[25] Lattice parameters are the constant spacing and three-dimensional arrangement of the atoms in a unit cell of a metallic crystal.

possibility of counterfeiting for higher denomination coins. It also is austenitic because of the relatively high nickel content. Austenitic stainless steels are typically non-ferromagnetic, but some can become ferromagnetic when heavily deformed. Grade 430 stainless steel, a nominal Fe-17%Cr alloy, is an inexpensive stainless steel because the high Cr content can be realized by adding ferrochrome, an inexpensive raw material. In addition, 430 stainless steel does not contain nickel, which is an expensive alloying element, resulting in lower corrosion resistance than 304 and many other stainless steels. Grade 430 is also ferromagnetic because of the absence of nickel and other austenite stabilizers. Nevertheless, low cost has been cited as a major reason for using 430 stainless steel for coinage in several nations. Note that the low electrical conductivity of 430 stainless steel coupled with its ferromagnetism creates significant issues with some coin-acceptance equipment; therefore, it is not a good option for denominations beyond the one-cent coin, which is rarely accepted for payment in automated systems.

It is interesting that nitrogen is an austenite stabilizer in stainless steels and is a much lower-cost alloying addition than is nickel. Nitrogen is a potent interstitial solid solution strengthener and can be expected to increase coining forces.

Stainless steels are likely to have a long service life with good color, good wear resistance and corrosion resistance. However, their densities are significantly different from Cu-25%Ni and copper (see Table 1-3), which requires conversion of equipment and/or handling procedures for some stakeholders (see the Outreach Chapter). Several inexpensive stainless steels include 430, Enduramet 32 and 302HQ. The range of electrical conductivity among the various stainless steel alloys is relatively narrow: between 2–3% IACS leading to potential fraud issues. This provides little flexibility for designing a stainless steel coin alloy with unique electrical conductivity. Stainless steels were expected to provide affordable, durable coinage, but EMS must be carefully considered.

Nickel has been an important coinage element as an alloying addition to copper. Nickel in sufficient quantities causes copper alloys to become silver-white and Cu-25%Ni alloy C713 has been a mainstay US coinage alloy for many years in several coins (see Table 1-2). Unfortunately, nickel prices have been very volatile and have been so high in recent years that as of March 2012, the United States Mint loses money for each 5-cent coin minted. Nevertheless, nickel is an important alloying element for coinage alloys used by other countries in lower concentrations. Nickel also is an important element for plating and surface engineering. Nickel has an attractive silver-white color and provides corrosion resistance.

Copper has been an important coinage alloy since antiquity. It also served as the US one-cent coin alloy until its price increased to the point that its intrinsic value exceeded its face value. Among metals, copper also has the second highest electrical conductivity to silver, so its use as a coin's core alloy is widely desired by and exploited by coin-processing equipment, which can easily detect the high conductivity by eddy current measurements.[26] The electrical conductivity of commercially pure copper is about 100% IACS, although ultra-pure copper alloys can exceed 100% IACS [11]. Copper alloy C110 has been a mainstay as the core alloy in the US dime,

[26] Eddy current measurement methods rely upon the interaction of an energized electrical coil whose alternating voltage (or current) changes in the presence of conducting and/or magnetic materials. Since different metals create different amounts of change in a given coil's voltage, the measured signal from such a coil in the presence of a coin can be compared to the changes from known coins as a validation method in coin-processing equipment.

quarter dollar and half dollar clad coins since 1964. At approximately $7.92–8.80/kilogram ($/kg) ($3.60–4.00/lb), the affordability of copper in coinage is becoming more difficult to achieve. Copper is still a strong candidate for high-denomination coins because of its high EMS, its intrinsic value and the possibility to contribute to seamless coin construction. With the next two highest electrical conductivity elements being gold at 70% IACS and aluminum at 61–65% IACS, if a new coin that is both economical and of sufficient weight is to approximate or match the EMS of incumbent high-denomination US coins, a copper core offers a reasonable possibility of a seamless transition. Nevertheless, reducing or eliminating copper content in coinage and replacing it with aluminum, zinc or iron offers the potential for significant cost savings to the United States Mint.

Before introducing circulating coins of a new construction in 2006, the Reserve Bank of New Zealand (RBNZ), which has responsibility to oversee New Zealand's circulating coinage, sought public opinion about several alloys being considered for their then-pending new coinage [13, 14]. The public opinion was not favorable towards aluminum as a result of its significantly lower density than cupronickel – the alloy commonly used in New Zealand's coins prior to 2006. In an unrelated action, opinion expressed in a call for public comment that was posted by the United States Mint in the Federal Register [15] showed some public resistance to the use of lightweight coinage alloys (such as aluminum and magnesium). Several respondents expressed the opinion that using such lightweight coins would cheapen the feel of US circulating coins; others commented that such lightweight coins would signal devaluation in the US dollar. Therefore, it is assumed that the public would be likely to be more receptive of a new coin if its weight is similar to that of the coin it replaces. The three leading lower-cost candidates, aluminum, zinc and iron, each have lower density than copper. If the dimensions (diameter and thickness) of a new coin are to remain the same as those for the coin it replaces, which is advantageous for public acceptance and use in many coin-processing machines (see the Outreach Chapter), coins will be lighter to varying degrees if aluminum, zinc or iron replaces copper or cupronickel. An alloy/coinage designer is then faced with developing ways to compensate for the lower density material(s); use of denser metallic elements is a possibility. The denser metal could be alloyed with another metal, or used as a layer in a laminar coin, each of which raises EMS concerns. Unfortunately, as shown in Table 1-3, elements that are denser than copper and nickel have toxicity issues or are more expensive than copper. For example, lead is inexpensive, malleable and has a high density of 11.35 g/cm^3. However, it is toxic and even as a core material in a clad construction, EH&S concerns during fabrication and public acceptance make lead an unacceptable candidate.

Bismuth has a high density of 9.75 g/cm^3 and has been used as a lead substitute in "green" ammunition. Unfortunately, bismuth prices have been too high in recent years for extensive use in coinage.

Molybdenum has a high density of 10.22 g/cm^3, which approaches that of silver at 10.50 g/cm^3. However, molybdenum's price is too high for extensive use in coinage, but it is a well-known alloying element for increasing the strength of steels. Molybdenum also increases the corrosion resistance of stainless steels. It is possible that molybdenum could see service in coinage as a dilute alloying element if certain ferrous alloys are selected.

Tungsten has a very high density (19.3 g/cm^3) but is far too expensive in pure form. Its price is lower when purchased as ferrotungsten, an intermediate product in the reduction process, but it is still too costly for coinage at March 2012 prices.

Depleted uranium, which has a density (18.95 g/cm^3) very close to that of gold (19.3 g/cm^3), cannot be a viable candidate because of radiation concerns and chemical toxicity. At present, CTC knows of no low-cost, high-density element or alloy that can practically compensate for the low density (relative to copper, nickel and cupronickel) of the three leading low-cost metals: iron, zinc and aluminum. Therefore, coins of denominations greater than one cent whose primary metal is iron, zinc and/or aluminum will be lower in weight than their incumbent counterpart.

1.4 COINAGE ALLOYS AND CONCEPTS FOR STUDY

As discussed above, the iron, zinc and aluminum alloy systems have the most promising combinations of low cost and formability for coinage. The experience and capability of the industrial base present at the time of this project was successfully harnessed. Plated concepts were heavily considered because of their affordability and the ability to control color and wear resistance by thin surface layers. As there are fewer facilities capable of roll cladding than facilities that can perform electroplating, clad concepts were also considered for high-denomination coins because of the inherent security of clad coins over plated ones. Furthermore, over their 46 plus years of service in the US, clad coins have proven to be difficult to match in EMS by counterfeiters. Monolithic concepts received strong consideration for low-denomination coins (the one- and 5-cent coins) in an attempt to minimize costs. For example, austenitic stainless steels with low nickel content and ferritic stainless steels that are nickel-free such as 430 were considered. In all cases, the recyclability of candidate materials was considered. Detailed discussions can be found in the Cost Trends Analysis and Environmental Assessment Chapters.

The existing coinage alloy suppliers to the United States Mint were each asked to provide innovative coinage compositions and concepts that could lower costs. Several novel concepts were provided. To complement the efforts of existing coinage alloy suppliers, other domestic metallic material suppliers were contacted to determine what existing alloys may offer additional options for coinage production. Several additional material samples were received from these non-traditional United States Mint materials suppliers. Finally the RCM and RM were consulted on material options; each of these mints provided samples for testing.

The list of desired material properties presented in the Introduction and Background Section of this chapter was discussed with each supplier. Emphasis was placed on the production costs as well as the delivery cost of the raw materials to the United States Mint. Working with each of the suppliers, and based upon available property measurements and performance experience, selected materials were chosen for further, detailed evaluation in the present study. In some cases, laboratory heats of material were produced in an attempt to more closely match all desired material attributes.

1.4.1 Candidates for the One-Cent Coin

The FY2011 indirect costs—overhead, G&A and distribution to the FRB—allocated to the one-cent coin is $0.0107 per coin; therefore using these indirect costs, it was not possible to make this coin for less than face value.[27] The fully burdened cost to make the one-cent coin in FY2011 was $0.0241. Nevertheless, metal candidates were identified that reduce the material cost to produce the one-cent coin. Steel was carefully considered for the one-cent coin, but low-cost steels have not been successfully used by other mints to obtain positive seigniorage for their lowest-value circulating coin(s), such as those from the RCM and RM. It is for this reason that the government of Canada announced in April 2012 that the one-cent Canadian coin will be eliminated [16]. Ultra-low-carbon steel (e.g., less than 0.01%C) is preferred to reduce coining forces and die fatigue. Ultra-low-carbon steels cost about twice as much as low-cost, low-carbon steels like 1005 (0.05%C). For example, 0.006%C steel costs about $1.23/kg ($0.56/lb) as compared with about $0.59/kg ($0.27/lb) for 1005 steel in large quantities. Unfortunately, carbon steels rust and must be protected. Galvanizing is a zinc electroplating process on steel, which uses zinc as a sacrificial anode to cathodically protect the steel substrate. Hot-dip galvanizing is a process by which steel is dipped into molten zinc to place a zinc layer on the surface. Galvanizing was used to protect the steel one-cent coin in 1943, but galvanizing planchets is more expensive than other options and the resulting coins do not look attractive after moderate circulation. Strip galvanizing is less expensive than batch galvanizing of planchets or coins; however, the edges of the blanks would be largely unprotected after blanks are punched from the galvanized strip.

Aluminized steel is an alternative to galvanizing where an aluminum coating is the sacrificial anode that protects the steel. Prices were obtained for small quantities of aluminized strip in a one-cent gage and were slightly lower than the prices for galvanized strip. Several square meters were purchased from suppliers for initial testing, recognizing that the edges of the steel would not be protected after blanking. Two different suppliers were identified having significantly different aluminized steel properties. CTC purchased and tested materials from both suppliers.

Stainless steels have the advantage of corrosion resistance, attractive silver-white luster and wear resistance, but die fatigue and price are concerns. The silver-white color of stainless steels is not preferred for the one-cent coin because its size is similar to the US dime coin; some confusion during hand-to-hand transactions could occur with a silver-white one-cent coin and the incumbent dime coin. Nevertheless, stainless steel coins have been used successfully in other nations. Grade 430 stainless steel strip was acquired for preliminary screening tests.

Aluminum and its alloys have advantages for one-cent coins [17] including relatively low cost (similar price per unit weight to that of zinc), low coining forces and corrosion resistance. A 1980 study at the United States Mint [18] recommended aluminum as a strong candidate for the one-cent coin, but resistance from coin-processing industries prevented use of aluminum. One problem with aluminum and its alloys is its silver-white color, which differs from that of the incumbent one-cent coin and which could cause confusion with the dime coin. Aluminum is soft, so coin wear resistance and die sticking is a concern. Nevertheless, aluminum alloys were recommended for the first round of screening tests. The aluminum-magnesium (Al-Mg) alloy

[27] That is, if the metal was free and fabrication costs were zero, the United States Mint would still have lost $0.0007 per one-cent coin minted in FY2011. For more details, see the Cost Trends Analysis Chapter.

subsystem is particularly advantageous because magnesium provides solid solution strengthening and work hardening during coining, which would increase wear resistance. Common Al-Mg alloys are non-heat treatable yet attain moderate strength levels. The authors of the 1980 United States Mint study [18] recommended 5005, a dilute Al-0.7%Mg alloy. Various token manufacturers use 1100 (a commercially pure aluminum alloy strengthened by impurities) and 3003 (Al-Mn alloy) because of low cost and good cold formability. CTC recommended 5052, a nominal aluminum-magnesium-chromium (Al-2.5%Mg-0.25%Cr) alloy, which is common, produced in large volumes and has higher strength and wear resistance than 5005, 1100 and 3003. Alloy 5052 is non-heat-treatable and would be supplied in a hardened temper such as H32, with sufficient cold work to increase the probability of clean blanking. One-cent gage 5052-H32 sheet was acquired.

Copper-plated 0.006%C steel planchets were also evaluated as fabricated by either JZP or the RM. Note that several of the one-cent coin candidates are currently only available in coiled strip form. The blank, upset and anneal steps would be required at the United States Mint for coiled material, but not for material delivered as planchets, as is the case for the incumbent one-cent coin. It is anticipated that if any of these candidates move forward, the producers may consider delivering these materials in planchet form to the United States Mint. Since the metal content of these candidates is low in cost, the final cost in either form could result in significant cost savings for the one-cent coin.

1.4.2 Candidates for the 5-Cent Coin

As is the case with the one-cent coin, the United States Mint costs exceed revenue on each 5-cent coin minted. However, the metal value for the monolithic cupronickel alloy in the 5-cent coin is greater than five cents, thereby providing a potential financial incentive for melting coins for metal value, which is illegal. This makes developing an alternative metal for the 5-cent coin of paramount importance. The FY2011 indirect costs for making the 5-cent coin is $0.0322, thereby leaving little room to make the 5-cent coin for face value or less. Nevertheless, several promising candidates were identified that can significantly reduce material costs.

A copper-based coinage alloy that has been under development by JZP for several years, 31157 with nickel plating and unplated, was selected for evaluation. This alloy can be considered a modified cartridge brass alloy with low amounts of expensive alloying elements. The unplated alloy has a slightly golden hue and has good formability. Nickel-plated 31157 was tested to maintain a similar color to the incumbent 5-cent coin. Unplated 31157 was also tested in a second round of tests as discussed below.

The RCM developed Multi-Ply technology to take advantage of the low cost of plating steel while ensuring security for coins by inducing a unique EMS of any given coin through careful design of the thicknesses of selected plating materials. Multi-Ply-plated steel comprises a flash plating of nickel over 0.006% C steel, a relatively thick copper plating (~20 microns) for EMS and then a top plated layer of nickel for color. Layer thicknesses can be tailored to provide a unique EMS and the RCM has a large database of signatures measured by the state-of-the-art SCAN COIN SC4000 machines. The RCM designed a Multi-Ply-plated steel for the US 5-cent coin that was designed to be unique among all coins worldwide. A quantity of 45 kg (100 lbs) of planchets were purchased for testing in the present study with ~2.3 kg (5 lbs) allocated for preliminary testing and the remainder for coining experiments in several iterations. It is recognized that plated-steel coins can be more difficult to recycle than the incumbent copper-based alloys. Nevertheless, the RCM has found companies that buy Multi-Ply-plated steel scrap at less than metal value. This scrap would be recycled into products other than coins since the resulting iron-copper-nickel composition would differ from the composition required for the plating of steel for coinage. Multi-Ply-plated-steel coins with a tailored EMS would not match incumbent 5-cent coins in EMS. Consequently, coin-processing equipment configured to validate incumbent 5-cent coins via EMS would require upgrades if US 5-cent coins were made from Multi-Ply technology. More details can be found in the Outreach Chapter.

Stainless steels, despite the having an electrical conductivity that is about half that of cupronickel, were recommended for testing for the 5-cent coin. The ideal stainless steel for coinage would be non-ferromagnetic (so it would not be mistaken for a steel slug), have low flow stress (i.e., result in low striking loads), have excellent corrosion resistance and be comprised to the greatest extent practical of elements that are not as expensive as nickel. Nickel and molybdenum contents should be low to reduce costs. Austenitic stainless steels (3xx series) are preferred because they are non-ferromagnetic and thereby are more likely to be accepted by a majority of fielded coin-processing equipment. Nitrogen (N) is the least-expensive austenite stabilizer; therefore, nitrogen-containing steels such as Enduramet 32 and 15-15LC were considered for use in the 5-cent coin. However, nitrogen dramatically increases material flow stress and may also increase die fatigue. Nickel is among the best austenite stabilizers in steel, but its high cost is a big driver for minimizing its content in coinage. Silicon is an affordable austenite stabilizer and is present in many stainless steels up to 1%. Chromium is the lowest-cost hardener that maintains stainless behavior, but it induces a ferromagnetic signature. The ability of a stainless steel to be annealed to the lowest practical hardness would be an advantage for extending die life during coining. Consequently, several stainless steels were considered including 201, 202, 301, 302HQ, Enduramet 32, 15-15LC, 405, 409, 430 and the commonly used 304. Note that 4xx stainless steel alloys are ferromagnetic—but they typically are the lowest-cost stainless steels. The nominal compositions of the major alloying elements in these stainless steels are provided in Table 1-4.

Table 1-4. Potential Low-Cost Stainless Steels and Compositions for Coinage

Alloy	**C**	**Mn**	**Si* (max)**	**Cr**	**Ni**	**N**	**Other**	**Ferromagnetic**
201	0.15	6.5	1.00	17.0	4.5	0.25	-	no
202	0.15	8.75	1.00	18.0	5.0	0.25	-	no
301	0.15	2.0	1.00	17.0	7.0	-	-	no
302HQ	0.03	2.0	1.00	18.0	9.0	-	3.5 Cu	no
Enduramet 32	0.05	12.5	1.00	17.7	1.5	0.32	-	no
15-15LC	0.04	17.0	1.00	18.5	3.00 max	0.50	1.75 Mo	no
405	0.08	1.00	1.00	13.0	-	-	0.20 Al	yes
409	0.08	1.00	1.00	11.1	-	-	0.48 Ti	yes
430	0.12	1.00	1.00	17.0	-	-	-	yes
304	0.08	2.00	1.00	19.0	9.25	-	-	no

* Si is the chemical symbol for silicon.

After extensive discussions with metallurgists specializing in stainless steels, CTC decided to evaluate alloy 302HQ because it had properties that showed promise for a coinage alloy and ingots were available that could be immediately rolled to 5-cent coin gage. Furthermore, this alloy is designed for cold-heading applications for fasteners; therefore, it is anticipated that 302HQ, with its relatively low flow stress, would have good coining characteristics. Note that the composition could be modified slightly in production for coinage to decrease costs or obtain other desirable characteristics.

Grade 430 stainless steel was also selected for evaluation based on its successful use for coinage by other nations and its low cost. The other low-cost alloys such as 405 and 409 were not readily available and were removed from consideration in the present study.

The literature was surveyed for various copper-based alloys that have been used for coinage in foreign nations as well as copper alloys that are lower in content of expensive elements such as nickel and copper. Olin Brass proposed compositions that are potentially lower in cost based on elemental content, have electrical conductivities that are close to that of incumbent 5-cent coin alloy cupronickel (~5.4 to 5.9% IACS), and have color that is silver-white for US circulating coins of denominations 5 cents through half dollar. Several compositions were also identified that have a color that could be used for dollar coins. Olin Brass-identified candidate alloys are listed in Table 1-5.

Table 1-5. Compositions of Copper-Based Alloys with Electrical Conductivity Close to That of Cu-25%Ni

(Courtesy of Olin Brass)

Alloy	Composition (wt%)					%IACS		Copper-Equivalent[28] (wt %)	Color	Metal Value Relative to C713	Touch Test Rank	Humidity Test Rank
	Mn	Zn	Ni	Al	Other	Observed	Calculated					
C713	–	–	25	–	–	6	5.4	–	W++	100.0%	1	1
Y90	6.6	12.1	3.7	–	–	6	5.6	88.0	YG	69.2%	–	–
C69250	5.8	7.8	2.5	1.5	–	6.5	6.4	83.4	YG	70.0%	1	3
C710	–	–	21	–	–	6.5	6.1	–	W	95.9%	1	3
C752	–	17	18	–	–	6	6.2	–	W	83.4%	–	–
Y42	–	25	15	–	–	–	6.7	91.6	W?	75.8%	–	–
G6 Modified	2	22	10	–	0.5	–	5.9	–	W	72.9%	–	–
K474	5.9	10.4	–	2.4	–	5.8	5.7	74.6	G	65.6%	2	2

Color Descriptions

G – Gold
W – White
YG – Yellow-gold
± – Intensity of color
? – Best estimate based on chemistry

Touch Test Rank

1 – Little if any discoloration
2 – Light discoloration, incomplete
3 – Discolored more than 75%, but not deep
4 – Deep discolored spots
5 – Deep and complete discoloration

Humidity Test Rank (28 °C/95% relative humidity [RH] 3 weeks)

1 – Slight water marking
2 – Some water marks
3 – Water marks no pits
4 – Some pits with water marks
5 – Many pits with water marks

[28] Copper equivalent as defined here relies on a proprietary methodology used by Olin Brass.

It is advantageous for a candidate alloy to potentially serve in monolithic form for the 5-cent coin and also serve as cladding for the dime, quarter dollar and half dollar coins. From the list in Table 1-5, alloy G6 modified (G6 mod), was selected as a candidate clad material for the dime, quarter dollar and half dollar coins. It was also evaluated as a monolithic material for the 5-cent coin. Relatively low metal value and similarity to cupronickel alloy in electrical conductivity were the main reasons for selecting G6 mod for further evaluation.

CTC was given access to experimental alloys under development at PMX Industries, Inc.® (PMX). PMX measured electrical conductivity of numerous experimental alloys (see Table 1-6). Alloy 669z was selected for evaluation as monolithic sheet for the 5-cent coin with roll cladding planned to evaluate this alloy for higher denominations. This alloy is a Cu-Zn-Mn-Ni-Fe alloy with relatively low nickel content and an electrical conductivity almost identical to C713. The alloy is expected to have the added benefit of enhanced antimicrobial performance if the surface is bare and free of lubricants or oils.

Table 1-6. Electrical Conductivity of Experimental PMX and Commercial Alloys along with Selected Coins and Coinage Alloys

Alloy	**Frequency (kHz)**	**Electrical Conductivity (%IACS)**
Cupronickel (C713)	240	5.46
1970 5-cent coin	240	5.31
A. Johnson dollar coin	240	12.89
C110 2.5% CW	240	99.52
70/30 brass	240	28.1
Center section of Canadian $2 coin	240	12.8
PMX 604A	240	6.63
301 stainless steel	240	1.88
66913	240	3.30
68600	240	4.85
626	240	6.45
605	240	6.13
669	240	5.35
669z	240	5.27, 5.28
CZM68	240	6.16
Experimental Cu/Al Won roll clad	240	92.0
US one-cent coin	240	27.0
Golden dollar	240	12.3
Golden dollar	480	7.00
Golden dollar cladding alloy	240	4.33
Golden dollar cladding alloy	480	5.40
316 stainless steel	240	2.30
Pure zinc	240	28.8
Multi-Ply Canadian 25-cent blank	240	1.069
Multi-Ply Canadian 25-cent blank	480	1.060

From this list, one can observe that there are copper-based alloy candidates for the 5-cent coin that have the potential to provide an EMS match to the incumbent coin for potentially seamless options. There are also plated options and monolithic stainless steels that have the potential for reduced metal costs, but coins of this construction would be non-seamless in circulation.

1.4.3 Candidates for the Dime, Quarter Dollar and Half Dollar Coins

The incumbent dime, quarter dollar and half dollar coins are Cu-25%Ni clad to a copper C110 core. The candidate alloys for the three coins will generally be the same with one caveat. The half dollar coin is not currently minted as a circulating coin, not used in large quantities and not used to a significant extent in the vending industry or others that depend upon an unattended point-of-sale transaction. Note that the half dollar coin is made in such low quantities (for numismatic purposes) that the scrap rate is significantly higher for this coin than all other circulating denominations.[29]

The quarter dollar coin is the most commonly used coin in the vending, laundromat, car wash, amusement and other industries and therefore introducing a secure, seamless coin is of paramount importance for this coin. The clad quarter dollar coin has served the US well for 47 years offering excellent security features for coin-processing equipment. The EMS of the clad design is similar to that of the predecessor Ag-10%Cu alloy and coin-processing equipment has used the difference in electrical conductivity of the three layers—C713/C110/C713—to provide excellent security. When a coin passes by an EMS-based sensor in a vending machine (or other machine designed for unattended points of sale), magnetic fields are induced in the coins at different frequencies.[30] The magnetic fields produce eddy currents (i.e., electrical energy losses) in the coin and the penetration depth of the magnetic field (or more precisely the magnetic flux lines) is related to the frequency of the field—higher frequencies have a lower depth of penetration and lower frequencies have a greater depth of penetration. The EMS of the three-layer quarter dollar coin depends upon the individual layer thicknesses and each layer's electrical conductivity, which are about 5.4–5.9% IACS for C713 and about 100% IACS for C110. For the quarter dollar coin, several roll-clad concepts were proposed with EMS as the major alloy/concept design criterion. Compositions were selected for the clad layers that have similar conductivity to cupronickel, but are less expensive because of metal content, particularly by lowering nickel content. CTC recommends keeping the core C110 to optimize the probability of developing a quarter dollar coin that could be potentially introduced seamlessly to the coin-acceptance equipment infrastructure in the US. Cladding alloys selected were: G6 mod, 669z and unplated 31157. These alloys were evaluated monolithically, while the metals producers were ask to consider developing roll-cladding parameters. The metal value of the clad compositions allows a modest cost savings (~12.6–13.9%) over the incumbent quarter dollar coin materials, using March 2012 pricing, but is proposed as relatively safe options for a potential seamless transition.

Multi-Ply-plated steel coins have been in circulation in Canada for about a decade and both the coin-processing industry and the public at large have accepted the low-cost, steel-cored coins. Multi-Ply-plated steel coins cannot be produced to match the EMS of US incumbent cupronickel and cupronickel-clad copper coins. Consequently, Multi-Ply-plated steel coins would have to be

[29] These values are for discrete periods and the condemned flow back is not always in synchronization with production so scrap rate values can vary significantly from year to year.
[30] Note that the various models of coin-processing equipment use different sets of frequencies and there is no industry standard, which further complicates coinage design for seamless transition.

co-circulated with incumbent US coins. Planchets of Multi-Ply-plated 0.006%C steel were provided for the US quarter dollar coin, as well as for the 5-cent coin mentioned earlier.

The compositions recommended are candidates for the dime, quarter dollar and half dollar coins. Since the half dollar coin is a high-denomination coin, security must be a major consideration in the selection of its alternative material candidates. Any non-seamless material option for the half dollar coin should have security features to make counterfeiting difficult.

1.4.4 Candidates for the Dollar Coin

While the Alternative Metals Study was being conducted, the Department of the Treasury suspended production of the dollar coin. Nevertheless, the following considerations provide documentation of the study's findings on alternative material candidates for the dollar coin. Experimental testing on the dollar coin alternative material candidates was limited by the United States Mint program manager.

The Native American coin and Presidential Dollar coins are commonly referred to as the dollar coin. They both comprise a manganese brass with a golden hue clad to copper alloy C110. The composition of the brass, Cu-6%Zn-3.5%Mn-2%Ni, in conjunction with the clad layer thickness, were selected to match the EMS of the Susan B. Anthony dollar coin, that was Cu-25%Ni (C713) clad to a copper core. The incumbent dollar coin construction has generally been successful, although tarnishing poses problems with the cladding alloy. Several cladding alloys were considered in the present study; C69250 and K474 were selected based on color and reduced metal value. The conductivity of C69250 is slightly higher (6.5% IACS, see Table 1-5) than that of C713, but this higher conductivity could be compensated for by changes in cladding thickness or heat treatment. The corrosion resistance of each of these alloys was assessed to determine whether they were superior to the manganese-brass alloy used in the incumbent dollar coin. A yellow bronze- (88Cu-12Sn) plated zinc planchet was also evaluated for corrosion resistance. Because of nearly identical unit cost and lack of improved tarnish resistance, the three candidate alloys have a relatively low probability of replacing the incumbent dollar coin construction.

1.5 SUMMARY OF RECOMMENDED ALLOYS FROM ROUND ONE DOWN-SELECTION TESTING

The alloys described above are summarized in Table 1-7 with candidate denominations noted. Some of the one-cent coin candidates were only available in coiled sheet form. As a result of reduced transportation costs and reduced handling and processing of web scrap, it is possible that costs could decrease if the metal supplier manufactured and delivered the material in planchet form to the United States Mint. As mentioned, several candidate materials are applicable to the 5-cent coin as a monolithic layer and also for higher denomination coins when clad with C110. Suppliers are developing roll cladding parameters for their respective candidates and will produce a pilot production coil, if requested.

Table 1-7. Down-Selected Recommendations for Round One Testing*

Candidates	Alternative Materials	Denomi-nation (cents)	Planchet (P)/Strip (S)	Estimated Unit Burdened Cost ($/coin) (Production Costs)
1	Aluminized Steel	1	S	0.0202
2	5052-H32 Aluminum	1	S	0.0180
3	Copper-Plated Steel	1	P	0.0276
4	430 Stainless Steel	1	S	0.0237
5	Dura-White-Plated Zinc 190	5	P	0.0547
6	Multi-Ply-Plated 0.006%C Steel	5	P	0.0634
7	302 Stainless Steel	5	S	0.0677
8	430 Stainless Steel	5	S	0.0485
9	G6 Mod (Copper Based)	5	S	0.0821
10	669z (Copper Based)	5	S	0.0813
11	Plated 31157 (Copper Based)	5	P	0.0995
12	Multi-Ply-Plated 0.006%C Steel	25	P	0.0720
13	Dura-White-Plated Zinc 190	25	P	0.0679
14	White Bronze-Plated Zinc	25	P	N/A
15	G6 Mod-Clad C110	25	S	0.0939
16	669z-Clad C110	25	S	0.0937
17	Stainless Steel-Clad C110	25	S	0.0870
18	88Cu-12Sn-Plated Zinc	100	P	0.1648
19	C69250-Clad C110	100	S	0.1683
20	K474-Clad C110	100	S	0.1650

* March 2012 Prices.

See the Testing Program Chapter for test results. Note that several of the recommendations were eliminated based on preliminary testing before striking trials were performed.

1.6 CANDIDATE ALLOYS FOR ROUND TWO DOWN-SELECTION TESTING

For completeness, the alloys down-selected from Round One and newer alloy concepts uncovered/obtained after Round One testing are summarized in Table 1-8. After striking tests and review, promising Round One candidate materials were carried into Round Two testing. In addition, the RM offered to produce nickel-plated steel fabricated by their aRMour process available for Round Two striking and testing. Finally, conventional planchets of the incumbent alloys were struck with nonsense dies. These nonsense pieces, along with various circulating coins were evaluated in coin-processing equipment as discussed in the Outreach Chapter.

Table 1-8. Down-Selected Recommendations for Round Two Testing

Candidate	Denomination	Description of Test Pieces	Comment	Supplier
1	One-Cent	Newly Minted 2012	Incumbent	United States Mint
2		Circulated – Pre-1982	Incumbent	United States Mint
3		Circulated – Post-1982	Incumbent	United States Mint
4		Newly Minted with Nonsense Dies	Incumbent	United States Mint
5		5052-H32		Aleris
6		Copper-Plated Steel		JZP
7		Copper-Plated Steel		RM
8		302HQ Stainless Steel		Carpenter
9	5-Cent	Newly Minted 2012	Incumbent	United States Mint
10		Circulated	Incumbent	United States Mint
11		Newly Minted with Nonsense Dies	Incumbent	United States Mint
12		Nickel-Plated Steel		RM
13		Unplated 31157		JZP
14		Multi-Ply-Plated Steel		RCM
15		Dura-White-Plated Zinc		JZP
16		669z		PMX
17		G6 Mod*		Olin Brass
18		302HQ Stainless Steel		Carpenter
19	Quarter Dollar	Newly Minted 2012	Incumbent	United States Mint
20		Circulated	Incumbent	United States Mint
21		Newly Minted with Nonsense Dies	Incumbent	United States Mint
22		Nickel-Plated Steel		RM
23		Multi-Ply-Plated Steel		RCM
24		302HQ Stainless Steel	25¢** Gage	Carpenter
25		302HQ Stainless Steel	5¢ Gage	Carpenter
26		669z-Clad C110*		PMX
27		Dura-White-Plated Zinc	5-µm** Tin	JZP
28		Dura-White-Plated Zinc	8-µm Tin	JZP
29		Dura-White-Plated Zinc	10-µm Tin	JZP

*Copper-based alloy G6 mod was not available to roll clad to C110 at the time the nonsense pieces were struck. The striking performance from the monolithic G6 mod was used as a surrogate for the G6 mod-clad C110 dime, quarter dollar and half dollar coins.
** ¢ = cent; µm = micron

Testing and striking are reported and discussed in the Testing Program Chapter.

1.7 THE CARBONYL COIN MANUFACTURING CONCEPT

Plated coins are typically fabricated by depositing metals such as nickel on coin surfaces from a liquid bath. The carbonyl process is a commercially proven process that can deposit nickel from a *gaseous phase* on a wide variety of substrates. Furthermore, the process can be reversed to remove nickel from a surface and thereby has potential for metal reclamation. Moreover, the process works to varying degrees for any of the 15 transition elements in Groups VIA to VIIIA of the Periodic Table of the Elements. The carbonyl process provides the potential to deposit alloys on surfaces such as iron-nickel alloys to reduce the amount of nickel used. A cost analysis and technical summary of the potential for the carbonyl process to coat coins, and reclaim nickel from scrap or old coins, is provided in Appendix 1-B. This process was evaluated in the present study as a potential future process for coin production.

1.8 REFERENCES – CHAPTER 1

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1.9 APPENDICES – CHAPTER 1

1.9.1 Appendix 1-A: Copy of Public Law 111-302

PUBLIC LAW 111–302—DEC. 14, 2010

COIN MODERNIZATION, OVERSIGHT, AND CONTINUITY ACT OF 2010

124 STAT. 3272 PUBLIC LAW 111–302—DEC. 14, 2010

Public Law 111–302

111th Congress

An Act

To provide research and development authority for alternative coinage materials to the Secretary of the Treasury, increase congressional oversight over coin production, and ensure the continuity of certain numismatic items.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the ''Coin Modernization, Oversight, and Continuity Act of 2010''.

SEC. 2. AUTHORITY TO CONDUCT RESEARCH AND DEVELOPMENT ON ALL CIRCULATING COINS.

(a) IN GENERAL.—To accomplish the goals of this Act and the requirements of subchapter II of chapter 51 of title 31, United States Code, the Secretary of the Treasury may—

(1) conduct any appropriate testing of appropriate coinage metallic materials within or outside of the Department of the Treasury; and

(2) solicit input from or otherwise work in conjunction with entities within or outside of the Federal Government including independent research facilities or current or potential suppliers of the metallic material used in volume production of circulating coins,

to complete the report referred to in this Act and to develop and evaluate the use of new metallic materials.

(b) FACTORS TO BE CONSIDERED.—In the conduct of research, development, and the solicitation of input or work in conjunction with entities within and outside the Federal Government, and in reporting to the Congress with recommendations, as required by this Act, the Secretary of the Treasury shall consider the following:

(1) Factors relevant to the potential impact of any revisions to the composition of the material used in coin production on the current coinage material suppliers.

(2) Factors relevant to the ease of use and ability to cocirculate of new coinage materials, including the effect on vending machines and commercial coin processing equipment and making certain, to the greatest extent practicable, that any new coins work without interruption in existing coin acceptance equipment without modification.

(3) Such other factors that the Secretary of the Treasury, in consultation with merchants who would be affected by any change in the composition of circulating coins, vending machine and other coin acceptor manufacturers, vending machine

31 USC 5112 note.

31 USC 5101
note.
Coin
Modernization,
Oversight, and
Continuity Act of
2010.
Dec. 14, 2010
[H.R. 6162]

owners and operators, transit officials, municipal parking officials, depository institutions, coin and currency handlers, armored-car operators, car wash operators, and American owned manufacturers of commercial coin processing equipment, considers to be appropriate and in the public interest, after notice and opportunity for comment.

SEC. 3. BIENNIAL REPORT TO THE CONGRESS ON THE CURRENT STATUS OF COIN PRODUCTION COSTS AND ANALYSIS OF ALTERNATIVE CONTENT.

(a) REPORT REQUIRED.—Before the end of the 2-year period beginning on the date of the enactment of this Act, and at 2-year intervals following the end of such period, the Secretary of the Treasury shall submit a report to the Committee on Financial Services of the House of Representatives and the Committee on Banking, Housing, and Urban Affairs of the Senate analyzing production costs for each circulating coin, cost trends for such production, and possible new metallic materials or technologies for the production of circulating coins.

(b) DETAILED RECOMMENDATIONS.—In preparing and submitting the reports required under subsection (a), the Secretary of the Treasury shall include detailed recommendations for any appropriate changes to the metallic content of circulating coins in such a form that the recommendations could be enacted into law as appropriate.

(c) IMPROVED PRODUCTION EFFICIENCY.—In preparing and submitting the reports required under subsection (a), the Secretary of the Treasury shall include recommendations for changes in the methods of producing coins that would further reduce the costs to produce circulating coins, and include notes on the legislative changes that are necessary to achieve such goals.

(d) MINIMIZING CONVERSION COSTS.—In preparing and submitting the reports required under subsection (a), the Secretary of the Treasury, to the greatest extent possible, may not include any recommendation for new specifications for producing a circulating coin that would require any significant change to coinaccepting and coin-handling equipment to accommodate changes to all circulating coins simultaneously.

(e) FRAUD PREVENTION.—The reports required under this section shall make no recommendation for a specification change that would facilitate or allow the use of a coin with a lesser value produced, minted, or issued by another country, or the use of any token or other easily or regularly produced metal device of minimal value, in the place of a circulating coin produced by the Secretary.

(f) RULE OF CONSTRUCTION.—No provision of this Act shall be construed as requiring that additional research and development be conducted for any report under this Act but any such report shall include information on any such research and development during the period covered by the report.

SEC. 4. MEETING DEMAND FOR SILVER AND GOLD NUMISMATIC ITEMS.

Subsections (e) and (i) of section 5112 of title 31, United States Code are each amended by striking ‘‘quantities’’ and inserting ‘‘qualities and quantities that the Secretary determines are’’.

SEC. 5. TECHNICAL CORRECTIONS.

Section 5112(u)(1) of title 31, United States Code is amended—

31 USC 5112
note.

LEGISLATIVE HISTORY—H.R. 6162:
CONGRESSIONAL RECORD, Vol. 156 (2010):
Sept. 29, considered and passed House.
Nov. 30, considered and passed Senate.

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(1) by striking ‘‘exact duplicates’’ and inserting ‘‘likenesses’’;
(2) by striking subparagraph (C);
(3) by redesignating subparagraphs (D) and (E) as subparagraphs (C) and (D), respectively; and
(4) in subparagraph (A), by striking ‘‘of 3.0 inches’’ and inserting ‘‘determined by the Secretary that is no less than 2.5 inches and no greater than 3.0 inches’’.

SEC. 6. BUDGETARY EFFECT.

The budgetary effects of this Act, for the purpose of complying with the Statutory Pay-As-You-Go Act of 2010, shall be determined by reference to the latest statement titled ‘‘Budgetary Effects of PAYGO Legislation’’ for this Act, submitted for printing in the Congressional Record by the Chairman of the House Budget Committee, provided that such statement has been submitted prior to the vote on passage.

Approved December 14, 2010.

1.9.2 Appendix 1-B: The Carbonyl Nickel Coin Manufacturing Concept

1.9.2.1 Background

The carbonyl or Mond process was discovered in 1884 when Ludwig Mond noticed that hot carbon monoxide (CO) gas would severely corrode nickel. The carbonyl process exploits the ability of CO to form compounds with many of the transition elements in Groups VIA to VIIIA of the Periodic Table of Elements. The process works particularly well for nickel and it is reversible. That is, nickel can be extracted from a substrate, or deposited onto a substrate depending upon temperature. In general, at about 80 °C (176 °F), nickel reacts to form nickel carbonyl ($Ni(CO)_4$)

$$Ni + 4CO \rightarrow Ni(CO)_4.$$

At 150–175 °C (302–347 °F), the reaction is reversed with nickel being chemically reduced and can be made to deposit on most substrates. The process has the ability to extract nickel from low-cost, low-value-added sources such that it is about 20% less expensive to produce nickel by the carbonyl process than by conventional extraction process metallurgy. Similarly, the process can be used to deposit nickel onto substrates such as planchets or coins at about 80% of the prevailing nickel price on the London Metal Exchange.[31]

The carbonyl process is used by CVMR Corporation and Vale Inco Limited (a former International Nickel Company) commercially in several nations including the US, Canada, Germany, Great Britain and China. Carbon monoxide and nickel carbonyl are poisonous, so extreme care is exercised in building and operating carbonyl reactors. Each of the major carbonyl producers claims impeccable safety records. This claim was considered and verified through extensive discussions with CVMR Corporation and Vale Inco Limited. Furthermore, no known safety issues were uncovered from application of the process at Inco since its first production implementation in 1910. Major products produced from the process include nickel pellets for plating electrodes, nickel powders of various sizes and morphologies, coated parts for corrosion and wear resistance, and bulk nickel parts with extremely fine detail. Since the cost of the clad or monolithic Ni/Cu coins had escalated sharply in recent decades, the carbonyl process was evaluated as a potential process to cost-effectively deposit nickel and nickel alloys on planchets and to also use the process for metal reclamation of worn coins. There being no known prototype or commercial practice of nickel carbonyl on coins, feasibility studies and scale-up were needed to assess and optimize the process, define plant configuration and to minimize the processing and plant capital costs. Experiments were proposed to corroborate these claims, some of which the United States Mint recently funded to be performed in cooperation with CVMR Corporation. In short, the high price of nickel is a major driver for US circulating coins and the carbonyl process has the potential to reduce the cost of nickel coatings and to earn revenues by nickel reclamation as nickel-containing coins are replaced by lower-cost metals.

CVMR Corporation can make a turnkey facility to deposit nickel on planchets or coins and also to reclaim nickel. The industrial base for carbonyl coinage in the US needs to be developed, but this could be done quickly with a firm financial commitment. CVMR Corporation estimates that for approximately $30 million (M), a turnkey facility could be established at the United States Mint, a

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[31] J.R. Pickens and R.F. Decker, “Visit to CVMR Corporation,” Toronto, Canada, September 22–23, 2011, Trip Report to the United States Mint.

satellite facility or a commercial supplier. This one facility could meet US coinage production rate needs. Discussions with Vale Inco Limited indicated that a purposeful carbonyl facility dedicated to a single denomination, such as the 5-cent coin, could be purchased for about $10M.

Although the advantages of carbonyl nickel processing such as cost, recycling and low energy are well established commercially, there are possible barriers to good commercial coin practice that need to be addressed during a research and development campaign. These might include surface treatment before coating, adhesion of nickel to the base alloys such as zinc, copper and steel, distortion of the planchets in the reactor, residual stresses and coinability. The nickel layer may need alloying for wear resistance and for use in coin-processing equipment. It is possible that an alloyed nickel layer on zinc alloy planchets could be developed to approximate the electromagnetic signature (EMS) of the incumbent 5-cent coin.

The carbonyl manufacturing concept utilizes a modular extraction and coating facility. Its functions are a) to extract nickel from low-cost mining intermediates and worn nickel-containing components and b) to condense nickel as a coating on low-cost coin planchets.

The modular concept is to design and construct the plant as individual reactors dedicated to specific denominations as the volume of coins grows. For example, the first module could be dedicated to 5-cent coins, at a volume of 500M coins/year (coins/yr). The following cost analysis assumes that this 5-cent coin module could be constructed for $10M, with a return on investment (ROI) of less than 1 year. The expectation is that this module would be used to deposit a nickel carbonyl coating on steel or zinc planchets, at a cost of $0.001/coin.

The cost of depositing nickel by the carbonyl process is significantly lower than electroplating nickel. The metal cost savings versus the existing Cu-25%Ni 5-cent coin at the 500M coins/yr volume would be $19,981,500/yr for zinc-based coins and $21,904,000/yr for steel-based coins coated with a nominal 10 microns of carbonyl nickel. Also, this would open the door to nickel-coated-zinc coins, which are not now feasible by nickel plating due to plating stresses. The cost analysis follows.

1.9.2.2 Cost Analyses[32]

I. Electroplating Nickel Costs (Mazzilli Method[33])

$$C_t \text{ (Total Cost)} = C_m \text{ (Material Cost)} + C_l \text{ (Labor Cost)} + C_e \text{ (Equipment Cost)} \quad (1)$$

A. Material Cost of Ni Coating

$$C_m = \$8.70/\text{lb} \times 0.10 \text{ g/coin}/(454 \text{ g/lb}) = \$0.0019/\text{coin} \quad (2)$$

B. Labor Cost, C_l

Hourly Wages (with overhead), W = $30/h

[32] All metal prices are current as of April 2012.

[33] http://polynet.dk/ingpro/surface/elecomk.htm, Andrea Mazzilli, "Electroplating Costs Calculation," April 30, 2012.

Plating Time, T_b (minutes, min) = t (thickness, µm) x d_m (density, g/cc) x 60/[Amp/dm^2(area) x g/Amp-h x current yield, %] = 20 x 8.9 x 60/[4 x 1.04 x 95] = 27 min; where dm is decimeter and h is hours; g/cc = grams/cubic centimeter (3)

Specific Plating Time, $t_b = T_b$ x surface area/b (bath size in dm^2) = 27 x 0.03/400 = 0.002 min/coin (4)

Labor Time (min), t_a = 0.002 min/coin

$C_l = W \times (t_a + t_b)/60 = 30 \times 0.004/60 = \$0.002$/coin (5)

C. Equipment Costs, $C_e = \$35/h \times (t_a + t_b)/60 = 35 \times 0.004/60 = \$0.002$/coin (6)

Therefore, Total Cost, C_t, for Electroplating Nickel = \$0.00192 + \$0.002 + \$0.002 = <u>\$0.006/coin</u>. (7)

II. Carbonyl Nickel Coating Costs

Material Costs, C_m = \$8.70/lb Nickel x 0.05 g/coin/(454 g/lb) = \$0.00096/coin (8)

Processing Costs = \$0.60/lb Nickel* x 0.05/454 = \$0.00007/coin (9)

Therefore, Total Cost of Carbonyl Coating of Ni = <u>\$0.001/coin</u>. (10)

* CVMR Corporation estimate

III. Metal Cost Savings by Replacing Cupronickel 5-Cent Coin by Carbonyl Nickel-Coated Base Metal

A. Incumbent 5-Cent Coin

500M coins/yr/100 coins/lb = 5M lb coins/yr	
Ni @ 25% = 1.25M lb/yr x \$8.70 =	\$10,875,000/yr
Cu @ 75% = 3.75M lb/yr x \$3.85 =	<u>\$14,437,500/yr</u>
Total Metal Cost =	\$25,312,500/yr

B. 10-µm Carbonyl Nickel on Zinc Planchet

Ni @ 500M coins/yr x \$0.001/coin =	\$500,000/yr
Zn @ 500M coin/yr x 3.99 g/coin/(454 g/lb) x \$1.10/lb =	<u>\$4,831,000/yr</u>
Total Metal Cost =	\$5,331,000/yr
Saving vs. cupronickel 5-cent coin =	\$19,981,500/yr

C. 10-µm Carbonyl Nickel on Steel Planchet

Ni @ 500M coins/yr x \$0.001/coin =	\$500,000/yr
Steel @ 500M coins/yr x 5 g/coin/(454 g/lb) x \$0.60/lb =	<u>\$2,908,500/yr</u>
Total Metal Cost =	\$3,408,500/yr
Saving vs. cupronickel 5-cent coin =	\$21,904,000/yr

Technically, the nickel extraction process from intermediates is mature commercially at a rate of greater than 64M kg/yr (140M lbs/yr) at Vale Inco Limited carbonyl facilities in Canada. The extraction from spent coins would require prototype runs on granulated coins.[34] Furthermore, the copper content could be removed from the extractor as a valuable copper compound for other markets.

As to technical challenges, the surface finish on the carbonyl nickel coating needs leveling by burnishing inside or outside the depositor, or by trace element additions to the carbonyl gas, an art already practiced in carbonyl-nickel powder production. Hardness for good coinability can also be optimized by these same trace element additions. Finally, there is a technical opportunity to engineer magnetic permeability of the nickel coating on zinc planchets, to mimic the EMS of the incumbent 5-cent coin, thus minimizing the onerous costs of modifying coin-processing equipment.

Towards the end of the project, the United States Mint authorized a preliminary assessment of carbonyl technology. CTC and the United States Mint had a kick-off meeting on February 15, 2012 at CVMR Corporation in Toronto, Canada. The statement of work was gated into four stages as follows.

- Stage 1. Prove that there is 1) good adhesion and 2) good thickness control of carbonyl nickel on several substrates. CTC will provide coin gage strip of zinc alloy, steel and copper to which CVMR Corporation would coat ~10 microns of nickel on one side. CVMR Corporation may do quality control tests as necessary. When CVMR Corporation is satisfied with the adhesion strength and uniformity of the thickness, send the coated strip to CTC who will perform bend tests and blanking evaluations. If the coated planchets are received in time, the United States Mint will upset (i.e., rim) and strike test coins, recognizing that the nickel will only be on one side of the test pieces. Some circulating coins may be included with the strip to observe surface detail when covered with carbonyl nickel. Test pieces will be measured for any dog-boning[35] of the plated material.
- Stage 2. Develop a planchet/coin flipping mechanism to produce 4.5–45-kg (10–100-lb) lots. Demonstrate the mechanism by producing a several-kilogram run with 10 microns of nickel deposited on the planchets and coins. CTC will provide the planchets and coins.
- Stage 3. Make a quality run of approximately 4.5 kg (10 lbs) for the United States Mint to use during striking trials. CTC will provide the planchets.
- Stage 4. Provide 45 kg (100 lbs) of carbonyl-nickel-plated planchets for the United States Mint to perform a trial striking run. CTC will provide the uncoated planchets.

At the time of this writing, CVMR Corporation, is midway through Stage 2, see Appendix 2-G, Section 2.7.7.2 for additional details.

[34] Granulation is a commercial process that would cost about 30 cents per pound; but could offer enhanced security over selling waffled scrap coins on the open scrap market. Granulation is only recommended for prototype evaluations; under production conditions, coins to be recycled would not require granulation.

[35] Due to the physics of the electroplating process, the thickness of plated material tends to be 1.5 to 2.5 times thicker at the edges and outer radii of coins compared to that at the center of the face of the coins. This non-uniform coating can have some impact on the acceptability of coins in some coin-processing equipment.

2.0 TESTING PROGRAM

2.1 GOALS

Section 2(a)(1) of Public Law 111-302 (known as the Coin Modernization, Oversight, and Continuity Act of 2010) authorizes the Secretary of the Treasury to "conduct any appropriate testing of appropriate coinage metallic materials within or outside of the Department of the Treasury." This chapter discusses the testing that was completed in fulfillment of this article. The testing program was designed with several goals in mind. The primary goal was to develop a consistent set of quantitative measures to define the ability of alternative material candidates to meet the requirements of coinage production and circulation. A secondary goal was to quantify the properties of incoming raw materials so that specifications can be developed[36] for and used by suppliers. Meeting these specifications will ensure consistent performance during processing at and the quality of products produced by the United States Mint. Finally, by comparing the performance of alternative material candidates with known characteristics and properties of incumbent coinage materials, the acceptability of alternative materials as suitable replacements for incumbent materials was determined.

2.2 APPROACH

During the testing program, Concurrent Technologies Corporation (CTC) evaluated materials in three distinct product forms: 1) incoming material, 2) ready-to-strike (RTS) planchets[37] and 3) struck pieces. In addition, the response of alternative material candidates during striking trials was evaluated. Parallel tests were performed on materials provided by the United States Mint, representing incumbent coinage materials and on the alternative material candidates. Table 2-1 presents an outline of the testing program. Two types of test materials were received from the material suppliers: strip and planchets. Test protocols differed slightly based on the form of the materials received. Those that were received as rolled strip required more extensive preparation and underwent additional tests compared with those materials that arrived as RTS planchets. The additional tests for strip materials were included to characterize material response to the additional processing steps (blanking, annealing and cleaning) needed to prepare the materials for striking at the United States Mint.

The tests were chosen to evaluate material qualities that were identified by the United States Mint as important in the production and longevity of circulating coinage. As described below, well-accepted test protocols were chosen that are directly related to the performance of coinage materials.

The testing program consisted of four phases.

- Phase 1: measure basic material properties needed to characterize the state of incoming alternative material candidates and compare these properties to those of incumbent materials.

[36] Defining final specifications for individual materials was beyond the scope of the present study.
[37] A planchet is the product form at an intermediate step in processing. It is a round disk with a raised rim and is in a condition that is ready for striking to the final coin dimensions and image.

- Phase 2: conduct testing to evaluate material properties after blanks were prepared from the alternative material candidates and on those materials supplied in planchet form.
- Phase 3: complete striking trials[38] to investigate how well the alternative material candidates fill the fine details present in nonsense dies[39] during conventional striking operations.
- Phase 4: evaluate performance of nonsense pieces.

Table 2-1 summarizes the four phases of the Testing Program.

Table 2-1. Test Program Summary

Test Phase	Strip Tests*	Planchet Tests
1: Testing Incoming Materials	Hardness Tensile Strength Steam Corrosion (bare metal) Electrical Conductivity	Hardness Not Applicable (N/A)** Steam Corrosion (bare metal) Electrical Conductivity
2: Testing Blanks/RTS Planchets	Hardness Steam Corrosion (prepared surface) Grain Size Electrical Conductivity	N/A (Identical to incoming materials)** Steam Corrosion (prepared surface) Grain Size N/A (Identical to incoming materials)**
3: Striking Trials (Conducted at the United States Mint)	Edge thickness Design fill Diameter Progressive Strikes-Tonnage/Load Tests	
4: Testing Struck Pieces	Steam Corrosion Wear Coin-Acceptance Equipment Tests	

* Strip product required material preparation including: blanking, annealing, cleaning and lubricating.
** Tests not performed on planchets during this phase of testing.

The first test phase was intended to measure basic properties needed to characterize the state of incoming alternative material candidates and compare these properties to those of incumbent coinage materials. These tests provided quantitative information on material hardness, tensile strength, corrosion and electrical conductivity. Materials received as planchets were tested for hardness, corrosion and electrical conductivity. Standard tensile tests could not be performed on planchets due to their small size.

- Hardness is a quick test to characterize anticipated material behavior in blanking.[40] Soft materials (i.e., those with low hardness) tend to deform into a shape like a saucer during blanking, leading to discs that are not flat, which can jam coin-production machinery during subsequent processing. Relatively hard materials, on the other hand, tend to fracture cleanly during blanking to form relatively flat discs.

[38] Upsetting of blanks was completed at the United States Mint when alternative material candidates were delivered to CTC as sheet material.
[39] Nonsense dies included an image of Martha Washington on the obverse, a scene on the reverse and letters that were scrambled. These features were designed to replicate the detailed images common to circulating coins.
[40] Blanking involves punching a flat circular disk of material from sheet.

- Tensile properties define the strength and ductility of materials. These properties are influenced by the material's elemental composition and the manufacturing steps taken to prepare the material, including cold and hot working (i.e., rolling) and heat treatment to control microstructure (grain size).
- Steam corrosion tests determine the inherent tendency of a material to change in appearance over time; high corrosion numbers indicate that the material will substantially change in appearance during circulation, creating a potential public acceptance issue.
- Eddy current electrical conductivity is a primary material property used by coin-acceptance equipment in vending machines and other devices; a material's electrical conductivity indicates how well it can perform in vending machines and other coin-processing equipment.

The second phase of testing was conducted after blanks were prepared from the alternative material candidates and on those materials supplied in planchet form. In the case of materials received as strip, blanks were punched first. The blanks were then annealed to reduce their hardness, making them more suitable for upsetting and striking. After being annealed, the blanks were cleaned and lubricated in preparation for upsetting and striking at the United States Mint. Procedures for blanking, annealing, cleaning and lubricating are discussed in Appendix 2-A. Following these processes, hardness, color, corrosion response, grain size and electrical conductivity were measured.

- While blanking requires a relatively hard, easily sheared material for effective processing, soft materials have a tendency to perform well, both in terms of low press tonnage and in completeness of coin fill, during coin striking. Therefore, blanks are annealed prior to upsetting and striking. Note that if a struck coin is too soft, it will be susceptible to rapid wear during circulation. Therefore, careful control of material hardness is necessary through each step of producing coins.
- Color measurements provide a quantitative standard for comparing the appearance of alternative material candidates with incumbent coinage.
- The steam corrosion test provides quantitative information about the performance of materials. However, in some instances the material response during processing at the United States Mint differs after application of corrosion inhibitors are introduced in the cleaning/lubricating operation.
- Grain[41] size measurements were performed on RTS planchets. Grain size is important during striking. Grain sizes over 50 microns (µm) have been correlated with visible surface finish problems for incumbent coinage materials. This is often referred to as "orange peel" due to the mottled appearance of surfaces showing this effect. Annealing temperature and time were controlled to prevent grain growth that could significantly impact mechanical properties and coin appearance.
- Electrical conductivity measurements were repeated to ensure that the annealing heat treatment did not change the electrical conductivity of the materials.

The third phase of testing involved striking trials to investigate how well the alternative material candidates fill nonsense dies during conventional striking operations. The striking trials were

[41] All metallic materials have defined grains, which are three-dimensional regions of similarly ordered atomic structure. Collectively, a number of grains constitute a particular piece of metal and the average size of the grains has a strong influence on its mechanical properties.

completed at the United States Mint in Philadelphia. Two rounds of striking tests were conducted.

During Round One striking tests, a wide range of alternative materials was tested. Approximately 4.5 kilograms (kg) (10 pounds [lbs]) of each material were obtained from suppliers. Fewer than 100 nonsense test pieces were produced from each material. Results from this first striking trial were used to select a subset of these materials for testing in a more comprehensive striking trial (Round Two) where a larger number of nonsense test pieces were struck. The material selection process is described in detail in the Material Down Select for Round Two Striking Trials Section of this chapter.

A second round of striking trials was conducted using the materials that performed well in Round One; additional materials were also tested in Round Two. Typically, approximately 500 nonsense pieces[42] were produced from each material in the second striking trail. In many cases 45 kg (100 lbs) of material were obtained but only 500 nonsense pieces were struck; minimizing the number of struck nonsense pieces helped to keep security of these unique assets manageable.[43] During both rounds of strike tests, a progressive striking load test was completed first for each alternative material candidate. This test was used to determine each material's response to striking load within production press dies. The progressive striking load test consisted of a series of strikes at increasing tonnages until edge thickness, diameter and design fill were considered optimum as defined by both an experienced press operator and a United States Mint development engineer. The progressive striking force tests yielded valuable information about the properties and performance of each alternative material candidate (as discussed throughout this chapter). After selecting the optimum striking load, approximately 500 nonsense pieces were struck from each alternative material candidate.

Phase 4 testing was performed on the nonsense pieces to evaluate material performance. These tests included: wear tests to evaluate relative performance in circulation; steam corrosion tests to evaluate any possible color-change or appearance issues of the nonsense pieces during circulation; and coin-processing equipment tests to determine the ability of these devices to discriminate and accept the nonsense pieces relative to incumbent circulating coins. Phase 4 tests were performed on nonsense pieces from both rounds of striking trials.

2.3 TEST PROTOCOLS

Standard test methods, where practical, were followed to characterize the alternative material candidates. In addition, test methods, developed by the United States Mint; including steam corrosion, wear and progressive striking were followed,[44] to characterize alternative material candidates for US circulating coinage. Tests developed by the coin-processing equipment manufacturers were also followed. The application of these test methods for each phase of material processing is discussed below.

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[42] The term "nonsense pieces" (or similar terminology) is used to identify those items resulting from strikes with nonsense dies. The term "coin" refers to items that are fit for circulation. Obviously, candidate materials would yield nonsense pieces.

[43] Security of such rare and unique pieces requires strict control and accountability.

[44] Selected wear tests were halted after a two weeks as discussed in this chapter.

Phase 1 – Standard protocols, where practical, were used for the tests performed on incoming materials.

- Hardness readings were obtained following the ASTM International (formerly American Society for Testing and Materials) E18 standard [1]. The Rockwell 15T measurement protocol was used since it is the United States Mint standard and is well correlated with striking experience. Calibration blocks were used before and after making readings on test materials to confirm that the readings were accurate.
- Tensile testing was conducted in accordance with the ASTM E8 standard [2] using a Tinius-Olsen test machine.
- Steam corrosion tests were conducted following the United States Mint Two-Hour Steam Test Procedure, defined in Appendix 2-B. This procedure has been proven to correlate with the behavior of circulated incumbent coins.
- Electrical conductivity testing was conducted in accordance with the ASTM E1004 standard [3] using a Foerster Sigmatest 2.069 instrument.

Phase 2 – Standard protocols, where practical, were used for the tests performed after blanking and cleaning/lubricating.

- Hardness, steam corrosion and electrical conductivity testing was performed as described above.
- Color measurement was performed according to the ASTM E308 standard [4] using an X-Rite SP62 spectrophotometer.
- Grain size determinations were made following the ASTM E112 standard [5]. Cut cross sections of the blanks were mounted in plastic surrounds (for ease of handling) and polished. The polished surfaces were etched to reveal grain boundaries using etchant chemicals tailored to each material, and the surfaces examined at 100x to 500x using a Leco metallograph optical microscope.

Phase 3 – First round striking trials were conducted at the United States Mint in Philadelphia in the Research and Development (R&D) room, a separate area with production equipment where controlled tests and strikes can be conducted without jeopardizing production equipment or contaminating production material. Blanks were upset in a Schuler ST 50 machine using production tooling. For Round One tests, one-cent blanks were upset with dime profile tooling, since the United States Mint does not upset one-cent coins, which arrive as RTS planchets from Jarden Zinc Products (JZP). The configuration of dime upset tooling closely approximates that of one-cent upset tooling. Blanks for the second round test strikes were upset with correctly sized one-cent coin upset tooling that was specifically prepared for these tests. The planchets were then struck using nonsense dies on a Schuler MRH 150 press, the same model press utilized for circulating coin production.

- One-cent striking trials included several pieces each struck at 20, 30, 40 and 50 metric tons (tonnes[45]) force.
- 5-cent striking trials spanned 30, 40, 50, 60 and 70 tonnes.
- Quarter dollar striking trials included 27, 36, 45, 54, 62, 65 and 73 tonnes.

Following progressive striking load trials, the nonsense pieces were examined for coin fill, diameter and edge thickness. At least 40 nonsense pieces were made from each material using the

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[45] 1 tonne = 2204.6 pounds.

lowest force that produced acceptable images and dimensions. The highest allowable press load was used when acceptable results could not be achieved.

Round Two striking trials were also conducted following the same process described under the Round One striking trials at the United States Mint in Philadelphia in the R&D room. The same basic procedure of progressively increasing the striking force was followed until the dimensions of the finished piece matched United States Mint requirements for a specific denomination and fine details of the images were observed. For the second round of striking tests, 500 nonsense pieces of each candidate material were struck in order to have a sufficient quantity of nonsense pieces for more extensive coin-processing equipment trials.

Phase 4 – Post striking testing included the steam corrosion test described above as well as wear and coin-processing equipment testing. Wear testing was conducted following the United States Mint protocol, and involved tumbling the nonsense pieces in a plastic drum with leather, cork and fabric materials dampened with artificial sweat solution; see test protocol details in Appendix 2-C.

Wear testing during the course of this project was problematic. Test results proved to be inconsistent, particularly for some materials that were subject to galvanic corrosion, depending on the precise nature of the mix of different nonsense pieces being wear tested. Performing wear tests with a specific candidate material by itself would frequently provide different results compared to wear tests completed with mixed candidate materials. While the wear test was developed to include several commonly encountered wear mechanisms in a single test, i.e., rubbing against cloth, leather and cork materials in a simulated sweat solution to imitate different usage conditions, it is a difficult test to perform in a controlled manner so as to ensure consistent results. The detailed chemistry of actual sweat varies considerably from one individual to another, for example. The wear test results should be taken as a qualitative indication of potential fitness of a candidate material, and small variations do not represent reproducible differences. Using the United States Mint's wear test protocol, the alternative materials can be judged as 'better than', 'roughly equivalent to' or 'worse than' incumbent materials, but no confident prediction of a service lifetime can be made based on the results of this wear test protocol.

Deviations were made to the United States Mint's wear procedure. Preliminary wear testing of material samples before actual wear testing of nonsense pieces showed a continuous increase in weight loss with time; the results followed a very clear trend. There was no indication of sudden changes in weight loss that would alter the relative ranking of one material with respect to others after a two-week test. As discussed below, in Section 2.4.9.2, Additional Round Two Wear Testing; wear test results are best utilized as a relative measure of wear in comparison with incumbent materials; a two-week duration is expected to be fully sufficient to fulfill this purpose.

Round One coin-acceptance equipment trials were conducted using a SCAN COIN SC4000 high-speed coin sorter. For Round One test coins, each batch of 40 nonsense pieces was separately run through the SC4000 on two occasions. Dimensions (diameter and thickness), electrical conductivity and magnetic permeability were measured and recorded for each individual nonsense piece. Incumbent coinage was also measured and used as the baseline to compare the results of nonsense pieces.

Post-strike testing of nonsense pieces from Round Two striking trials followed the United States Mint protocols for steam corrosion and wear testing. A more comprehensive set of validation tests was completed by the coin-processing equipment manufacturers. Three industry representatives (Coinco, MEI and SCAN COIN) were selected to complete these validation tests. Each received 100 nonsense pieces of each alternative material candidate to determine if these candidates could be validated (i.e., recognized as legitimate) in their devices that are currently tuned to accept only US circulating coins. Nonsense pieces that pass these validation tests could be introduced as seamless options for the markets and clients that these industry representatives serve. One of the testing organizations also compared their test results to their databases of coins from over 120 countries throughout the world. This was done to determine the uniqueness of each coin's signature relative to coins in circulation in other countries.

2.4 RESULTS

Test results have been consolidated in the following tables. In some cases, Phases One, Two and/or Four test results are combined in a given table where direct comparisons are desired for a particular property as the candidate materials progressed through the test matrix. Alternative material candidates are grouped by denomination: one-cent, 5-cent, quarter dollar and dollar. All alternative material candidates, with the exception of those for the dollar coin, were tested according to the test plan described above. Dollar coin materials were only tested for steam corrosion as it was deemed that revising the incumbent dollar coin material would have minimal impact to overall United States Mint costs and thus this coin received a lower priority than the other denominations.

2.4.1 Materials Testing

2.4.1.1 Hardness

Rockwell 15T hardness tests results, before and after annealing for incoming materials are shown in Tables 2-2 through 2-4. For materials received as planchets, only post-anneal values are given since pre-anneal hardness values were not received (nor were they required) from the suppliers. The reported values represent the mean of at least four readings taken on each of three separate samples. Hardness between 62 and 72 Rockwell 15T are considered nominal for RTS planchets at the United States Mint. Some of the alternative material candidates could not be produced or annealed to a hardness value within this range. For example, the aluminized steel samples could not be annealed to soften the steel since the aluminum coating would melt at temperatures below that required to anneal the steel core. Stainless steels are inherently hard and could not be further softened to meet this hardness range. Other alternative material candidates, however, could either be supplied or heat treated to fall in the desirable hardness range.

Table 2-2. Rockwell 15T Hardness for One-Cent Coin Alternative Material Candidates

Material	Phase 1 Hardness Incoming Material (pre anneal)	Phase 2 Hardness RTS (post anneal)
Copper-Plated Zinc (Incumbent Material)	N/A	62–72
Aluminized Steel (Ryerson)	N/A*	83
Aluminized Steel (Atlas)	N/A*	74
Aluminum-Magnesium (Al-Mg) Alloy 5052-H32	N/A*	70
Copper-Plated Steel – JZP	N/A**	61
Copper-Plated Steel – Royal Mint	N/A**	78
302HQ Stainless Steel	82	73
430 Stainless Steel	N/A*	83

* Material supplied as strip, but not annealed for these tests.
** Material supplied as RTS planchet; therefore, no annealing required.

Table 2-3. Rockwell 15T Hardness for 5-Cent Coin Alternative Material Candidates

Material	Phase 1 Hardness Incoming Material (pre anneal)	Phase 2 Hardness RTS (post anneal)
Cupronickel (Incumbent Material)	88	60–69
Dura-White-Plated Zinc	N/A**	69.5
Multi-Ply-Plated Steel (Lot # 11-137)	N/A**	65.5
Multi-Ply-Plated Steel (Lot # 11-170)	N/A**	65
Nickel-Plated Steel	N/A**	75
G6 Mod	88.5	69
302HQ Stainless Steel (Blanked at CTC)	82	77
302HQ Stainless Steel (Blanked at Carpenter Technology)	82	74
430 Stainless Steel	N/A*	87.5
669z	90	73.5
Nickel-Plated 31157	N/A*	71
Unplated 31157	N/A*	68

* Material supplied as strip, but not annealed for these tests.
** Material supplied as RTS planchet; therefore, no annealing required.

Table 2-4. Rockwell 15T Hardness for Quarter Dollar Coin Alternative Material Candidates

Material	Phase 1 Hardness Incoming Materials (pre anneal)	Phase 2 Hardness RTS (post anneal)
Cupronickel-Clad C110 (Incumbent Material)	83	50–60
Multi-Ply-Plated Steel	N/A**	65
Nickel-Plated Steel	N/A**	77.5
669z-Clad C110	87.5	45
302HQ Stainless Steel	N/A*	73.5
Dura-White-Plated Zinc	N/A**	66.5

* Material supplied as strip, but not annealed for these tests.
** Material supplied as RTS planchet; therefore, no annealing required.

2.4.1.2 Tensile Properties

Tensile properties for incoming materials delivered in sheet or strip form are shown in Tables 2-5 through 2-7; tensile tests were not performed on material received as planchets. As mentioned above, the primary purpose of these measurements was to more fully characterize the incoming materials.

From the results of these tensile tests, there does not seem to be a direct correlation between tensile properties and coining performance, particularly since these properties were measured in the as-delivered state, without heat treatments or further preparations for producing RTS planchets.

- Yield strength represents the point at which a material begins to deform plastically (0.2% plastic offset), measured in thousands of pounds of force applied per square inch of cross section of material (ksi).[46]
- Ultimate tensile strength (UTS) is the maximum load per initial unit area (ksi) that the material can withstand before fracture.
- Elongation measures how much the material stretches plastically before breaking. It is measured in percentage, which refers to the ratio of the extension (i.e., the linear amount that the specimen was stretched) divided by the original length of the unloaded specimen.
- Young's Modulus is a measure of material stiffness and is measured in millions of pounds per square inch (Msi).

[46] Pascals are used to measure load per unit in the metric system. 1 Pascal = 0.000145037 psi.

Table 2-5. Tensile Properties of One-Cent Coin Alternative Material Candidates

Material	Tensile Properties			
	Yield Strength (ksi)	**UTS (ksi)**	**Elongation (%)**	**Young's Modulus (Msi)**
Copper-Plated Zinc (Incumbent Material)	22	26	80	10
Aluminized Steel (Ryerson)	52	62	27	37
Aluminized Steel (Atlas)	29	49	37	13
Al-Mg Alloy 5052-H32	25	36	11	11
Copper-Plated Steel	N/A	N/A	N/A	N/A
302HQ Stainless Steel	N/A*	N/A	N/A	N/A
430 Stainless Steel	47	73	32	45

*See 5-cent coin alternative material candidates result below.

Table 2-6. Tensile Properties of 5-Cent Coin Alternative Material Candidates

Material	Tensile Properties			
	Yield Strength (ksi)	**UTS (ksi)**	**Elongation (%)**	**Young's Modulus (Msi)**
Cupronickel (Incumbent Material)	95	96	2.5	32
Dura-White-Plated Zinc	N/A	N/A	N/A	N/A
Multi-Ply-Plated Steel (Lot # 11-137)	N/A	N/A	N/A	N/A
Multi-Ply-Plated Steel (Lot # 11-170)	N/A	N/A	N/A	N/A
Nickel-Plated Steel	N/A	N/A	N/A	N/A
G6 Mod	122	126	3.5	23
302HQ Stainless Steel	35.5	83.5	43.5	33
430 Stainless Steel	56.5	86.5	27	32
669z	112	112	3	25
31157 (Plated and Unplated)	N/A	N/A	N/A	N/A

Table 2-7. Tensile Properties of Quarter Dollar Coin Alternative Material Candidates

Material	Tensile Properties			
	Yield Strength (ksi)	**UTS (ksi)**	**Elongation (%)**	**Young's Modulus (Msi)**
Cupronickel-Clad C110 (Incumbent Material)	64.5	65.5	5.3	26
Multi-Ply-Plated Steel	N/A	N/A	N/A	N/A
Nickel-Plated Steel	N/A	N/A	N/A	N/A
669z-Clad C110	74.3	74.5	3	29
302HQ Stainless Steel	N/A	N/A	N/A	N/A
Dura-White-Plated Zinc	N/A	N/A	N/A	N/A

2.4.1.3 Steam Corrosion Testing

Steam corrosion tests results from Phases 1, 2 and 4 are shown in Tables 2-8 through 2-11. The test values represent the total change of the color of the material surface in three-dimensional (3-D) CIE Lab space after 2 hours of exposure to low-pressure steam. The International Commission on Illumination (CIE) established the first scientific system for defining color in 1931 [6]. The modified version of this system, CIE Lab, is still considered the best quantitative definition of perceived color. Three values are measured: "L" represents the lightness of the color; "a" the degree to which a color is more red or more green; and "b" the degree of yellowness versus blueness. "L" can only take positive values; "a" is positive for red colors and negative for green colors; and "b" is positive for yellow colors and negative for blue colors. The 3-D Lab number can be treated as a vector which points to a specific color. Determining the 'total color vector change' provides a single number that represents the magnitude of color change. The total color vector change was used to define the color change resulting from corrosion during the steam corrosion tests. The details of how the color changes are less important than identifying the magnitude of any change in color.

Higher 'total color vector change' numbers, as shown in Tables 2-8 through 2-11, represent larger changes in visual appearance. Previous United States Mint studies have shown that Phase 1 total color vector change numbers are better predicators of color change during circulation and Phase 2 and Phase 4 total color vector change numbers are indicative of blank/planchet finishing effectiveness in maintaining a consistent workpiece color.[47]

As indicated in Tables 2-9 and 2-10, the three copper alloys (G6 mod, 669z and unplated 31157) have a greater total color vector change than the incumbent cupronickel alloy. This suggests that these alloys may undergo greater discoloration during circulation.

[47] This information was received from a United States Mint engineer in approximately March 2012.

Table 2-11 includes results for dollar coin alternative materials. These materials were not subjected to the full range of tests in this study; only their corrosion performance and color values were measured. Of these potential materials, only 88Cu-12Sn-plated zinc is not significantly worse in color change resulting from the two-hour steam corrosion tests.

RTS planchets are treated with chemicals designed to protect the surface and provide some lubrication during striking. As a result, these product forms are expected to show less color change than untreated materials. Prior to testing, incoming materials were lightly sanded according to United States Mint Steam Corrosion Test Protocol (using 1200-grit silicon carbide paper), to remove any surface treatments and provide a measurement of the inherent corrosion behavior of a given material.

Appendix 2-D contains pictures of incoming candidate material and RTS planchets after steam corrosion testing. Appendix 2-E contains pictures of nonsense pieces before and after steam corrosion testing. It is very difficult to show the subtle color shifts typical of this test in photographs; however, the relative magnitude of the sensitivity of these materials to steam corrosion can be easily seen from the photographs by comparing the results of several different alloys.

Table 2-8. Steam Corrosion Color Change of One-Cent Coin Alternative Material Candidates

Material	**Phase 1 Steam Corrosion Incoming Material**	**Phase 2 Steam Corrosion RTS**	**Phase 4 Steam Corrosion as Struck**
	Total Color Vector Change	Total Color Vector Change	Total Color Vector Change
Copper-Plated Zinc (Incumbent Material)	N/A	5.5	6.6
Aluminized Steel (Ryerson)	13.7	N/A*	10
Aluminized Steel (Atlas)	14	N/A*	7.7
Al-Mg Alloy 5052-H32	2.5	2.6	4.9
Copper-Plated Steel – JZP	N/A**	16.3	14.9
Copper-Plated Steel – RM	N/A**	5.7	6.5
302HQ Stainless Steel	8.4	3.5	2.8
430 Stainless Steel	1.3	1.3	N/A***

* Materials were not processed further for striking. RTS results are equivalent to “Incoming Material” results.
** Supplied as RTS planchets.
*** Material did not feed through the press during striking trials at the United States Mint. Therefore, no 430 stainless steel one-cent nonsense pieces were available for subsequent evaluations.

Table 2-9. Steam Corrosion Color Change of 5-Cent Coin Alternative Material Candidates

Material	**Phase 1 Steam Corrosion Incoming Material**	**Phase 2 Steam Corrosion RTS**	**Phase 4 Steam Corrosion as Struck**
	Total Color Vector Change	Total Color Vector Change	Total Color Vector Change
Cupronickel (Incumbent Material)	19	4.7	4.4
Dura-White-Plated Zinc	N/A*	1.0	2.7
Multi-Ply-Plated Steel (Lot # 11-137)	N/A*	2.3	0.9
Multi-Ply-Plated Steel (Lot # 11-170)	N/A*	3.4	0.7
Nickel-Plated Steel	4.2	3.9	3.3
G6 Mod	33	5.9	7.1
302HQ Stainless Steel	8.4	3.5	0.8
430 Stainless Steel	8.0	1.2	0.4
669z	34.5	8.7	6
Nickel-Plated 31157	N/A*	0.5	0.7
Unplated 31157	25.5	12	5.5

* Supplied as RTS planchets.

Table 2-10. Steam Corrosion Color Change of Quarter Dollar Coin Alternative Material Candidates

Material	**Phase 1 Steam Corrosion Incoming Material**	**Phase 2 Steam Corrosion RTS**	**Phase 4 Steam Corrosion as Struck**
	Total Color Vector Change	Total Color Vector Change	Total Color Vector Change
Cupronickel-Clad C110 (Incumbent Material)	21.5	8.5	4.5
Multi-Ply-Plated Steel	N/A*	4.2	2.4
Nickel-Plated Steel	4.1	2.1	3.3
669z-Clad C110	34.5	8.7	4.8
302HQ Stainless Steel	**	**	4.4
Dura-White-Plated Zinc	**	**	1.8

* Supplied as RTS planchets.
** See results under 5-cent coin alternative material candidates table.

Table 2-11. Steam Corrosion Color Change of Dollar Coin Alternative Material Candidates

Material	Phase 1 Steam Corrosion Incoming Material	Phase 2 Steam Corrosion RTS
	Total Color Vector Change	Total Color Vector Change
Manganese Brass-Clad C110 (Incumbent Material)	14.5	4
88Cu-12Sn-Plated Zinc	14	4.2
C69250	39	5.7
K474	37	7.0

2.4.1.4 Eddy Current Electrical Conductivity

Eddy current electrical conductivity[48] measurements from Phases 1 and 2 are reported in Tables 2-12 through 2-14. These measurements were conducted over a range of frequencies. The highest and lowest frequency values are reported in the tables.

- At high frequencies (e.g., 960 kilohertz [kHz]), the input signal is quickly absorbed by the test material. Therefore, under these frequencies, the test method is sensitive only to the materials near the surface of a specimen. Conversely, at low frequencies (e.g., 60 kHz), the signal passes further into the specimen allowing for the determination of the materials below the surface (i.e., at the core) of a test specimen.[49] The standard eddy current measurements cannot be directly correlated with coin-processing equipment performance. Each model of coin-processing equipment must be tested using established and proprietary test methods developed by each coin-processing equipment manufacturer. However, if eddy current electrical conductivity values across the frequency spectrum are similar for two materials, it is likely that they will be recognized as the same material by those sensors that rely upon electrical conductivity. Note that no standard exists among coin-processing equipment manufacturers relative to frequency; each manufacturer relies upon its own frequency (or frequencies). The 60 to 960 kHz frequency range approximately covers the full range of values used among the many coin-processing equipment manufacturers that fabricate and/or market their products within the US. There is further discussion of coin-processing technology in the Outreach Chapter.
- In order for any material to be recognized by current coin-processing equipment, an alternative material must have a stable and detectable electrical conductivity signature. A value of ‘F’ in Tables 2-12 through 2-14 signifies that the instrument could not determine

[48] Electrical conductivity is given as percentage of the International Annealed Copper Standard (%IACS) electrical conductivity of pure copper at 20 degree Celsius (°C). In other words, %IACS is a ratio (expressed as a percentage) of the electrical conductivity of a given material to that of pure copper at 20 °C.

[49] This difference in response to different frequencies, and the corresponding ability to predict the surface material from that of the core of a coin, is important in modern coin-processing technology. It points to the increased security inherent in clad coins (and plated coins to a lesser degree). Note that the specific frequencies used and signal processing algorithms applied varies with each coin-processing equipment manufacturer. Electrical conductivity performance across a range of frequencies is therefore important for each of the alternative material candidates.

an electrical conductivity value, indicating that the material was ferromagnetic.[50] These materials create a signature that is so far removed from those of incumbent US circulating coins that some coin-processing equipment would not identify coins made from these materials. When this occurs, coins cannot be validated, which significantly reduces the security of coins. For example, 430 stainless steel would not be recognizable to some of the coin-processing equipment currently fielded in the US.

- As-received materials were tested. In addition, the electrical conductivity for RTS planchets was also measured for each of the alternative material candidates. Since little or no difference was seen between the two measurements for any given alternative material candidate, it is clear that the blanking, annealing, cleaning, drying and upsetting processes (necessary for materials received as sheet) did not impact the electrical conductivity of these candidate materials.

Table 2-12. Electrical Conductivity for One-Cent Coin Alternative Material Candidates

Material	Phase 1 Electrical Conductivity Incoming Material		Phase 2 Electrical Conductivity RTS	
	%IACS		%IACS	
Test Frequency	60 kHz	960 kHz	60 kHz	960 kHz
Copper-Plated Zinc (Incumbent Material)	N/A	N/A	28	29.5
Aluminized Steel (Ryerson)	F	1.1	F	1.1
Aluminized Steel (Atlas)	F	1.4	F	1.4
Al-Mg Alloy 5052-H32	35	35.5	35	35.5
Copper-Plated Steel – JZP	N/A	N/A	0.3	11.5
Copper-Plated Steel – RM	N/A	N/A	0.5	9.1
302HQ Stainless Steel	1.6	2.3	1.6	2.3
430 Stainless Steel	F	F	F	F

[50] A ferromagnetic material is attracted to a magnetic.

Table 2-13. Electrical Conductivity for 5-Cent Coin Alternative Material Candidates

Material	Phase 1 Electrical Conductivity Incoming Material %IACS		Phase 2 Electrical Conductivity RTS %IACS	
Test Frequency	60 kHz	960 kHz	60 kHz	960 kHz
Cupronickel (Incumbent Material)	N/A	N/A	5.1	5.5
Dura-White-Plated Zinc	N/A	N/A	28.4	29.0
Multi-Ply-Plated Steel (Lot # 11-137)	N/A	N/A	0.3	13.8
Multi-Ply-Plated Steel (Lot # 11-170)	N/A	N/A	0.7	9.5
Nickel-Plated Steel	N/A	N/A	F	0.8
G6 Mod	5.3	6.4	5.3	6.4
302 Stainless Steel	1.6	2.3	1.6	2.3
430 Stainless Steel	F	F	F	F
669z	5.45	5.8	5.4	5.8
Nickel-Plated 31157	N/A	N/A	4.8	5.2
Unplated 31157	N/A	N/A	5.4	5.5

Table 2-14. Electrical Conductivity for Quarter Dollar Coin Alternative Material Candidates

Material	Phase 1 Electrical Conductivity Incoming Material %IACS		Phase 2 Electrical Conductivity RTS %IACS	
Test Frequency	60 kHz	960 kHz	60 kHz	960 kHz
Cupronickel-Clad C110 (Incumbent Material)	N/A	N/A	81	10
Multi-Ply Plated Steel	N/A	N/A	0.3	12.7
Nickel-Plated Steel	N/A	N/A	F	0.7
669z-Clad C110	79.5	10	79.5	10
302HQ Stainless Steel	1.6	2.3	1.6	2.3
Dura-White-Plated Zinc	N/A	N/A	28.7	31.6

2.4.1.5 Color Measurement

Color measurements were performed in Phase 2 on cleaned materials in the RTS state, as shown in Tables 2-15 through 2-18. The spectrophotometer provides three values in the CIE Lab color space.

- The “L” value represents relative ‘lightness’, with 0 representing pitch black and 100 bright white.
- Positive “a” values correspond to red colors, while negative values represent green colors.
- Positive “b” values correspond to yellow colors, while negative values indicate blue colors.

Coppery colors, such as those of a newly minted incumbent one-cent coin, have positive “a” and “b” values. Yellow colors have low “a” and positive “b”, and white colors have low “a” and “b” values.

Table 2-15. Color Measurement of One-Cent Coin Alternative Material Candidates

Material	Color Measurement – CIE		
	L	**a**	**b**
Copper-Plated Zinc (Incumbent Material)	78.3	13.6	17.1
Aluminized Steel (Ryerson)	77.0	0.02	1.1
Aluminized Steel (Atlas)	83.2	–0.02	0.6
Al-Mg Alloy 5052-H32	87.5	–1.2	1.5
Copper-Plated Steel – JZP	81.5	15.8	19.1
Copper-Plated Steel – RM	83.7	15.2	19.0
302HQ Stainless Steel	72.1	0.9	4.9
430 Stainless Steel	76.2	0.2	1.5

Table 2-16. Color Measurement of 5-Cent Coin Alternative Material Candidates

Material	Color Measurement – CIE		
	L	**a**	**b**
Cupronickel (Incumbent Material)	76.3	0.8	6.7
Dura-White-Plated Zinc	89.7	–0.7	5.8
Multi-Ply-Plated Steel (Lot # 11-137)	77.8	0.6	8.9
Multi-Ply-Plated Steel (Lot # 11-170)	81.6	1.2	8.1
Nickel-Plated Steel	84.3	0.3	7.3
G6 Mod	88.4	–1.2	14.1
302HQ Stainless Steel (blanked at CTC)	72.1	0.9	4.9
430 Stainless Steel	73.1	0.2	1.7
669z	86.0	0.4	15.3
Nickel-Plated 31157	78.5	0.7	10.5
Unplated 31157	84.3	–1.0	30.1

Table 2-17. Color Measurement of Quarter Dollar Coin Alternative Material Candidates

Material	Color Measurement – CIE		
	L	**a**	**b**
Cupronickel-Clad C110 (Incumbent Material)	78.5	1.0	7.0
Multi-Ply-Plated Steel	77.6	0.9	9.4
Nickel-Plated Steel	81.1	0.50	8.5
669z-Clad C110	83.6	2.3	16.7
302HQ Stainless Steel	75.5	0.4	6.7
Dura-White-Plated Zinc	89.6	–0.5	5.9

Table 2-18. Color Measurement of Dollar Coin Alternative Material Candidates

Material	**Color Measurement – CIE**		
	L	**a**	**b**
Manganese Brass-Clad C110 (Incumbent Material)	82.3	2.9	14.6
88Cu-12Sn-Plated Zinc	79.3	7.9	20.3
C69250	80.8	1.7	13.6
K474	81.9	0.5	15.5

2.4.1.6 Grain Size

Phase 2 grain size measurements and typical photomicrographs of each test material are shown in Tables 2-19 through 2-21. Alternative material candidates used in more than one denomination are only shown once among these three tables. The reported grain size represents a statistical mean of grains using the ASTM E112 methodology [5]. In cases where the grains are not approximately the same overall dimension in all directions, the ASTM E112 methodology declares the grains 'deformed' and the method cannot be used. Those instances are denoted in the tables with an asterisk; engineering estimates are provided for typical grain dimensions for these cases. Grain sizes over 50 microns (µm) have been correlated with visible surface finish problems for incumbent coinage materials. This is often referred to as "orange peel" due to the mottled appearance of surfaces showing this effect. Material with a grain size greater than 50 µm is therefore undesirable.

Table 2-19. Grain Size of One-Cent Coin Alternative Material Candidates

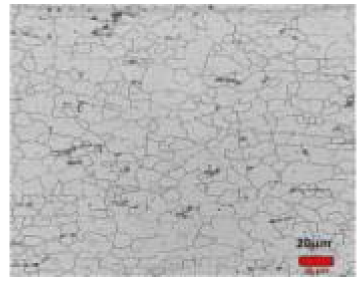
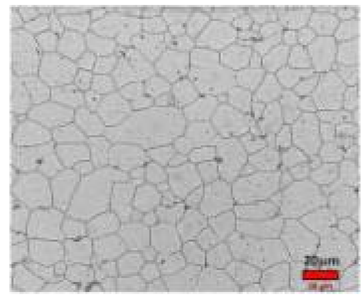
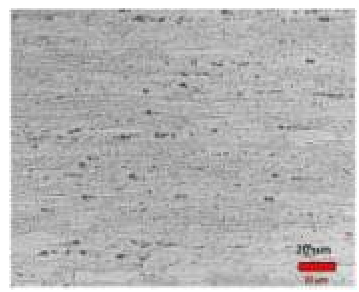
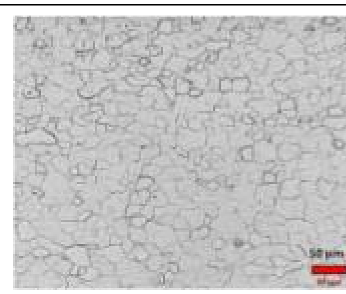
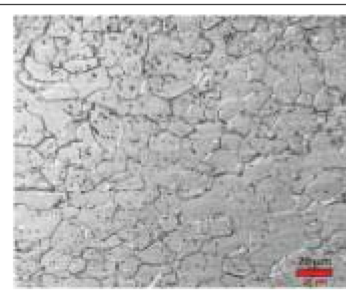
Material	**Mean Grain Size (microns)**	**Photomicrograph**
Aluminized Steel (Ryerson)	7.7	
Aluminized Steel (Atlas)	12.1	
Al-Mg Alloy 5052-H32	20 by 80*	
Copper-Plated Steel (JZP)	17.9	
430 Stainless Steel	9.8	

Table 2-20. Grain Size of 5-Cent Coin Alternative Material Candidates

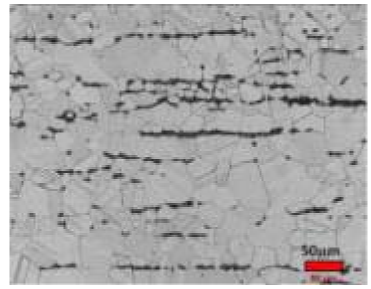
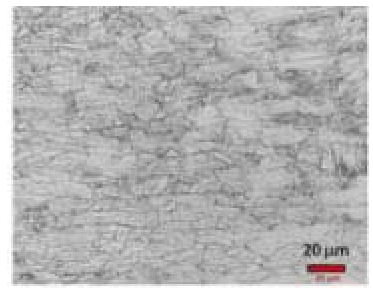
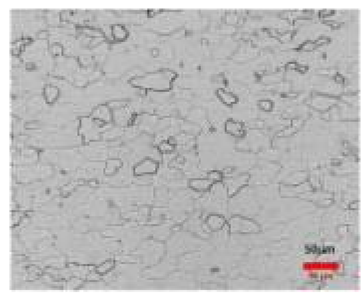
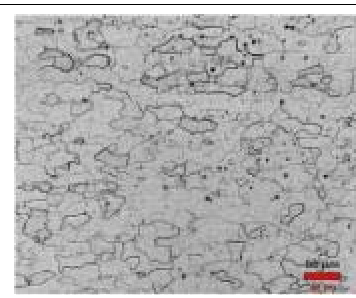
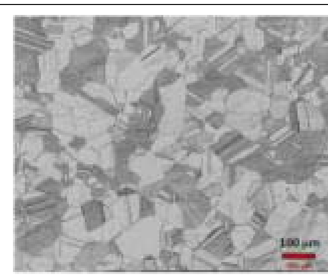
Material	Mean Grain Size (microns)	Photomicrograph
Cupronickel (Incumbent Material)	23.0	
Dura-White-Plated Zinc	varied	
Multi-Ply-Plated Steel (Lot # 11-137)	21.5	
Multi-Ply-Plated Steel (Lot # 11-170)	19.8	
G6 Mod	49.5	

Table 2-20. Grain Size of 5-Cent Coin Alternative Material Candidates (continued)

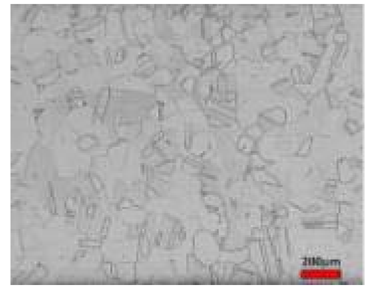
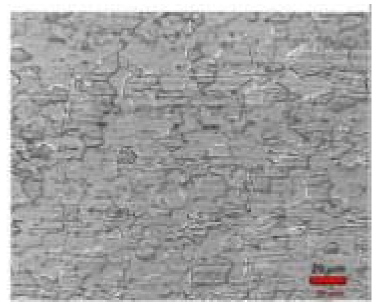
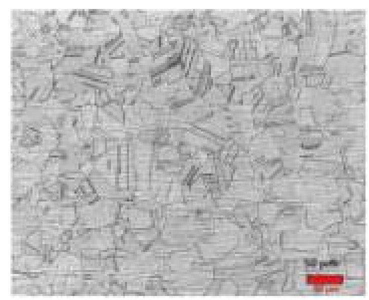
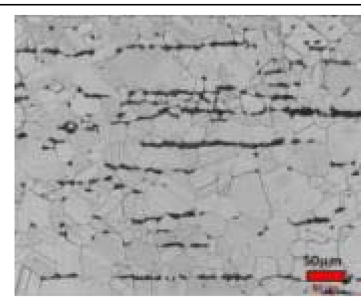
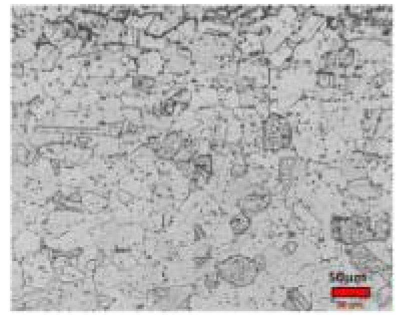
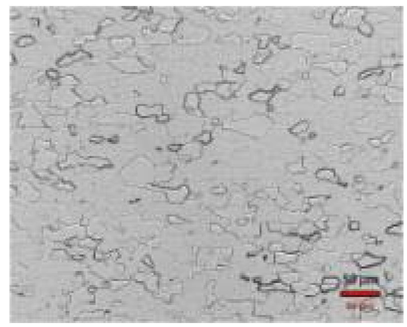
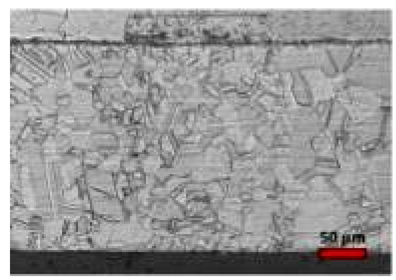
Material	Mean Grain Size (microns)	Photomicrograph
302HQ Stainless Steel	76.2	
430 Stainless Steel	8.8	
669z	20.7	
Plated 31157	23.0	

Table 2-21. Grain Size of Quarter Dollar Coin Alternative Material Candidates

Material	Mean Grain Size (microns)	Photomicrograph
Cupronickel-Clad C110 (Incumbent Material)	22.4	
Multi-Ply-Plated Steel	19.2	
669z-Clad on C110	19.1	

2.4.2 Round One Striking Trails

Progressive striking trials were conducted for each alternative material candidate. Round One striking tests consisted of approximately 4.5-kg (10-lb) lots of each candidate material, with the single exception of the 430 stainless steel in one-cent gage. This material was undersized and too thin to feed reliably through the striking press. Tables 2-22 through 2-24 show the striking loads used to produce the Round One (40-piece) lots of nonsense pieces. In most cases the materials performed in similar fashion to the incumbent materials. The exceptions were the aluminized and stainless steels. At nominal striking loads or even at the highest safe striking load permitted by the coin presses and dies, nonsense pieces produced with aluminized and stainless steel did not exhibit complete coin fill (i.e., the struck imagine lacked some details of the desired image). Incumbent materials were struck in advance of Round One striking trials in order to generate baseline data; information related to incumbent coinage materials is included in the tables for comparison only.

Table 2-22. Progressive Strike Results for One-Cent Coin Alternative Material Candidates – Round One

Material	Test Coin Striking Load (tonne)	Difference from Incumbent Coin (tonne)	Comment
Copper-Plated Zinc (Incumbent Material)	40	--	N/A
Aluminized Steel (Ryerson)	50	+10	Insufficient coin fill
Aluminized Steel (Atlas)	50	+10	Insufficient coin fill
Al-Mg Alloy 5052-H32	35	–5	None
Copper-Plated Steel	40	0	None
430 Stainless Steel	N/A	N/A	Too thin to strike

Table 2-23. Progressive Strike Results for 5-Cent Coin Alternative Material Candidates – Round One

Material	Test Coin Striking Load (tonne)	Difference from Incumbent Coin (tonne)	Comment
Cupronickel (Incumbent Material)	54	--	N/A
Dura-White-Plated Zinc	54	0	None
Multi-Ply-Plated Steel (Lot # 11-137)	54	0	Met low end of dimensional specifications*
Multi-Ply-Plated Steel (Lot # 11-170)	54	0	Met low end of dimensional specifications*
G6 Mod	54	0	None
669z	54	0	None
Nickel-Plated 31157	54	0	None
302HQ Stainless Steel (blanked at CTC)	70	+16	Insufficient coin fill
302HQ Stainless Steel (blanked by Carpenter Technology)	70	+16	Insufficient coin fill
430 Stainless Steel	70	+16	Insufficient coin fill

* United States Mint's finished coin specifications for incumbent coins.

Table 2-24. Progressive Strike Results for Quarter Dollar Coin Alternative Material Candidates – Round One

Material	Test Coin Striking Load (tonne)	Difference from Incumbent Coin (tonne)	Comment
Cupronickel-Clad C110 (Incumbent Material)	62	--	N/A
Multi-Ply-Plated Steel	62	0	None
669z-Clad C110	62	0	None

2.4.3 Observations from Striking Trails – Round One

Nonsense pieces were successfully produced from most of the candidate materials. Photographs of nonsense pieces produced at the specified press tonnage are included below. Surface details can be reliably compared in these photographs. Note however that the lighting conditions were not optimized for photography; therefore colors in the photographs that follow are not reliable indications of the actual nonsense piece colors.

2.4.3.1 One-Cent Nonsense Pieces

One-cent nonsense pieces of aluminized steel from Atlas and Ryerson are shown in Figure 2-1. These nonsense pieces were struck at 50 tonnes. Note that 40 tonnes is the nominal striking load for the incumbent copper-plated zinc one-cent coin.

(a) Atlas Material (b) Ryerson Material

Figure 2-1. Aluminized steel one-cent nonsense pieces struck at 50 tonnes.

Aluminum alloy 5052-H32 purchased from a warehouse showed excellent coin fill at low striking loads (Figure 2-2). Note that a mechanical malfunction caused the dies to clash before the 5052-H32 nonsense pieces were struck. The damage resulting from the die clash caused some blurring of the letters. Nevertheless the 5052-H32 had excellent surface detail at a low striking load of 35 tonnes.

Note: The visible scoring is from a die clash that damaged the dies before this nonsense piece was struck.

Figure 2-2. 5052-H32 one-cent nonsense piece struck at 35 tonnes.

The copper-plated steel planchets produced by JZP (Figure 2-3) displayed good fill at a nominal striking load of 40 tonnes.

Figure 2-3. JZP copper-plated steel one-cent nonsense piece struck at 40 tonnes.

Grade 430 stainless steel was purchased from a warehouse and was significantly under the gage ordered; therefore, it did not feed properly into the press. The progressive striking trial was halted after a die clash when it was determined that the sample pieces were getting stuck underneath the feed fingers. Those 430 stainless steel nonsense pieces that were successfully struck were found to have inadequate coin fill.

2.4.3.2 5-Cent Nonsense Pieces

The Dura-White material provided by JZP comprised copper plated on a zinc alloy (A190) and subsequentially plated with tin. The Dura-White-plated zinc was struck at 54 tonnes. This material showed good coin fill as noted in Figure 2-4.

Figure 2-4. Dura-White-plated zinc 5-cent nonsense piece struck at 54 tonnes.

The Multi-Ply-plated steel material striking trials were performed at 54 tonnes, the nominal striking load for the incumbent 5-cent coin. The surface was shiny and attractive as seen in Figure 2-5.

(a) Lot # 11-137 (b) Lot # 11-170

Figure 2-5. Multi-Ply-plated steel 5-cent nonsense pieces struck at 54 tonnes.

The three copper-based alloys designed to be seamless replacements for cupronickel all had good coinability; showing complete coin fill at nominal press loads – see Figure 2-6. Each nonsense piece had an attractive appearance, but G6 mod and 669z displayed a slight yellow cast. The color cast was reduced during striking, but returned once the nonsense pieces were exposed to the atmosphere for several days. The nickel-plated 31157 nonsense piece was found to have a shinier white color than incumbent cupronickel 5-cent coins. Alloys were obtained from Olin Brass (G6 mod), PMX Industries, Inc. (PMX) (669z) and JZP (nickel-plated 31157).

(a) G6 mod

(b) 669z

(c) Nickel-plated 31157

Figure 2-6. Copper-based alloys G6 mod, 669z and nickel-plated 31157 5-cent nonsense pieces struck at 50–54 tonnes.

Grade 302HQ stainless steel from Carpenter Technology required a higher striking load and did not achieve acceptable edge fill at the highest allowable press load. Two different annealing heat treatments were tested to determine if improved coin fill could be achieved at lower striking loads.[51] Despite a 4% difference in measured hardness, the two variants did not show substantial differences in coin fill, as seen in Figure 2-7.

(a) Standard anneal – blanked at CTC (b) Alternative anneal – blanked at Carpenter Technology

Figure 2-7. 302HQ stainless steel 5-cent nonsense pieces struck at 70 tonnes.

Commercial-off-the-shelf 430 stainless steel, purchased from a warehouse, displayed poor coinability.[52] Note the poor fill in the lettering near the rim as shown in Figure 2-8. The material's high hardness, reflected in a Rockwell 15T hardness of 88, caused fill and dimensions to be inadequate at a high striking load of 70 tonnes.

Figure 2-8. 430 stainless steel 5-cent nonsense piece struck at 70 tonnes.

[51] Lower striking loads reduce die striking stresses resulting in a reduced rate of die fatigue damage and thereby achieve longer die life.
[52] The pedigree of the 430 stainless steel was not provided and therefore it is unknown.

2.4.3.3 Quarter Dollar Nonsense Pieces

A few factors limited the selection of alternative materials for the quarter dollar candidate materials. Some of the producers could not provide starting stock in the desired gage for quarter dollar alternative material candidates in time for Round One striking trials. In addition, roll cladding of G6 mod or 31157 onto a C110 copper core could not be accomplished in time for these striking trials. CTC was able to obtain 669z roll clad to C110 from PMX and Multi-Ply-plated steel from the Royal Canadian Mint. The Multi-Ply-plated steel planchets were specifically designed to have a unique electromagnetic signature[53] (EMS) based on a database available at the RCM of such signatures for coins throughout the world. Figure 2-9 shows a nonsense piece produced from 669z-clad C110. This material candidate struck to a finished appearance comparable to the incumbent cupronickel-clad quarter dollar coin. The Multi-Ply-plated steel nonsense pieces showed good detail as seen in Figure 2-10.

Figure 2-9. 669z-clad C110 quarter dollar nonsense piece struck at 62 tonnes.

[53] Electromagnetic signature (EMS) is understood in the industry to mean the electrical signal strength of a nearby electromagnetic sensor as a coin passes in close proximity to the sensor. The magnetic field in the vicinity of the emitting sensor, and therefore the electrical current in the EMS receiving sensor, changes as the coin passes by. The change in electrical signal strength is influenced by the materials of construction along with the thickness and distribution of materials within the coin. The signal strength and/or its decay rate are then used by software to validate the coin and determine its denomination. One key determiner of EMS is electrical conductivity.

Figure 2-10. Multi-Ply-plated steel quarter dollar nonsense piece struck at 62 tonnes.

2.4.4 Phase 4 Post Striking Trial Testing – Round One

Two-hour steam corrosion tests were performed on the as-struck nonsense pieces. Total color vector change values were calculated from the spectrophotometer measurements taken before and after exposure. No comparable tests were performed on incumbent materials using the nonsense striking dies; therefore values from steam corrosion testing of unstruck planchets are included in Tables 2-25 through 2-27 for comparison. In general, nonsense pieces with a copper-based exterior had higher total color vector change readings that those with nickel surfaces; the magnitude of total color vector changes for other surfaces were typically between the extreme values represented by the copper-based and nickel-based materials. In general, stainless steel had very low steam corrosion total color vector change readings, although the 302HQ blanked by Carpenter Technology[54] had a distinct oxide coating due to a non-optimized heat treatment. This undesirable oxide appeared to react to the low-pressure steam with a visible color change.

Wear test results are also shown in Tables 2-25 through 2-27. Nominally, the total weight loss in the wear test should not exceed 2% of the original weight according to United States Mint's test procedures. Several of the alternative material candidates met this criterion, while others showed wear beyond 2% after only 309 hours of testing. In the case of Al-Mg alloy 5052-H32 and Dura-White-plated zinc specimens, the excessive wear could be correlated with testing a mixture of different materials at the same time. Materials were grouped for the wear tests by hardness: those with low hardness were placed in one test container; all other samples were placed in a second test container for this round of wear testing. Performing tests on mixed batches of materials does give some insight into possible wear rates during co-circulation of incumbent coins and those made of the alternative material candidates.

Wear testing during the course of this project was problematic. Test results proved to be inconsistent, particularly for some materials that were subject to galvanic corrosion, depending on the precise mix of different nonsense pieces being tested. Performing wear tests with a specific

[54] Due to lack of proper blanking equipment, Carpenter Technology cut blanks with either a waterjet cutter or a wire electro-discharge machine (EDM).

candidate material by itself typically provided different results than when wear tests were completed with mixed materials. While the wear test was developed to include several commonly encountered wear mechanisms in a single test, i.e., rubbing against cloth, leather and cork materials in a simulated sweat solution to simulate different usage conditions, it is a difficult test to perform in a well-controlled manner so as to ensure consistent results. The detailed chemistry of actual sweat varies considerably from one individual to another, for example. The wear test results should be taken as a qualitative indication of potential fitness of a candidate material, and small variations should not be interpreted to represent reproducible differences. Using the United States Mint's wear test procedure, the alternative materials can be judged as 'better than', 'approximately equivalent to' or 'worse than' incumbent materials, but no confident prediction of a service lifetime can be made based on the results of this wear test procedure.

Accelerated corrosion of certain materials occurs when contact between them leads to galvanic corrosion. Dissimilar metals that are simultaneously in contact with one another and a conductive solution (such as artificial sweat) act like a battery, leading to rapid chemical attack of the anodic element of the couple. When aluminum- and tin-plated materials were tested along with other types of coins containing copper or cupronickel in the artificial sweat solution, the aluminum- and tin-plated materials appeared to wear rapidly. This rapid wear was due to a chemical reaction that was dissolving the metal leading to significant weight loss. Subsequent testing of these materials in isolation (see Round Two wear results) shows that they are not particularly susceptible to normal rubbing and sliding wear. Co-circulation with copper-based coins is of concern for the aluminum- and tin-plated alternative material candidates.

As described above, Round One wear testing was performed with materials being mixed according to hardness. It is believed that due to galvanic corrosion between the various materials, all the alternative material candidates can be judged as having worse wear characteristics than the incumbent materials. The only alternative material candidate providing better wear characteristics than the incumbent material; was 302 stainless steel for the 5-cent coin.

Table 2-25. Post Striking Steam Corrosion and Wear Test Results for One-Cent Coin Alternative Material Candidates – Round One

Material	**Steam Corrosion (Total Color Vector Change)**	**Wear Test (% Weight Change)**	
		139 hours	309 hours
Copper-Plated Zinc (Incumbent Material)	5.5	–0.19	–0.89
Aluminized Steel (Ryerson)	10.0	–1.0	--*
Aluminized Steel (Atlas)	7.7	–0.9	–12.6
Al-Mg Alloy 5052-H32	4.9	–1.3	–6.3
Copper-Plated Steel	14.9	–0.67	–3.3
430 Stainless Steel	N/A**	N/A	N/A

* Removed from testing early due to rapid and excessive weight loss in excess of 2%.
** Grade 430 stainless steel was not successfully coined.
Note: Weight loss of all alternative material candidates is above 2% after 309 hours.

Table 2-26. Post Striking Steam Corrosion and Wear Test Results for 5-Cent Coin Alternative Material Candidates – Round One

Material	Steam Corrosion (Total Color Vector Change)	Wear Test (% Weight Change)	
		139 hours	309 hours
Cupronickel (Incumbent Material)	4.7	–0.12	–0.23
Dura-White-Plated Zinc	2.7	–1.8	–10.5
Multi-Ply-Plated Steel (Lot # 11-137)	0.9	–0.10	–0.67
Multi-Ply-Plated Steel (Lot # 11-170)	0.7	–0.07	–0.46
G6 Mod	7.1	–0.26	–0.63
302HQ Stainless Steel (blanked at CTC)*	0.8	N/A	N/A
302HQ Stainless Steel (blanked at Carpenter Technology)	3.0	–0.03	–0.08
430 Stainless Steel**	0.4	N/A	N/A
669z	6.0	–0.28	–0.64
Nickel-Plated 31157	0.7	–0.12	–0.46

* 302HQ stainless steel blanked at CTC was not wear tested. Material from Carpenter Technology was expected to provide comparable wear.
** Grade 430 stainless steel was not successfully coined.

Table 2-27. Post Striking Steam Corrosion and Wear Test Results for Quarter Dollar Coin Alternative Material Candidates – Round One

Material	Steam Corrosion (Total Color Vector Change)	Wear Test (% Weight Change)	
		139 hours	309 hours
Cupronickel-Clad C110 (Incumbent Material)	8.5	–0.17	–0.32
Multi-Ply-Plated Steel	2.4	–0.07	–0.70
669z-Clad C110	4.8	–0.27	–0.61

2.4.5 Phase 4 Coin-Processing Equipment Testing – Round One

Lots consisting of 40 nonsense pieces from each alternative material candidate striking trial were drop tested[55] in a SCAN COIN SC4000 coin sorting machine. These drop tests evaluated several

[55] Although no known industry standard terminology exists for such tests, the basic elements of a "drop test" involves passing test pieces through a coin-processing device while measuring and recording each characteristic and property used by the device to validate coins in fielded units. Comparison of these measured values to known values for

parameters critical to many types of coin-processing equipment for each nonsense piece. These tests are described in detail in the Outreach Chapter.

None of the one-cent alternative material candidates matched the EMS of incumbent one-cent coins. The aluminized steel nonsense pieces were the only alternative candidate failing to meet the diameter size criterion, reflecting resistance to fill during striking.

Alternative material candidates for the 5-cent coin fell into three categories.

- Multi-Ply-plated steel, Dura-White-plated zinc and 302HQ stainless steel nonsense pieces did not match the EMS of the incumbent 5-cent coin; however, these pieces did provide a unique EMS compared to other coins in the world.
- Nonsense pieces of the copper-alloy alternative material candidates, 669z, G6 mod and nickel-plated 31157, demonstrated a good match to the EMS of the incumbent 5-cent coin.
- Grade 430 stainless steel nonsense pieces were rejected by the SC4000 coin sorter as being ferromagnetic and were not passed through the mechanism with the preset test limits used during testing.

Quarter dollar coin alternative material candidates followed the same pattern as 5-cent coin alternative material candidates. The Multi-Ply-plated steel nonsense pieces had measurable EMS properties, but the EMS values were very different than those of the incumbent coins. The 669z-clad copper nonsense pieces had essentially identical measured values compared to those of the incumbent quarter dollar coins.

2.4.6 Material Down Select for Round Two Striking Trials

Materials testing and Round One striking trials were intended to provide guidance for down selecting a more limited number of materials for Round Two striking trials. Those materials with unacceptable Round One test results were dropped from Round Two striking trials, where a larger number of nonsense pieces were to be produced, particularly for more extensive coin-processing equipment testing.

Based on poor coinability, steam corrosion and wear performance, aluminized steel was not considered a worthwhile candidate for further testing. The high striking force required for 430 stainless steel and the substantial difficulty that a purely ferromagnetic material would pose to coin-processing equipment caused its removal from further consideration. One of the two trial Multi-Ply-plated steel alternative material candidates for the 5-cent coin was selected for further testing; there was no indication that the small difference in thickness of individual plated layers that characterized the two Round One candidates would have a substantial impact on acceptability of this material. All other candidate materials were carried into Round Two striking trials unchanged with two minor modifications; new 5052-H32 aluminum strip was obtained from a source with better known material pedigree and 31157 material to be tested in the second round was supplied without nickel plating. Although plating would provide a pure white surface, the plating step increased the costs, and it was decided that testing without plating would provide useful information to guide potential material selection.

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circulating coins, is useful in determining how close the measured characteristics and properties of nonsense pieces are to the desired values. The measured values can also be compared to similar values of known coins and common slugs throughout the world to determine the likelihood of fraud or misvalidation (i.e., acceptance as a different coin than that intended).

Several other changes occurred in the down-selection list before Round Two striking trials began. After discussions with the Royal Mint (RM), it was decided that their extensive experience with plated-steel coinage would be useful to provide additional candidate materials in the present study; in addition, further assessments of plated-steel coins led to a more comprehensive understanding of the issues associated with a material that many are convinced is a low-cost option to incumbent materials used in US circulating coins. Furthermore, the number of global circulating coins that are steel-based is expanding. Accordingly, RTS planchets were procured in three sizes, subjected to the incoming material tests described above, and submitted for Round Two striking trials. Copper-plated steel (CPS) one-cent planchets were tested, along with 5-cent and quarter dollar nickel-plated (aRMour™[56]) steel planchets. The RM's practice of maintaining coin weight, rather than coin thickness, resulted in some deviation from United States Mint specifications for planchets. The one-cent CPS alternative material candidate was thinner than the incumbent one-cent coin. The 5-cent and quarter dollar nickel-plated steel planchets were thicker than those for the incumbent coins. Therefore, it is unclear whether any deviations in the nonsense pieces from the RM-supplied planchets are due to the material properties or to the deviation in planchet thickness.

Although 302HQ stainless steel was primarily considered a viable candidate for the 5-cent coin, 302HQ stainless steel planchets were struck in various denominations as part of a work hardening study for this alternative material candidate. This alloy was originally designed to have exceptional ductility for fastener applications such as rivets. An unintended consequence of this alloy's high ductility is that cupping occurs during blanking—i.e., the blanks are not sufficiently flat to upset and strike. CTC endeavored to work harden the 302HQ to promote cleaner blanking. Unfortunately, all of the available 302HQ had already been rolled to 5-cent coin gage. CTC worked with Carpenter Technology to cold roll some 302HQ to quarter dollar, one-cent and dime coin gages, which would have increasing amounts of cold work. Blanking was observed to be cleaner with reduced cupping with 302HQ in the cold-worked condition. There was also concern that work hardening during striking might lead to the development of a ferromagnetic microstructure in this alloy. By striking materials with different thicknesses, different degrees of work hardening would be induced so that a wider range of potential striking conditions could be investigated.

Several quarter dollar coin-sized Dura-White-plated zinc planchets were tested in Round Two. The thickness of the Dura-White plating varied; planchets of plating thickness 5, 8 and 10 microns were prepared and tested. This effort was primarily intended to evaluate wear response of materials with different starting plating thickness. Given some disappointing results with early wear tests under specific test conditions, further investigation was deemed necessary. Dura-White-plated zinc planchets were also supplied in 5-cent coin size; however, only one plating thickness was delivered for these planchets.

2.4.7 Round Two Striking Trials

Round Two striking trials were conducted in similar fashion to the Round One striking trials; similar nonsense dies and progressive striking load trials were used to determine the minimum striking load necessary to produce nonsense pieces with acceptable dimensions and coin fill. One thousand blanks/planchets of each alternative material candidate were prepared/acquired for use

[56] aRMour™ is a registered trademark of the Royal Mint.

in Round Two striking trials. Once a proper striking load was determined for a given candidate material-denomination combination, a striking trial run of at least 400 nonsense pieces was conducted at normal press production speeds. Each striking trial was split into four 100-nonsense piece lots to be distributed for testing at CTC and three coin-processing equipment manufacturers for post-striking tests. Any additional coins and materials were retained at the United States Mint in Philadelphia.

Tables 2-28 through 2-30 show the striking loads used to produce each lot of nonsense pieces used for Phase 4 testing. During Round Two striking trials, incumbent coin materials were also struck for each denomination tested. These nonsense pieces were used as a baseline to determine if any differences in behavior of the nonsense pieces were due to the change in materials or to changes to the images used on the nonsense pieces. The response of these nonsense pieces (i.e., those made with incumbent materials) was also compared to newly minted 2012 circulating coins of the same denomination.

Table 2-28. Progressive Strike Results for One-Cent Coin Alternative Material Candidates – Round Two

Material	Test Coin Striking Load (tonne)	Difference from Incumbent Coin (tonne)	Comment
Copper-Plated Zinc (Incumbent Material)	40	--	N/A
302HQ Stainless Steel	60	+20	Insufficient coin fill
Al-Mg Alloy 5052-H32	25	–15	None
Copper-Plated Steel – RM	50	+10	None
Copper-Plated Steel – JZP	40	0	None

Table 2-29. Progressive Strike Results for 5-Cent Coin Alternative Material Candidates – Round Two

Material	Test Coin Striking Load (tonne)	Difference from Incumbent Coin (tonne)	Comment
Cupronickel (Incumbent Material)	54	--	N/A
302HQ Stainless Steel	70	+16	Insufficient coin fill
G6 Mod	54	0	None
669z	54	0	None
Unplated 31157	54	0	None
Dura-White-Plated Zinc	54	0	None
Multi-Ply-Plated Steel	60	+6	None
Nickel-Plated Steel	54	0	None

Table 2-30. Progressive Strike Results for Quarter Dollar Coin Alternative Material Candidates – Round Two

Material	Test Coin Striking Load (tonne)	Difference from Incumbent Coin (tonne)	Comment
Cupronickel-Clad C110 (Incumbent Material)	62	N/A	N/A
302HQ Stainless Steel	73	+11	Poor edge fill
Multi-Ply-Plated Steel	65	+3	None
Dura-White-Plated Zinc	54	–8	None
669z-Clad Copper	62	0	None
Nickel-Plated Steel	65	+3	None

One unexpected result of the striking trials was the lack of correlation between material Rockwell 15T hardness and the optimum striking load used for nonsense pieces. In several cases, such as Multi-Ply- and nickel-plated steel 5-cent coin alternative material candidates, two similar materials with substantially different hardness values did not show significant differences in striking performance. A different material with a similar hardness to the nickel-plated steel planchet, 302HQ stainless steel, was substantially more difficult to coin. Hardness has been a critical value for characterizing incoming lots of materials used by the United States Mint for production of incumbent coins. Although hardness may be a good quality discriminator for various lots of incumbent coinage materials, in the testing completed here hardness did not correlate with the relative performance of different materials in the striking trials.

2.4.8 Observations of Striking Trials – Round Two

2.4.8.1 One-Cent Nonsense Pieces

Grade 302HQ stainless steel specimens were struck to complete the blanking and ferromagnetism study. No evidence of such a change was found during these trials. Nonsense pieces were visually appealing at 40 tonnes as noted during progressive striking, but they were out of dimensional specifications. At 50 tonnes, the nonsense pieces still did not meet dimensional specifications. Dimensional specifications were met at 60 tonnes, which is 50% higher than the nominal 40 tonnes used for production of copper-plated zinc one-cent coins. The remaining 302HQ stainless steel nonsense pieces were struck at 60 tonnes. One of the nonsense pieces struck at 60 tonnes is shown in Figure 2-11.

Figure 2-11. 302HQ stainless steel one-cent nonsense piece struck at 60 tonnes.

Aluminum alloy 5052 was obtained in the cold worked and stabilized H32 temper from a warehouse in the nominal one-cent coin gage. This alloy had been a leading candidate for the one-cent coin because of good coinability and low cost. During progressive striking trials, fill was inadequate at 20 tonnes, but nonsense pieces looked excellent when struck at 25 tonnes as seen in Figure 2-12. In addition, dimensional specifications were met at a 25-tonne striking load. Therefore, this load was used for the subsequent striking trial.

Figure 2-12. 5052-H32 one-cent nonsense piece struck at 25 tonnes.

Copper-plated steel planchets were obtained from the RM. At a striking load of 35 tonnes, the nonsense pieces demonstrated excellent coin fill, but were inadequate in rim height. At 40 tonnes, the nominal striking load for the incumbent copper-plated zinc (CPZ), the nonsense pieces looked excellent and met the low end of dimensional specifications. However, the planchets were supplied in a thinner gage than normally used by the United States Mint.[57] Thus the rim height of these CPS nonsense pieces would be expected to be lower than incumbent CPZ coins. The United States Mint press operator commented that the surface of these CPS nonsense pieces looked better than that of the incumbent CPZ one-cent coin. At 60 tonnes of striking load, one United States Mint engineer remarked that the nonsense coins looked to be of numismatic quality.[58] The striking trial for these CPS nonsense pieces (from RM-supplied planchets) was performed at 50 tonnes – see Figure 2-13 for a representative CPS nonsense piece struck at this load.

[57] The Royal Mint maintained the weight of the planchet, rather than the thickness. Since steel is approximately 10% more dense than zinc, the resultant CPS planchets supplied by the Royal Mint were thinner than incumbent copper-plated zinc one-cent planchets.
[58] Numismatic refers to high quality coins minted for collectors.

Figure 2-13. Copper-plated steel one-cent nonsense piece struck at 50 tonnes from planchets supplied by the Royal Mint.

A striking trial was performed on a second supply of CPS material. JZP supplied CPS planchets having dimensions consistent with the incumbent one-cent coin. Good results were obtained for nonsense pieces struck at 40 tonnes – see Figure 2-14. One United States Mint engineer commented that the JZP-supplied CPS planchets struck at least as well as the incumbent CPZ planchets. The rim height was on the high side of the one-cent coin dimensional specifications. Detailed examination under magnifying glasses showed that both of the CPS nonsense pieces had better coin fill than the incumbent CPZ material.

Figure 2-14. Copper-plated steel one-cent nonsense piece struck at 40 tonnes from planchets supplied by JZP.

2.4.8.2 5-Cent Nonsense Pieces

Stainless steel is a good candidate material for the 5-cent coin due to its expected superior wear and corrosion resistance, along with its expected silver-white luster. However, coinability of the material, as noted in the Round One results, is an issue. Carpenter Technology succeeded in developing a proprietary annealing procedure to lower the hardness of 302HQ to 72.4 Rockwell 15T. Despite this relatively low hardness for a stainless steel, the nonsense pieces were not completely filled near the rim at a striking load of 70 tonnes, considerably above the nominal 54-tonne production load for incumbent cupronickel 5-cent coins. The maximum allowable load for the striking presses is 70 tonnes—a load that ensures the safety of both machinery and dies; therefore, the 302HQ striking trial was conducted at that load. As seen in Figure 2-15, the background surfaces showed some mottling even at a 70-tonne striking load.

Figure 2-15. 302HQ stainless steel 5-cent nonsense piece struck at 70 tonnes.

The three copper-based alloys, G6 mod, 669z and unplated 31157, coined extremely well at the incumbent 5-cent coin production load of 54 tonnes. Alloys G6 mod and 669z each had a slight yellow cast as seen in Figures 2-16 and 2-17, respectively. Unplated 31157 has a golden hue to the naked eye as seen in Figure 2-18. Each of these three copper alloys is a promising 5-cent coin alternative material candidate, since each has a very similar EMS to cupronickel.

Figure 2-16. G6 mod 5-cent nonsense piece struck at 54 tonnes.

Figure 2-17. 669z 5-cent nonsense piece struck at 54 tonnes.

Figure 2-18. Unplated 31157 5-cent nonsense piece struck at 54 tonnes.

Dura-White-plated zinc has a zinc substrate plated with copper and then tin (Sn) is plated on the surface to provide a white finish. For the 5-cent nonsense pieces, 3 microns of tin were plated. The Dura-White-plated zinc planchet struck extremely well (see Figure 2-19) at a striking load of 54 tonnes. The surface finish was grey-white.

Figure 2-19. Dura-White-plated zinc 5-cent nonsense piece struck at 54 tonnes.

The Multi-Ply-plated steel planchets required a higher load (66 tonnes) for complete coin fill and dimensional tolerance than the nominal striking load (54 tonnes) for incumbent cupronickel planchets. At 60 tonnes, fill and dimensions were acceptable and the coins minted well with good surface detail as shown in Figure 2-20. The additional 6 tonnes were required to ensure fill at the border of the coin adjacent to the rim.

(a) Obverse (b) Reverse

Figure 2-20. Multi-Ply-plated steel 5-cent nonsense piece struck at 60 tonnes.

The Royal Mint uses an electroplating process called aRMour. The technology is used to plate nickel on low-carbon steel; 25 microns of nickel in the center of the coin is typically deposited for high-denomination coins. A thick nickel layer is necessary for the coins to be recognized by the sensors in coin-processing equipment. As discussed above, the as-received aRMour planchets were thicker than incumbent 5-cent planchet specifications for rim thickness. The thicker planchets showed good coin fill at 54 tonnes – see Figure 2-21. Therefore, the striking trial for this candidate material was performed at 54 tonnes. Due to the thicker planchets, the striking trial was run at a lower rate; 350 pieces/minute, to ensure proper feeding through the press.

(a) Obverse (b) Reverse

Figure 2-21. Nickel-plated steel 5-cent nonsense piece struck at 54 tonnes.

2.4.8.3 Quarter Dollar Nonsense Pieces

As part of the cold-rolling study to improve blanking, Carpenter Technology rolled 5-cent coin gage to quarter dollar coin gage for stainless steel alloy 302HQ. Blanking was performed by waterjet cutting because of time constraints and the cut pieces were returned to Carpenter Technology for a proprietary anneal. The hardness was lowered to 73.4 Rockwell 15T as a result of this anneal. Despite the low hardness, the fill during striking was poor near the rim as shown in Figure 2-22. This was in spite of a 73-tonne striking load, which is above the nominal 62 tonnes used for the incumbent quarter dollar coins. The striking trial was performed at 73 tonnes; however, a United States Mint engineer cautioned that this high load might damage the machinery and dies during actual volume production.

(a) Obverse (b) Reverse

Figure 2-22. 302HQ stainless steel quarter dollar nonsense piece struck at 73 tonnes.

The Multi-Ply-plated steel nonsense pieces showed good detail at 54 tonnes, but they were not consistently within dimensional specification at this striking load. Therefore, the striking trial was performed at 65 tonnes, but fill was inadequate at the rim and for some of the letters: note that the “P” in the word “PROJECT” in Figure 2-23(a) is not completely filled. A few nonsense pieces had visible plating defects. Further research is needed to find solutions for these issues.

(a) Obverse (b) Reverse

Figure 2-23. Multi-Ply-plated steel quarter dollar nonsense piece struck at 65 tonnes.

Dura-White-plated zinc showed promise in earlier tests with the notable exception of wear resistance. Planchets of three different plating thicknesses, as described in Table 2-31, applied to A190 zinc substrates were used in the striking trial. Nominally, the copper layer was about 12 microns thick and the top plating of tin varied from 5–10 microns.

Table 2-31. Measured Thickness* of Dura-White Plating Layers by Metallographic Sectioning

Dura-White-Plated Zinc (variant)	Copper Thickness (micron)	Tin Thickness (micron)
12-5	12.0	5.0
12-8	12.7	7.7
11-10	11.2	10.2

*Thickness measured at the center of the obverse and reverse. Each datum is the mean of six measurements.

The three Dura-White-plated zinc variants struck well at 54 tonnes, but surface appearance looked better at 62 tonnes. United States Mint engineers advised striking the three variants at 54 tonnes because dimensional targets were met at the lower load. This load is lower than the 62 tonnes used for volume production of the incumbent quarter dollar coins. The surface color was slightly duller and grey-white relative to the incumbent 5-cent coin as shown in Figure 2-24.

(a) Variant 12-5

(b) Variant 12-8

(c) Variant 11-10

Figure 2-24. Dura-White-plated zinc quarter dollar nonsense pieces struck at 54 tonnes.

Roll-clad 669z on C110 strip was designed to provide an EMS match with the incumbent quarter dollar coin. The material struck very well at nominal press loads of 62 tonnes – see Figure 2-25.

(a) Obverse (b) Reverse

Figure 2-25. 669z-clad C110 quarter dollar nonsense piece struck at 62 tonnes.

Although neither of the other two copper-based alloys, i.e., G6 mod and unplated 31157, evaluated for the 5-cent coin were roll clad onto C110 and then tested during any striking trials, CTC has confidence from the 5-cent coin striking trials and from the compositions of these alloys that roll cladding to C110 can be successfully accomplished. Verification should be completed before committing to these materials for future quarter dollar coins.

To be consistent with the weight of incumbent quarter dollar coins, the nickel-plated steel quarter dollar planchets from the Royal Mint were approximately 10% thicker than the United States Mint planchet specifications for incumbent coins. These planchets also had a larger rim profile than incumbent quarter dollar planchets. The increased amount of material at the edge of the planchet allowed for early fill of the edge of the die; after the edge features were filled, resistance to additional deformation inhibited material flow into the central design features as seen in Figure 2-26. The striking trial for this material was performed at 65 tonnes to achieve good fill; however, it is speculated that properly sized planchets might require less tonnage to achieve comparable appearance and dimensional precision. Note that Figure 2-26 shows the nonsense piece at 62 tonnes.

(a) Obverse (b) Reverse

Figure 2-26. aRMour quarter dollar nonsense piece struck at 62 tonnes.

In summary, with the exception of 302HQ stainless steel, all of the quarter dollar coin alternative material candidates could produce acceptable circulating coins if the striking load was sufficiently high (but within the safe operating limits of the current presses and dies) and the planchet rim was of optimum size. The striking load required to attain good coin fill for 302HQ stainless steel was higher than could be safely completed on existing United States Mint production presses. In CTC's opinion, this alloy still shows promise as a candidate material, but only after added alloy development demonstrates the viability of the material.

2.4.9 Phase 4 Post Trial Testing – Round Two

2.4.9.1 Steam Corrosion and Wear Testing

Steam corrosion and wear tests were conducted on nonsense pieces struck during Round Two striking trials. Nonsense pieces from each alternative material candidate were subjected to the two-hour steam corrosion test. Results of the testing are summarized in Tables 2-32 through 2-34.

Steam corrosion testing of one-cent nonsense pieces showed copper-plated materials experienced the largest change in color, with the familiar darkening to deeper brown shades. Both the aluminum and stainless steel nonsense pieces showed less color change. For 5-cent candidate materials, the nickel-plated (including Multi-Ply), tin-plated (i.e., Dura-White) and stainless steel nonsense pieces showed only small changes in color. The other 5-cent alternative material candidates (all copper-based alloys) displayed color changes essentially equivalent to the incumbent cupronickel material. Color change, resulting from steam corrosion testing, of all but one of the quarter dollar candidate materials were similar to or better than the incumbent material; 669z-clad C110 demonstrated a marginally worse color change than the incumbent quarter dollar material.

Deviations were made to the United States Mint's wear procedure for the CTC tests. Preliminary wear testing showed a steady increase in weight loss with time. The results followed a smooth and predictable trend. There was no indication of sudden changes that would reorder the relative ranking of one material with respect to others after a two-week test. The wear test results should be taken as a relative indication of potential fitness of a candidate material. It is CTC's opinion that small variations probably do not represent reproducible and consistent differences. The candidate materials can be judged as 'better than', 'roughly equivalent to' or 'worse than' incumbent materials, but no confident prediction of a service lifetime appears to be possible based on the results of the United States Mint's wear test procedure.

As discussed in Section 2.4.4 concerning Round One wear testing of mixed materials and the associated galvanic corrosion affecting the results, Round Two wear testing was split into two groups. Group One wear testing isolated the materials as much as possible in order to eliminate any galvanic corrosion affects. Group Two was performed while isolating Dura-White nonsense pieces with only incumbent circulating coinage materials. This condition was deemed to represent a normal co-circulation situation if Dura-White coins were to be introduced into circulation. Group One wear results are discussed in this section while Group Two results are discussed in Section 2.4.9.2.

Wear for all Group One alternative material candidates was no worse, and in some cases was considerably better, than the incumbent materials for all Round Two alternative material candidates for all three denominations tested. All of the alternative material candidates would be acceptable from the standpoint of wear. Note that Dura-White-plated zinc and Al-Mg alloy 5052-H32 nonsense pieces were tested in isolation for Round Two. Each showed good inherent wear resistance in this test. Appendix 2-F contains photographs of test specimens after wear testing. Color changes and wear patterns can be compared in the photographs. Note that 1) some color effects are related to the materials from other samples in the test, 2) some surface corrosion can be induced by the surrounding materials and 3) material could be transferred from softer to harder materials, affecting the surface color and wear.

Table 2-32. Round Two Post Striking Trial Test Results – One-Cent Nonsense Pieces

Material	**Steam Corrosion**	**Wear (% weight change at specified time)**	
	Total Color Vector Change	120 hours	380 hours
Copper-Plated Zinc (Incumbent Material)	6.6	–1.4	–3.4
Al-Mg Alloy 5052-H32	1.8	–0.2	–0.3
Copper-Plated Steel – RM	11.2	–1.1	–1.5
Copper-Plated Steel – JZP	6.5	–1.0	–1.4
302HQ Stainless Steel	2.8	0	0

Table 2-33. Round Two Post Striking Trial Test Results – 5-Cent Nonsense Pieces

Material	Steam Corrosion	Wear (% weight change at specified time)	
	Total Color Vector Change	120 hours	380 hours
Cupronickel (Incumbent Material)	4.4	–0.5	–0.8
Nickel-Plated Steel	2.8	–0.2	–0.4
Unplated 31157	5.5	–0.2	–0.4
Multi-Ply-Plated Steel	1.3	–0.2	–0.5
Dura-White-Plated Zinc	1.4	–0.1	–0.6
669z	5.1	–0.4	–0.7
G6 Mod	4.0	–0.4	–0.7
302HQ Stainless Steel	1.5	0	0

Table 2-34. Round Two Post Striking Trial Test Results – Quarter Dollar Nonsense Pieces

Material	Steam Corrosion	Wear (% weight change at specified time)	
	Total Color Vector Change	120 hours	380 hours
Cupronickel-Clad C110 (Incumbent Material)	4.5	–1.0	–4.7
Nickel-Plated Steel	3.3	–0.2	–0.4
Multi-Ply-Plated Steel	3.6	–0.3	–0.5
302HQ Stainless Steel	4.4	0	0
669z-Clad C110	6.5	–0.4	–0.9
Dura-White-Plated Zinc	1.9	–0.1	–0.2

2.4.9.2 Additional Round Two Wear Testing

Wear testing during the course of this project was problematic. Test results proved to be inconsistent at times, particularly for some materials that were subject to galvanic corrosion, depending on the composition of the mix of different nonsense pieces being tested within the same batch. Performing wear tests with a specific alternative material candidate by itself often provided significantly different results than with wear tests of mixed materials. To gain further insight into this phenomenon, an additional wear test was performed concentrating specifically on Dura-White nonsense pieces being mixed with incumbent circulating coinage materials, a situation deemed to represent a typical co-circulation scenario if Dura-White coins were to be introduced into circulation.

Standard wear tests were conducted in two test chambers, one containing incumbent coinage materials only, and one with mixed Dura-White and incumbent materials. Table 2-35 shows the results of these wear tests, compared with selected earlier wear test results. Dura-White 5-cent nonsense pieces were wear tested in Round One (mixed with other materials), in Round Two (isolated with other Dura-White nonsense pieces in one test chamber) and mixed with incumbent coinage for this additional wear test. Dura-White quarter dollar nonsense pieces were wear tested in Round Two and also during this additional wear test. Results from corresponding one-cent, 5-

cent and quarter dollar incumbent materials are reported in Table 2-35 in planchet form, after striking and tested without other metal alloys (isolated), and combined with Dura-White test materials (mixed).

Table 2-35. Round Two Post Striking Trial Wear Test Comparison

Material	**Sample Condition***	**Wear (% weight change at specified time)**		
		24 hours	320 hours	650 hours
Copper-Plated Zinc (Incumbent One-Cent Material)	Planchet	–0.02	–0.88	–4.76
	Isolated	–0.61	–3.22	–4.17
	Mixed	–0.33	–3.59	–7.35
Cupronickel (Incumbent 5-Cent Material)	Planchet	–0.02	–0.25	–0.33
	Isolated	–0.28	–1.18	–1.36
	Mixed	–0.12	–0.89	–1.04
Cupronickel-Clad C110 (Incumbent Quarter Dollar Material)	Planchet	–0.05	–0.31	–0.88
	Isolated	–0.29	–0.80	–1.08
	Mixed	–0.13	–0.40	–1.10
Dura-White-Plated Zinc (5-Cent Nonsense Pieces)	Round One Mixed	–0.10	–10.5	N/A
	Round Two Isolated	–0.02	–0.55	N/A
	Round Two Mixed	–0.15	–1.67	–4.13
Dura-White-Plated Zinc (Quarter Dollar Nonsense Pieces)	Round One Mixed	N/A	N/A	N/A
	Round Two Isolated	–0.01	–0.16	N/A
	Round Two Mixed	–0.22	–1.17	–1.98

*Coins/nonsense pieces placed in the wear test: planchet – as stated; isolated – after striking and with no other metals; mixed – wear tested with other materials.

Several comments can be made about these wear test results. The relatively smooth planchets typically (but not always) wear less quickly than struck pieces, which have raised design features. The somewhat surprising result is the high wear rate observed for the copper-plated zinc nonsense pieces when tested 'mixed' with Dura-White materials. Copper and nickel have relatively similar corrosion potentials, tin would selectively corrode in the presence of either copper or nickel. Hence the substantial increase in wear rate for the mixed tests cannot readily be explained. The Dura-White surfaces certainly show higher wear rates in the presence of other materials. The mixed wear testing shows large differences between 5-cent and quarter dollar nonsense pieces and between Round One mixed test and the Round Two mixed test. While the wear test was developed to include several commonly encountered wear mechanisms in a single test, i.e., rubbing against cloth, leather and cork materials in a simulated sweat solution to simulate different usage conditions, it is a difficult test to perform in a controlled manner so as to ensure consistent results.

2.4.10 Phase 4 Coin-Processing Equipment Testing – Round Two

Lots consisting of 100 nonsense pieces of each alternative material candidate and incumbent material, in addition to incumbent circulating coinage were sent for drop testing to three manufacturers of coin-processing equipment: Coinco, MEI and SCAN COIN. Details of these drop tests are given in the Outreach Chapter. A summary of these results is presented here for completeness of the present chapter on material testing.

All one-cent coin alternative material candidates from Round Two striking trials were characterized as having different EMS than the incumbent one-cent coins. The EMS of CPS nonsense pieces was similar to many other coins in use throughout the world. However, fraud is not considered a significant issue with low-value coins.[59] Interestingly, the two coin-processing equipment manufacturers that provided recommendations on low-value coin material selections preferred plated-steel alternatives to the other candidate materials. They cited low cost and minimal security needs in their rationale for recommending plated-steel coins. The low density of aluminum as an alternative material candidate did cause coin-acceptance equipment jamming problems, and was therefore strongly discouraged by all the manufacturers; all three coin-processing equipment manufacturers have experienced problems with aluminum coins used in their equipment within other countries.

The 5-cent coin alternative material candidates drop test results fell into two categories. The copper alloy alternative materials closely matched the EMS of the incumbent cupronickel coins. Two of the three manufacturers did not detect any EMS difference between the incumbent 5-cent coin and any of the 5-cent nonsense pieces made of 669z, G6 mod or unplated 31157. The third manufacturer, however, did detect EMS differences between the incumbent 5-cent coin and both the G6 mod and 669z nonsense pieces; no detectable differences were observed by this manufacturer between incumbent 5-cent coins and the unplated 31157 nonsense pieces. Alloy 669z nonsense pieces had a low rate of acceptable (i.e., indistinguishable) matches with incumbent 5-cent coins; G6 mod consistently failed to be accepted during drop tests at this third coin-processing equipment manufacturer. It is speculated that minor changes to alloy composition, rolling practices and/or heat treatment may sufficiently change the EMS characteristics so that a later generation of these alloys would result in 5-cent coins that would correctly validate in the devices made by this third manufacturer using the currently fielded equipment settings. Doing so would avoid the need for changes to fielded units should one of these alternative material candidates be used in future US circulating coins. Determination of precise measures required to improve the EMS of these copper-based alloys would be an appropriate topic for future research and development.

The second category of alternative 5-cent materials consisted of those with distinctly different EMS than the incumbent cupronickel 5-cent coin; this category includes Multi-Ply- and nickel-plated steels and Dura-White-plated zinc. The plated-steel nonsense pieces exhibited a relatively large piece-to-piece variation in properties, which is commonly seen with plated-steel coins [7]. More problematic, however, is the fact that one of the coin-processing equipment manufacturers has sensors that cannot be adjusted to accept ferromagnetic-based coins. Use of the ferromagnetic-steel-based alternative material candidates evaluated for the 5-cent (or any other)

[59] Although no clear definition has been offered to define the transition in value from a low-value to a high-value coin, experts in the field typically place the transition at about 25 cents.

coin would require development of a new sensor and a major upgrade for each of the fielded units from this manufacturer. The Dura-White-plated zinc nonsense pieces had notably consistent EMS readings. These EMS readings were clearly unique and distinguishable from other coins throughout the world. The plated alternative material candidates differ in their EMS from incumbent coins; therefore, coins made of these alternative material candidates would require that EMS-based coin-processing equipment owners and operators acquire software/hardware upgrades for existing machines.

The quarter dollar nonsense pieces showed similar trends as the 5-cent alternative material candidates. The 669z-clad C110 nonsense pieces were indistinguishable, according to all three coin-processing equipment manufacturers, from incumbent circulating quarter dollar coins. Note that although the other two copper alloys, G6 mod and unplated 31157, were not tested in the clad-copper configuration, CTC expects that all three copper-based alloys clad to C110 would perform in a similar fashion relative to EMS.

Each plated-steel nonsense piece had a distinctly different EMS than incumbent cupronickel-clad C110 quarter dollar coins; however, the EMS of nickel-plated steel quarter dollar coin was found to be similar to many other plated-steel circulating coins used around the world. As with other plated-steel nonsense pieces, the EMS readings of plated-steel quarter dollar nonsense pieces exhibited a relatively large piece-to-piece variation in properties, which is common with plated-steel coins. The Dura-White-plated zinc coins demonstrated an EMS that was clearly unique and distinguished from other coins throughout the world. The Dura-White-plated zinc nonsense pieces also had the most narrowly observed EMS readings of all material-denomination combinations that were tested.

2.4.11 Alternative Coatings

Appendix 2-G shows results from surface-modified zinc materials. The purpose of these trials was to determine the long-term potential of modifying the color of one-cent coins to eliminate the need for copper plating while maintaining the color of incumbent one-cent coins. Before the United States Mint can incorporate surface-modification technology into coinage production, a significant amount of additional development needs to be completed. Also shown in Appendix 2-G are results from early trials of nickel coatings deposited by the carbonyl process. This process also requires significant development before it can be used in production of circulating coins. The early trials conducted in this study suggest that the carbonyl process should be considered for a more thorough evaluation and development for potential future application in the production of US circulating coins.

2.5 CONCLUSIONS – CHAPTER 2

Test results for the one-cent coin alternative material candidates are summarized in Table 2-36. These results demonstrate that several potential alternative material candidates could be used for future one-cent coins although further development and testing are needed to ensure production viability, consistent performance in coin-processing equipment and general acceptance by the public. In particular, stainless steels that have not been specifically developed to have very low strength/hardness cannot be struck effectively under current conditions of die profile and equipment capability at the United States Mint. Results of striking trials using commodity "aluminized" steels were unsatisfactory. Specially processed steels, like those used for the copper-plated steel tested for this study, did exhibit good coinability.

For one-cent coins, which are rarely used in vending machine commerce, but are routinely processed through coin sorters and counters, security is not a significant issue due to their low value. These coins must feed reliably through coin-handling equipment and should not jam or be misvalidated as another coin if mistakenly inserted into any coin-processing device. The low weight of aluminum one-cent nonsense pieces did cause coin-processing machine jamming problems, and was strongly discouraged by all manufacturers of coin-processing equipment. The combined test results indicate that copper-plated steel is the leading alternative metallic material to replace the incumbent copper-plated zinc used in one-cent coins. Of course, other factors discussed in the other chapters of this report must also be considered before any decision is made to change materials of construction for the US one-cent circulating coin.

Table 2-36. Performance Test Results of One-Cent Coin Alternative Material Candidates

Material	**Color**	**Striking Load (tonne)**	**Steam Corrosion Performance**	**Wear Rate Performance**	**Coin Machine Acceptance**
Copper-Plated Zinc (Incumbent Material)	Copper	40	Moderate	Moderate	Good
Aluminized Steel	White	60	Moderate	Poor	Marginal
Al-Mg Alloy 5052-H32	White	25	Good	Poor*	Unacceptable (low density)
Copper-Plated Steel	Copper	40	Moderate	Moderate	Marginal
302HQ Stainless Steel	Grey	60	Good	Good	Acceptable
430 Stainless Steel	Grey	Not Struck**	Good	Good	Unacceptable (ferromagnetic)

* Surface attack occurs under galvanic conditions that greatly accelerate wear when tested with mixed materials. The inherent material wear rating would be 'Good' if tested under non-galvanic conditions.
** The 430 stainless steel planchets were out of dimensional specification so they would not feed into the press.

A summary of test results for 5-cent coin alternative material candidates is listed in Table 2-37. The two stainless steels exhibited poor material flow during striking and required excessive striking loads. The other alternative material candidates coined well.

In some cases, public objection might be raised with some alternatives as a result of color differences between the incumbent 5-cent coin and these alternative material candidates, especially as a result of color change caused by corrosion after the coins have been in circulation. Overall steam corrosion and wear performance were acceptable among all 5-cent coin alternative material candidates.

Coin-processing equipment testing showed that if used in future coins most of the alternative material candidates would require software and/or hardware upgrades of coin-processing equipment. The ferromagnetic 430 stainless steel would pose significant problems with currently fielded equipment. The plated-steel materials would require substantially broader acceptance limits in coin-processing equipment that relies on EMS and could lead to less secure coin identification standards. Also at least one US-based coin-processing equipment manufacturer would need to undertake significant redesign of their product line to accommodate plated-steel coins. The three copper-based alloy materials, unplated 31157, 669z and G6 mod, are notable for their near EMS similarity to cupronickel, which is used in incumbent 5-cent coins (and as the outer layers of dime, quarter dollar and half dollar coins). These copper-based alloys offer a potentially seamless option for coin-processing equipment, although some further alloy and/or processing development is necessary to ensure a consistent and accurate match of the electrical conductivity between these materials and the incumbent cupronickel.

Table 2-37. Performance Test Results of 5-Cent Coin Alternative Material Candidates

Material	**Color**	**Striking Load (tonne)**	**Steam Corrosion Performance**	**Wear Performance**	**Coin Machine Acceptance**
Cupronickel (Incumbent Material)	White	54	Moderate	Moderate	Good
Dura-White-Plated Zinc	White	54	Good	Poor*	Acceptable**
Multi-Ply-Plated Steel	White	60	Good	Good	Marginal***
Nickel-Plated Steel	White	54	Good	Good	Marginal***
G6 Mod	Yellow white	54	Moderate	Moderate	Good
302HQ Stainless Steel	Dull white	70	Good	Good	Acceptable**
430 Stainless Steel	Grey	70	Good	Good	Unacceptable (ferromagnetic)
669z	Yellow white	54	Moderate	Good	Good
Nickel-Plated 31157	White	54	Good	Moderate	Good
Unplated 31157	Golden Hue	54	Moderate	Moderate	Good

* Surface attacks occurred under galvanic conditions that greatly accelerated wear when tested with mixed materials. The inherent material wear rating would be ‘Good’ if tested under non-galvanic conditions.

** Acceptable candidates would be recognized and validated after software/hardware upgrades to the equipment in the field.

*** Marginal candidates would require loose acceptance criteria and would be less secure than incumbent 5-cent coins.

Table 2-38 summarizes test results from the quarter dollar coin alternative material candidates. The 302HQ stainless steel planchets required excessive striking load; this material requires further development and testing before it could rationally be selected to replace the incumbent quarter dollar coin materials of construction. The Multi-Ply- and nickel-plated steel candidates meet all test criteria except for seamless transition to coin-processing equipment; these materials also lack a unique EMS that provides security among other circulating coins throughout the world. Dura-White-plated zinc has a unique EMS, but since the EMS is different from incumbent coins, coin-processing equipment would require software/hardware upgrades if future quarter dollar coins were constructed of these materials. The 669z-clad C110 nonsense pieces demonstrate that the incumbent quarter dollar coin can be mimicked with less-expensive materials; therefore, introduction of a future quarter dollar coin constructed of these materials could be seamless to coin-processing equipment. However, 669z-clad C110 has a slight yellow cast appearance that could be confused with the incumbent dollar coin, which also has a golden color.

Table 2-38. Performance Test Results of Quarter Dollar Coin Alternative Material Candidates

Material	**Color**	**Striking Load (tonne)**	**Steam Corrosion**	**Wear**	**Coin Machine Acceptance**
Cupronickel-Clad C110 (Incumbent Material)	White	62	Moderate	Moderate	Good
Multi-Ply-Plated Steel	White	65	Good	Good	Marginal***
Nickel-Plated Steel	White	62	Good	Good	Marginal***
669z-Clad C110	Yellow white	62	Moderate	Moderate	Good
302HQ Stainless Steel	Grey white	73	Good	Good	Acceptable**
Dura-White-Plated Zinc	White	54	Good	Good*	Acceptable**

* Wear is greatly accelerated under galvanic conditions.
** Acceptable candidates would be recognized and validated after software/hardware upgrades to the equipment in the field.
*** Marginal candidates would require loose acceptance criteria and would be less secure than incumbent quarter dollar coins.

Table 2-39 summarizes the (limited) test results performed on dollar coin candidate materials. The primary motivation of dollar coin tests was to improve upon the tarnishing apparent on the incumbent material during circulation. Color and corrosion measurements were the only tests conducted on these materials. As shown in Table 2-39, none of the alternative material candidates improved upon the incumbent materials’ steam corrosion characteristics.

Table 2-39. Performance Test Results of Dollar Coin Alternative Material Candidates

Material	**Color**	**Steam Corrosion**
Manganese-Brass-Clad C110 (Incumbent Material)	Golden	Moderate
88Cu-12Sn-Plated Zinc	Golden	Moderate
C69250	Yellowish	Moderate
K474	Yellowish	Moderate

2.6 REFERENCES – CHAPTER 2

1. ASTM Standard E18, "Standard Test Methods for Rockwell Hardness of Metallic Materials," ASTM International, West Conshohocken, PA, www.astm.org.

2. ASTM Standard E8, "Tension Testing of Metallic Materials," ASTM International, West Conshohocken, PA, www.astm.org.

3. ASTM Standard E1004, "Standard Test Method for Determining Electrical Conductivity Using the Electromagnetic (Eddy-Current) Method," ASTM International, West Conshohocken, PA, www.astm.org.

4. ASTM E308, "Standard Practice for Computing the Colors of Objects by Using the CIE System," ASTM International, West Conshohocken, PA, www.astm.org.

5. ASTM E112, "Standard Test Methods for Determining Average Grain Size," ASTM International, West Conshohocken, PA, www.astm.org.

6. G. Wyszecki and W. S. Stiles, Color Science, 2nd Edition, John Wiley and Sons, New York, 1982.

7. Conversations with Simon Scott Brown, SCAN COIN, and Concurrent Technologies Corporation, various dates from August 2011 through May 2012.

2.7 APPENDICES – CHAPTER 2

2.7.1 Appendix 2-A: Blanking, Annealing, Cleaning and Lubricating Procedures

2.7.1.1 Introduction

To conduct progressive striking tests at the United States Mint in Philadelphia, Concurrent Technologies Corporation (CTC) prepared blanks for some of the alternative materials and purchased planchets of other alternative materials for testing. To preclude any chance of mixing test materials with production products and to avoid any disruption in normal production processes, all experimental operations that could not be contained in the United States Mint's Research and Development (R&D) room were performed at the Environmental Test Facility of CTC in Johnstown, PA. For materials procured in strip form, this included blanking, annealing and cleaning. Upsetting and striking trials were conducted in the United States Mint's R&D room. Procedures used by the United States Mint in Philadelphia were used as the prototype for designing the respective processes at CTC, although using different materials dictated some modifications to these written procedures to allow testing and evaluation of these alternative material candidates based upon their particular properties. CTC strove to maintain the current United States Mint's standards for blanks.

2.7.1.2 Baseline Specifications

The target blank specifications are based on the documents that CTC received from the United States Mint, i.e., "Coinage Specification 2004a.pdf", "1 cent Planchet Contract Sections C + E Excerpts.doc" and "Coinage Strip Contracts Sections C + E Excerpts.doc". Table 2-A-1 lists critical parameters from these coinage specifications. Table 2-A-2 lists the critical specifications for upset blanks, called planchets, which were supplied in lieu of blanks for plated test pieces. Based on the results of outreach efforts, it was decided that the overall diameter and thickness of nonsense pieces will be identical to incumbent coinage, so diameter and gage stay the same, but blank or planchet weight would vary depending on the density of a given material.

Table 2-A-1. Baseline Coin Blank Specifications

Denomination	**Diameter (mm)**	**Gage (mm)**	**Weight (gm)**	**Hardness (Rockwell 15T)**
One-cent	18.758–18.834	1.212–1.298	2.400–2.600	62–72
5-cent	21.220–21.300	1.534–1.610	4.756–5.144	60–69
Dime	17.600–17.680	1.003–1.079	2.177–2.359	50–60
Quarter dollar	24.220–24.300	1.346–1.422	5.443–5.897	50–60
Dollar	26.75–26.85	1.587–1.664	7.730–8.330	60–68

Table 2-A-2. Baseline Planchet Specifications*

Denomination	Diameter (mm)	Edge Thickness (mm)	Weight (gm)	Hardness (Rockwell 15T)
One-cent	18.70–18.80	1.38–1.54	2.400–2.600	62–72
5-cent	20.98–21.08	1.72–1.88	4.756–5.144	60–69
Dime	17.40–17.50	1.19–1.35	2.177–2.359	50–60
Quarter dollar	23.67–23.77	1.65–1.85	5.443–5.897	50–60
Dollar	26.24–26.34	1.93–2.09	7.730–8.330	60–68

* Surfaces should be free of deep scratches and visible blemishes, and blanks shall not be noticeably dished or bowed.

2.7.1.3 In-House Blank Preparation

A "Metal Muncher" model MM40 hydraulic press was used to produce blanks from strip materials. The press has a 36-tonne (40-ton) capacity; its tooling will hold commercial punch/die sets without modification. A single-station steel punch and die of appropriate size, supplied by American Punch Company, was used to produce the blanks for each denomination. This was sufficient for the production of prototype quantities, but the relatively slow production rate, 15–25 pieces per minute, makes use of this machine problematic for larger quantities of blanks.

Post blank annealing was used for several test materials. The gas atmosphere used by the United States Mint during annealing operations to prevent oxidation of the metal surfaces is very difficult to simulate on a laboratory scale. Small lots of 100 to 300 pieces were sealed in stainless steel heat treatment bags, as shown in Figure 2-A-1, after purging the atmosphere with argon gas, and placed in electric box furnaces for annealing. Standard type K thermocouples were placed in contact with the outside of the bags in order to monitor the temperature of the process. Additional time (five minutes) was allotted after the outside surface reached the desired temperature in order to allow the heat to diffuse into the interior. The bags were then taken out of the furnace and immediately plunged in a water quench tank. The bags were opened under water to allow the test blanks to be quickly cooled. Hardness measurements were taken from randomly selected representative samples to confirm that the annealing operation provided the desired results.

Figure 2-A-1. Stainless steel heat treatment bag prior to sealing.

Cleaning and burnishing procedures were conducted when blanks were produced from sheet materials, using 254-mm-(10-inch-) diameter jar mills with 3.2-mm-(1/8-inch-) diameter stainless steel ball media. Batches of up to 500 blanks were placed in the jars, with a roughly equivalent weight of burnishing media, and run through several process stages to emulate the current procedures used by the United States Mint in Philadelphia to produce circulating coinage.

Copper-based alloys were cleaned with a solution consisting of 200 milliliters (ml) of AC-67[60] (product of Alex Fergusson Incorporated), 200 ml of 3% hydrogen peroxide and 600 ml of tap water for ten minutes in the jar mill. Following rinsing with tap water the test blanks were tumbled for 5 minutes in tap water. A mixture of 100 ml of Carboshield BTX[61] (product of Lonza Incorporated) solution mixed with 900 ml of distilled water was added to the jar after draining, and the mill was run for 5 to 6 minutes. Following distilled water rinses, the jar mill was finally run for five more minutes with fresh distilled water. The test blanks were drained and dried on clean absorbent paper before being packaged for shipment.

Steel and aluminum surfaces were degreased in a detergent solution for 10 minutes in the jar mills. After rinsing, the jar mill was run for 5 more minutes with tap water covering the contents of the jar. The test blanks were then lubricated with a 100-ml solution of Interlube 5305 stamping lubricant (product of Chemtool Incorporated) in 900 ml of distilled water and run in the jar mill for 5 to 6 minutes. After rinsing with distilled water, the test blanks were run for 5 minutes under distilled water in the jar mill, removed and dried on clean absorbent paper before being packaged for shipment.

Planchets, supplied by the Royal Canadian Mint (RCM), the Royal Mint (RM) and Jarden Zinc Products (JZP), were not processed through the cleaning, burnishing and lubricating procedures. JZP representatives report using a proprietary chemical process and would not reveal further details. The RCM uses "very trace amount of mineral oil during the end of the burnishing process." The RM says "a small amount of the finishing solution (which is referred to as 'soap' within the United States [US]) may remain on the blanks, which can aid lubrication through the striking operation." Note that the RM specifically adds lubricants to the edges (only) of their planchets during the striking operation.

2.7.1.4 Blanking Tests

Blanks produced at CTC were essentially equivalent to those from the United States Mint production line. Strip material from the United States Mint was blanked at CTC and compared to production line blanks. The CTC-produced blanks had the same flatness and edge deformation characteristics as those produced at the United States Mint. Alternative material candidates generally blanked well, and exhibited good flatness with minimal burrs. The notable exception was 302HQ stainless steel. Using strip supplied in a partially annealed state, severe cupping was encountered when blanking 5-cent test pieces. Ultimately, a small number (100) of trial blanks were flattened after blanking in a compression test machine at 13.6 tonnes (30,000 lb). For subsequent trials, the 5-cent coin gage 302HQ stainless steel was cold rolled to thinner one-cent coin and dime coin gages, and the added cold work hardened the base material. Blanking the one-

[60] AC-67 is a mild acidic solution containing citric acid that is intended to remove surface oxides on the metal blanks.
[61] Carboshield BTX contains long-chain hydrocarbons that adhere to the clean metal, providing a lubrication and corrosion prevention layer on the metal surface.

cent and quarter dollar trial pieces was more successful; these samples did not show excessive cupping.

Another set of experiments was conducted to determine if cooling a relatively soft incoming strip material below room temperature would allow clean and flat blanking. Liquid nitrogen was used to cool metal strip prior to placing it in the blanking press. This approach did show promise for zinc-based alloys and is expected to perform well for low-carbon steels, but it did not produce quality blanks from metals, such as copper alloys, with different crystal structures. It did not alleviate the 302HQ stainless steel cupping problems.

2.7.2 Appendix 2-B: Two-Hour Steam Corrosion Test Procedure

2.7.2.1 Materials/Equipment Needed:

1. 0.015 to 0.020 cubic meter (m^3) capacity autoclave with carrier. 0–207,000 Pascals (0–30 pounds per square inch [psi]), 100 to 134 degrees Celsius (°C) (212 to 274 degrees Fahrenheit [°F]); stainless steel or cast aluminum alloy construction (All-American Autoclave, Model 1925X…..$260, or similar design).

2. Teflon-coated slotted blank tray. Avoid metal-to-metal contact, such as aluminum on silver, which may produce whitish stains.

3. Distilled or deionized (DI) water.

4. Powder-free latex gloves.

2.7.2.2 Procedure:

1. Randomly collect at least 50 blanks from each shipment. The blanks should be collected by operators wearing powder-free latex gloves.

2. Use a color spectrophotometer to measure initial color per the CIE 1976 (L^*, a^*, b^*) color space.

3. Pour distilled water into autoclave. Water level should remain below the carrier. Insert the carrier inside the autoclave.

4. Place racked blanks atop the carrier. The autoclave capacity should be 10–20 blanks per test. Place a paper towel above the blanks to protect them from falling condensate. Ensure that the paper towel tests negative for sulfur and chloride.

5. Place the lid atop the autoclave, but do not secure or bolt the lid in place.

6. Bring the vessel to boiling (100 °C [212 °F]) and maintain for two hours.

7. After two hours, turn-off autoclave and allow to cool.

8. Remove blanks without touching by bare hands. Operators should wear powder-free latex gloves.

9. Inspect blanks or coins under good light (fluorescent) for yellow or white spots.

10. Use the color spectrophotometer to measure ending color.

2.7.3 Appendix 2-C: Wear Test Procedure

2.7.3.1 Purpose:

To simulate the amount of wear that would occur to a typical coin if it were in circulation for 30 years.

2.7.3.2 Materials:

254-mm- (10-inch-) diameter high-density polyethylene (HDPE) jar

254-mm- (10-inch-) diameter aluminum sleeve

13 grams of leather strips for every 8 coins/nonsense pieces

7 grams of cork for every 8 coins/nonsense pieces

7 grams of cotton/polyester cloth strips for every 8 coins/nonsense pieces

1 jar mill

2.7.3.3 Artificial Sweat Solution:

40 grams of sodium chloride (NaCl)

5 grams of sodium phosphate (Na_2HPO_4)

4 milliliters of lactic acid

2 liters of distilled water

The leather strips are 38 mm x 3 mm x 1.5 mm in size.

The cork is 0.24 centimeter (cm) in diameter (Size 000).

The cloth strips are 2 cm x 10 cm.

2.7.3.4 Procedure:

1. Measure the diameter, weight and rim height of each coin/nonsense piece.
2. Soak the leather strips in artificial sweat for an initial 30 minutes. Drain and place in HDPE jar. Add cork, cloth and coins/nonsense pieces.
3. Seal jar and place in aluminum sleeve. Place on jar mill and set rotation at 37 rotations per minute.
4. Remove coins/nonsense pieces every 1–2 days and weigh each coin/nonsense piece. Also note type of wear on coins/nonsense pieces.
5. When replacing coins/nonsense pieces in jar, add 20 milliliters of artificial sweat to jar to maintain moisture. Restart rotation.

2.7.4 Appendix 2-D: Steam Corrosion Test Photographs of Incoming and Ready-to-Strike Materials

The corrosion test measurement of total color vector change described in this appendix is a good quantitative measurement of average color and reflectivity changes, but it is difficult to assess the aesthetic effect of steam corrosion from the number that results from the test. The photographs attempt to show the optical difference between the incoming metal specimens in three states. The leftmost discs represent the as-received material that has not been subjected to testing. The middle column shows discs that were steam corrosion tested after being lightly sanded with 1200-grit silicon carbide sandpaper to remove any surface contamination and expose bare material. The rightmost column shows discs that were steam corrosion tested in the ready-to-strike condition with an applied corrosion inhibitor/lubricant. Unfortunately it is very difficult to show often-subtle surface color differences using photographs, but the photos provided here should give the reader a good sense of the appearance of the materials after steam corrosion testing. Results are presented here without comments for alternative material candidates for each of the following denominations: one-cent, 5-cent, quarter dollar and dollar coins. Results are shown in Figures 2-D-1 through 2-D-22.

2.7.4.1 One-Cent Coin Alternative Material Candidates

Untested, as-received on left, lightly sanded and tested in middle, and tested in ready-to-strike condition on right.

Figure 2-D-1. Steam corrosion tested copper-plated zinc planchets (incumbent US one-cent coin material).

Untested, as-received on left, lightly sanded and tested in middle, and tested in ready-to-strike condition on right.

Figure 2-D-2. Steam corrosion tested copper-plated steel one-cent planchets from Jarden Zinc Products.

Untested, as-received on left, lightly sanded and tested in middle, and tested in ready-to-strike condition on right.

Figure 2-D-3. Steam corrosion tested copper-plated steel one-cent planchets from the Royal Mint.

Untested, as-received on left (one-cent coin size blank), lightly sanded and tested in middle (5-cent coin size blank), and tested one-cent coin size blanks on right.

Figure 2-D-4. Steam corrosion tested 5052-H32 blanks.

Untested, as-received on left (one-cent coin size blank), lightly sanded and tested in middle (5-cent coin size blank), and tested one-cent coin size blanks on right.

Figure 2-D-5. Steam corrosion tested aluminized steel blanks from Atlas.

2.7.4.2 5-Cent Coin Alternative Material Candidates

Untested, as-received on left, lightly sanded and tested in middle, and tested in ready-to-strike condition on right.

Figure 2-D-6. Steam corrosion tested cupronickel 5-cent planchets (incumbent US 5-cent coin material).

Untested, as-received on left and tested in ready-to-strike condition on right.

Figure 2-D-7. Steam corrosion tested Dura-White-plated zinc 5-cent planchets.

As-received on left and ready-to-strike and tested on right, quarter dollar planchet on top and 5-cent planchet on bottom.

Figure 2-D-8. Steam corrosion tested Multi-Ply-plated steel 5-cent and quarter dollar planchets.

Untested, as-received on left, lightly sanded and tested in middle, and tested in ready-to-strike condition on right.

Figure 2-D-9. Steam corrosion tested nickel-plated steel 5-cent planchets.

Untested, as-received on left, lightly sanded and tested in middle, and tested blanks on right.

Figure 2-D-10.Steam corrosion tested G6 mod 5-cent blanks.

Untested, as-received on left, lightly sanded and tested in middle, and tested blanks on right.

Figure 2-D-11.Steam corrosion tested 669z 5-cent blanks.

Untested, as-received on left, lightly sanded and tested in middle, and tested blanks on right.

Figure 2-D-12.Steam corrosion tested 430 stainless steel 5-cent blanks.

Untested, as-received on left and corrosion tested on right.

Figure 2-D-13.Steam corrosion tested 302HQ stainless steel 5-cent blanks.

Nickel-plated surface after corrosion test on left, unplated, lightly sanded surface after test in middle, and unplated ready-to-strike after corrosion test on right.

Figure 2-D-14.Steam corrosion tested 31157 5-cent planchets.

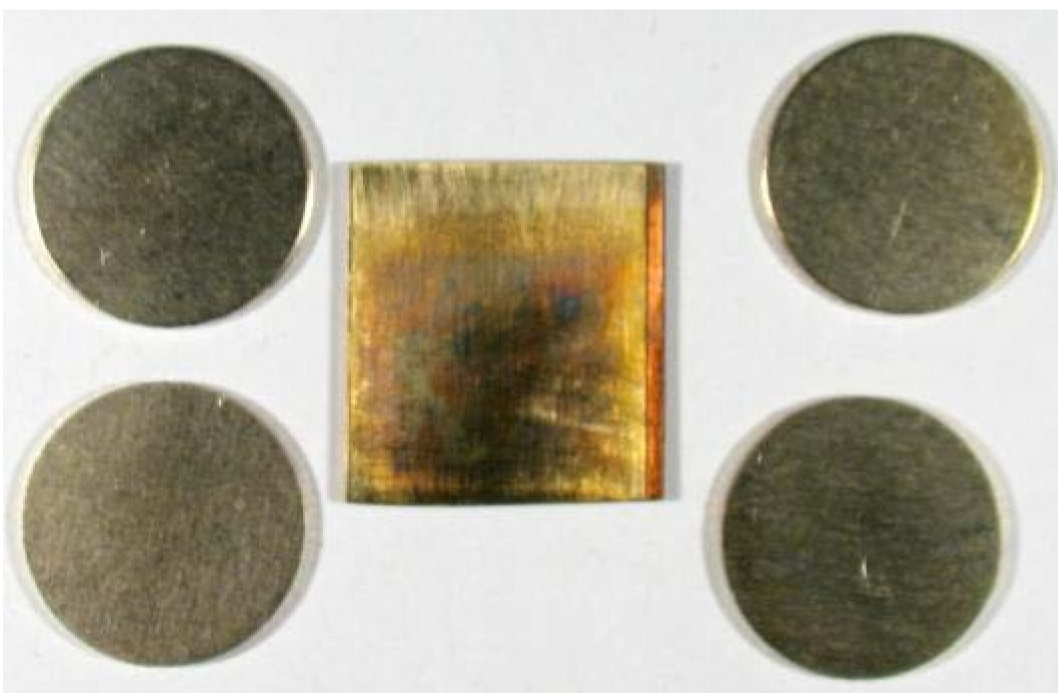
2.7.4.3 Quarter Dollar Coin Alternative Material Candidates

Untested, as-received on left, lightly sanded and tested in middle, and tested in ready-to-strike condition on right.

Figure 2-D-15.Steam corrosion tested cupronickel-clad C110 quarter dollar planchets (incumbent quarter dollar coin material).

Untested, as-received on left, lightly sanded and tested in middle, and tested in ready-to-strike condition on right.

Figure 2-D-16.Steam corrosion tested nickel-plated steel quarter dollar planchets.



Untested, as-received on left, lightly sanded and tested in middle (as cut from incoming sheet material), and tested blank on right.

Figure 2-D-17.Steam corrosion tested 669z-clad C110 material.

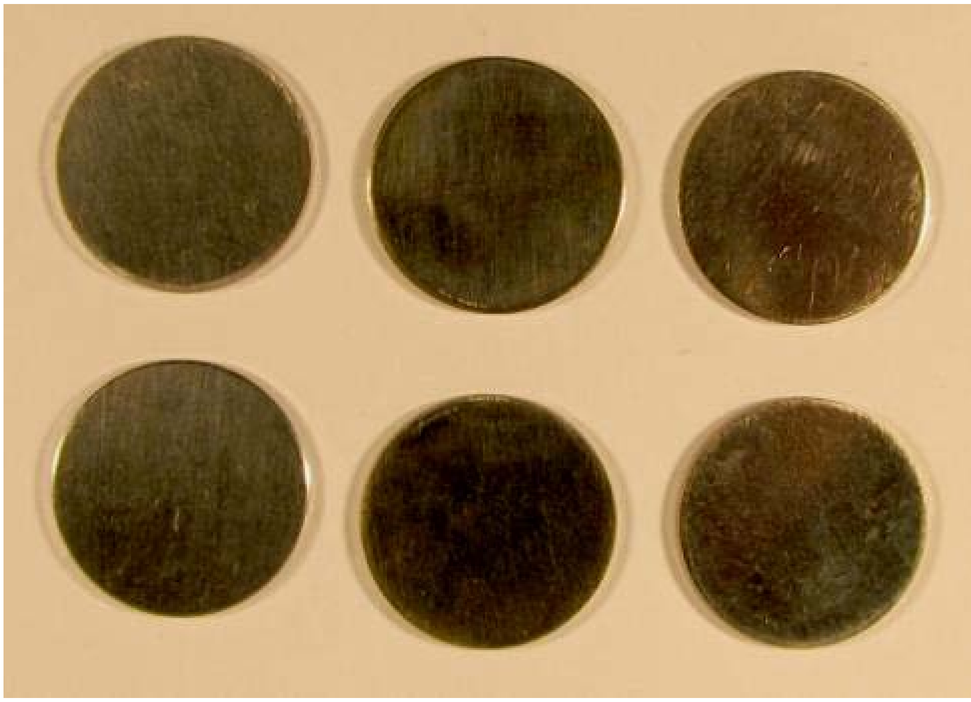
2.7.4.4 Dollar Coin Alternative Material Candidates

Untested, as-received on left, lightly sanded and corrosion tested in middle, and tested in ready-to-strike condition on right.

Figure 2-D-18.Steam corrosion tested incumbent dollar coin planchets.

Untested, as-received on left, lightly sanded and tested in middle, and tested blanks on right.

Figure 2-D-19.Steam corrosion tested Y42 copper alloy dollar blanks.



Untested, as-received on left, lightly sanded and tested in middle, and tested blanks on right.

Figure 2-D-20.Steam corrosion tested K474 copper alloy dollar blanks.

Untested, as-received on left, lightly sanded and tested in middle, and tested blanks on right.

Figure 2-D-21.Steam corrosion tested C69250 copper alloy dollar blanks.

Untested, as-received on left, lightly sanded and tested in middle, and tested blanks on right.
Figure 2-D-22.Steam corrosion tested yellow bronze- (88Cu-12Sn-) plated zinc dollar blanks.

2.7.5 Appendix 2-E: Post-Striking Steam Corrosion Test Photographs

Photographs of the nonsense pieces before and after steam corrosion testing are presented in this appendix. For each of the below figures (Figure 2-E-1 through 2-E-23), the two pieces on the left are as-struck and the two on the right are after a 2-hour steam corrosion test. Results are presented here, without comments for alternative material candidates for each of the following denominations: one-cent, 5-cent and quarter dollar nonsense pieces.

2.7.5.1 One-Cent Coin Alternative Material Candidates

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-1. Steam corrosion tested one-cent nonsense pieces (incumbent material).

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-2. Steam corrosion tested copper-plated steel (Jarden Zinc Products) one-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-3. Steam corrosion tested copper-plated steel (Royal Mint) one-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-4. Steam corrosion tested 5052-H32 one-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-5. Steam corrosion tested aluminized steel (Atlas) one-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-6. Steam corrosion tested aluminized steel (Ryerson) one-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-7. Steam corrosion tested 302HQ stainless steel one-cent nonsense pieces.

2.7.5.2 5-Cent Coin Alternative Material Candidates

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-8. Steam corrosion tested 5-cent nonsense pieces (incumbent material).

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-9. Steam corrosion tested Dura-White-plated zinc 5-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-10. Steam corrosion tested Multi-Ply-plated steel 5-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-11. Steam corrosion tested nickel-plated steel 5-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-12. Steam corrosion tested G6 mod 5-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-13. Steam corrosion tested 669z 5-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-14. Steam corrosion tested 430 stainless steel 5-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-15. Steam corrosion tested 302HQ stainless steel 5-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-16. Steam corrosion tested nickel-plated 31157 5-cent nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-17. Steam corrosion tested unplated 31157 5-cent nonsense pieces.

2.7.5.3 Quarter Dollar Coin Alternative Material Candidates

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-18. Steam corrosion tested quarter dollar nonsense pieces (incumbent material).

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-19. Steam corrosion tested Multi-Ply-plated steel quarter dollar nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.
Figure 2-E-20. Steam corrosion tested nickel-plated steel quarter dollar nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.
Figure 2-E-21. Steam corrosion tested 669z-clad C110 quarter dollar nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-22. Steam corrosion tested 302HQ stainless steel quarter dollar nonsense pieces.

Two pieces on left are as-struck and two on right are after a 2-hour steam corrosion test.

Figure 2-E-23. Steam corrosion tested Dura-White-plated zinc quarter dollar nonsense pieces.

2.7.6 Appendix 2-F: Wear Test Photographs

Pictures of the nonsense wear test pieces are included in this appendix. Unless otherwise stated the nonsense pieces spent two weeks in the wear test tumblers with leather, cloth and cork materials, and with artificial sweat solution. All the copper-plated nonsense pieces, including the incumbent one-cent copper-plated zinc coins, showed significant color changes, but only minor wear. Copper alloy nonsense pieces showed darkened surfaces and visible wear, much like incumbent 5-cent and quarter dollar nonsense pieces.

Nickel- and Multi-Ply-plated steel nonsense pieces showed some discoloration, but only minor wear. Aluminum and Dura-White-plated zinc nonsense pieces showed minimal wear when tested separately, but both showed significant wear when tested with other alternative material candidates; this is indicative of galvanic corrosion. It is difficult to predict how these alloys would wear in typical co-circulating conditions with incumbent coinage. Aluminized steel nonsense pieces showed significant wear. Stainless steel nonsense pieces were nearly unaffected by the wear test. Results are presented here, with a few comments under each photo for alternative material candidates for each of the following denominations: one-cent, 5-cent and quarter dollar coins. Results are shown in Figures 2-F-1 through 2-F-23.

2.7.6.1 One-Cent Coin Alternative Material Candidates

Considerable color change, but details still present.

Figure 2-F-1. Wear tested one-cent nonsense pieces (incumbent material).

Color change but only slight edge wear.

Figure 2-F-2. Wear tested copper-plated steel (Jarden Zinc Products) one-cent nonsense pieces.

Color change but only minor edge wear.

Figure 2-F-3. Wear tested copper-plated steel (Royal Mint) one-cent nonsense pieces.

Very little visible sign of wear.

Figure 2-F-4. Wear tested 5052-H32 one-cent nonsense pieces.

Considerable wear (galvanic corrosion).

Figure 2-F-5. Wear tested aluminized steel (Atlas) one-cent nonsense pieces.

Considerable wear after one week.

Figure 2-F-6. Wear tested aluminized steel (Ryerson) one-cent nonsense pieces.

Good wear characteristics.

Figure 2-F-7. Wear tested 302HQ stainless steel one-cent nonsense pieces.

2.7.6.2 5-Cent Coin Alternative Material Candidates

Color change and moderate wear visible at high points of design.

Figure 2-F-8. Wear tested 5-cent nonsense pieces (incumbent material).

Relatively little wear.

Figure 2-F-9. Wear tested Dura-White-plated zinc 5-cent nonsense pieces.

Some color change and wear on high points of design.

Figure 2-F-10. Wear tested Multi-Ply-plated steel 5-cent nonsense pieces.

Some color change and wear at high points of design.

Figure 2-F-11. Wear tested nickel-plated steel 5-cent nonsense pieces.

Color change and minor wear.

Figure 2-F-12. Wear tested G6 mod 5-cent nonsense pieces.

Color change and minor wear.

Figure 2-F-13. Wear tested 669z 5-cent nonsense pieces.

Minor wear (note that design was not filled during striking trial in spite of excessive coining load).

Figure 2-F-14. Wear tested 430 stainless steel 5-cent nonsense pieces.

Slight discoloration and minimal wear.

Figure 2-F-15. Wear tested 302HQ stainless steel 5-cent nonsense pieces.

Some edge wear, underlying copper alloy barely visible.

Figure 2-F-16. Wear tested nickel-plated 31157 5-cent nonsense pieces.

Some color change and moderate visible wear.

Figure 2-F-17. Wear tested unplated 31157 5-cent nonsense pieces.

2.7.6.3 Quarter Dollar Coin Alternative Material Candidates

Significant surface wear (may be due to mixing with dissimilar metals during wear test, i.e., stainless steel).

Figure 2-F-18. Wear tested quarter dollar nonsense pieces (incumbent material).

Color change with wear.

Figure 2-F-19. Wear tested Multi-Ply-plated steel quarter dollar nonsense pieces.

Color change and wear. Copper visible on rim may have rubbed off from other nonsense pieces of different composition during the wear test.

Figure 2-F-20. Wear tested nickel-plated steel quarter dollar nonsense pieces.

Considerable color change and some wear.

Figure 2-F-21. Wear tested 669z-clad C110 quarter dollar nonsense pieces.

Minor discoloration and minimal wear.

Figure 2-F-22. Wear tested 302HQ stainless steel quarter dollar nonsense pieces.

Very little wear.

Figure 2-F-23. Wear tested Dura-White-plated zinc quarter dollar nonsense pieces.

2.7.7 Appendix 2-G: Surface Engineering Trials

Several additional tests were performed to evaluate the impact of some non-conventional surface treatments being applied to alternative material candidates. The ability to inexpensively modify the color and corrosion behavior of some alternative material candidates would be highly desirable. Although it was recognized that none of these techniques could be fully developed during the course of this study, CTC completed some feasibility studies that may be valuable to suggest areas for possible future research.

2.7.7.1 Ross Technology Surface Coatings

Ross Technology Corporation is developing several proprietary surface-adsorbed compounds[62] including two variants known as A26 and B21 to improve corrosion resistance. Preliminary tests were conducted using coated planchets to determine if these coatings would allow for successful striking while maintaining their adherence to the surface of nonsense pieces and inhibiting corrosion. The long-term goal (beyond the scope of the current study) is to evaluate if such coatings can obviate the need for copper or nickel electroplating to reduce the costs of producing coins. As can be seen in the photographs that appear below, the application of these coatings to blanks was not optimized; therefore, the coating was not fully applied to the blanks causing striations across the surface. Coatings were applied by hand dipping planchets into the coating bath hence leaving uncoated areas and a clear demarcation of coated and uncoated regions.

A26 was applied to bare zinc alloy A190 one-cent planchets provided by Jarden Zinc Products (JZP). B21 was applied to bare zinc A190 5-cent planchets. Several examples of each type were struck during the second striking trials at the United States Mint in Philadelphia to evaluate whether the coatings would survive coining. Nonsense pieces were subsequently steam corrosion tested to evaluate how well the coatings inhibit corrosion. Both coatings are nominally colorless. For the 5-cent coin, such a coating could make bare zinc a viable option to obviate the costs of electroplating. Both sets of test samples struck well at the normal press load used for their respective denomination, and showed no evidence of flaking or delamination. Figures 2-G-1 and 2-G-2 show the nonsense pieces after striking.

[62] A26 is an ultraviolet-cured compound and B21 is a thermally cured compound.

Figure 2-G-1. A26-coated A190 one-cent nonsense piece struck at 40 tonnes.

Figure 2-G-2. B21-coated A190 5-cent nonsense piece struck at 54 tonnes.

Steam corrosion tests were subsequently performed on the nonsense pieces. The test protocol included measuring color before steam corrosion testing and then after a two hour-exposure to steam at 100 °C (212 °F), as described in Appendix 2-B. Lower total color vector change indicates better corrosion resistance. Table 2-G-1 shows both the initial color readings and the total color vector change after steam corrosion testing for the nonsense pieces and an uncoated (i.e., bare) zinc planchet for comparison. Steam corrosion results were disappointing. Figures 2-G-3 shows the as-coated planchets (left) and planchets after the steam corrosion test (right). Figure 2-G-4 shows comparisons of the as-struck one-cent nonsense pieces (on the left) with steam corrosion tested pieces (on the right); Figure 2-G-5 shows the corresponding 5-cent nonsense pieces. Darkening or graying of the surfaces after steam exposure is clearly evident.

A second batch of A26-coated planchets was prepared using a modified curing procedure (Type II); this second batch was also steam corrosion tested. In this case zinc, copper-plated zinc and raw steel surfaces were prepared using the coatings. Steam corrosion performance was improved, although the coatings themselves were no longer colorless. Steam corrosion total color vector change readings were low for the A190 surfaces before and after steam corrosion testing as shown in Figure 2-G-6, and copper-plated surfaces as shown in Figure 2-G-7. The A26-coated steel surfaces experienced some spotting and higher total color vector change, but the steel showed much less color change than would be expected on raw steel (Figure 2-G-8). Test results are shown in Table 2-G-1. The Type II curing procedure showed a marked improvement compared with the first coating trials. However, it must be noted that the relatively darkly colored coatings are difficult to compare with shiny metal surfaces and comparing numerical values may be misleading.

Table 2-G-1. Color Measurements and Total Color Vector Change Readings for Corrosion Inhibitor Treated Surfaces

	Color as Treated			**Corrosion Test**
Sample	**L**	**a**	**b**	**Total Color Vector Change**
Bare Zinc Planchet	84.8	–1.3	1.7	27.9
A26-Coated Zinc One-Cent Nonsense Piece	89.5	–1.6	1.0	37.7
B21-Coated Zinc 5-Cent Nonsense Piece	87.3	–1.6	1.1	25.2
Type II A26-Coated Zinc Planchet	49.8	0.2	7.1	3.7
Type II A26-Coated Copper-Plated Zinc Planchet	79.5	16.1	21.9	5.5
Type II A26-Coated Copper	74.1	18.8	19.3	4.6
Type II A26-Coated Steel	46.5	0.6	10.6	12.7

A26-coated one-cent blanks (top) and B21-coated 5-cent blanks (bottom).

Figure 2-G-3. Coated A190 planchets as-coated (left) and after steam corrosion testing (right).

Figure 2-G-4. A26-coated A190 one-cent nonsense pieces before (left) and after (right) steam corrosion testing.

Figure 2-G-5. B21-coated A190 5-cent nonsense pieces before (left) and after (right) steam corrosion testing.

Figure 2-G-6. Type II A26-coated A190 one-cent planchets before (left) and after (right) steam corrosion testing.

Figure 2-G-7. Type II A26-coated copper-plated zinc one-cent planchets before (left) and after (right) steam corrosion testing.

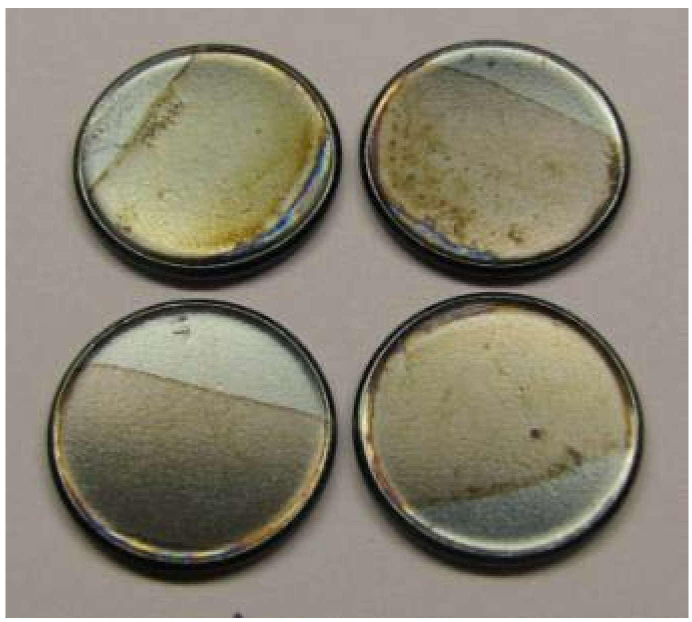


Figure 2-G-8. Type II A26-coated steel planchets before (left) and after (right) steam corrosion testing.

The preliminary tests results shown in Table 2-G-1 demonstrate that the Type II curing process is an improvement upon earlier curing methods. The preliminary tests demonstrated that striking performance is not substantially affected by the coatings. The Type II curing procedure improved steam corrosion performance, but did have a significant color cast. Further testing is required to determine whether the coatings would withstand normal wear and still provide protection. A zinc planchet with an optimized coating may provide an alternative candidate for copper-electroplated zinc planchets at lower cost. Several other factors must also be fully vetted before this coating technology can be accepted for production coinage. These factors include a compatibility of these coatings for exposed edges, full toxicology evaluation, an environmental assessment, a review of recyclability, a small production run, cost analysis and public opinion assessment.

Although the coating minimized corrosion of planchets during steam corrosion testing as noted in Figure 2-G-8, the coated steel nonsense pieces did not perform any better than similar steel nonsense pieces that were not coated with these materials. Therefore, no improvement in performance is expected from the use of these coatings, as formulated and used in these tests, for either zinc- or steel-based coins.

2.7.7.2 Carbonyl Surface Coating

2.7.7.2.1 Stage 1

A preliminary test applying a carbonyl nickel coating to several substrates was performed at CVMR Corporation in Toronto, Ontario, Canada (see Appendix 1-B in the Introduction Chapter). Zinc alloy A190, copper alloy C110 and low-carbon steel surfaces were prepared by depositing carbonyl nickel at 175 °C (347 °F). The coated specimens were subjected to various thermal exposures to increase interface bonding and to reduce residual stresses. The specimen geometries comprised planchets, approximately rectangular 51-mm x 32-mm (2-inch x 1.25-inch) coupons and 152-mm x 25-mm (6-inch x 1-inch bend specimens). Hammer impact and bend tests were performed as a preliminary assessment on how well the coatings were bonded to the substrates.

The carbonyl nickel layers were well bonded to the copper and steel substrates. Both hammer and bend tests showed no evidence of delamination or cracking. The coatings were at times well bonded to zinc (Figure 2-G-9),[63] but not consistently well attached (see Figure 2-G-10).[64] Normal electroplating stresses are removed by annealing heat treatments. Unfortunately zinc pieces melt at a lower temperature (420 °C [790 °F]) than is needed to anneal the nickel surface layer, hence zinc cannot be effectively electroplated with nickel. The carbonyl coating process offers a potential alternative to electroplating. The carbonyl process needs further development as post-deposition annealing is needed for zinc substrates.

[63] The coating is unaffected along the edges of the hammer strike. This specimen was annealed at 240 °C (460 °F).
[64] This coating split along the edge of the indent and was readily peeled away, indicating poor adhesion. This specimen was annealed after deposition at a relatively low 200 °C (390 °F).

Figure 2-G-9. Carbonyl nickel-coated zinc surface after hammer indent testing with a steel punch.

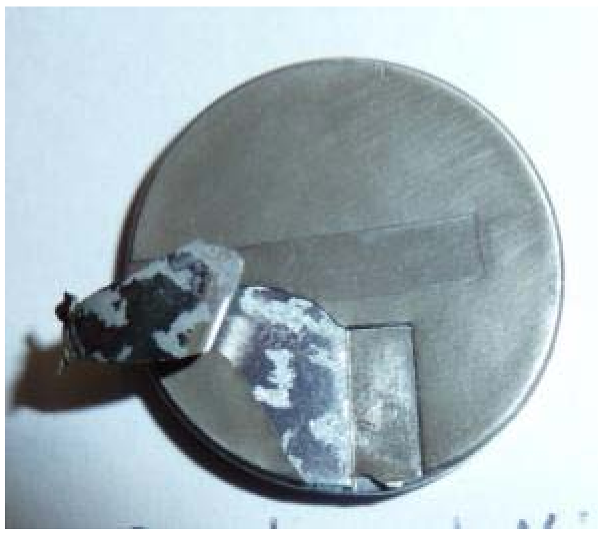


Figure 2-G-10.Carbonyl nickel-coated zinc surface after hammer indent testing.

Bend test results show no evidence of delamination or cracking for either the steel (Figures 2-G-11 and 2-G-12) or copper (Figures 2-G-13 and 2-G-14) carbonyl nickel-coated specimens throughout the bend region. The scratches in these figures are marks from the vise used to hold the specimens during bending.

Figure 2-G-11.Carbonyl nickel-coated steel specimen after single-bend testing.

Figure 2-G-12.Carbonyl nickel-coated steel specimen bent back and forth several times.

Figure 2-G-13.Single bend test of carbonyl nickel deposited on C110.

Figure 2-G-14.Carbonyl nickel deposited on C110 strip bent back and forth several times.

2.7.7.2.2 Stage 2

R&D on Carbonyl Ni-Coated Fe, Cu and Zn Strips.

The objective was aimed at improving the adherence of the carbonyl Ni coating to Fe, Cu and Zn substrates. The solution to the improved adherence was an annealing heat treatment after carbonyl Ni deposition: at 300 °C for the Zn strip, 350 °C for the Cu strip and 450 °C for the Fe strip. These annealing heat treatments were selected by successful bend tests on the three substrates at CVMR Corporation. Three coated and annealed Zn strips were shipped to CTC for bend testing, with the results on one specimen seen in Figure 2-G-15. All three Ni/Zn specimens were crack free showing good adherence of the coating.

Figure 2-G-15.Bent carbonyl Ni-coated and annealed Zn alloy A190 strip.

A second objective was to improve the surface smoothness and to brighten the earlier dull carbonyl Ni coatings. To accomplish this, the strips were burnished by ball milling in zirconium oxide (ZrO_2) media for 20 minutes at room temperature. The surface was brightened to a significant degree.

R&D on Prototype Tilting Carbonyl Reactor

The R&D was extended to coating of planchets in a small prototype carbonyl reactor (see Figure 2-G-16). This reactor was utilized to simulate the cyclic heating/deposition of commercial carbonyl Ni reactors that exist in the UK and Canada, which produce at the accumulated rate of nearly 200,000,000 pounds of carbonyl Ni per annum (p.a.)—far more than the capacity that would be required for US 5-cent coins. The 5,000,000 pound p.a. carbonyl reactor designed by CVMR Corporation and constructed in China is also simulated. The CVMR Corporation prototype unit used here consists of a heating chamber at one end and a deposition chamber at the other. The mechanism was designed to heat planchets to 200 °C in the heating chamber and then tilt 180 degrees to drop the planchets into the deposition chamber held at 80 °C, then re-tilt 180 degrees to return the planchets to the heating chamber. The device shown in Figure 2-G-16 is currently flipped 180 degrees by a primitive chain mechanism.

The primitive flipping sequence was practiced 6 times for a total of 10 minutes, with 1–2 seconds of deposition in each cycle. This cycle was practiced to carbonyl-Ni-coat 10 Cu planchets so the coating could be readily discerned on the reddish-gold colored copper. Deposition did occur, but further runs will be needed to optimize the cycles for larger batches of carbonyl Ni-coated Fe and

Zn planchets. These planchets are not worthy of evaluation other than to show that nickel was indeed being deposited.

Figure 2-G-16.CVMR prototype carbonyl reactor.

In very recent work for another client, CVMR was able to alter processing parameters that would cause carbonyl nickel to be shiny as deposited, thereby obviating the need for burnishing. Concerns have been raised about deformation of planchets that undergo long drops that are seen in large commercial reactors. It seems that this could be moderated by designing inclined or baffled slopes in a commercial scale-up.

3.0 COST TRENDS ANALYSIS

3.1 BACKGROUND

This chapter analyzes the production costs for each circulating coin and cost trends for current and potential changes in processes and metallic materials of construction for circulating coinage produced by the United States (US) Mint. Coin production practices and their effect on unit costs will be discussed in this chapter as some alternative material candidates require different production methods compared to current United States Mint and existing supplier production practices.

The unit cost to produce US circulating coins has risen substantially since the incumbent alloy formulations were introduced (1982 for the one-cent, 1866 for the 5-cent, 1965 for the dime, quarter dollar and half dollar, and 2000 for the dollar coins). Since 2006, the cost to produce the one-cent and 5-cent coins has exceeded their face value and thus the United States Mint is considering alternative coinage compositions as one means of lowering costs.

The total alloy compositions of incumbent US circulating coinage is shown in Table 3-1 and the current pricing of alternative material candidates initially considered in this study (commodity spot prices) is shown in Table 3-2. For the silver-white coins (5-cent, dime, quarter dollar and half dollar coins) a reduction in nickel (Ni) content could result in cost reductions, although using different alternative compositions that include low-cost metals such as aluminum (Al), zinc (Zn) and/or steel may result in material cost savings for production of these coins. There are several factors in addition to material cost that must be considered including material availability, supplier fabrication and manufacturing issues, durability, appearance, impact on stakeholders (including vending machine acceptance), ease of use, co-circulation, recyclability, and security and fraud protection. These factors are considered throughout the report.

Table 3-1. Incumbent Composition (weight percent [%]) of US Circulating Coinage

One-Cent	5-Cent	Dime / Quarter Dollar / Half Dollar	Dollar
97.5Zn-2.5Cu	75Cu-25Ni	91.67Cu-8.33Ni	88.5Cu-6Zn-3.5Mn-2Ni

Cu = copper; Mn = manganese

Table 3-2. Cost (dollars per kilogram [$/kg]) for Candidate Coin Metals (as of March 2012)

Cu	Ni	Zn	Al	Low-Carbon Steel	Ultra-Low Carbon Steel	430 Stainless Steel	302 Stainless Steel
8.53	19.91	2.13	2.29	1.32	2.75	2.34	6.56

Currently, the starting stock for the one-cent coin is delivered to the United States Mint as a copper-plated zinc (CPZ) ready-to-strike (RTS) planchet, the 5-cent coin starts as cupronickel monolithic coiled strip and the other denominations are coiled strip of cupronickel (dime, quarter dollar and half dollar) or manganese brass (dollar) roll clad on a copper core.

The same general process steps are used around the world to produce coins from rolled strip. The first step is blanking, or the punching out of circular ‘blanks’ from the strip. This is best accomplished from hardened strip such that a material will punch cleanly resulting in a flat blank. This is followed by annealing,[65] and after a cleaning operation, upsetting.[66] Since upsetting involves deforming metal to form a raised rim around the edge of the blank, it is best accomplished on a softened blank; thus the annealing step is applied. After upsetting, the product is referred to as a planchet and is RTS (or stamp) the design of the coin. Some coins require additional steps such as burnishing[67] or edge lettering.

Since coiled strip requires additional processing steps at the United States Mint beyond that required for an RTS planchet, a calculation is made in the present analysis to determine whether it is more efficient to purchase starting stock materials as planchets that are upset at suppliers, or as rolled strip, which would require blanking, annealing and upsetting in-house at the United States Mint. However, for higher denomination coins, additional considerations may be warranted to ensure the security of external planchet shipments from suppliers. For each denomination considered, it should be determined if secure production at the supplier and/or secure transportation (such as armored-car transport) is required for RTS planchet delivery to the United States Mint. Finally, some metals require more or less (relative to that of incumbent coins) die striking load and different annealing treatments; these considerations were accounted for in the calculated production costs.

3.2 COIN SECURITY

Fraud protection and the security of US circulating coins was one of the factors used to match alternative material candidates to coin denominations. Coin-acceptance and coin-handling equipment use a variety of coin characteristics and/or properties to recognize and validate coins. Most validate physical attributes, including diameter and thickness, while more sophisticated coin-validation methods measure and rely on the electromagnetic signature[68] (EMS) of coins. While each machine manufacturer uses their own proprietary algorithm to determine the EMS, they are all based upon reading the materials' electrical conductivity and magnetic permeability to the extent that they affect an electric signal of a receiver in the vicinity of the coin during the validation process. Security is more important for high-denomination coins and thus these coins should have a unique EMS, unlike that of ordinary uniform metals and other world coinage, making them more difficult to counterfeit. The point at which a coin can be designated as high denomination (as opposed to low or medium denomination) is subject to individual interpretation; however, the threshold is approximately at the US quarter dollar coin. Additional information concerning coin security and fraud is presented in the Outreach Chapter.

The construction of the incumbent dime, quarter dollar and half dollar coins is a cupronickel alloy (Cu-25%Ni) clad onto a copper core. The dollar coin has a manganese brass alloy clad onto a

[65] Annealing is a heat treatment used to soften the alloy.
[66] Upsetting is a deformation process used to raise a rim around the circumference of both surfaces of the blank.
[67] Burnishing is a cleaning and polishing process used on metals.
[68] Electromagnetic signature (EMS) is understood in the industry to mean the electrical signal strength of a nearby electromagnetic sensor as a coin passes in close proximity to the sensor. The magnetic field in the vicinity of the emitting sensor, and therefore the electrical current in the EMS receiving sensor, changes as the coin passes by. The change in electrical signal strength is influenced by the materials of construction along with the thickness and distribution of materials within the coin. The signal strength and/or its decay rate are then used by software to validate the coin and determine its denomination. One key determiner of EMS is electrical conductivity, typically measured by the percent of the conductivity of the International Annealed Copper Standard (%IACS).

copper core. By utilizing different frequencies, detectors evaluate the EMS at different depths and thus a coin with a clad or thick enough plated construction may have an EMS signature that cannot be replicated by a monolithic counterfeit or slug. Hence, these detectors foil attempts by fraudsters who attempt to use single-material slugs in place of clad coins. This feature also creates a limitation on the ability to seamlessly introduce a monolithic coin into circulation to replace incumbent clad coins.

Clad construction can provide greater security as has been proven since 1965 in the US. Other world mints believe plated construction, where a layer (or layers) of one (or more) metal(s) is deposited on an upset blank to provide a RTS planchet, may also provide adequate security for low-denomination coins[69] that would be too cost prohibitive to attempt to counterfeit. Plated construction is not often used for high-value denominations (noted as denominations above the US quarter dollar coin) since plated counterfeit coins can be made relatively easily and inexpensively at numerous commercial metal-plating facilities or by readily constructed metal-plating facilities.

Plated coins have been introduced in many countries as a cost-reduction technique; these coins resemble higher-cost metals by using a low-cost core (e.g., steel) and a higher-cost outer layer (e.g., copper or nickel). For plated construction, the key is that the plating must be thick enough to affect the EMS reading and be consistent with regard to layer thickness [1]. Since plated coins are in use in several countries around the world, it is also important to distinguish coins from each other by plating thickness, metal composition, coin diameter and overall coin thickness so that one country's low-denomination coins are not used as counterfeit high-denomination coins in another country. Plated coins are generally accepted in the coinage community as inherently less secure than clad coins, as outlined in The WVA Coin Design Handbook [1]. Plated coins require enlarged acceptance windows[70] that reduce the effective sensitivity of the coin-processing equipment to discriminate valid coins from counterfeit, since slight variability in plating thickness (from fabrication or from wear) can have a large effect on measured properties.

For some denominations, alternative material candidates have been identified that enable a potentially seamless transition with the incumbent coins. However, the cost savings to the United States Mint for such candidates are generally relatively modest.

For the alternative material candidates with higher potential cost savings to the United States Mint, the coin's EMS, and potentially other characteristics and/or properties, is different than the incumbent coinage, which has been designed to be unique among the world's circulating coins. While a unique EMS may help with fraud protection, it also requires the reprogramming or replacement of coin-validation equipment to recognize the alternative coins as they co-circulate with the incumbent coins.[71] Co-circulation of coinage is necessary because the US has never withdrawn or changed the legal-tender status of issued coins. It is also unrealistic given the

[69] Although opinions vary among coin experts, the demarcation between low-value and high-value coins is typically at approximately 25 cents. Other experts use the term medium-value to define coins of approximately 20 to 40 cents in face value.
[70] The industry defines acceptance windows as the range in measured characteristics and/or properties that have been determined to match a given coin. When all measured values fall within each of the acceptance windows, then a coin is declared valid, its denomination accounted for and further actions taken within the coin-processing equipment.
[71] The cost of this conversion and the consideration of the Public Law to minimize conversion costs are addressed in the Outreach Chapter.

logistics of exchanging coins and the high production capacity needed to generate replacement coins in a short period of time. The estimated peak production capacity of the United States Mint is approximately 18 billion (B) coins per year. At this production rate, it would require approximately 20 years to replace the estimated 366B US circulating coins in existence as of January 2012.[72]

Ferromagnetic materials[73] such as steel or ferritic stainless steels (4xx series) present a challenge to coin-processing equipment because ferromagnetic steels cannot be validated by a large number of EMS-based coin-processing equipment currently fielded in the US. Plating, if thick enough, can be used to imbue steel coins with a unique EMS and the manipulation of the plating metal and thickness can be used to distinguish different steel coins from each other. High-denomination steel core coins must be constructed such that readily available foils and metal sheets are not mechanically combined to make cheap, 'high-tech' slugs.

3.3 COINAGE METALS

Candidate alloys for specific circulating coin denominations and an analysis of their production and materials costs is presented. Before detailing these specifics, it is important to understand the price trends of the metals of interest and the factors that affect these trends. In general, the coinage alloys to be discussed are comprised primarily of one or more of the metals copper, nickel, zinc, aluminum and iron (as steel).

The price of metals and commodities in general is mainly a function of supply and demand as well as production costs and overall economic trends. As such, metal prices are intrinsically highly volatile. While the economy has been going through significant upheaval over the past three years, it is instructive to review historical data as short-term spikes in pricing tend to revert back to the mean over extended periods of time. The United States Geological Survey (USGS) conducted an analysis of trends in copper, nickel and steel commodity pricing (along with additional metals) for the years 1900–2004 and found that although there was an upward trend in prices, the price held relatively constant when adjusted for inflation as shown in Figure 3-1 [2]. In addition, although price fluctuations currently are greater than they have been historically, they are quite similar to historical fluctuations when measured in inflation-adjusted dollars.

[72] See Appendix 4-D: "Estimate of the Number of US Coins in Circulation" for further details on how this number was estimated.

[73] Ferromagnetic materials are drawn to a magnet.

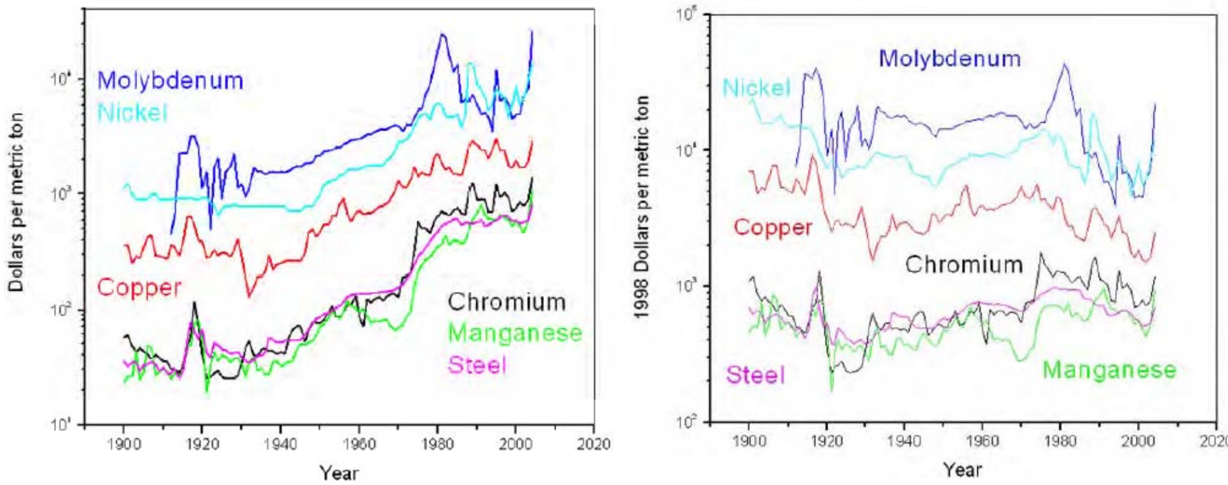


Figure 3-1. Current and inflation-adjusted US dollars per tonne of selected metals [2].

The global demand for metals has risen over the last century. For example, annual domestic steel consumption was approximately 9.1 million (M) metric tons (tonnes) (10M tons) at the start of the 20th century and over 91M tonnes (100M tons) at the end. As of 2011, the US accounts for less than 20% of world consumption of any metal reported in the study (steel, copper, nickel, molybdenum, chromium and manganese), much less (as a percentage) than during its peak after World War II. Demand is only one factor that affects commodity prices; supply, reserves, scrap, speculation and geo-political factors are also significant contributors to commodity metal prices. Copper and nickel in particular are traded by investors like gold and silver, and are subject to additional speculative pricing pressure [2].

3.4 COPPER

The US is both a significant copper producer and consumer. In general, copper pricing reflects a balance between production and consumption; relating directly to the strength or forecasted future strength of the economy. The primary industries that consume copper include construction, electrical products, transportation equipment, consumer products and industrial machinery.

In 2011, US mine production of copper was about 1.0M tonnes (1.1M tons) from 29 mines, located primarily in Arizona, Utah, New Mexico, Nevada and Montana. Contributions from scrap contributed about 35% of the US copper supply. The net import reliance as a percentage of consumption was 35% in 2011 with the imports primarily coming from Chile, Canada, Peru and Mexico [3]. A 1998 USGS assessment estimated 500M tonnes (550M tons) of copper resources exist in the US with a subsequent assessment reporting global land-based resources exceeding 2.7B tonnes (3B tons).

Copper prices are difficult to forecast. In a 2006 analysis [4] prices were thought to have peaked and the trend, even for the analyst's most optimistic vision, was for lower prices in 2010 and lower yet in 2020. However, after a slump in 2008, copper prices regained their 2007 peak levels. In early 2011, an analyst released a new forecast that copper prices would peak in 2011 and then fade, followed by a steep rise in 2012 and a drastic collapse into 2016 [5]. Another forecaster sees the current price remaining constant through 2012 followed by a slight decrease into a long-term equilibrium of about \$5.75/kg (vs. \$8.53/kg as of March 2012) from 2014 onward [6].

Substitutes for copper are increasingly used when prices climb; these substitutes include aluminum for electrical and radiator uses, titanium and steel for heat exchangers, optical fibers for telecommunications and plastics in pipes and plumbing fixtures.

3.5 NICKEL

The US imports virtually all of its nickel and did not have any active nickel mines in 2010. The major import source over the past few years has been Canada, followed by Russia, Australia and Norway. However 43% of 2011 consumption of nickel was from recovered scrap. The USGS report [3] identified worldwide land-based resources of at least 118M tonnes (130M tons) of nickel. Production is widespread and the major producers are Russia, Indonesia, Australia, Canada and the Philippines. Nickel is primarily used to alloy stainless steel and nonferrous and superalloys[74] with end uses in transportation, the chemical industry, electrical equipment, the petroleum industry, construction, household appliances and industrial machinery.

It should also be noted and is discussed further in the Environmental Assessment Chapter (Section 6.7.4.1), that a small percentage of the population has an allergic reaction to nickel; manifesting itself during both the coin-production process and during coin handling by the public. The incumbent cupronickel alloy, nickel plated steels and the Multi-Ply-plated steel coins would have to be assessed for this reaction.

Nickel prices are driven mainly by stainless steel consumption, which is forecast to gradually increase over the next decade [7] although a wide range of prices is possible [8]. As alternatives to high and volatile nickel prices, low-nickel grades of stainless steel or titanium have been used instead of higher nickel content stainless steels such as 3xx grade. Lithium ion batteries have become more competitive with nickel metal hydride batteries for some applications. When considering future prices, it is instructive to review the long-term price history of nickel. Figure 3-2 shows that the price spike of 2006–2008 seems like an anomaly versus the otherwise relatively stable price of the last 20 years.

[74] A superalloy is one that exhibits good high-temperature properties, especially those related to strength, creep resistance and corrosion. These alloys are often used in the hot sections of aerospace turbine engines. Many superalloys are nickel-based in composition.

Figure 3-2. Nickel price behavior since 1989 [9].

3.6 ZINC

The demand for zinc follows industrial production and thus global economic growth. In 2011 zinc was produced domestically in 13 mines in four states. The USGS reports [3] global resources of zinc to be about 1.9B tonnes (2.1B tons). Zinc consumption is primarily driven by galvanizing followed by zinc alloys and as an addition to brass and bronze alloys. While the US exports zinc ore and concentrate, the US imports refined zinc, primarily from Canada, Mexico and Peru.

As with nickel, a price spike in 2006–2008 to approximately $4840/tonne ($4400/ton) was unusual as the 20-year trend has been relatively stable, in the $1100–1650/tonne ($1000–1500/ton) range [8]. Forecasts for zinc generally show higher pricing with one model showing prices peaking in 2014, and then declining. Another forecast shows a more gradual increase into 2015, then stabilizing [8]. However, a forecast from 2006 predicted a continued decline into 2025 [4].

The commodity price trend for nickel, copper and zinc over the past 10 years is shown in Figure 3-3. While the price trends of these individual metals do not exactly follow each other, it is clear that all rose steeply in 2005 to mid-2007 and declined steeply from mid-2007 to 2009. This reflected the (weakness or instability) of the global economy, although the recent price action shows copper advancing above the trend line of nickel and zinc, an effect of copper being increasingly used as an investment vehicle in addition to being an industrial metal.

Figure 3-3. Nickel, copper and zinc 10-year commodity pricing [9].

3.7 ALUMINUM

The US is a producer as well as an importer and exporter of aluminum. The domestic supply of aluminum ore (bauxite) cannot meet the domestic demand, and therefore the US is somewhat dependent upon imports. Most of the imports come from Canada, Russia and the United Arab Emirates. Recycling is significant; aluminum recovered from old scrap (e.g., discarded products) was equivalent to approximately 36% of consumption in 2011, and a slightly higher percentage was from new (manufacturing) scrap. Globally, there are sufficient bauxite reserves to meet world demand well into the future. In 2011, there were ten operational primary aluminum smelters in the US. Aluminum is primarily used in transportation, packaging, building, electrical, machinery and consumer durables. Substitutes including other metals and composites can be used as replacements.

Aluminum prices are driven primarily by both demand and production costs. Aluminum extraction from bauxite is very energy intensive. Production costs have historically acted as a floor for aluminum prices. Forecasts for aluminum are for lower prices in 2012, followed by moderately increasing prices in the long term [10]. Substitutes for aluminum include composites for aerospace; glass, paper, plastics and steel for packaging; and other metal alloys, composites, polymers and wood for structural and construction applications. The historical price trend of aluminum is shown in Figure 3-4.

Note: 3-month futures, though one of many methods used to express average metal prices, appears to be the most commonly cited. Steel was not a traded commodity until July 2008.

Figure 3-4. Aluminum and steel (3-month futures) commodity pricing [9].

3.8 IRON

Steel is produced and consumed in far greater quantities than any other metal; the US is both a major producer and consumer of steel. The US reserves are estimated at 25B tonnes (27B tons) of iron contained in ore; world resources exceed 210B tonnes (230B tons) of iron [3]. Domestically, pig iron (an intermediate iron-containing product with relatively high carbon [C] content) was produced in fifteen locations, while raw steel was produced at about 108 mini-mills in 2011 [3]. The domestic steel industry is highly dependent upon recycled iron and steel scrap; the primary source of old scrap is from automobiles. The US both imports and exports scrap steel. The US imports more steel final products than it exports; imports come primarily from Canada, the European Union, China and Mexico. Steel is widely used for construction, transportation and containers.

The price of stainless steel is sensitive to its main alloying ingredients, chromium and nickel. Domestic chromium production and recycling is not sufficient to meet demand and must be imported.

The commodity price trend of aluminum and steel is shown in Figure 3-4. These metals generally trend alike. A steep drop in 2008–2009 reflects the weak global economy.

3.9 OTHER METALS RELEVANT TO COINAGE

Worldwide, coins are produced primarily from the metals described previously or alloys thereof; copper, nickel, zinc, aluminum and iron (steel). A summary table of the composition of selected coins from around the world can be found in Appendix 3-A. Additional important metals for consideration in circulation coinage include tin (Sn), manganese (Mn), chromium (Cr) and magnesium (Mg), as they are used as significant alloying additions or coatings.

Tin has not been mined or smelted in the US since 1993 and 1989, respectively. The US has limited resources of tin, while world resources are sufficient to sustain production well into the future. Import sources include Peru, Bolivia, Indonesia and China. Recycled scrap is also a major source of tin. Industrial uses of tin include applications in the electrical, container, construction and transportation industries. Tin was evaluated in this study as a possible coating for zinc or steel coins; Dura-White-plated zinc included a tin outer layer.

Manganese has not been produced domestically since 1970, since US resources are primarily low grade. Of the world's identified land-based resources of manganese, 75% is located in South Africa, a US supplier along with Gabon, followed by China and Australia. The main use of manganese is as an alloying element in iron and steel including stainless steels. Manganese is also an alloying element for copper and aluminum.

Chromium resources are primarily concentrated in Kazakhstan, India and southern Africa with a small reserve in the US, which has one active mine in Oregon. Recycled stainless steel accounts for 40% of the domestic supply of chromium. Import sources include South Africa, Kazakhstan, Russia and China. Stainless steel, heat resistant steel and superalloys consume most of the chromium produced. Chromium is the primary alloying addition in stainless steel.

Magnesium is mined by one company in Utah. Seawater and brines are used to produce magnesium and its compounds and thus the global resources are vast. A significant amount of product is recovered from old scrap and import sources include Israel, Canada and China. Magnesium is used for alloying aluminum cast and wrought products, magnesium alloy structural products, and iron and steel desulfurization. Magnesium compounds are used in refractories, agricultural, chemical, construction, environmental and industrial applications.

3.10 CANDIDATE COINAGE MATERIALS

Candidate coinage materials and incumbent metals used for each denomination of US circulating coins were evaluated for cost. This analysis is categorized by denomination for projected annual production quantities. The dime and half dollar coins are not shown in this section as their compositions are assumed to be equivalent to that of the quarter dollar coin. Cost figures for some dime coin candidates are included after this section; the half dollar coin, not currently being minted for circulation, was omitted. Costs components in the tables include:

- Metal and fabrication costs for suppliers
- Credit for recycled web scrap and condemned scrap
- United States Mint production costs incurred, further broken down into direct and plant overhead components
- Distribution to the Federal Reserve Banks (FRBs)
- General and Administrative (G&A) costs.

The first row of each table below shows the incumbent circulating coin unit costs as per the latest information from the United States Mint for fiscal year (FY) 2011. Metal prices fluctuate; therefore, the second row of each table shows the cost of the coin using metal prices as of March 1, 2012; this will provide a more direct comparison with the alternative material candidates. Input for the costs of the candidate alloys are from actual vendor quotations or engineering estimates from the best information available including metals commodity market data. The total cost is calculated from the number of circulating coins minted for each denomination by the United States Mint in FY2011.

For convenience, an abbreviated table, in which sums of the preliminary fixed and variable costs are shown, is presented within the discussion of each denomination. The full tables showing the breakout of these preliminary costs are provided in Appendix 3-B. These preliminary costs are based upon actual vendor quotations or engineering estimates from the best information available including metals commodity market data. Actual quotes from vendors to include any relevant licenses fees for certain proprietary or patented intellectual property will be needed to validate these preliminary costs.

In the tables, found in Appendix 3-B, the column labeled "USM Direct Production" includes the United States Mint costs for the combined procedures of blanking, annealing, upsetting, burnishing and striking, as required for any given denomination during production at the United States Mint. For some alternative material candidates, not all of these procedures are required and so the formula used by the United States Mint for a 'standard' coin is used. Specifically, the production allocation assigns the following fractional production cost to each procedure: blanking (0.15), annealing (0.25), upsetting (0.10), burnishing (0.05)[75] and striking (0.45) as shown in Figure 3-5. For any denomination, the savings for any eliminated procedure is limited to the direct portion of costs; estimated at 28% of what is characterized as total production costs in the United States Mint financial system. That is, the plant overhead component of the United States Mint production costs is 72% of the total and is applied to the denominations based upon plant activity and the volume of coins produced. For example, if blanking were eliminated for a 'standard' coin that uses all of the process steps, the cost savings would be 28% of the blanking portion, or 28% of 15% (or 4.2%) of the total production costs for this 'standard' coin.

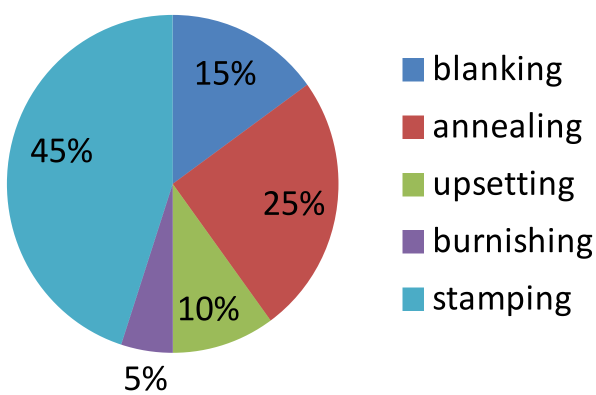


Figure 3-5. Components of standard coin production costs.

[75] As of March 2012, only the dollar coin is burnished.

The column labeled “Supplier Fabrication” in the tables of Appendix 3-B is a supplier fabrication cost; it is essentially their costs to produce the product in the form delivered to the United States Mint. It is difficult to separate the fabrication cost from the metal cost if not directly provided by the supplier, because other factors including supplier profit or licensing fees, if appropriate, are included in the delivered price. Consequently, for some estimations, the metal and fabrication costs are combined in the “March 2012 Metal Cost” column. For coiled strip products, scrap credit was estimated by calculating the historical average of condemned material from United States Mint production and multiplying this weight of metal by a recovery factor supplied by the United States Mint. Coin alloy cost is a composite of the individual metals as priced on the commodities market (as of March 1, 2012). For plated products, where planchets are supplied, web scrap is zero and the returned condemned scrap is estimated to be less than 2% of the total planchets delivered (as it is currently for the one-cent coin). While there is some credit for this scrap, it is fairly insignificant for plated planchets. The scrap credit as a separate component is not given for the 2011 coin unit costs as it is already included in the metal and so a better direct comparison of alternative material candidates is with the circulating coin current (as of March 2012) cost (second row of each table).

Note that distribution costs and G&A were assumed to remain constant for each alternative material candidate. Each candidate is presented as either a planchet (P) or strip (S) and a key for the annotations is provided after the cost breakdown tables in Appendix 3-B. This key details the assumptions and origin of the factors involved in calculating the costs. Additional minor cost impacts, such as changes in transportation costs due to changes in coin weight, were not easily quantifiable. These cost impacts are not factored into the total unit costs, but they are discussed in the text. Costs that are shown in parentheses are negative values. All costs shown in the tables assume the diameter and thickness of all coinage will remain the same as the incumbent coins.

Supplier quotes were not received for all alternative material candidates; commodity pricing was used to calculate cost for these candidates. Some of the alternative material candidates have unique formulations. The formulation and pricing of candidates provided by suppliers, identified in the annotated notes for each table, are supplier proprietary information. Where suppliers have provided quotations for patent pending alloy formulations, any licensing fee or other rights issues are included, along with supplier profit, in their quotations.

Each denomination has alternative material candidates that are identical with respect to fabrication processes and are seamless with respect to coin-processing equipment/EMS considerations. Plated options are presented as coins that have different EMS values (non-seamless) as compared to incumbent coins and need to co-circulate. A non-seamless co-circulating model entails significant expenses for the conversion of coin-processing equipment owners and operators to recognize a non-seamless coin and therefore makes it necessary that a non-seamless co-circulated coin provide a very significant per-unit cost savings be realized by the United States Mint.

3.11 ONE-CENT COIN

Table 3-3 summarizes the cost elements for the one-cent alternative material candidates considered throughout this report.

3.11.1 Copper-Plated Zinc (CPZ)

Since 1982, the one-cent coin has been comprised of a copper-plated zinc alloy. Ready-to-strike CPZ planchets for one-cent coins are supplied to the United States Mint and production is limited to receipt, striking, counting and packaging. The core zinc alloy of CPZ contains copper (0.8%) such that the entire one-cent coin could be recycled for production of future one-cent coins. As shown in Figure 3-6, the cost of the metal in a one-cent coin comprises 29% of the total cost of the coin.

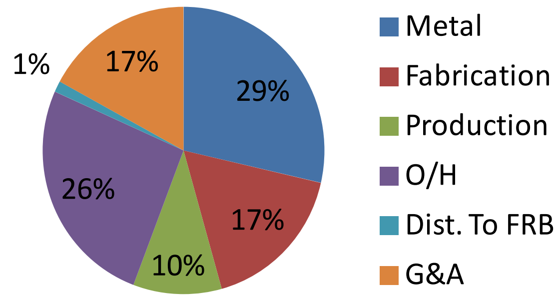


Figure 3-6. Cost components of the one-cent coin (FY2011).

While the total cost of the one-cent coin in 2011 was $0.0241, the cost as of March 2012 is approximately $0.0225 due to lower metal prices. Of this total, the indirect costs of plant overhead (O/H), G&A and distribution (Dist.) total $0.0107; therefore, it is currently impossible to reduce the total cost below $0.01 by using alternative metallic materials alone under the FY2011 indirect cost structure. For example, even a 30% reduction in the metal cost results in only a 8.7% total cost reduction in coin production costs.

Table 3-3. One-Cent Coin Alternative Material Candidates Unit Costs

	Weight (g)	**Metal + Fabrication + USM Production – Scrap**	**USM O/H + G&A + Distribution**	**Total Unit Cost**	**Savings vs. March 2012 Cost for 4289M Coins**	**Savings vs. USM FY2011 4289M Coins**
2011 One-Cent Coin (P)	2.50	$0.0134	$0.0107	$0.0241	--	--
CPZ March 2012 Costs (P)	2.50	$0.0118	$0.0107	$0.0225	--	$6,896,712
CPS (P)	2.82	$0.0170	$0.0107	$0.0276	$(21,961,855)	$(15,099,455)
5052-H32 (S)	0.94	$0.0074	$0.0107	$0.0180	$19,193,065	$26,055,465
430 Stainless Steel (S)	2.74	$0.0130	$0.0107	$0.0237	$(5,196,342)	$1,666,058
CPS (S)	2.82	$0.0146	$0.0107	$0.0253	$(11,826,752)	$(4,964,352)
Aluminized Steel (S)	2.74	$0.0095	$0.0107	$0.0202	$10,029,698	$16,892,098

CPS = Copper-plated steel; USM = United States Mint; g = Gram; P = Material supplied as planchet; S = Material supplied as strip.

3.11.2 Copper-Plated Steel

Low-carbon steel is a natural choice for a low-cost coin because of its very low metal cost and availability. However, steel coins will rust over time, necessitating a coated product to protect appearance and increase their service life. CPS coins are used in many countries for their lowest denomination coins. Countries using steel-based coins include those using the Euro, Canada, United Kingdom (UK), South Africa and Brazil where coins are struck from plated planchets. For proper striking, steel must be annealed to a soft state, although annealing steel is performed at a much higher temperature than that for cupronickel. If delivered as a plated, coiled strip, furnace modifications would be needed within the United States Mint; alternatively, suppliers would have to develop a steel alloy that is sufficiently soft such that both blanking and stamping could be performed without an additional annealing step. Even annealed, steel is a relatively hard material and requires an increase in striking load resulting in a reduction in die life for any steel-based coin. Adopting steel coinage materials will require modifications to the United States Mint die manufacturing process and/or coin design (such as lower-relief designs). If CPS coins were to be blanked and struck from a coiled strip, the unprotected steel edges of the coin would readily corrode while in circulation. However, this practice was used for many years for pre-Euro German pfennigs where it was claimed that the frequent rubbing of coin edges during circulation prevented significant buildup of corrosion products. After introduction of the Euro monetary system, this coin was no longer accepted as legal tender.

In Table 3-3, CPZ costs and CPS costs are calculated from quotations provided from Jarden Zinc Products (JZP). Rough estimate costs for these products were also received from the Royal Canadian Mint (RCM) and the Royal Mint. These estimates are not shown here because details that affect the cost, including the ability to meet the United States Mint production needs and cross-border shipping costs have not been addressed, but the estimates were useful in validating the domestic quotation. CPS results in a slightly higher total coin cost than CPZ. There are a few factors that result in this price differential. Although the core steel for the CPS planchet is lower in cost than the CPZ core, CPS needs a 25-micron copper coating to effectively protect the steel from corrosion, whereas the CPZ planchet is coated with only an 8-micron copper plating. The additional plating on the steel-cored alternative not only results in a higher cost of materials (e.g., more copper) but a longer plating cycle. In addition, CPS requires an annealing step after plating whereas CPZ does not. There are different industrial methods to plate copper onto steel; the lowest-cost procedure generally involves a cyanide salt electroplating bath. While this is common practice, there are demanding environmental safety practices that must be followed. Some suppliers (including the RCM) use an alternative acid bath process. This process may require an intermediate metal layer, such as zinc, for proper adhesion; increasing the costs further for the steel-cored alternative. For plated-steel coins it is typically not easy or cost effective to separate plated layers during recycling and thus the 25-micron copper plating would not be reclaimed; scrapped one-cent CPS coins would be recycled as scrapped steel. Although most vending machines do not accept one-cent coins, coin sorters/counters do and so a recognizable and distinguishable EMS is valuable. Since the steel core does not provide a recognizable EMS to a large number of coin-processing equipment, a thick-plated layer (e.g., 25 microns) is needed for coin recognition.

It should be mentioned that some foreign mints, including the Royal Mint have developed a steel for coinage that is delivered as annealed strip and would not require an anneal step in the United States Mint. In addition, these mints have had some success with thinner plated layers. If these capabilities were developed in the US, the cost of CPS may be reduced, although only marginally, below that of CPZ. However, the associated capital investment to develop this capability domestically is not justifiable based strictly on producing product for CPS coins.

3.11.3 Aluminum Alloy 5052-H32

Aluminum alloy 5052 is strengthened by the addition of 2.5% Mg and 0.25% Cr. Hardening of this alloy is through solid solution strengthening and is enhanced by cold working. For the cupronickel-based alloys of the higher denomination coins, strip is typically delivered in a hard condition for optimum blanking, and then annealed soft for subsequent upsetting and striking. It is not clear if an aluminum alloy would require these same processing steps or if blanking and striking could both be managed under the same temper condition, thus eliminating an annealing step. While this cost savings is not yet factored into the calculations, it will be an important consideration when considering alloy options as will the possibility of cost savings from lower die fatigue (i.e., longer die life) due to lower required striking loads. Alloy 5052-H32 (i.e., alloy 5052 with an H32 heat treatment) is much harder than pure aluminum and is thought to provide a good balance between coinability and coin durability in circulation. Calculations are based upon quotations from multiple aluminum alloy suppliers. Aluminum also has a well-established recycling market for scrap.

While 5052-H32 aluminum provides a significant cost savings over the incumbent one-cent coin materials, there is some uncertainty about United States Mint production costs. While the calculations represent the cost of production based upon the contributions from each process step, the United States Mint has not blanked nor upset one-cent coins in 30 years. Since the one-cent coin represents approximately half of the circulating coin production, adjustments to production and capital expenditures may be needed to allow for blanking and upsetting of an additional four-plus billion units per year.

Aluminum alloys have been used for low-denomination coins in some countries including Japan, Korea, China and in some earlier European countries. There have been some reports of poor wear resistance, galling and jamming in coin-processing equipment; cold welding of aluminum coins during processing have been known to cause permanent damage to high-speed coin sorters/counters. The coin-processing equipment manufacturers and their clients are strenuously opposed to aluminum coinage for these reasons. Because of aluminum's low density, more one-cent coins could be minted per pound than the incumbent material; approximately five aluminum one-cent coins would weigh the same as two incumbent one-cent coins. This weight difference would necessitate adjustments for weight-based coin counting and may be a challenge for coin acceptors that utilize a coin's weight to trip a mechanical sorting device.

Aluminum alloy 5052-H32 is very corrosion resistant and does not require a coating like steel and zinc; however, it is silver-white in color and could be confused with the dime coin. Coatings such as anodizing to provide a darker or more copper-like color to mimic the incumbent one-cent coin have been investigated. These coatings have not yet been found to be cost effective and some concepts are still in the research and development (R&D) stage.

Previous studies for the Department of the Treasury performed in 1973 and 1980 [11, 12] have concluded that aluminum is an acceptable material for one-cent coins although various reasons such as reduced press speeds to prevent jamming during coin striking, corrosion issues, and light weight causing either 1) jamming in coin-acceptors or 2) galling or jamming in high-speed coin sorting/counting equipment prevented the production of aluminum one-cent coins. In addition, decreasing copper prices during the time of these reports reduced the interest in making a material change to aluminum one-cent coins.

3.11.4 Grade 430 Stainless Steel

Although stainless steels are priced at a premium over carbon steels, no surface treatment is necessary for corrosion protection. Stainless steels are defined as containing greater than 12% chromium although they also contain other elements, importantly nickel. Ferritic stainless steels (4xx series) have relatively low nickel content and are a lower-cost option than the austenitic grades. Ferritic stainless steel coins are currently in use within other countries including India and Mexico. Grade 430 stainless steel is a commodity alloy that is available from multiple suppliers and has an established recycling market. Stainless steels are typically hard and require higher striking loads than incumbent coin materials. In addition, to facilitate quality striking of stainless steel, the design of the coin may have to be adjusted to a lower relief. The United States Mint direct production cost has been adjusted by a difficulty factor in that shorter die life is anticipated if one-cent coins were fabricated from 430 stainless steel.

There are not significant cost savings if one-cent coins were to be minted from 430 stainless steel. Since the one-cent coin is not used by vending and most other coin-acceptance equipment, the ferromagnetic character of the coin is not a major concern and in fact may be a benefit to coin sorters, as a simple magnet may be used for sorting. However, the significantly shorter die life and restrictions on coin design are obstacles that may be best overcome with future research and alloy development instead of using the currently available 430 stainless steel.

3.11.5 Aluminized Steel

One of the most economical means to provide corrosion protection for steel substrates is via hot dip coating. While zinc-coated steel (also known as galvanized steel) was considered in this study, it was not pursued due to the poor appearance such coins would have after only a short time in circulation. Galvanizing protects steel by acting as a sacrificial anode that corrodes preferentially to the steel. This results in a flaky gray corrosion product on galvanized steel. Aluminized steel is an alternative to galvanized steel and is used for industrial components such as mufflers, heat exchangers, ovens, common bake ware, as well as roofing and siding. Aluminized steel coins would be grey-white in color. Aluminized steel can be recycled as steel scrap; it is not practical or cost effective to separate the very thin aluminum surface layers. Aluminized steel is currently available only as coiled strip. During the blanking operation, unprotected blank edges would be exposed and thereby edges of the coin would be susceptible to corrosion. Issues such as higher striking loads (of steel-based materials), as discussed earlier, would also apply. In addition, annealing of the steel could not be achieved since the usual steel annealing temperature is above the melting point of aluminum. The aluminum surface would be susceptible to galling and cold welding, cited by the coin-processing equipment manufacturers as potentially damaging to their equipment. Aluminized steel strip is a commodity product that is available from a number of suppliers.

3.12 5-CENT COIN

3.12.1 Cupronickel

The starting stock material for the incumbent 5-cent coin is monolithic cupronickel coiled strip from either Olin Brass (Olin) or PMX Industries, Inc. (PMX); the same material is used as the clad layer on the dime, quarter dollar and half dollar coins. Coiled materials go through blanking, annealing, upsetting and striking at the United States Mint. The current cost of the 5-cent coin has decreased relative to the FY2011 average cost due to decreasing commodity prices of copper and nickel. The fixed cost components of United States Mint plant overhead, G&A and distribution total $0.0322 for the 5-cent coin for FY2011.

As shown in Figure 3-7, the metal cost of the 5-cent coin was 60% of the total cost in FY2011. This is the highest percentage of all US circulating coins; the primary reasons are the coin's monolithic (i.e., not clad) construction, low fabrication costs and of all the US circulating coins the composition of the 5-cent coin has the highest percentage (25%) of costly nickel. Cost details for cupronickel and other alternative material candidates for the 5-cent coin are shown in Table 3-4.

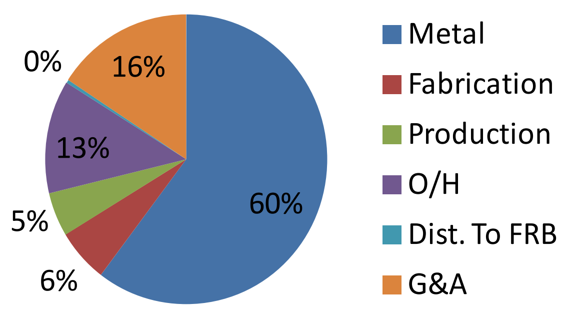


Figure 3-7. Cost components of the 5-cent coin (FY2011).

Table 3-4. 5-Cent Coin Alternative Material Candidates Unit Costs

	Weight (g)	Metal + Fabrication + USM Production – Scrap	USM O/H + G&A + Distribution	Total Unit Cost	Savings vs. March 2012 Cost for 914M Coins	Savings vs. USM FY2011 914M Coins
2011 5-Cent Coin (S)	5.00	$0.0796	$0.0322	$0.1118	--	--
5-Cent March 2012 Costs (S)	5.00	$0.0674	$0.0322	$0.0995	--	$11,206,159
G6 Mod (S)	4.72	$0.0499	$0.0322	$0.0821	$15,942,757	$27,184,957
669z (S)	4.79	$0.0491	$0.0322	$0.0813	$16,668,857	$27,911,057
Unplated 31157 (S)	4.58	$0.0401	$0.0322	$0.0723	$24,898,153	$36,140,353
Nickel-Plated 31157 (P)	4.26	$0.0673	$0.0322	$0.0995	$36,560	$11,278,760
Dura-White™-Plated Zn (P)	4.10	$0.0226	$0.0322	$0.0547	$40,910,640	$52,152,840
Multi-Ply-Plated Steel (P)	4.37	$0.0312	$0.0322	$0.0634	$32,995,400	$44,237,600
Nickel-Plated Steel (P)	4.40	$0.0448	$0.0322	$0.0770	$20,556,171	$31,798,371
CPZ (P)	4.06	$0.0199	$0.0322	$0.0520	$43,378,440	$54,620,640
302 Stainless Steel (S)	4.40	$0.0355	$0.0322	$0.0677	$29,041,632	$40,283,832
430 Stainless Steel (S)	4.40	$0.0163	$0.0322	$0.0485	$46,590,679	$57,832,879

3.12.2 Alternative Copper Alloys

A modified-copper alloy option for the 5-cent coin can retain the same EMS with a modest cost reduction, primarily by reducing the total nickel content in the alloy. Three alternative copper alloys were identified: G6 modified (mod) (from Olin Brass),[76] 669z[77] and 31157 (nickel plated and unplated).[78] Each of these alloys is proprietary to the respective producer. The cost of the metal in these alloys was calculated using the commodity costs of the component metals as of March 1, 2012. The supplier fabrication cost for these candidates are all assumed to be equivalent to that of the cupronickel 5-cent coin in 2011.

The alternative copper alloys provide an 18–28% total unit cost reduction (as compared to March 2012 metal costs) for the incumbent 5-cent coin, and up to a 49% reduction in metals cost. However, if each of these materials ultimately result in about the same striking efficiency and EMS properties, then it may be possible to write the specification for a future alternative copper alloy for the 5-cent coin broadly so that all would be suitable. The specification could designate a fixed EMS, hardness, density and other properties so that the suppliers can compete on cost with their own version of an alloy that fits the specification.

The United States Mint production of these candidates is expected be identical to that of cupronickel, although these candidates utilize a reduced annealing temperature over that for cupronickel. The incumbent 5-cent coin requires a higher annealing temperature than the dime, quarter dollar and half dollar coins and therefore dedicated furnaces, requiring additional maintenance and energy are needed. These candidate 5-cent coin alloys can be annealed at the same temperature as the dime, quarter dollar and half dollar coins resulting in associated cost savings. These associated cost savings are not reflected in Table 3-4.

With a reduction in nickel content, the alternative copper alloys do not appear as white as the incumbent cupronickel coins. Alloys G6 mod and 669z have a yellowish cast, or a hint of yellow, while unplated 31157 has a more golden hue color. To ensure a white coin, JZP provided quotations on a nickel-plated (4 micron) 31157 alloy. However, this option does not provide for any significant cost savings because of the cost of plating and the limitations of cost reduction possible for RTS planchets versus coiled strip. If color is a lower order property than EMS, a slightly golden hue coin could be a seamless option with regard to the coin-processing equipment community.

3.12.3 Dura-White™[79]-Plated Zinc

Dura-White is a proprietary patent-pending process developed by JZP to coat a zinc planchet with a copper and tin plating. The product can be thought of as a large tin-coated version of the incumbent one-cent coin. Tin is not an inexpensive alloying element, but the plating layer is thin and so the cost impact is limited. As a white metal, tin is a better choice than nickel for coating onto a zinc substrate. Electroplated nickel typically requires a stress relief annealing treatment after plating at a temperature higher than the melting point of zinc. The zinc alloy core of a Dura-White-plated 5-cent coin does not contain tin and thus direct recycling back into coins is not possible. However, Dura-White-plated zinc coins could be recycled at a number of foundries that cast copper-tin-zinc alloys. As with all of the 5-cent alternative metal candidates, weights are reduced compared to the incumbent cupronickel alloy; this reduced weight may be cause for

[76] Olin Brass researched and developed this material prior to the start of this project. Information about the alloy was provided pursuant to a Confidentiality Agreement between GBC Metals and CTC.
[77] PMX has a patent pending for this alloy.
[78] JZP has a patent pending for this alloy.
[79] Dura-White™ is a trademark of Jarden Zinc Products, Greeneville, Tennessee.

concern for the bulk-coin-handling stakeholders as described in the Outreach Chapter. This copper/tin-plated zinc coin has a unique EMS, although different from the incumbent 5-cent coin. The costs of the coin were calculated from a JZP quote for Dura-White-plated zinc RTS planchets; United States Mint direct production costs were modified to reflect striking only. A Dura-White 5-cent coin was found to be approximately 36% lower in cost than the incumbent cupronickel 5-cent coin.

3.12.4 Multi-Ply-Plated Steel

Multi-Ply-plated steel is a patented process developed by the RCM in which a flash nickel layer is plated onto low-carbon steel, followed by a (non-cyanide) plated-copper layer and a second nickel layer. The copper layer allows for EMS control (via its thickness) and the nickel outer surface provides a white coin with good wear resistance. The plating is applied to an upset steel blank and delivered as a RTS planchet. If a cyanide plating process is used, the copper layer can be deposited on the steel without the initial flash nickel coating; thus the process may provide equivalent EMS control utilizing a two-layer (Cu-Ni) plating as a Multi-Ply (Ni-Cu-Ni) plating.

Multi-Ply-plated steel construction is used for circulating coins in Canada; in addition, the RCM is minting Multi-Ply-plated steel coins for several other countries. JZP manufactures Multi-Ply-plated steel coins under license from the RCM, and there is a memorandum of understanding between the RCM and Sunshine Minting, Incorporated, Coeur d'Alene, Idaho, to license future production. Two domestic US sources could therefore provide Multi-Ply-plated steel planchets to the United States Mint. Although the RCM has provided pricing guidance, JZP has provided a quotation for the price calculations. A Multi-Ply-plated steel 5-cent coin would have a unique EMS; however, it would be different than that of cupronickel. More information is provided in the Outreach Chapter concerning the EMS of Multi-Ply-plated steel coins. It is important that the EMS, coupled with the coin's dimensions (diameter and thickness), are used to provide for a truly unique coin, distinguishable from other Multi-Ply-plated steel coins in use around the world. The nickel- and copper-plated layers of Multi-Ply coins could not be economically separated and reclaimed for their recycling value and essentially worn coins would be classified as steel scrap.

As seen in Table 3-4, the cost reduction projected with Multi-Ply-plated steel 5-cent coins is slightly more than that for the seamless alternative copper alloy candidates.

3.12.5 Nickel-Plated Steel (NPS)

Estimated prices for NPS 5-cent RTS planchets were received from the Royal Mint and are included in Table 3-4. While the total cost of this candidate is reasonably low, it is higher than some of the alternative copper alloys. NPS also still has the concerns of higher striking loads and annealing temperature than cupronickel and it is not clear if the nickel layer, which is quite thick at 25 microns, could be recovered during recycling. NPS 5-cent coins have an EMS that is different than cupronickel and would need to be co-circulated as a non-seamless coin. In the UK, NPS 5- and 10-pence coins have recently been introduced as cupronickel-coin replacements. While the technology to electroplate nickel onto steel is mature, the ability of a domestic supplier to provide millions of planchets per week to the United States Mint needs to be developed to ensure a domestic source is available if this candidate material system is selected for construction of future 5-cent coins.

3.12.6 Stainless Steel

Ferritic 430 stainless steel is a nickel-free alloy (Fe with 0.05% C and 17% Cr) while austenitic 302HQ stainless steel contains nickel (Fe with 18% Cr, 9% Ni and 3.5% Cu) and is higher in cost. Grade 302HQ stainless steel is a very low-carbon grade to reduce flow stress and increase ductility. The primary difference between these alloys, relative to use in circulating coins, is that 430 stainless steel is ferromagnetic and does not respond to annealing treatments; on the other hand, 302HQ stainless steel is non-ferromagnetic and can be softened by an annealing heat treatment. Of the commercially available grades of stainless steel, 302HQ was selected because it was developed to be a low-cost rivet alloy where extensive cold forming would be required. Grade 430 stainless steel was selected because of its proven use in some other country's coinage (e.g., India and Mexico) as well as its low cost.

An issue for either stainless steel grade is that the loads required to strike coins are higher than that required for the incumbent 5-cent coins; so a difficulty factor was calculated into the United States Mint direct production costs. For 302HQ stainless steel, the cost of a higher anneal temperature was also factored into this calculation. The material cost for 302HQ stainless steel was calculated using a quotation from Carpenter Technology, while material costs for 430 stainless steel were calculated from commodity metals prices. A web-scrap factor was also assigned to both materials, as these alloys would be supplied as coiled strip. The scrap credit was assumed to be 10% (approximately that of the 5-cent coin for 2011) of the total metal plus fabrication cost. Grade 302HQ stainless steel has an EMS that is different from cupronickel, although it is very similar to other austenitic stainless steel grades. Approximately 33% of fielded EMS sensors used to validate coins cannot recognize ferromagnetic 430 stainless steel since these sensors are not able to distinguish materials with an ability to be magnetized.

3.13 DIME AND QUARTER DOLLAR COINS

3.13.1 Cupronickel-Clad Copper

The starting stock for the dime and quarter dollar coins is cupronickel clad on a copper core; the material is produced by Olin and PMX as coiled strip. The description of the process and alloys are the same for both coins and are grouped together here for efficiency as any changes to the materials of construction would likely be implemented for both denominations simultaneously. The cost table for the dime (Table 3-5) only shows the costs/savings for the three alternative copper alloy candidates. Table 3-6 shows costs/savings for additional material candidates; quotations for these other alternative material candidates were only received for the quarter dollar coin.

As with the 5-cent coin, the starting stock coils for the dime and quarter dollar coins are blanked, annealed and upset prior to striking; however some of the alternative material candidates shown in Table 3-6 are plated and supplied as RTS planchets. The quarter dollar coin is the most utilized coin for vending and other machines designed for unattended points of sale, followed by the dime coin. Due to their use rate in circulation and due to their higher value, EMS and security take on added importance for the quarter dollar coin than for the one-cent or 5-cent coins; therefore, monolithic candidates have not been selected for the quarter dollar coin in the present study. It is difficult for a counterfeiter to produce a one-cent or a 5-cent slug for much less than face value, but attempts at counterfeiting become more attractive as the coin face value increases. In addition, the dime and quarter dollar coins are at a relatively high positive seigniorage and so the expense of higher security materials, such as clad sheet, can be tolerated. Furthermore, a clad construction using materials having the proper properties would minimize or eliminate the conversion cost to many stakeholders to upgrade their coin-processing equipment to recognize the alternative coins.

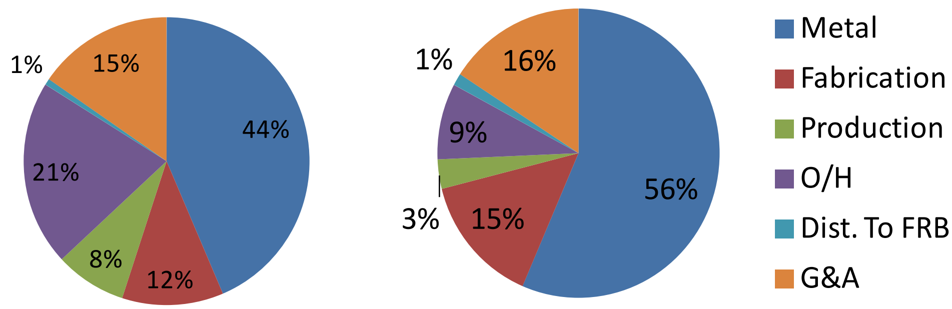


Figure 3-8. Cost components of the dime (left) and quarter dollar (right) coins (FY2011).

Table 3-5. Dime Coin Alternative Material Candidates Unit Costs

	Weight (g)	**Metal + Fabrication + USM Production – Scrap**	**USM O/H + G&A + Distribution**	**Total Unit Cost**	**Savings vs. March 2012 Cost for 1403M Coins**	**Savings vs. USM FY2011 1403M Coins**
2011 Dime Coin (S)	2.27	$0.0357	$0.0208	$0.0565	--	--
Dime March 2012 Costs (S)	2.27	$0.0319	$0.0208	$0.0527	--	$5,271,219
G6 Mod-Clad Cu (S)	2.22	$0.0292	$0.0208	$0.0501	$3,774,068	$9,045,287
669z-Clad Cu (S)	2.23	$0.0291	$0.0208	$0.0500	$3,893,837	$9,165,056
Unplated 31157-Clad Cu (S)	2.20	$0.0277	$0.0208	$0.0485	$5,923,437	$11,194,656

Table 3-6. Quarter Dollar Coin Alternative Material Candidates Unit Costs

	Weight (g)	Metal + Fabrication + USM Production – Scrap	USM O/H + G&A + Distribution	Total Unit Cost	Savings vs. March 2012 Cost for 323M Coins	Savings vs. USM FY2011 323M Coins
2011 Quarter Dollar Coin (S)	5.67	$0.0828	$0.0286	$0.1114	--	--
Quarter Dollar March 2012 Costs (S)	5.67	$0.0720	$0.0286	$0.1006	--	$3,486,062
G6 Mod-Clad Cu (S)	5.55	$0.0653	$0.0286	$0.0939	$2,172,174	$5,658,236
669z-Clad Cu (S)	5.59	$0.0651	$0.0286	$0.0937	$2,241,107	$5,727,170
Unplated 31157-Clad Cu (S)	5.51	$0.0614	$0.0286	$0.0901	$3,409,248	$6,895,311
Ni-Plated-31157-Clad Cu (P)	5.26	$0.0774	$0.0286	$0.1060	$(1,741,862)	$1,744,200
Nickel-Plated Steel (P)	5.03	$0.0521	$0.0286	$0.0807	$6,415,847	$9,901,910
Multi-Ply-Plated Steel (P)	5.03	$0.0434	$0.0286	$0.0720	$9,240,138	$12,726,200
Dura-White-Plated Zn (P)	4.54	$0.0393	$0.0286	$0.0679	$10,564,438	$14,050,500
SS/Cu/SS (S)	5.56	$0.0584	$0.0286	$0.0870	$4,380,423	$7,866,485

SS = stainless steel

3.13.2 Alternative Clad Copper

The three copper alloy alternative material candidates offered by Olin (G6 mod), PMX (669z) and JZP (31157 [nickel plated and unplated]) for the 5-cent coin are also suitable seamless options as clad layers over a copper core for the dime and quarter dollar coins. These candidates provide coins that are similar in weight and EMS to the incumbent coins, albeit with modest cost savings. The cost savings for a candidate with an equivalent EMS to the incumbent dime and quarter dollar coins is limited. There is no lower-cost alternative material to copper that approaches its electrical conductivity; therefore, a copper core must be retained to maintain the same EMS as incumbent dime and quarter dollar coins.

As with the 5-cent coin, G6 mod and 669z have a slight yellow cast, whereas unplated 31157 is more of a golden hue. For the quarter dollar coin in particular, the use of unplated 31157 may result in some confusion with the golden dollar coin, although the golden dollar coin is not widely used in transactions. The starting stock for these coins would be delivered as coiled sheet with presumably equivalent processing to the incumbent cupronickel-clad coins. These copper alloy alternative material candidates could be recycled in the same manner as the incumbent clad coins: scrap coins and/or web scrap can be melted and additional elements added to obtain the desired material composition for the clad layer alloy on future coins. Because the copper core remains and the clad comprises about 33% of the coin thickness, less cost savings are possible for the quarter dollar coin than for the 5-cent coin. The total cost savings for the alternative copper-clad quarter dollar coins range from 7–10%, based on March 2012 metal cost, depending upon the outer-clad copper alloy selected.

As with the 5-cent coin, JZP has also proposed a nickel-plated version of 31157 as an RTS quarter dollar planchet, although this option appears to provide no significant cost benefit from incumbent coin material construction.

3.13.3 Dura-White-Plated Zinc

As described above for the 5-cent coin, Dura-White-plated zinc quarter dollar coins would be produced from RTS planchets; resulting in significant cost reductions primarily from the replacement of the incumbent copper core with a zinc core. This coin would have a unique EMS; although different from the incumbent quarter dollar coin; a Dura-White-plated zinc quarter dollar coin would require significant conversion costs to several stakeholders as discussed in the Outreach Chapter. The material costs were calculated from a JZP quotation. Dura-White-plated zinc is the lowest cost alternative material candidate for the quarter dollar coin with an approximate 33% total cost savings over the incumbent quarter dollar coin, using March 2012 metal costs. The weight of the coin would be approximately 20% lighter than the incumbent quarter dollar coin. When co-circulated as a non-seamless coin with incumbent coins, this would necessitate changes to the procedures used and costs required to validate large quantities of these coins by coin-processing equipment.

3.13.4 Multi-Ply-Plated Steel

The Multi-Ply-plated-steel coin costs were calculated from a JZP quotation. This alternative material candidate has a unique EMS, which is different than that of the incumbent quarter dollar coin. Therefore, many stakeholders would be required to endure conversion costs to upgrade coin-processing equipment. The uniqueness of the associated EMS is a result of the copper-plated layer thickness. Since Multi-Ply technology is licensed and sold by the RCM, the RCM will be instrumental in ensuring that US Multi-Ply-plated quarter dollar coin has an EMS distinguishable from all other Multi-Ply-plated steel coins used around the world. As a result of the difference in density between steel and cupronickel, Multi-Ply-plated steel quarter dollar coins would weigh only 89% of the incumbent quarter dollar coins. Changes would be required to the procedures used and costs required to handle large sums of Multi-Ply-plated coins that are co-circulated with incumbent coins. More details may be found in the Outreach Chapter.

3.13.5 Stainless Steel-Clad Copper

During its preliminary investigation of alloys, CTC speculated that an inexpensive non-ferromagnetic stainless steel-clad copper coin may offer a less costly and seamless alternative coin construction. A supplier of such material was not found; therefore, a simple experiment consisting of gluing stainless steel to C110 was completed for limited analysis. Preliminary test results, which included electrical conductivity measurements, have shown that this coin construction is a potentially seamless option for the cupronickel-clad coinage. Potential seamless being that this construction would mimic the EMS of the incumbent quarter-dollar coin. Due to differences in densities of these materials, a weight difference between cupronickel- and stainless steel-clad quarter dollar coins would require those who use coin weight to verify coin count to modify their current procedures.

3.14 DOLLAR COIN

3.14.1 Manganese-Brass-Clad Copper

The dollar coin starting stock is delivered to the United States Mint as a manganese-brass-clad copper coiled strip; it is the only denomination that currently goes through a separate burnishing step. The cost components of the dollar coin are shown in Figure 3-9. The dollar coin is also the only US denomination that has edge lettering for additional security. In addition to metal cost savings, an alternative material for the dollar coin should have improved tarnish resistance and the possible elimination of the burnishing step to further reduce the fabrication costs of the coin. Table 3-7 shows the cost elements of several alternative material candidates for the dollar coin.

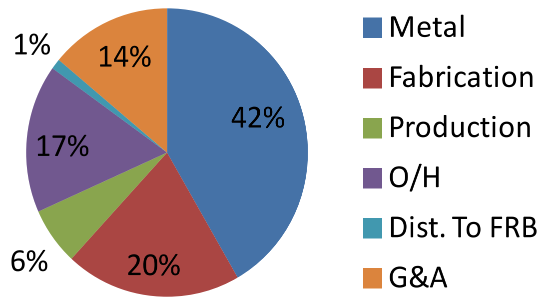


Figure 3-9. Cost components of the dollar coin (FY2011).

Table 3-7. Dollar Coin Alternative Material Candidates Unit Costs

	Weight (g)	**Metal + Fabrication + USM Production – Scrap**	**USM O/H + G&A + Distribution**	**Total Unit Cost**	**Savings vs. March 2012 Cost for 467M Coins**	**Savings vs. USM FY2011 467M coins**
2011 Dollar Coin (S)	8.10	$0.1231	$0.0572	$0.1803	--	--
Dollar Coin March 2012 Costs (S)	8.10	$0.1124	$0.0572	$0.1696	--	$5,018,535
C69250-Clad Cu (S)	7.91	$0.1112	$0.0572	$0.1683	$593,622	$5,590,522
K474-Clad Cu (S)	7.74	$0.1078	$0.0572	$0.1650	$2,154,460	$7,151,360
Yellow-Bronze (88Cu-12Sn) -Plated Zn (P)	8.46	$0.1076	$0.0572	$0.1648	$2,241,600	$7,238,500

3.14.2 Alternative Clad Copper

Clad-copper candidates C69250 and K474 from Olin are relatively seamless with respect to production of the incumbent dollar coin; these two alloys also have lower costs using March 2012 metal costs, through less-expensive alloying additions. These materials have compositions that are proprietary to Olin. The composition change from the incumbent clad alloy for the dollar coin, which contains 77Cu-12Zn-4Ni-7Mn, limits material selections when considering a golden-colored alloy that matches the EMS of the incumbent dollar coin. Both of these alternative material candidates result in coins of similar density to the incumbent dollar coin. Unfortunately there is only a minimal cost savings associated with these alloys and the tarnish resistance has not been shown to be superior to that of the incumbent materials of construction (see Testing Program Chapter for more information).

3.14.3 Bronze-Plated Zinc

The metal costs were calculated from London Metal Exchange (LME) March 2012 commodity prices for the yellow-bronze-(88Cu-12Sn) plated zinc candidate. The fabrication and production costs were calculated by weight ratio from the Dura-White and the production cost at the United States Mint; these values were adjusted to reflect only striking at the United States Mint. This material is proprietary to JZP and would be delivered as a RTS planchet to the United States Mint. It has a unique EMS, which is different from the incumbent dollar coin. Consequently, conversion costs would be incurred by stakeholders to recognize, validate and accept coins made of yellow-bronze-plated zinc. Since the tarnish performance (see Testing Program Chapter) and the cost of these materials of construction is approximately the same as those for the incumbent dollar coin, a non-seamless co-circulation model for dollar coins minted from these materials would not be advised.

3.15 CONCLUSIONS – CHAPTER 3

The following provides a summary of the state of metals pricing, production costs and cost factors inherent for each denomination of the incumbent US circulating coinage and for each of the alternative material candidates evaluated in this study.

For the most part, all industrial metals have exhibited a similar general cost trend in the commodities market that reflects overall global economic trends. In 2006–2007, prices peaked for many metals after a steep run-up and then dropped quickly from mid-2007 through 2009. Today, prices have moderated and seem to be slowly increasing, although it is difficult to predict long-term pricing trends amongst short-term volatility. Nevertheless, there has been a fairly predictable trend in that the sequence in cost of metals does not seem to change and has been, from more to less costly in this order: nickel, copper, aluminum and zinc, and steel. Exploiting the low costs of steel, zinc and aluminum, while employing copper when necessary for EMS, was emphasized in the Alternative Metals Study for coinage material candidates. Use of steel, stainless steel and/or aluminum in coinage would likely necessitate the introduction of one or more new material suppliers to the United States Mint. If these alternative materials are chosen for future coins, then the supplier base may have to be expanded.

$$$$ Ni > $$$ Cu > $$ Al, Zn > $ steel

It is important to note that as of March 1, 2012, the cost of incumbent circulating coinage is significantly less than the average FY2011 cost due to reduced commodity metal prices. This is not necessarily indicative of future costs, but illustrates the volatility in metals pricing.

There are three major components of the cost equation for coins that can be affected by a change to its composition. These are the cost of the metal, the supplier fabrication costs of the coin starting stock and the United States Mint direct production costs. The other components, including the United States Mint production overhead, distribution to the Federal Reserve Banks and G&A are essentially fixed (for purposes of this study) and are calculated based upon a formula that assigns the total plant cost by activity and denomination.

Alternative material candidates studied would be supplied as either coiled strip or as RTS planchets. Plated coins are typically delivered as RTS planchets since the edges of the blank need to be plated. Monolithic or clad materials would be delivered as either coiled strip or RTS planchets. However, if production steps, such as blanking, annealing or upsetting, are eliminated only the direct portion of the costs associated with these steps could be saved from the overall costs to operate the United States Mint facilities since factors such as plant overhead must still be accounted for. Given these facts, CTC has estimated that monolithic and clad coins are lower in cost if their starting stock is delivered to the United States Mint as coiled strip rather than as RTS planchets. Planchet production would increase supplier fabrication costs, which would be passed onto the United States Mint; however, a concomitant decrease in the total United States Mint costs may not be realized, regardless if the supplier is more efficient or lower cost than the United States Mint.

Under the current practice of allocating indirect expenses at the individual product level, in FY2011 the United States Mint's indirect costs allocated to the one-cent coin were greater than $0.01 per unit. Positive seigniorage for the one-cent coin is impossible without a change in cost reporting or fundamental alteration of the United States Mint's fixed-cost structure. Metal, supplier fabrication and United States Mint direct production costs are over $0.01 using March 2012 metal prices. Zinc comprises 97.5% of the incumbent one-cent coin; zinc is one of the lowest-cost metals suitable for coin production. Zinc-based coins offer little opportunity for reduced costs by alternative metals. Zinc and carbon-steel are both low-cost materials and both require a coating to prevent corrosion during circulation. Both materials are used in many countries with a copper plating. Copper-plated zinc (CPZ) and copper-plated steel (CPS) coins are nearly identical in total cost to produce. As of March 2012, CPZ is slightly lower in cost than CPS as current CPS production requires a greater copper plating thickness and more costly processing (including annealing). Material costs for the one-cent coin could be lower by using a monolithic material that does not require plating. Aluminum alloy 5052-H32 was the lowest candidate material cost option evaluated. Earlier studies for the Department of the Treasury also concluded that aluminum alloys should be considered for use as one-cent coins; citing that the public would get used to a lighter, silver-white one-cent coin. However, the coin-processing equipment industry considers an aluminum alloy one-cent coin unsuitable as its light weight tends to jam machines and disrupt service resulting in significant repair costs. Future developments that could result in lower one-cent coin material costs include the elimination of the anneal step of CPS, thinner CPS plating and softer stainless steels that would provide longer die life.

For the remaining coins, there are two types of alternative material candidates presented for each denomination: 1) potentially seamless candidates having approximately the same EMS and weight as the incumbent coin and 2) non-seamless (co-circulate) alternative candidates having a different, albeit unique, EMS and/or a different weight from the incumbent coin. The seamless alternative material candidates provide for a modest cost savings, whereas the non-seamless alternative material candidates result in larger cost savings to the United States Mint. Use of non-seamless alternative material candidates may result in significant conversion costs to upgrade coin-processing equipment.

For the 5-cent coin, the allocated indirect United States Mint costs for FY2011 totaled $0.0322 per unit and so obtaining positive seigniorage is very challenging. Several alternative material candidates offer significantly reduced costs over the incumbent 5-cent coin. The seamless alternative copper alloy candidates provide up to a 35% total unit cost reduction compared to the FY2011 cost of the incumbent 5-cent coin (27% vs. March 2012 total unit costs). These alternative copper alloys would also be annealed at a lower temperature than the incumbent cupronickel material. These copper alloys are produced by the current United States Mint suppliers and utilize the same processing steps as cupronickel. As tested in this study, Alloys G6 mod, unplated 31157 and 669z were found to have densities within 9% and a similar EMS as the cupronickel material, as discussed in the Outreach Chapter. The G6 and 669z alloys have a slight yellow cast whereas the unplated 31157 has a golden hue color. Alloys G6 mod and 669z displayed similar wear and corrosion performance as the cupronickel material. Surface oxidation of the G6 mod and 669z darken toward golden hue while cupronickel oxidation darkens somewhat brown.

The range of elements comprised by the copper alloys (including copper, zinc, nickel, manganese and iron) are wide; additional development is required to optimize composition, EMS and color to mint a seamless 5-cent coin. No reliable method was discovered that predicts the EMS and color of multi-component copper alloys prior to producing and evaluating heats of a new alloy. To ensure an even closer match to incumbent coins, several more variants of these alloys could be produced and tested. These developments could also focus on narrowing the range of elements specified for G6 mod, 669z and unplated 31157; the optimized composition may lie somewhere in between these alloys. Note that even if the copper alloys were seamless with regard to dimensions and EMS, the weight of the alternative coin will likely be lower than the incumbent coin. The cost associated with the impact of this weight difference is discussed in the Outreach Chapter.

For the non-seamless alternative material candidates, stainless steel provides an interesting low-cost, silver-white choice for the 5-cent coin. Grade 430 stainless steel has the lowest material cost; however, it requires high striking loads and is ferromagnetic, which would not allow identification by a significant number of coin-processing equipment sensors. Non-ferromagnetic 302HQ stainless steel is a better candidate as it requires lower coining loads and is not drawn to a magnet. Stainless steel alloys require higher striking loads and to alleviate problems with higher striking loads (and therefore shorter die life); lower relief designs may have to be implemented if stainless steel coins are minted. Development of a stainless steel alloy specifically designed for coinage should be considered. Plated 5-cent coin candidates would have a unique EMS, but would not match that of the incumbent 5-cent coin; creating co-circulation concerns with a non-seamless coin. The different EMS would require reprogramming and/or hardware upgrades to coin-processing equipment. The associated conversion costs to those who own the coin-processing equipment would be significantly larger than the cost savings that would be realized by the United States Mint for the plated 5-cent coin alternative material candidates evaluated in this study.

The seamless alternative material candidates for the quarter dollar coin utilize the alternative copper alloys as clad layers on copper. Using March 2012 material costs, G6 mod- or 669z-clad copper provides an approximate 13% material costs savings (16% total unit costs for FY2011) for the incumbent quarter dollar coin, while providing seamless circulation with incumbent quarter dollar coins. These seamless candidate options retain the copper core; therefore, coin weight is within 3% of the incumbent quarter dollar coin. Unplated 31157-clad copper provides additional material savings, although the golden hue color may cause public confusion with the similarly sized golden dollar coin, although the dollar coin is not widely used in transactions. G6 mod- and 669z-clad copper have a slight yellow cast color as the monolithic alternative copper alloys for the 5-cent coin.

The plated alternative material candidates provide greater cost savings, although some further assurances are needed to ensure that plating thickness is consistent and wear of these coins will not pose security or appearance issues. Development of a stainless steel-clad copper may provide an EMS match to the incumbent cupronickel-clad copper quarter dollar coin. At this stage of development, the possible cost savings for a stainless steel-clad copper construction is unclear; material is not commercially available in the quantities required.

Alternative material candidates for the dollar coin were limited to material options that could be seamless with production and coin-processing equipment, while improving tarnish resistance over the incumbent coin materials of construction. Unfortunately, none of the candidates selected displayed any marked improvement in tarnish resistance. Furthermore, none of these candidate materials were found to be seamless alternatives to the incumbent materials of construction for the dollar coin.

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3.17 APPENDICES – CHAPTER 3

3.17.1 Appendix 3-A: Summary Table of World Coin Compositions

Table 3-A-1. Metallic Composition of Selected Coins Throughout the World

Country	Lowest to Highest Value Coins within Given Country (KEY: low value, medium value, high value)									
Australia	1 Cent Withdrawn from circulation	2 Cent Withdrawn from circulation	5 Cent 75% Cu 25% Ni	10 Cent 75% Cu 25% Ni	20 Cent 75% Cu 25% Ni	50 Cent 75% Cu 25% Ni	1 Dollar 92% Cu 6% Al 2% Ni	2 Dollar 92% Cu 6% Al 2% Ni		
Canada	1 Cent Production to end in 2012	5 Cent 94.5% steel 3.5% Cu 2% Ni	10 Cent 92% steel 5.5% Cu 2.5% Ni	25 Cent 94% steel 3.8% Cu 2.2% Ni	50 Cent 93.15% steel 4.75% Cu 2.1% Ni	1 Dollar 91.5% Ni 7.5% Cu 1% Sn	2 Dollar Ring: 99% Ni; Center: 92% Cu 6% Cu 2% Ni			
China	1 Jiao Aluminum									
European Union	1 Cent Cu-plated steel	2 Cent Cu-plated steel	5 Cent Cu-plated steel	10 Cent 89% Cu 5% Al 5% Zn 1% Sn	20 Cent 89% Cu 5% Al 5% Zn 1% Sn	50 Cent 89% Cu 5% Al 5% Zn 1% Sn	1 Euro Ring: Ni; Center: Cu-Ni; Ni and Cu-Ni (3 layers)	2 Euro Ring: Cu-Ni; Center: Ni-brass; Ni and Ni-brass (3 layers)		
Great Britain	1 Penny Cu-plated steel	2 Pence Cu-plated steel	5 Pence Ni-plated steel	10 Pence Ni-plated steel	20 Pence 84% Cu 16% Ni	50 Pence 75% Cu 25% Ni	1 Pound Ni-brass	2 Pound Ring: Cu-Ni; Center: Ni-brass		
Japan	1 Yen Aluminum	5 Yen 65% Cu 35% Zn	50 Yen 75% Cu 25% Ni	100 Yen 75% Cu 25% Ni	500 Yen 72% Cu 20% Zn 8% Ni					
South Korea	1 Won Withdrawn from circulation	5 Won Withdrawn from circulation	10 Won 65% Cu 35% Zn	50 Won 70% Cu 18% Zn 12% Ni	100 Won 75% Cu 25% Ni					
Mexico	5 Centavo Stainless steel	10 Centavo Stainless steel	20 Centavo Stainless steel	50 Centavo Stainless steel	1 Peso Ring: stainless steel; Center: Al-bronze	2 Peso Ring: stainless steel; Center: Al-bronze	5 Peso Ring: stainless steel; Center: Al-bronze	10 Peso Ring: Al-bronze; Center: 65% Cu 25% Zn 10% Ni	20 Peso Ring: Al-bronze; Center: 92.5% Ag 7.5% Cu	50 Peso Ring: Al-bronze; Center: 92.5% Ag 7.5% Cu
Russia	1 Kopeck Cupronickel	5 Kopeck Cupronickel	10 Kopeck Brass-plated steel	50 Kopeck Brass-plated steel	1 Ruble Ni-plated steel	2 Ruble Ni-plated steel	5 Ruble Ni-plated steel	10 Ruble Brass-plated steel		
United States	1 Cent 97.5% Zn 2.5% Cu	5 Cent 75% Cu 25% Ni	10 Cent 91.67% Cu 8.33% Ni	25 Cent 91.67% Cu 8.33% Ni	50 Cent 91.67% Cu 8.33% Ni	1 Dollar 88.5% Cu 6% Zn 3.5% Mn 2% Ni				

3.17.2 Appendix 3-B: Detailed Cost Summary of Each Candidate Material

Table 3-B-3. Cost Breakdown of Alternative Material Candidates for One-Cent Coin

	Weight (g)	Metal + Fabrication + USM Production – Scrap	USM O/H + G&A + Distribution	Total Unit Cost	Savings vs. March 2012 Cost for 4289M Coins	Savings vs. USM FY2011 4289M Coins	March 2012 Metal Cost	Supplier Fabrication	*	Scrap Credit	*	USM Direct Production	*
2011 One-Cent Coin	2.50	$0.0134	$0.0107	$0.0241	--	--	$0.0069	$0.0041	a	--	c	$0.0024	a
CPZ March 2012 Costs	2.50	$0.0118	$0.0107	$0.0225	--	$6,896,712	$0.0053	$0.0041	a	--	--	$0.0024	a
CPS (P)	2.82	$0.0170	$0.0107	$0.0276	$(21,961,855)	$(15,099,455)	$0.0061	$0.0084	b	--	--	$0.0024	a
5052 Al (S)	0.94	$0.0074	$0.0107	$0.0180	$19,193,065	$26,055,465	$0.0041		b, d	0.0008	d, f	$0.0041	e
430 Stainless Steel	2.74	$0.0130	$0.0107	$0.0237	$(5,196,342)	$1,666,058	$0.0085		b, d	0.0016	d, f	$0.0062	g, h
CPS (S)	2.82	$0.0146	$0.0107	$0.0253	$(11,826,752)	$(4,964,352)	$0.0105		b, d	--	--	$0.0041	e
Aluminized Steel (S)	2.74	$0.0095	$0.0107	$0.0202	$10,029,698	$16,892,098	$0.0054		b, d	--	--	$0.0041	e

Per coin costs for all materials include: Plant overhead (O/H) = $0.0063, Distribution to Federal Reserve Banks (FRBs) = $0.0003, General and Administrative (G&A) = $0.0041

* See Table 3-B-6 for details on each annotation listed here.

Table 3-B-4. Cost Breakdown of Alternative Material Candidates for 5-Cent Coin

	Weight (g)	Metal + Fabrication + USM Production – Scrap	USM O/H + G&A + Distribution	Total Unit Cost	Savings vs. March 2012 Cost for 914M Coins	Savings vs. USM FY2011 914M Coins	March 2012 Metal Cost	Supplier Fabrication	*	Scrap Credit	*	USM Direct Production	*
2011 5-Cent Coin	5.00	$0.0796	$0.0322	$0.1118	--	--	$0.0674	$0.0067	a	--	c	$0.0055	a
5-Cent March 2012 Costs	5.00	$0.0674	$0.0322	$0.0995	--	$11,206,159	$0.0569	$0.0067	a,j	0.0018	f,m	$0.0055	a
G6 Mod (S)	4.72	$0.0499	$0.0322	$0.0821	$15,942,757	$27,184,957	$0.0389	$0.0067	a,j	0.0012	f,m	$0.0055	a
669z (S)	4.79	$0.0491	$0.0322	$0.0813	$16,668,857	$27,911,057	$0.0380	$0.0067	a,j	0.0012	f,m	$0.0055	a
Unplated 31157 (S)	4.58	$0.0401	$0.0322	$0.0723	$24,898,153	$36,140,353	$0.0287	$0.0067	a,j	0.0009	f,m	$0.0055	i
Nickel-Plated 31157 (P)	4.26	$0.0673	$0.0322	$0.0995	$36,560	$11,278,760	$0.0618		b	--	--	$0.0055	i
Dura-White-Plated Zn (P)	4.10	$0.0226	$0.0322	$0.0547	$40,910,640	$52,152,840	$0.0197		b	--	--	$0.0028	i
Multi-Ply-Plated Steel (P)	4.37	$0.0312	$0.0322	$0.0634	$32,995,400	$44,237,600	$0.0284		b	--	--	$0.0028	i
Nickel-Plated Steel (P)	4.40	$0.0448	$0.0322	$0.0770	$20,556,171	$31,798,371	$0.0420		b	--	--	$0.0028	i
CPZ (P)	4.06	$0.0199	$0.0322	$0.0520	$43,378,440	$54,620,640	$0.0170		b	--	--	$0.0028	i
302 Stainless Steel (S)	4.40	$0.0355	$0.0322	$0.0677	$29,041,632	$40,283,832	$0.0350		b,d	0.006	d,f,l, m	$0.0066	h
430 Stainless Steel (S)	4.40	$0.0163	$0.0322	$0.0485	$46,590,679	$57,832,879	$0.0137		d,j,l	0.003	d,f, m	$0.0053	h, k

Per coin costs for all materials include: Plant O/H = $0.0142, Distribution to FRB = $0.0004, G&A = $0.0176.

* See Table 3-B-6 for details on each annotation listed here.

Table 3-B-5. Cost Breakdown of Alternative Material Candidates for Dime Coin

	Weight (g)	**Metal + Fabrication + USM Production – Scrap**	**USM O/H + G&A + Distribution**	**Total Unit Cost**	**Savings vs. March 2012 Cost for 1403M Coins**	**Savings vs. USM FY2011 1403M Coins**	**March 2012 Metal Cost**	**Supplier Fabrication**	*****	**Scrap Credit**	*****	**USM Direct Production**	*****
2011 Dime Coin	2.27	$0.0357	$0.0208	$0.0565	--	--	$0.0246	$0.0065	a	--	c	$0.0046	a
Dime March 2012 Costs	2.27	$0.0319	$0.0208	$0.0527	--	$5,271,219	$0.0215	$0.0065	a	0.0007	f, m	$0.0046	a
G6 Mod-Clad Cu (S)	2.22	$0.0292	$0.0208	$0.0501	$3,774,068	$9,045,287	$0.0187	$0.0065	a	0.0006	f, m	$0.0046	a
669z-Clad Cu (S)	2.23	$0.0291	$0.0208	$0.0500	$3,893,837	$9,165,056	$0.0186	$0.0065	a	0.0006	f, m	$0.0046	a
Unplated 31157-Clad Cu (S)	2.20	$0.0277	$0.0208	$0.0485	$5,923,437	$11,194,656	$0.0171	$0.0065	a	0.0005	f, m	$0.0046	a

Per coin costs for all materials include: Plant O/H = $0.0117, Distribution to FRB = $0.0004, G&A = $0.0087.

* See Table 3-B-6 for details on each annotation listed here.

Table 3-B-6. Cost Breakdown of Alternative Material Candidates for Quarter Dollar Coin

	Weight (g)	Metal + Fabrication + USM Production – Scrap	USM O/H + G&A + Distribution	Total Unit Cost	Savings vs. March 2012 Cost for 323M Coins	Savings vs. USM FY2011 323M Coins	March 2012 Metal Cost	Supplier Fabrication	*	Scrap Credit	*	USM Direct Production	*
2011 Quarter Dollar Coin	5.67	$0.0828	$0.0286	$0.1114	--	--	$0.0629	$0.0162	a	--	c	$0.0037	a
Quarter March 2012 Costs	5.67	$0.0720	$0.0286	$0.1006	--	$3,486,062	$0.0538	$0.0162	a	0.0017	f,m	$0.0037	a
G6 Mod-Clad Cu (S)	5.55	$0.0653	$0.0286	$0.0939	$2,172,174	$5,658,236	$0.0468	$0.0162	b,a	0.0014	f,m	$0.0037	a
669z-Clad Cu (S)	5.59	$0.0651	$0.0286	$0.0937	$2,241,107	$5,727,170	$0.0466	$0.0162	a	0.0014	f,m	$0.0037	a
Unplated 31157-Clad Cu (S)	5.51	$0.0614	$0.0286	$0.0901	$3,409,248	$6,895,311	$0.0429	$0.0162	a	0.0013	f,m	$0.0037	--
Nickel-Plated 31157-Clad Cu (P)	5.26	$0.0774	$0.0286	$0.1060	$(1,741,862)	$1,744,200	$0.0760		b	--	--	$0.0014	n
Nickel-Plated Steel (P)	5.03	$0.0521	$0.0286	$0.0807	$6,415,847	$9,901,910	$0.0505		b	--	--	$0.0017	n,h
Multi-Ply-Plated Steel (P)	5.03	$0.0434	$0.0286	$0.0720	$9,240,138	$12,726,200	$0.0420		b	--	--	$0.0014	n
Dura-White™-Plated Zn (P)	4.54	$0.0393	$0.0286	$0.0679	$10,564,438	$14,050,500	$0.0379		b	--	--	$0.0014	n
SS/Cu/SS (S)	5.56	$0.0584	$0.0286	$0.0870	$4,380,423	$7,866,485	$0.0378	$0.0162	d,e,a	--	--	$0.0044	a,h

Per coin costs for all materials include: Plant O/H = $0.0095, Distribution to FRB = $0.0015, G&A = $0.0176.

* See Table 3-B-6 for details on each annotation listed here.

Table 3-B-7. Cost Breakdown of Alternative Material Candidates for Dollar Coin

	Weight (g)	**Metal + Fabrication + USM Production – Scrap**	**USM O/H + G&A + Distribution**	**Total Unit Cost**	**Savings vs. March 2012 Cost for 467M Coins**	**Savings vs. USM FY2011 467M Coins**	**March 2012 Metal Cost**	**Supplier Fabrication**	*****	**Scrap Credit**	*****	**USM Direct Production**	*****
2011 Dollar Coin	8.10	$0.1231	$0.0572	$0.1803	--	--	$0.0751	$0.0364	a	--	c	$0.0116	a
Dollar March 2012 Costs	8.10	$0.1124	$0.0572	$0.1696	--	$5,018,535	$0.0664	$0.0364	a	0.002	f,m	$0.0116	a
C69250-Clad Cu (S)	7.91	$0.1112	$0.0572	$0.1683	$593,622	$5,590,522	$0.0651	$0.0364	b,a	0.002	f,m	$0.0116	a
K474-Clad Cu (S)	7.74	$0.1078	$0.0572	$0.1650	$2,154,460	$7,151,360	$0.0617	$0.0364	b,a	0.002	f,m	$0.0116	a
Yellow Bronze-Plated Zn (P)	8.46	$0.1076	$0.0572	$0.1648	$2,241,600	$7,238,500	$0.1010		b	--	--	$0.0066	o

Per coin costs for all materials include: Plant O/H = $0.0300, Distribution to FRB = $0.0021, G&A = $0.0251.

* See Table 3-B-6 for details on each annotation listed here.

Table 3-B-8. Annotation Key for Cost Breakdown Tables

Annotation	Key
a	United States Mint FY2011
b	From lowest quote
c	Included in metal cost
d	x 1.21 (web-scrap factor)
e	= USM x 0.75 (B + U + strike) / 0.45 (strike only)
f	x 1.04 (condemned recovery)
g	= USM x 0.95 (B + U + A + strike) / 0.45 (strike only)
h	= USM x 1.2 to account for higher striking load, annealing temperature
i	= USM – 0.0027 (striking only)
j	From commodity metals cost (March 1, 2012)
k	= USM – 0.0011 (remove anneal)
l	Assumes supplier fabrication = 10% of supplier cost
m	x 0.77 scrap recovery
n	= USM – 0.0023 (striking only)
o	= USM – 0.005 (striking only)

B = blanking costs; U = upsetting costs; USM = United States Mint coin costs; A = annealing costs.

Table 3-B-9. Commodity Metals Costs

Commodity	Cost	Unit	Source	Cost Date
Copper	$3.8705	lb	Comex	February 29, 2012
Zinc	$2,125.50	MT	LME	February 29, 2012
Nickel	$19,910.00	MT	LME	February 29, 2012
Manganese	$3,075.00	ton	Minerprices.com	February 28, 2012
Aluminum	$2,288.00	MT	LME	March 1, 2012
Tin	$23,875.00	MT	LME	March 1, 2012
IF Steel	$600.00	ton	Carpenter Technology	November 2011
Aluminized Steel	$0.75	lb	Ryerson	November 2011
430 Stainless Steel Cold Rolled	$2,335.00	MT	MEPS NA	August 2011

lb = pound; MT = metric ton (tonne); LME = London Metal Exchange.

4.0 OUTREACH, VALIDATION OF ALTERNATIVE MATERIAL CANDIDATE NONSENSE PIECES AND SECURITY

4.1 INTRODUCTION

Many of the metallic alternative material candidates researched, developed and/or tested in this study for the construction of United States (US) circulating coins will impact individuals and organizations (here referred to as "stakeholders") that rely upon specific characteristics and/or properties of incumbent (i.e., in circulation as of the date of this report) US circulating coins for conducting commerce. The impact includes conversion costs and preparation time required to upgrade existing automated equipment and operating practices reliant on incumbent coinage characteristics and properties. Impacts to current coinage material suppliers (including recycling of scrap from the production of coins) are described in the Cost Trends Analysis Chapter. This chapter is primarily focused on the stakeholders that rely on automated equipment whose function depends in large part on circulating coins; note that automated equipment may accept other forms of payment besides coins.

To ensure compliance with the Coin Modernization, Oversight, and Continuity Act of 2010 (Public Law 111-302), the project team completed a comprehensive evaluation to quantify the stakeholder impacts resulting from changes in the construction of US circulating coins. These stakeholder impacts included:

- Equipment conversion costs
- Estimated time required to upgrade equipment
- Ease of use and ability to co-circulate new coins of alternative metallic material construction.

Specific changes to US circulating coins that would impact stakeholders and coin security include:

- Coin material and construction method
- Coin dimensions (diameter and thickness), shape and rim height
- Edge profile (smooth vs. reeds)
- Inductive coin thickness (i.e., average thickness of coin material as measured by sensors that validate coins)
- Design embossing or relief height
- Density (manifested as a difference in coin weight when incumbent coin dimensions are maintained)
- Electrical/magnetic properties, which are exploited by sensors to validate and differentiate between coins via automated methods.

General information was gathered from members and industry trade groups throughout each of several stakeholder groups, which included (but was not limited to) vending machine[80] and other

[80] As used here, vending machines include those devices that dispense a tangible product such as food, beverage, transit tickets or cigarettes. Coin-operated machines that provide services, which include, but are not limited to, laundering clothes, entertainment, parking, car washing and pay phone calls, are treated separately from vending machines. Note that the vending machine owners and operators, along with the laundromat owners and operators,

coin-acceptance equipment manufacturers, vending machine owners and operators, transit officials, municipal parking officials, depository institutions, coin and currency handlers, armored-car operators, car wash operators, American-owned manufacturers of commercial coin processing equipment and merchants [Reference: Public Law 111-302, section 2(b)(3)]. The general information was then used to estimate the impact, if any, to each of the stakeholder groups as a result of introducing coins having different characteristics and/or properties from those of incumbent coins. As discussed in this chapter and elsewhere in this report, alternative metallic materials were evaluated for potential use in future US circulating coins. Depending upon the characteristics and properties of the specific metallic materials and denominations chosen, relative to incumbent US circulating coins, the extent and magnitude of the impact varies greatly to those stakeholders who rely upon coins to conduct commerce. Specific details for each of the stakeholders are discussed below.

As a point of clarification, *as used throughout this chapter, the term "change" refers to differences that result in non-seamless coins, i.e., those coins having discernible deviations from incumbent coinage that would require an upgrade to current, fielded coin-acceptance and coin-handling equipment to enable this equipment to correctly accept both incumbent and alternative material circulating coins.*[81] *In other words, the term "change" in this chapter refers to a difference in some characteristic and/or property that would impact stakeholders such that it would require a response to correctly and consistently identify, differentiate, validate, accept (or not validate and reject) or otherwise handle coins minted from the alternative materials so that co-circulation of incumbent and new coins will be permitted.* As defined in this chapter, a change to coin dimensions refers to any alteration in the diameter and/or thickness of the coin that would disrupt the stakeholder group under discussion. One other important point, the analyses below assume that any alternative material circulating coins would co-circulate with incumbent US circulating coins (as opposed to withdrawing from circulation or demonetizing all incumbent US circulating coins) to aid in US commerce.

This chapter outlines the methods used to identify the nature of the impact, and quantifies both the financial impact (i.e., the conversion costs) and preparation time required by various stakeholder groups that would be impacted by changes in the construction of US circulating coins. Estimates were made, based upon direct stakeholder feedback and information available in public forums[82] to define the magnitude of the impact to each of the stakeholder groups considered during this outreach effort.

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were found to represent the two most significantly impacted stakeholder groups (in terms of total financial impact) in the current study should coin characteristics and/or properties change.

[81] Coin-acceptance equipment is that which rely upon validating, accepting and processing coins for further transactions (generally the delivery of a product or service). Coin-handling equipment is that whose primary purpose is to mechanically process coins, typically in large quantities, for separating, counting, packaging, transporting, making change and/or similar actions. Collectively, these two general classes of equipment are referred to in this document as "coin-processing" equipment.

[82] Public forums from which information was obtained include: 1) technical reports from trade group publications, professional organizations and the *Government Accountability Office* of the United States, 2) presentations made at gatherings sponsored by professional and trade groups, 3) publically available testimonies before the United States Congress and 4) data available from Internet sites.

The current chapter discusses:

- The numbers and types of coin-processing units potentially impacted within each of the stakeholder groups resulting from changes to US circulating coins
- Unique issues faced by individual stakeholder groups
- The approximate conversion costs to 1) upgrade coin-processing equipment and 2) adapt operational strategies to enable commerce with co-circulated coins of differing characteristics and/or properties.

This is followed by a discussion of the impact of introducing into circulation coins produced from alternative material candidates, including seamless options, identified in the Introduction of the report. The goal is to quantify the conversion costs to the greatest extent possible [Reference: Public Law 111-302, section 3(d)]. The magnitude of the conversion costs required of all stakeholders is also summarized for each of the alternative material-denomination combinations evaluated in this study.

Results are summarized and discussed from nonsense coin validation tests completed by three coin-processing equipment manufacturers on experimental nonsense pieces struck by the United States Mint. Coin validation tests were completed to define which, if any nonsense pieces, could be validated seamlessly without changes to fielded coin-processing equipment, including (but not limited to) those used in vending, car washes, laundromats and other devices that allow for unattended points of sale or that sort, count and/or handle coins in some manner. Finally, a summary of security issues is presented, both as they apply generally to coinage and specifically as they apply to the nonsense pieces defined and evaluated throughout this study.

4.2 ORGANIZATIONS PROVIDING OUTREACH FEEDBACK

Outreach efforts were started by defining the stakeholder groups from which feedback was desired. Stakeholder groups were identified based upon the following considerations.

- The stakeholder groups included those identified throughout the Coin Modernization, Oversight, and Continuity Act of 2010 (Public Law 111-302). These groups included (but are not limited to) merchants, vending machine and other coin-acceptor manufacturers, vending machine owners and operators, transit officials, municipal parking officials, depository institutions, coin and currency handlers, armored-car operators, car wash operators and American-owned manufacturers of commercial coin-processing equipment.

  Note that for convenience and due to similarity of coin-related issues, the vending machine owners and operators were further broken down into four subgroups:
  - Large owners and operators (i.e., at least $5 million [M] annual revenue)
  - Small owners and operators (less than $5M annual revenue)
  - Owners and operators of vending machines without modern internal communications protocols
  - Bulk vending, i.e., machines having unwrapped or unsorted merchandise, which has different issues and needs from the traditional vending machine owners and operators.

Transit officials were further divided into categories of:
  - Public transportation fare boxes (where riders deposit payments)
  - Tollway collection units (where drivers deposit payments into automated coin collection devices along pay-for-use highways, bridges and similar transportation systems).

- The United States Mint shared a list of stakeholder groups (and several organizations i.e., stakeholder group members) identified and used during the United States Mint's outreach efforts completed during development of the currently minted dollar coin prior to its introduction into circulation in 2000 [1].
- The stakeholder group list was supplemented through consultation with SCAN COIN, a manufacturer of automated coin sorting/counting equipment, who was hired as a subcontractor to Concurrent Technologies Corporation (CTC).
- The United States Mint also shared feedback from a notice for public comment posted on the Federal Register [2]. Respondents included the general public, current and potential materials suppliers to the United States Mint, manufacturers of coin-processing equipment and others.

Members of each stakeholder group, including specific commercial companies and trade associations, were identified through Internet searches and by referrals from others who were interviewed as part of the outreach efforts. While the majority of the data presented below was obtained from one-on-one discussions with stakeholders, additional input was obtained from a series of anonymous online questionnaires that were offered to stakeholder groups through national and/or regional organizations and trade associations that represent the interests of those stakeholder groups. These questionnaires focused on the denominations and numbers of coins typically processed, the age and type of fielded coin-processing equipment and other factors used to quantify the impact resulting from potential changes to the characteristics and/or properties of US circulating coins.

Table 4-1 identifies the stakeholder groups (approximately ordered in magnitude of the conversion costs required for the group to prepare for circulation of any coins of new metallic materials of construction) whose input was gathered, evaluated and discussed below. The approximate size of the stakeholder group (from available information) and potential issues of concern to each stakeholder group are highlighted. Those organizations within each stakeholder group that provided CTC with direct feedback are also listed in Table 4-1. Organizations that represent more than one stakeholder group are reported in each such group. Consistent with the understanding that information collected from the one-on-one interviews would not be associated with the organizations that volunteered the information; data in this chapter are presented in a manner that allows anonymity in individual responses from those who voluntarily completed interviews for this study. Information obtained from public forums is referenced. Permission was obtained for use of any information or statements not in the public domain and attributed to an organization. Beyond those organizations listed in Table 4-1, approximately 75 other organizations were contacted, but they were either unable or unwilling to participate in the associated one-on-one interviews or e-mail exchanges. Information from questionnaires, discussed below, was also used to quantify the impact of coin changes to stakeholders. Comments from a public invitation for input [2] were received by CTC and a summary of these comments is presented in the section entitled "Public" below.

Table 4-1. Stakeholder Groups Directly Contributing to Outreach

Stakeholder Group (Corresponding Report Section)	Organizations Providing Direct Feedback	Approximate Size of Stakeholder Group (Information as available)	Potential Issues and Operational Strategies of Concern
Vending Machine Owners and Operators* (4.5.1)†	Coca-Cola National Automatic Merchandising Association (NAMA) Coin Acceptors, Inc. (Coinco)+ MEI+ Crane Payment Solutions+ **Additional 49 anonymous questionnaire results**	5.3M vending machines $42.2 billion (B) annual revenue 200,000 vending machines that do not use modern communications protocols 2.0M bulk vending machines generating $388M annual revenue	Mean of 3 vending machines per site
Laundromat Owners and Operators* (4.5.2)	Coin Laundry Association Multi-Housing Laundry Association IDX, Incorporated▼ Imonex, Inc. ▼ **Additional 95 anonymous questionnaire results**	5.1M units $3.8B annual revenue	Heavily dependent upon quarter dollar coins; dollar coins to a lesser extent
Pay Phone Owners and Operators* (4.5.3)	Payphone.com Phones Plus Telephonix Coin Acceptors, Inc. (Coinco)◊ Imonex, Inc. ◊	425,000 units	Large number of retired units in warehouses Dominated by small businesses
Municipal Parking Officials* (4.5.4)	POM Parking Meters	2.0M units	Upgrade/replacement costs generally borne by local governments
Amusement Machine Owners and Operators* (4.5.5)	American Amusement Machine Association Chuck E. Cheese's – Johnstown, PA franchise Imonex, Inc. ◊ Coin Acceptors, Inc. (Coinco)◊	1.7M coin acceptors $750M annual revenue	Currently dominated by low-technology coin acceptors
Gaming Machine Owners and Operators* (4.5.6)	Louisiana Amusement and Music Operators Association Osborne Coinage◊	Estimated 1.0M units	State laws do not favor use of coins in these devices

Table 4-1. Stakeholder Groups Directly Contributing to Outreach (continued)

Stakeholder Group (Corresponding Report Section)	**Organizations Providing Direct Feedback**	**Approximate Size of Stakeholder Group (Information as available)**	**Potential Issues and Operational Strategies of Concern**
Transit Officials* (4.5.7)▲	GFI Genfare◊ International Bridge, Turnpike and Toll Association Main Fare Box◊ Pennsylvania Public Transportation Association VenTek International◊ Washington Metropolitan Area Transit Authority Imonex, Inc. ◊ **Additional 4 anonymous questionnaire results**	60,000 public buses Estimated 10,000 toll collection units $10.5B annual revenue for tollways	Increasing use of cashless payment options on tollways
Car Wash Owners and Operators* (4.5.8)	International Carwash Association Mid-Atlantic Carwash Association New York State Car Wash Association IDX, Incorporated◊ Imonex◊ Parker Engineering◊ Coin Acceptors, Inc. (Coinco) ◊ **Additional 5 anonymous questionnaire results**	300,000 coin acceptors	Quarter dollar and dollar coin dominate coin payments May switch to tokens, notes and/or credit/debit card payments
Merchants** (4.5.9)	Giant Eagle – Corporate Offices Giant Eagle – Northern Cambria, Pennsylvania Mr. Kent Ford (owner of several convenience stores in Pennsylvania) Brinks, Inc.^ Dunbar Armored^ Crane Payment Solutions^ Coin Acceptors, Inc. (Coinco) ^	250,000 size-based automated coin changers 56,000 self-checkout stations	One of the few stakeholders that accept one-cent coins for payment (in self-checkout stations) Increasing number of self-checkout units or kiosks
Manufacturers of Commercial Coin-Handling Equipment** (4.5.10)	Coinstar■ SCAN COIN☼ Klopp Coin, Inc. ■ Cummins-Allison■ Coin Wrap☼	30,000 high-speed coin-sorting/counting units 250,000 size-only coin-sorting/counting units	Aluminum coins can permanently damage high-speed coin-sorting and counting units

Table 4-1. Stakeholder Groups Directly Contributing to Outreach (continued)

Stakeholder Group (Corresponding Report Section)	**Organizations Providing Direct Feedback**	**Approximate Size of Stakeholder Group (Information as available)**	**Potential Issues and Operational Strategies of Concern**
Vending Machine and Other Coin-Acceptor Manufacturers* (4.5.11)	Betson[■] Coin Acceptors, Inc. (Coinco)[■] IDX, Incorporated[■] Imonex, Inc.[■] MEI[■] Parker Engineering[■] Crane Payment Solutions[☼] Osborne Coinage[■]	More than 10 domestic manufacturers	Must respond quickly to accommodate new coin characteristics and/or properties Several different technologies used to validate coins
Depository Institutions** (4.5.12)	Brinks, Inc.[#] Garda Cash Logistics[#]	7265 Federal Deposit Insurance Corporation (FDIC)-insured institutions	Large banks rely upon armored-car operators to manage coins
Coin and Currency Handlers/ Armored-Car Operators** (4.5.13)	Brinks, Inc. Dunbar Armored Garda Cash Logistics Independent Armored Car Operators Association Intertrust Armored Service, LLC United States Armored Company Via Mat International, Inc. Federal Reserve Bank of Governors – Cash Product Office	200 coin terminals	Up to one permanent staff addition at all coin terminals to count all incoming coins resulting from changes to coin weight and/or dimensions Security Managing multiple sets of coins with differing dimensions and/or weight
Blind and Visually-Impaired (4.5.14)	National Federation of the Blind (NFB)	3.4M citizens of the US	Continued ability to distinguish coin denominations
Public (4.5.15)	Comments received from request for comment in the Federal Register	314M US citizens	Acceptance of new coins
Federal Agencies[Δ]	United States Secret Service United States Postal Service United States Mint	N/A	Continued support of commerce Security/fraud Validation of coins Sorting and handling Methods of processing and accepting large quantities of coins Public acceptance of new coins

Table 4-1. Stakeholder Groups Directly Contributing to Outreach (continued)

Stakeholder Group (Corresponding Report Section)	Organizations Providing Direct Feedback	Approximate Size of Stakeholder Group (Information as available)	Potential Issues and Operational Strategies of Concern
Others[Δ]	American Numismatic Association European Vending Association Royal Canadian Mint Royal Mint (of the United Kingdom) Reserve Bank of New Zealand	N/A	Uniqueness of coin characteristics and properties relative to existing coinage throughout the world Public awareness Numismatic coin product sales

Sources for statistics are provided in the text that follows. N/A = not applicable
* Stakeholder is associated primarily with coin-acceptance equipment.
** Stakeholder is associated primarily with coin-handling equipment.
[†] Vending machine owners and operators are further broken down into four separate subgroups: large owners and operators, small owners and operators, owners and operators having vending machines without modern internal communication protocols and bulk vending.
[+] Although not vending machine owners and operators, these organizations provided information that was useful in understanding and quantifying issues to be faced by the vending machine owners and operators.
[▼] Although not laundromat owners and operators, these organizations provided information that was useful in understanding and quantifying the issues to be faced by the laundromat owners and operators.
[◊] Although not an owner or operator within the stakeholder group, these organizations provided information that was useful in understanding and quantifying the issues to be faced by the laundromat owners and operators.
[▲] Transit officials are further broken down into two separate subdivisions: public transportation fare boxes and tollway collection units.
[▪] American-owned manufacturer of commercial coin-processing equipment.
[☼] Sales and service center are resident in the US.
[^] These organizations are not merchants; however, they provided information that was useful in understanding and quantifying issues associated with changes to coins relative to the merchant stakeholders.
[#] Public depository institutions generally rely upon third-party providers to manage their coins. Therefore, all public depository institutions and their professional organizations contacted for the present study referred the project team to armored-car carriers for information to support the purposes and objectives of this study.
[Δ] Information from these stakeholders is not highlighted in a separate section of this chapter. However, input from these organizations was included in the discussion that follows.

The questionnaires (see Appendix 4-A) developed by CTC were posted on a secure Web site and were provided to industry trade associations. The industry trade associations then forwarded the Web address and instructions for accessing the questionnaire to their members via e-mail. Voluntary questionnaire feedback could be given by any organizational member; all information provided was kept anonymous. Results within any stakeholder group were aggregated prior to reporting to avoid accidentally releasing any individual respondent's confidential information. The questionnaires were principally designed to gather quantitative and qualitative information about the automated devices used to recognize, accept, sort, count, package or process coins. Summaries of the questionnaire results are provided for the vending (i.e., respondents solicited by industry trade groups representing the vending industry) and laundromat (i.e., respondents solicited by trade groups representing the laundromat industry) stakeholders in Appendix 4-B. Sample sizes for the other stakeholder groups to whom surveys were sent (including car wash owners and operators, transit officials, and amusement machine owners and operators) were fewer than six total responses. The response rate for these stakeholder groups was not sufficiently large enough to provide CTC with confidence that anonymity could be properly maintained even if aggregated results for these stakeholders were presented. In addition, CTC did not believe that extrapolating from such limited data to the associated stakeholder group at large would result in robust and defensible conclusions. Therefore, the magnitude of the impact to these stakeholders was primarily based upon information from other sources. However, information from these questionnaires was used to supplement/validate data gathered from other sources.

4.3 COIN-PROCESSING EQUIPMENT

At the center of any conversion cost assessment is the equipment that processes coins. Dividing the equipment into those that directly provide a product or service (i.e., coin-acceptance equipment) and those that sort, count, package or perform like functions (i.e., coin-handling equipment) allows for a more straightforward analysis since equipment manufacturers are generally divided along these lines. Further division of coin-processing equipment is discussed below. A brief discussion of coin-processing equipment is presented here so that the reader has a better understanding of the discussion that follows. The hardware or software that performs other functions in these various machines is not relevant to this analysis, except as noted.

A further subdivision of coin-processing equipment can be made based upon the type of sensing technology used to validate coins: passive (hardware-based) and active (hardware- and software-based).

- Passive devices mechanically validate a coin based upon physical properties including dimensions (diameter and thickness), weight and/or edge profile (smooth vs. reeds).
- Active devices rely upon input from electronic sensors whose output is interpreted through software. The sensors measure any of several coin characteristics and/or properties including thickness, diameter, edge profile and electromagnetic signature (EMS).[83] To validate a coin, the sensor output is compared to known values of circulating coins.

A large number (estimated to be in excess of 75%) of passive devices will require hardware upgrades if the dimensions of coins change. A relatively small percentage (less than an estimated 5%) of passive devices will require hardware upgrades if weight and/or edge profile of coins change. Many active devices, on the other hand, can be reprogrammed to recognize and accept coins of alternative material construction and/or size without requiring any hardware changes. Generally, the only instance where hardware changes are required for active devices is when a new coin set falls outside the dimensional range of the smallest (i.e., the US dime coin) and largest (i.e., generally the half dollar, dollar or quarter dollar coins, depending on the coin set recognized by the given coin-processing equipment) coins currently accepted by the device.

[83] Electromagnetic signature (EMS) is understood in the industry to mean the electrical signal strength of a nearby electromagnetic sensor as a coin passes in close proximity to the sensor. The magnetic field in the vicinity of the emitting sensor, and therefore the electrical current in the EMS receiving sensor, changes as the coin passes by. The change in electrical signal strength is influenced by the materials of construction along with the thickness and distribution of materials within the coin. The signal strength and/or its decay rate are then used by software to validate the coin and determine its denomination. One key determiner of EMS is electrical conductivity, typically measured by the percent of the conductivity of the International Annealed Copper Standard (%IACS).

Since some degree of variability in coin properties is allowed within coin-processing equipment due to customary variations in coin manufacture, coin and machine wear, dirt, location of the coin with respect to the coin validation sensor as the coin passes by, temperature effects and other factors, upper and lower acceptance limits for each measured characteristic and/or property for each coin denomination are defined for every model or type of coin-processing device.[84] This range of acceptable values (referred to as the "acceptance window") is typically plus/minus three standard deviations from the mean of the associated measured values from a representative sample of coins.

The level of sophistication of the technology used in any given coin-processing device depends upon the level of security deemed to be necessary to support commerce and the operating conditions (temperature, cleanliness, vibration and other factors) under which the device is expected to operate. If the product or service being offered has a low value (for example, playing time on an amusement machine), then the coin-validation device (called a coin validator or a coin acceptor) tends to be of relatively low sophistication. Passive coin validators are commonly used in these cases. However, when providing a relatively high-priced item (such as that common to the vending industry) more sophisticated coin validators are generally used since the owners/operators of the machines not only have a missed sale, but they suffer direct financial loss (of nearly equal value to the price of the product) from use of slugs or other successful attempts to steal a product. Active coin validators are commonly used in these applications.

Any given stakeholder group tends to favor a certain level of sophistication in the coin-processing equipment used in their machines. The technology commonly used by each stakeholder to validate coins is identified and discussed below in the sections that detail impacts to each of the stakeholder groups. Costs to upgrade or replace the hardware and/or software used in the coin-processing equipment resulting from changes to various coin characteristics are then presented.

4.4 RECENT EXAMPLES OF NEW COIN INTRODUCTIONS IN OTHER COUNTRIES

Major changes to the materials of construction and/or to the size of coins are a common practice in the circulating coins throughout the world. Although no "rule" as such exists, according to technical experts at two major coin-processing equipment manufacturers, other countries routinely make significant changes to the materials of construction and/or size of their circulating coins approximately every 20 to 25 years. Inflation is often the principal driver for making the change when the total cost to produce incumbent coins approaches or exceeds the coin's face value. Three such recent examples are discussed here. In all three cases, the current project team interviewed individuals who were directly involved with planning for and implementing the new coins into circulation into their respective countries. Although not specifically called out in this report, the lessons learned from these individuals were incorporated into the execution of the project and the resulting knowledge is implicit in much of the discussion that follows.

[84] More advanced acceptance software uses neural network or fuzzy logic technology to define the acceptance conditions, which are more complex in shape than those defined here. However, in principle, they operate in much the same way as that described here: when the various sensor values are collectively within acceptable domains, the coin is considered valid and the corresponding coin value is credited.

Recent material changes in the construction of Canadian circulating coins were made by the Royal Canadian Mint (RCM). Plated-steel one- and two-dollar Canadian coins were placed into circulation in early 2012 [3]. New Canadian one- and two-dollar coins have the same dimensions as their incumbent counterparts, but the new coins have lower weight due to the lower density of the new materials of construction. The public announcement came approximately 10 months in advance of the RCM releasing the new coins into circulation. It is not clear when the stakeholders were given coin samples to use for upgrading their equipment.

Her Majesty's (HM) Treasury (of the United Kingdom [UK]) selected a plated-steel composition and updated the dimensions for the new UK 5-pence and 10-pence coins entering circulation in 2012 [4]. The Royal Mint (RM) took a different approach to the construction of their new coins than did the RCM. The RM kept the weights and diameters of the new coins the same as the corresponding incumbent coins. This necessitated an increase in the thickness of the new 5-pence and 10-pence coins, since the new materials of construction are of lower density than the incumbent cupronickel composition previously used for these coins. Approximately 12 months was allotted by the RM between announcing their intention to and then releasing 5-pence and 10-pence coins of new construction. Stakeholders were expected to prepare themselves for the new coins during that time period.

Finally, in mid-2006 the Reserve Bank of New Zealand (RBNZ) introduced new circulating coins having both different metallic materials of construction and smaller dimensions (diameter and thickness).[85] This required a significant upgrade to the coin-processing equipment throughout New Zealand. A well-coordinated public relations effort was conducted by the RBNZ to garner public and commercial support for the change in coinage. Few details have been posted about the conversion costs required of New Zealand to complete this coinage update.[86] However, the coin-processing infrastructure was able to successfully upgrade their equipment to accept and process the new coins. The RBNZ provided stakeholders with sample coins six months in advance of releasing these coins into circulation. During this time stakeholders were expected to upgrade their coin-processing equipment in preparation for release of the new circulating coins.

4.5 DISCUSSIONS WITH STAKEHOLDERS

Information aggregated from the many sources from which the information was gathered resulted in some data inconsistencies.[87] While most of the data differences were resolved by looking deeper into the factors that make up the various values presented by any given source of information, other inconsistencies were not able to be resolved to a single clear and certain value.

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[85] The incumbent coins in circulation in New Zealand prior to the release of the new coins were considered to be too large and cumbersome based upon standards defined in The WVA Coin Design Handbook [5]. After introducing the new coins into circulation, the incumbent coins were quickly withdrawn from circulation since the New Zealand government declared that three months after introduction of the new coins, merchants were no longer required to accept the incumbent coins for payment.

[86] It is also worthy of note that the incumbent coinage of New Zealand was similar to that of neighboring Australia and a few other countries in the southern hemisphere [6]. Foreign coins were frequently confused with the incumbent New Zealand coins, which was further motivation for the 2006 change in coinage dimensions and materials of construction.

[87] For example, the size of the vending industry in the US for 2010 was estimated by various sources to be between $19.25B and $60B. Other data conflicts from vending and other stakeholders were also observed.

Data inconsistencies are explained below, when the basis for such inconsistencies was known. The references consulted by CTC, in its best judgment, to be most reliable were used as the basis for calculating the conversion costs or other impact estimates defined below. When uncertainty remained in any of the values used to define the magnitude of these impacts, a range of outcomes was computed. Although no precise definition of "most reliable" can be given, published information from trade groups was considered more reliable than comments made by individuals during one-on-one or group discussions. In addition, information from organizations with a dominant share of any given market (especially when the spokesperson was perceived by CTC to have a broad understanding of the many issues involved) was considered to have a high degree of reliability since the dominant members of any stakeholder group typically would have to endure the greatest magnitude of any impact to the stakeholder group.

Discussions with several coin-processing equipment manufacturers indicated that these devices have continued to evolve over the past 20 years, which is beyond the normal lifetime of the majority of these devices. Fielded coin acceptors used in the vending industry, for example, can be reasonably well characterized by a few generations of technology implementation; however, the methods of validating coins by other stakeholder groups varies widely, making the job of computing the associated impacts relatively more challenging, especially given the limited amount of public data available to define the number and types of equipment used by these stakeholders.

To simplify the analyses completed for the present study, several assumptions were made based upon the approximate dates that several technologies were commonly available and incorporated into coin-processing equipment. In general, older-generation devices rely on technology that is more costly to upgrade. Based upon feedback from several coin-acceptance equipment manufacturers, the method of computing the conversion costs to the vending and laundromat stakeholders (the two groups who would be most significantly impacted by a change to the metallic construction and/or size of coins) is conservative in the sense that the below computed values are likely to <u>overestimate</u> the actual conversion costs that would be required from each stakeholder group to correctly process alternative material coins that are non-seamless (i.e., those having characteristics and/or properties that lie outside of current acceptance windows of the coin-processing equipment).

In the present analysis all coin acceptors manufactured before 2001 are assumed to be replaced with new units when any measured coin characteristic and/or property validated by the acceptor differs between the incumbent and alternative material candidates. For example, if a coin validator manufactured prior to 2001 uses EMS to validate coins and the EMS of an alternative material candidate differs from that of the incumbent coin, then a new coin acceptor was assumed to be required.

Many vending and laundromat active coin acceptors sold between approximately 2001 and 2006 can be reprogrammed on site by placing the unit into teach mode and introducing sample coins to train the unit to recognize new coins or tokens. Other active coin-acceptor units constructed during this time period require that the coin mechanisms be returned to a service center to have updated software uploaded so that non-seamless coins can be correctly validated and processed. The costs to upgrade devices of either of these designs are approximately the same.

Many active coin acceptors manufactured after 2006 can be upgraded by simply uploading software directly to the coin acceptors where they reside. Software uploads are typically completed through use of a small, portable, dedicated computer device with a universal serial bus (USB) port. Today's most advanced units allow software uploads directly by wireless Internet; in other instances, upgraded software can be e-mailed to the machine owners who can then upload the software upgrades to their units. The number of units that are wirelessly connected to the Internet or that accept software upgrades through e-mail delivery are small in number (i.e., less than 1 percent [%] of fielded units in the US).[88]

From the analyses completed for this evaluation, it is clear that the vending and laundromat industries would be significantly impacted by introduction of non-seamless US circulating coins. Other industries would also be impacted, depending upon the specific coin characteristics and/or properties that are changed. These other industries do not appear to be as well represented by industry trade groups as the vending and laundromat stakeholders. Therefore, gathering information about the impact of changes to coins for these other stakeholders was more difficult and fragmented. As with the vending and laundromat stakeholders, input from individual contributors during the one-on-one interviews is not referenced to maintain the confidentiality of data that many contributors considered to be business sensitive.

In the analyses that follow, three levels of costs were computed for each stakeholder group.

- Low- and high-cost values are computed based upon the extreme conditions uncovered by the information gathering efforts defined above.
- The third level of cost computed was a most-probable cost, which was based upon CTC's best judgment of the actual conversion costs to upgrade equipment.

The most-probable costs are used elsewhere in the report when discussing total conversion costs for the candidate materials.

4.5.1 Vending Machine Owners and Operators

Historically, the vending stakeholder group has garnered a significant amount of attention throughout the world by mints and government financial ministries contemplating alternative material coin construction. See Appendix 4-C for detailed background data on the vending machine owners and operators. Of the stakeholder groups considered for this study, the vending industry has the largest number of potential machines (5.3M [7]) impacted and the largest number of individual sites where impacted machines reside. Both of these factors greatly impact the conversion costs to upgrade coin-acceptance equipment throughout the vending industry to accommodate any changes to circulating coins.

Based upon observations from the coin-acceptor manufacturers and those who operate service centers for vending machines coin acceptors, an unknown number of vending machine owners and operators will choose to upgrade (rather than replace) units manufactured prior to 2001 at a lower conversion cost than that required for a new coin acceptor. Furthermore, the experience of

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[88] The coin-processing equipment manufacturers interviewed during this study were unable to provide the exact number of fielded units that would accept software uploads from wireless methods or that allow for owner upload of software delivered by e-mail. These manufacturers did, however, indicate that such options result in the lowest-cost software upload available within the coin-processing market. For this report, these units were included in the post-2006 coin-acceptor totals.

the coin-acceptor manufacturers and service center operators indicate that an unknown fraction of vending machine operators will choose to wait up to four or more years (beyond the release date of alternative coins) before they update their coin acceptors, perhaps until the current devices can no longer be economically repaired. Others will simply choose to reject non-seamless coins until vend sales drop to an unacceptable level as a result of sales lost from not accepting any non-seamless coins. Still others will likely hold off upgrades until the devices need other forms of maintenance or repairs for which funds have already been allocated. Since CTC did not have a defensible method to define how many vending machine owners and operators will delay purchasing new coin acceptors or delay making upgrades to their current equipment, 100% of those fielded units manufactured prior to 2001 were assumed to be replaced in the below calculations for non-seamless coins. Therefore, the magnitude of the computed conversion costs described in this report is expected to be larger than what would actually be spent by the vending machine owners and operators should alternative material non-seamless coins be introduced into circulation.

Should any commonly accepted vending machine coin (i.e., 5-cent, dime, quarter dollar or dollar coin) change dimensions, hardware changes would be required for the vast majority of vending machines (exact values are discussed in Appendix 4-C). Changes to coin weight are assumed to impact only the passive coin acceptors since the active coin acceptors used in the vending industry rarely, if ever, use weight to validate coins. To be conservative (i.e., estimate on the high side of conversion costs), 100% of the passive coin acceptors in vending machines are assumed to be replaced with modern active units when weight is the only characteristic that changes in alternative material coins.[89] Changes to the EMS of circulating coins would impact virtually 100% of all active coin acceptors that accept the associated coins. The cost analysis assumed that 100% of affected coin acceptors would be upgraded or replaced if the EMS of coins were changed.

4.5.1.1 Large Vending Machine Owners and Operators

Table 4-2 summarizes the conversion costs required of large vending machine owners and operators to accommodate changes to US circulating coins, assuming 100% of the impacted coin acceptors are upgraded (or replaced if older than 10 years). Impacts from alternative materials having an EMS that differs from incumbent US circulating coins, as well as impacts due to changes to coin dimensions (defined to be diameter changes greater than 1% of current values and/or thickness changes of more than 3% of current values) are shown. To be conservative (i.e., estimate on the high side of calculated values), 100% of the passive coin acceptors in vending machines are assumed to be replaced with modern active units when weight differences greater than 3% exists in new coins.

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[89] The actual number of vending machine passive units that rely upon weight is thought to be (however, no specific data were found to support or refute the conclusion that) for less than the majority of those units currently in operation.

Table 4-2. Conversion Costs ($M) for Large Vending Machine Owners and Operators

Coin Characteristic Changed	One-Cent Coin	5-Cent Coin	Dime Coin	Quarter Dollar Coin	Half Dollar Coin	Dollar Coin
Immediate Out-of-Pocket Expense in Fall 2014						
Diameter	None	660.8–1035.5	660.8–1035.5	668.0–1046.9	None	587.8–911.2
Thickness	None	660.8–1035.5	660.8–1035.5	668.0–1046.9	None	587.8–911.2
Weight	None	9.3–14.5	9.3–14.5	9.4–14.7	None	8.3–12.9
EMS	None	111.8–177.1	111.8–177.1	113.0–179.1	None	99.4–157.6
Final Cost Impact at 20% Corporate Tax Rate						
Diameter	None	528.6–828.4	528.6–828.4	534.4–837.5	None	470.3–737.0
Thickness	None	528.6–828.4	528.6–828.4	534.4–837.5	None	470.3–737.0
Weight	None	7.4–11.6	7.4–11.6	7.5–11.8	None	6.6–10.4
EMS	None	89.4–141.7	89.4–141.7	90.4–143.3	None	79.5–126.1

Changes to coin characteristics are defined as follows (relative to incumbent US circulating coins): diameter > 1%, thickness > 3% and weight > 3%. EMS is more complex and requires a detailed analysis from each coin-acceptor manufacturer to define when changes are required for their equipment.

Two other factors are considered in computing the conversion costs provided in Table 4-2. First, US coins of alternative material construction were assumed by CTC to be released into circulation in the Fall of 2014.[90] Many coin acceptors manufactured prior to 2001 are expected to be replaced not long after the Fall of 2011 (when the coin-acceptor information discussed in Appendices 4-B and 4-C was gathered from the vending industry) due to natural attrition of this older equipment. An assumption was made that 20% of fielded coin acceptors manufactured prior to 2001 are replaced annually with units that can be upgraded by a software upload. All coin acceptors manufactured after 2001 were assumed to remain in service through the Fall of 2014. A second factor considered in the results shown in Table 4-2 is the net effect of corporate tax. Since the replacement and/or upgrade costs are a business expense, these costs would reduce net profits resulting in less corporate taxes being paid. This would reduce the net effective conversion costs to the industry. Given that federal corporate taxes are between 15% and 35% [8], state corporate taxes are between 0% and 10% and that some cities charge up to 9% corporate tax, the assumption was made that the average total corporate tax is 20%, meaning that the industry net effective conversion costs are only 80% of the immediate out-of-pocket expenses. Conversion costs that reflect corporate tax effects are also shown in Table 4-2 for large vending machine owners and operators.

4.5.1.2 Small Vending Machine Owners and Operators

Table 4-3 summarizes the conversion costs to small vending machine owners and operators resulting from changes to US circulating coins. Impacts from alternative materials having an EMS that differs from incumbent US circulating coins, as well as impacts due to changes to coin dimensions (as an engineering estimate, defined to be diameter changes greater than 1% of current values and/or thickness changes of more than 3% of current values) are shown. To be conservative (i.e., estimate on the high side of calculated values), 100% of the passive coin acceptors in vending machines are assumed to be replaced with modern active units when a

[90] The Fall of 2014 was selected as a potential time when alternative material coins will be introduced into circulation based upon assumed further development of coinage materials and production readiness evaluations at the United States Mint. The actual date of introducing new coins, if any are to be introduced at all, has not been announced by the United States Mint.

weight difference greater than 3% exists in any proposed coinage material. Projections to the Fall of 2014 were made and a lower effective conversion costs due to corporate taxes at 20% are also summarized in Table 4-3.

Table 4-3. Conversion Costs ($M) for Small Vending Machine Owners and Operators

Coin Characteristic Changed	One-Cent Coin	5-Cent Coin	Dime Coin	Quarter Dollar Coin	Half Dollar Coin	Dollar Coin
Immediate Out-of-Pocket Expense in Fall 2014						
Diameter	None	121.8–191.4	121.8–191.4	123.2–193.5	None	108.4–170.3
Thickness	None	121.8–191.4	121.8–191.4	123.2–193.5	None	108.4–170.3
Weight	None	1.7–2.7	1.7–2.7	1.7–2.7	None	1.5–2.4
EMS	None	28.5–37.7	28.5–37.7	28.8–38.1	None	25.3–33.5
Final Cost Impact at 20% Corporate Tax Rate						
Diameter	None	97.4–153.1	97.4–153.1	98.6–154.8	None	86.8–136.2
Thickness	None	97.4–153.1	97.4–153.1	98.6–154.8	None	86.8–136.2
Weight	None	1.4–2.2	1.4–2.2	1.4–2.2	None	1.2–1.9
EMS	None	22.8–30.2	22.8–30.2	23.0–30.5	None	20.2–26.8

Changes to coin characteristics are defined as follows (relative to incumbent US circulating coins): diameter > 1%, thickness > 3% and weight > 3%. EMS is more complex and requires a detailed analysis from each coin-acceptor manufacturer to define when changes are required for their equipment.

4.5.1.3 Additional Comments about Vending Machine Owners and Operators

As a point of reference for the above vending machine upgrade costs, the projected cost was $40M to upgrade the 200,000 vending machines in Canada [3] to accept the newly introduced Canadian plated-steel one-dollar and two-dollar circulating coins.[91] This is an average of $200 per vending machine, which is of similar magnitude to the values defined here. HM Treasury (of the UK) made a similar assessment [4] prior to authorizing the RM to develop and release in 2012 new nickel-plated steel 5-pence and 10-pence circulating coins.[92] HM Treasury determined that approximately 50% of the nation's 1.0M machines impacted by the alternative material coin constructions would be vending machines. Among the vending machines, 87% required a firmware upgrade costing £12 ($19[93]) each, 11% required a new mechanism costing £250 ($395) each and the final 2% of the vending machines required a software upgrade costing £15 ($24) each. When service fees (i.e., labor) are added, HM Treasury's best estimate of the total impact for all 1.0M machines was £80M ($126M), which is an average of £80 ($126) per machine.[94] These conversion costs are also of similar magnitude to those discussed above for US vending machines. In both cases, the new Canadian and the new UK coins are expected to co-circulate with incumbent coins.

[91] The change to the plated-steel Canadian one-dollar and two-dollar coins is projected to save the RCM $16M annually [3].

[92] The incumbent five-pence and ten-pence coins were of cupronickel composition (75% copper/25% nickel). The change in the construction of these coins was projected to save the RM an estimated £7.5M ($11.8M) annually [4].

[93] The exchange rate was assumed to be 1.58 US dollars ($) per British pound (£) [9].

[94] HM Treasury states, while most other automated machines would have a similar conversion cost to vending, parking meters in the UK are more expensive to upgrade than vending machines. This is due to a higher rate (40%) of parking meters mechanisms needing to be replaced (a direct result of the new coins being approximately 10% thicker than their incumbent counterparts), a higher cost for firmware and software upgrades, and the higher labor cost associated with upgrades to parking meters [4]. Therefore, the $126 per machine conversion cost would appear to be a potentially high value for the United Kingdom's 0.5M vending machines.

Changes to any one, two, three or all four of the most significant US circulating coins to the vending industry (5-cent, dime, quarter dollar and dollar coins) would all require approximately the same conversion costs to the vending industry. To keep the industry from having to make multiple coin-acceptor upgrades (and repeatedly incur the associated costs to do so) over a period of years, changes planned for these coins should be made all at one time. Although a second, third or fourth coin acceptor update would likely cost less than the numbers projected in Tables 4-2 and 4-3, the costs would nonetheless be significant for an industry that had a pre-tax profit of only 1.0% to 2.0% in 2010 [7]. Therefore, if the United States Congress contemplates changing more than one of the incumbent 5-cent, dime, quarter dollar and/or dollar coins, then it would be in the best interest of the vending industry for the United States Mint to make all changes and to introduce each new coin into circulation at the same time or as an engineering judgment, within approximately a 2–4-month time period.

Another factor that could lower the actual conversion costs (over those defined above) for vending machine owners and operators is associated with upgrades to units that could be completed during regularly scheduled and/or emergency maintenance to vending machines as opposed to the singular-focused, dedicated upgrade effort assumed in the above calculations. One industry expert estimated that coin acceptors owned by the large vending machine owners and operators receive service twice a year on average. Another industry expert conservatively indicated that coin acceptors generally receive a minimum of four visits by trained maintenance staff during their lifetime. Two of these visits would include the unit being brought to a service center, where the latest software would routinely be uploaded as a part of a standard service agreement. Even with a 14-year average life span, slightly more than 1/3 of the coin acceptors are visited each year by trained maintenance personnel. These individuals have the training to upgrade these units on site (if the units allow for on-site upgrades). It is expected that many of the fielded units would be upgraded as part of these maintenance visits, thus affording the vending machine owners and operators an opportunity to leverage a service call to also upgrade software and/or hardware to accept the new alternative metallic coins.

All key stakeholders and the general public are expected to be given ample advanced warning about the timing of introducing alternative material US circulating coins. Even so, it is anticipated that many vending machine owners and operators will not upgrade their machines until after the new coins have been introduced into circulation. Based upon the fact that US circulating coins are designed to be in circulation for 30 years, and based upon two analyses completed by CTC (see Appendix 4-D) to determine the total number of US coins currently in circulation, about 3% of the US circulating coin supply is replenished each year with newly minted coins. At this replenishment rate, two years after introduction of an alternative material coin set, only about 6% of US coins would be of the alternative material coin construction, assuming that the incumbent coins are not withdrawn from circulation by either the United States Mint or hoarders. It is speculated that many vending machine owners and operators would rely upon such low quantities of alternative material coins that they would delay upgrading their coin acceptors until either the machines required service for another purpose or they lost a sufficient number of vending sales.

Changes to coin dimensions would have a very significant impact on the vending industry. First, the coin-acceptor manufacturers would have to redesign their mechanisms to recognize the newly-dimensioned coins. The industry has estimated that changes in coin dimensions would require up to a two-year effort to complete and test new hardware after the new coin dimensions were defined. Once coins of the final metallic composition and dimensions were available, another six to 12 months would be required to finish updating and testing software and other design features. If the 5-cent, dime or quarter dollar coins changed diameter by more than about 1% or if these coins changed thickness by more than a few percent,[95] then essentially 100% of the coin mechanisms,[96] which accept and process these coins, would have to be replaced. This replacement would be required as a result of hardware (including tubes to store coins of a given denomination for customer change) needing to be altered to accommodate the dimensions of such new coins while still processing the incumbent coins.

Additional conversion costs would be imposed on the vending industry if coins having new characteristics and/or properties (such as dimensions or EMS) were issued. Very old vending machines that do not rely upon today's industry standard of multi-drop bus (MDB) communication protocol would have to be modified with conversion kits that are currently commercially available at $800. Alternatively, these machines would have to be replaced in their entirety for $3000. Assuming an annual retirement rate of 5% of the estimated 200,000 units in existence in the Fall of 2011, approximately 170,000 of these units would be in existence in the Fall of 2014. This would result in a one-time upgrade conversion cost of between $136M and $510M. The most-probable conversion cost is considered to be $136M. Factoring in the impact of a 20% corporate tax, the net conversion cost to upgrade these non-MDB-based units is between $109M to $408M, with a most-probable value of $109M.

Summing the above totals for the large- and small-vending machine owners and operators, while including the costs for upgrading all non-MDB-based vending machines, the vending industry total conversion costs would be between $199M and $500M. These conversion costs assume that alternative material coin dimensions are maintained the same as incumbent coins, but EMS between the coin sets differ. The impact of 20% corporate taxes is also reflected in these numbers. Independently of changes to EMS, the conversion costs are estimated to be between $713M and $1.319B if coin dimensions are changed from incumbent coins. The most-probable conversion costs for vending machine owners and operators are $224M for coins of the same dimensions but different EMS; the most-probable conversion cost is $900M for new coins of different dimensions than incumbent coins.[97]

In 2010 the vending industry had $42.2B in revenue [10]. Assuming that the industry-wide average vend price is between $1 and $2 per item, this represents approximately 21 billion to 42 billion vends each year. If the average vend price was increased by 5 cents per vend (i.e.,

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[95] One estimate from a coin-acceptance manufacturer indicated that a 10% difference in coin thickness would require that all fielded coin mechanisms be replaced. The threshold on coin thickness was thought to be even smaller than 10%. The actual threshold values are not known by the industry. A very detailed engineering analysis is required to define a more accurate threshold values for diameter and thickness.

[96] Coin mechanisms include the coin acceptor, where coins are validated, tubes to store coins for making change and other hardware to process coins.

[97] The cost summaries defined in this paragraph are associated with changes to the quarter dollar coin, which is the most widely accepted coin within the vending industry. If no changes are made to the quarter dollar coin, but changes are made to either one or both of the 5-cent or dime coins, then the conversion costs would be approximately 98.9% of the conversion costs listed in this paragraph. Change to the dollar coin, with no changes to the 5-cent, dime or quarter dollar coins would result in conversion costs of approximately 88% of the values defined in this paragraph.

approximately between 2.5% and 5% of current totals), then the conversion costs required by the vending industry could be fully recovered in 1.4 months to 7 months (if no changes are made to coin dimensions) without impacting current profit margins. If coin dimensions were changed, then the conversion costs could be fully recovered between 4.4 months and 16 months as a result of increasing the average vend price by 5 cents.

4.5.1.4 Bulk Vending

One often overlooked segment of the broader vending industry is bulk vending, which in 2010 comprised 2.0M machines.[98] Bulk vending machines dispense loose candy, gum balls, nuts, capsules and small rubber balls (among other items). These units, which in 2010 generated $388M in revenue [10], are commonly found in shopping malls, and in entryways and on checkout counters of restaurants and other businesses. They are operated by placing a coin or coins into a slot on the front of the machine and manually rotating a handle to engage the mechanical dispensing unit to deliver the desired product. According to Reference 10, virtually all of these machines require payments in increments of 25 cents. Therefore, the overwhelming majority of bulk vending machines only accept quarter dollar coins. For the present analysis, only quarter dollar coins have been assumed to be accepted by bulk vending machines. In virtually all such devices, coin dimensions are the only characteristic validated; in some instances, only coin diameter is validated. Changes to US circulating coin materials of construction will therefore not impact the bulk vending industry if coin dimensions are maintained at their current values. However, if the quarter dollar coin dimensions are changed, then the simple coin-acceptor mechanism used in bulk vending machines would have to be redesigned to accept multiple coin dimensions (the incumbent and new quarter dollar coins) for the required vend amount. Given the relatively low cost of these units, most owners may choose to discard the old single-coin-dimension units for a new (though not currently developed) multi-coin-dimension unit. At $50 per machine [11], the total out-of-pocket conversion cost would be on the order of $100M to $150M, where the higher value also assumes an additional $75 service fee per site and three bulk vending machines per site. The most-probable conversion costs for bulk vending resulting from changes to the dimensions of the quarter dollar coin is $150M. Accounting for a 20% corporate tax impact as discussed above for the vending machine owners and operators, the expected net conversion costs are estimated to be between $80M and $120M, with $120M being the most-probable net conversion costs if quarter dollar coin dimensions were changed.

4.5.2 Laundromat Owners and Operators

Details on the 5.1M laundromat coin acceptors can be found in the section entitled “Laundromat Owners and Operators” in Appendix 4-C. Highlights include the following:

- The industry has a heavy dependence on quarter dollar coins (representing 96% of all coins collected); some equipment also accepts dollar coins.
- One of five machines does not accept coins for payment.
- Coin acceptors for laundromat machines are generally lower cost than those used in the vending industry.

[98] While the standard terminology used in the industry may cause some confusion for those not familiar with the industry, bulk vending machines (a separate classification of machines) are not included in the 5.3M vending machines mentioned in the above report sections on large- and small-vending machine owners and operators.

- The industry is very hands-on; typically owners/operators complete their own maintenance, upgrades and installation of new devices.

Table 4-4 summarizes the conversion costs to laundromat owners and operators resulting from changes to US circulating coins. Conversion costs associated with alternative material coins having an EMS that differs from incumbent US circulating coins, as well as changes to coin dimensions (defined to be diameter changes greater than 1% of current values and/or thickness changes of more than 3% of current values) are shown. The costs are associated with all units being upgraded in the Fall of 2014. An assumption was made that 20% of fielded coin acceptors manufactured prior to 2001 are replaced annually with units that can be upgraded by a software upload. All coin acceptors manufactured after 2001 were assumed to remain in service through the Fall of 2014. The net effective conversion costs due to corporate taxes of 20% are also shown in Table 4-4.

Table 4-4. Conversion Costs ($M) for Laundromat Owners and Operators

Coin Characteristic Changed	One-Cent Coin	5-Cent Coin	Dime Coin	Quarter Dollar Coin	Half Dollar Coin	Dollar Coin
Immediate Out-of-Pocket Expense in Fall 2014						
Diameter	None	None	None	96.3–192.1	None	14.4–28.8
Thickness	None	None	None	96.3–192.1	None	14.4–28.8
Weight	None	None	None	None known	None	None known
EMS	None	None	None	60.6–111.7	None	9.1–16.8
Final Cost Impact at 20% Corporate Tax Rate						
Diameter	None	None	None	77.0–153.7	None	11.6–23.1
Thickness	None	None	None	77.0–153.7	None	11.6–23.1
Weight	None	None	None	None known	None	None known
EMS	None	None	None	48.5–89.4	None	7.3–13.4

Changes to coin characteristics are defined as follows (relative to incumbent US circulating coins): diameter > 1% and thickness > 3%. EMS is more complex and requires a detailed analysis from each coin-acceptor manufacturer to define when changes are required for their equipment.

The number of turns per day (TPDs), i.e., the average number of times in a typical day that each machine is used, for public laundromat equipment is between 3 and 8 [12]. No similar statistic was available for the multi-housing industry. If the average price to use a machine is raised by 25 cents (an increment that is consistent with the industry's heavy reliance on the quarter dollar coin), then the time required to recuperate the investment required to upgrade to new US circulating coins would be between 5 and 40 days. The 25-cent increase in cost would represent an increase in prices between 5% and 12.5% of current rates, which typically vary between $2 and $5. If the public coin-laundromat industry took 12 months to recuperate their investment in upgraded coin acceptors, then the average cost increase would be approximately 0.1% to 1.4%. This is based upon the coin-laundry industry annual revenue of $4.165B [13] and 2.1M units in operation at approximately 35,000 public laundromats in the US [12].

4.5.3 Pay Phone Owners and Operators

Details on the 425,000 pay phones [14] can be found in the section entitled "Pay Phone Owners and Operators" in Appendix 4-C. Highlights include the following:

- The industry is in significant decline in the total number of units.
- Approximately 85% of pay phones rely on passive coin acceptors.

- Virtually 100% of pay phones accept quarter dollar coins; approximately 90% accept 5-cent and dime coins; none were found that accept one-cent, half dollar or dollar coins.

Unlike many other devices that require coins to operate, pay phones are not typically serviced unless coin jams or other serious operational problems are reported. Therefore, taking advantage of scheduled or unscheduled maintenance to simultaneously upgrade pay phones for alternative coins having characteristics (either dimensions or EMS) that differ from the incumbent coins would not lead to a significant reduction in the number of focused service calls to accommodate any upgrades. Pay phone coin acceptors typically have a 10-year lifespan. Table 4-5 summarizes the conversion costs to the pay phone owners and operators resulting from any changes to coins. As with the other stakeholder groups discussed above, the number of units projected for the Fall of 2014 is used (an annual reduction of 10% of total units was assumed for pay phones). The net conversion cost resulting from corporate taxes of 20% is also given in Table 4-5.

Table 4-5. Conversion Costs ($M) for Pay Phone Owners and Operators

Coin Characteristic Changed	One-Cent Coin	5-Cent Coin	Dime Coin	Quarter Dollar Coin	Half Dollar Coin	Dollar Coin
Immediate Out-of-Pocket Expense in Fall 2014						
Diameter	None	44.6–56.0	44.6–56.0	49.5–62.2	None	None Known
Thickness	None	44.6–56.0	44.6–56.0	49.5–62.2	None	None Known
Weight	None	42.7–54.1	42.7–54.1	47.4–60.1	None	None Known
EMS	None	1.5–1.9	1.5–1.9	1.7–2.1	None	None Known
Final Cost Impact at 20% Corporate Tax Rate						
Diameter	None	35.7–44.8	35.7–44.8	39.6–49.8	None	None Known
Thickness	None	35.7–44.8	35.7–44.8	39.6–49.8	None	None Known
Weight	None	34.2–43.3	34.2–43.3	37.9–48.1	None	None Known
EMS	None	1.2–1.5	1.2–1.5	1.4–1.7	None	None Known

Changes to coin characteristics are assumed to be (relative to incumbent US circulating coins): diameter > 1%, thickness > 3% and weight > 20%. EMS is more complex and requires a detailed analysis from each coin-acceptor manufacturer to define when changes are required for their equipment.

4.5.4 Municipal Parking Officials

The section entitled "Municipal Parking Officials" in Appendix 4-C provides the cost details used to compute the impact to parking meters (used by municipal parking officials) resulting from changes to US circulating coins. Highlights include the following:

- There are an estimated 2.0M parking meters in the US [15].
- A mix of passive (approximately 10% of total) and active (approximately 90% of total) units exist.
- Virtually 100% of the units accept quarter dollar coins; approximately 50% also accept 5-cent and dime coins; approximately 50% of the active parking meters accept dollar coins; none were found that accept either one-cent or half dollar coins.
- The number of parking meters offering non-cash payment options is increasing.

Table 4-6 summarizes the conversion costs to parking meters resulting from changes to US circulating coins. Projections to the Fall of 2014 assume that the number of passive parking meters drops by 10% annually. Note that no corporate tax effects on the net conversion costs are shown since municipal parking authorities, who own and operate the majority of parking meters in the US, are not subject to corporate taxes.

Table 4-6. Conversion Costs ($M) for Municipal Parking Authorities

Coin Characteristic Changed	One-Cent Coin	5-Cent Coin	Dime Coin	Quarter Dollar Coin	Half Dollar Coin	Dollar Coin
Immediate Out-of-Pocket Expense in Fall 2014						
Diameter	None	21.9–28.1	21.9–28.1	43.7–56.3	None	None Known
Thickness	None	21.9–28.1	21.9–28.1	43.7–56.3	None	None Known
Weight	None	None	None	None	None	None Known
EMS	None	13.2–17.0	13.2–17.0	26.4–34.1	None	None Known

Changes to coin characteristics are defined as follows (relative to incumbent US circulating coins): diameter > 1% and thickness > 3%. EMS is more complex and requires a detailed analysis from each coin-acceptor manufacturer to define when changes are required for their equipment.

4.5.5 Amusement Machine Owners and Operators

Details on the 1.7M amusement machine coin acceptors can be found in the section entitled "Amusement Machine Owners and Operators" in Appendix 4-C. Highlights include the following:

- Quarter dollar coins dominate the amusement machine industry.
- Resident maintenance staff (or other on-site staff) complete most machine repairs and upgrades; they also install new equipment.
- The industry is dominated by passive coin-acceptance equipment.

Table 4-7 summarized the conversion costs to the amusement machine owners and operators resulting from changes to US circulating coins. The number of machines in the Fall of 2014 is assumed to be the same as that in the Fall of 2011. The net conversion costs due to corporate taxes of 20% are also shown.

Table 4-7. Conversion Costs ($M) for Amusement Machine Owners and Operators

Coin Characteristic Changed	One-Cent Coin	5-Cent Coin	Dime Coin	Quarter Dollar Coin	Half Dollar Coin	Dollar Coin
Immediate Out-of-Pocket Expense in Fall 2014						
Diameter	None	None Known	None Known	59.5–197.6	None	None Known
Thickness	None	None Known	None Known	59.5–197.6	None	None Known
Weight	None	None Known	None Known	None Known	None	None Known
EMS	None	None Known	None Known	0–4.2	None	None Known
Final Cost Impact at 20% Corporate Tax Rate						
Diameter	None	None Known	None Known	47.6–158.1	None	None Known
Thickness	None	None Known	None Known	47.6–158.1	None	None Known
Weight	None	None Known	None Known	None Known	None	None Known
EMS	None	None Known	None Known	0–3.4	None	None Known

Changes to coin characteristics are defined as follows (relative to incumbent US circulating coins): diameter > 1% and thickness > 3%. EMS is more complex and requires a detailed analysis from each coin-acceptor manufacturer to define when changes are required for their equipment.

A vast majority of amusement machines have two coin acceptors, either of which can be used by a client. If a quarter dollar coin of new dimensions and/or EMS was co-circulated with incumbent quarter dollar coins, owners of amusement machines that have two coin acceptors could choose to have one coin acceptor for each of the two quarter dollar coin types, which would cut the impact of accepting two different quarter dollar coin types by an estimated 40% to 50% over the values shown in Table 4-7.

4.5.6 Gaming Machine Owners and Operators

This industry has recently invested heavily in machines that no longer require or accept circulating coins to operate. Fewer than 5% of gaming machines in operation accept any sort of circulating coins. Today, casinos largely depend upon payment cards and tokens. Small games of chance, common in taverns, are typically dependent upon notes or other forms of payment. Rarely do machines that accept circulating coins recognize one-cent, 5-cent, dime or half dollar coins. Those that recognize quarter dollar and/or dollar coins are of an older design that is no longer domestically manufactured and is not well supported.

Pending legislation, to more closely monitor the use of these machines, in some states require modifications to small games of chance that cannot be accommodated with the majority of the gaming machines that currently accept coins. Enactment of this legislation, which is expected to occur in several states in 2015, will effectively eliminate use of coin-based gaming machines in those states. In general, this industry was reluctant to provide many details about their dependence on coin use. Therefore, it was difficult to confidently provide a quantitative assessment of the conversion costs required by this stakeholder group resulting from changes to coin characteristics and/or properties.

From the limited information that was gathered for this stakeholder group, and based upon the cost to update coin validators for other stakeholders, it was assumed that this industry will only require upgrades if quarter dollar and/or dollar coins are updated. In this analysis, 1.0M small games of chances are assumed to exist in the US; as of the Fall of 2011, only 5% of them accept quarter dollar and/or dollar coins.

For a change in EMS only and projecting to the Fall of 2014 with an annual reduction of 20% of the number of machines that accept coins, the out-of-pocket conversion costs to update the gaming coin acceptors are: low-cost estimate of $0.5M, high-cost estimate of $1.5M, and most-probable cost estimate of $1.0M.

These estimates are based upon a low-cost estimate of $25 per machine, a high-cost estimate of $75 per machine and a most-probable estimate of $50 per machine for upgrades to accept coins of a different construction. Accounting for the net conversion costs related to corporate tax of 20%:

- Low-cost estimate is $0.4M
- High-cost estimate is $1.2M
- Most-probable cost estimate is $0.8M for a change in the EMS of the quarter dollar coin and/or the dollar coin.

If quarter dollar and/or dollar coin dimensions change, then the per-unit upgrade costs are assumed to be the following values: low-cost estimate of $50; high-cost estimate of $250; most-probable cost estimate of $100. This would require out-of-pocket conversion costs for the gaming owners and operators with the number of units projected for the Fall of 2014 of: low-cost estimate of $1.0M; high-cost estimate of $5.0M; and most-probable cost estimate of $2.0M. Accounting for the net conversion costs related to corporate tax of 20%, for a change in the dimensions of the quarter dollar coin and/or the dollar coin the cost impact would be as follows:

- The low-cost estimate is $0.8M.
- The high-cost estimate is $4.0M.
- The most-probable cost estimate is $1.6M.

4.5.7 Transit Officials

As a result of distinctive and easily separated issues, transit official cost impacts are broken into two categories: public transportation fare boxes and tollway collection units. Each is discussed separately as noted below.

4.5.7.1 Public Transportation Fare Boxes

Details on this stakeholder can be found in the section entitled “Transit Officials – Public Transportation Fare Boxes” in Appendix 4-C. Highlights include the following:

- There are approximately 60,000 public buses throughout the US.
- Approximately 40,000 of these public buses rely upon active coin-acceptance devices.
- Upgrades to fare boxes can be competed using existing transit staff.

Industry experts expect the number of automated coin acceptors on public transit buses to grow in number over the next several years. Assuming a growth of 10% per year, the number of these units in public buses in the Fall of 2014 would be 52,000. Upgrading all 52,000 units would require conversion costs of $0.953M for a loaded-labor rate of $50 per hour, an average of 10 minutes per software upload and a $10 per bus software upload fee. Therefore, the impact from alternative coin designs to the bus fare boxes appears to be minimal relative to vending, laundromat, amusement and other stakeholder groups. Note that no corporate tax implications exist for public buses, which are typically operated through local governments.

Similar fare boxes on other forms of public transportation are assumed to be of similar complexity and magnitude. All six US denominations of US circulating coins are accepted by the typical fare box, although many transit authorities do not accept the one-cent coin, while other transit authorities do not accept the half dollar coin for payment.

For purposes of this analysis, the total fare box impact will be assumed double that for the public transit buses for total conversion costs of $1.907M to the public transportation industry as a whole. For this analysis, these values are considered a high-cost estimate. The low-cost estimate assumed here is based on existing maintenance staff uploading software as part of their current work activities, which means that no additional, unbudgeted labor costs are required. Under this scenario, the only cost would be the assumed $10 software upload fee for each fare box. For actual implementation, this scenario may require that uploads be spread out over a period of several months. The conversion costs for the fare box stakeholder group for the low-cost scenario (in the Fall of 2014) is $1.040M. The most-probable cost scenario (projecting to the Fall of 2014) assumes that half of the fare boxes will be upgraded by existing staff as part of their daily activities and the other half of the fare boxes will be upgraded by currently unbudgeted labor hours at a loaded rate of $50 per hour. This most-probable scenario would require conversion costs of $1.470M for fare box upgrades. In all three scenarios (low-estimate, high-estimate and most-probable estimate), the cost impact would be the same for EMS changes as for changes to coin dimensions and/or weight.

Fare boxes are replaced about every 10 years. Due to the shock and vibration received during operation upon moving buses and other transit vehicles, these units receive regular maintenance on average every 6 months. Presumably, most units could be reprogrammed with upgraded acceptor software as part of this maintenance work. Doing so would reduce the realized conversion costs from those identified above as high-estimate.

4.5.7.2 Tollway Collection Units

Systems are in place to collect and accept coins at most facilities that have automated toll collection mechanisms.[99] Such systems are common along turnpikes, toll roads, toll bridges and other motorized transportation systems. Multiple forms of payment are typically accepted at the payment checkpoints; today, cashless forms of payment account for approximately 50% of revenue. That percentage is expected to rise into the foreseeable future. Coins are typically accepted for payment; however, one-cent coins are not universally accepted for payment through automated systems as a result of the processing time required to handle large sums of one-cent coins. Industry best estimates are that less than 10,000 automated tollway coin collection devices exist throughout the US. Given the harsh environment that these collection devices must endure, including weather extremes, road salt, potential foreign objects and other hazards, tollway collection units are ruggedized coin acceptors.

In each scenario for the tollway collection stakeholder group, a $10 software upload fee was assumed. In addition, it is assumed that only 50% of the units will accept one-cent coins. The typical tollway site is assumed to have five coin acceptors. A per site service fee of between $50 (low-cost scenario) and $75 (high-cost and most-probable scenarios) has been quoted by various providers. An additional cost element was assumed for the high-cost scenario: the service technician will require an additional 20 minutes per unit to upgrade each coin acceptor. This labor was assumed to be fully burdened at $50 per hour. Assuming a total of 10,000 automated coin collection units, the estimated conversions costs for all US tollway collection units are a low of $200,000 for either EMS or coin size changes to a maximum of $417,000. The most-probable conversion costs were estimated at $250,000. No corporate tax implications exist for these fares as most of these operators are exempt from paying corporate taxes. These costs would be required if changes were made to either the 5-cent, dime or quarter dollar coins. Changes to just the one-cent coin would result in costs that are 50% of these values. Presumably, changes to the half dollar and dollar coins would also require conversion costs of a similar amount as those for the 5-cent, dime and quarter dollar coins.

One final note, an industry expert opined that in 10 years, 60–80% of the major tollway agencies will be cashless. As such, the number of automated coin collection devices at tollway collection sites will be greatly reduced in the future and the actual conversion costs will be less than those stated here.

The tollway collection stakeholders typically have a high-speed automatic coin separating and counting machine to service one or more cash collection sites, each of which receives customer coins from multiple coin collection units. Collected coins are received by armored-car operators

[99] The transit authorities annually collect $10.5B, which includes all forms of payment.

for credit to the toll collector's account. The impact of changes to these coin sorters/counters resulting from changes in coin EMS and/or dimensions is accounted for in the section below entitled "Manufacturers of Commercial Coin-Handling Equipment."

4.5.8 Car Wash Owners and Operators

Details on the 300,000 car wash coin acceptors can be found in the section entitled "Car Wash Owners and Operators" in Appendix 4-C. Highlights include the following:

- Quarter dollar coins dominate the car wash industry; some facilities also rely upon dollar coins.
- This industry is dominated by hands-on owners and operators who perform most maintenance and upgrades to equipment; they also install new equipment.

Table 4-8 summarizes the conversion costs to car wash owners and operators resulting from changes to US circulating coins. The number of units and the distribution of the types of coin acceptors in the Fall of 2014 were assumed to remain the same as those for the Fall of 2011. The corporate tax impact of 20% on the net conversion costs is also shown in Table 4-8.

Table 4-8. Conversion Costs ($M) for Car Wash Owners and Operators

Coin Characteristic Changed	One-Cent Coin	5-Cent Coin	Dime Coin	Quarter Dollar Coin	Half Dollar Coin	Dollar Coin
Immediate Out-of-Pocket Expense in Fall 2014						
Diameter	None	None	None Known	18.0–24.8	None	18.0–24.8
Thickness	None	None	None Known	18.0–24.8	None	18.0–24.8
Weight	None	None	None Known	9.0–13.1	None	9.0–13.1
EMS	None	None	None Known	9.0–13.1	None	9.0–13.1
Final Cost Impact at 20% Corporate Tax Rate						
Diameter	None	None	None Known	14.4–19.8	None	14.4–19.8
Thickness	None	None	None Known	14.4–19.8	None	14.4–19.8
Weight	None	None	None Known	7.2–10.5	None	7.2–10.5
EMS	None	None	None Known	7.2–10.5	None	7.2–10.5

Changes to coin characteristics are defined as follows (relative to incumbent US circulating coins): diameter > 1%, thickness > 3% and weight > 3%. EMS is more complex and requires a detailed analysis from each coin-acceptor manufacturer to define when changes are required for their equipment.

Several car wash owners and operators indicated that they could easily and quickly convert their coin-based payment system to a token-based payment system if they found that option to be more economically acceptable than making upgrades to or replacing their existing devices to accept both new and incumbent coins that differ from each other in EMS, size and/or weight. Changing to a token-based payment system may eliminate the need to transport large sums of coins to the bank on a regular basis. Tokens are simply directly recycled on site. Brass tokens can be purchased for approximately 10 to 20 cents each. Therefore, 1000 brass tokens would typically cost between $100 and $200. These tokens could then be used in existing coin-acceptance equipment. If faced with an unfavorable cost to accommodate alternative coins, other operators may choose to stop accepting coins for payment in favor of notes and/or credit/debit cards.

4.5.9 Merchants

The general flow of coins in the retail business is from a third-party bulk coin supplier, such as a bank or a coin terminal, to the retailer's cash vault, to the cashier's drawers (or automated change dispenser) to the customer as change. Low-denomination notes generally flow in that same direction, while higher-denomination notes generally flow in the opposite direction. Therefore, the most significant coin-usage issue expected to be faced by a majority of merchants (including grocery stores, department stores, restaurants and others) is correctly managing hand-to-hand transactions between cashiers and customers. This requires that any coins be quickly visually and tactically identified as to their authenticity and denomination. It is CTC's opinion, supported by comments made by several retailers who were interviewed for this outreach effort, that the general public, and retail cashiers in particular, will quickly learn to recognize and visually validate coins made from new metallic materials of construction. Therefore, hand-to-hand transactions are not expected to create any measurable financial burden to merchants or to the general public. Coins of two different materials of construction can easily share the current slots in cashier till drawers. For purposes of this study, the cost was assumed to be zero for learning, adapting to and then completing hand-to-hand transactions with any new coins.

Detailed numerical values on the cost impact to merchants resulting from changes to coins can be found in the section entitled "Merchants" in Appendix 4-C. Highlights include the following:

- Four types of equipment are common to merchants:
    - Automated coin sorters/counters
    - Coin change makers
    - Automated coin return kiosks
    - Self-checkout stations.
- Self-checkout lanes are growing in number in the US.

The conversion costs for merchants resulting from changes in dimensions, weight or EMS are summarized in Table 4-9. Please note that neither half dollars nor dollar coins are dispensed from automated change makers in the US market. All coin denominations were assumed to be accepted at self-checkout stations. No difference in the number of automated coin change makers was assumed between the Fall of 2011 and the Fall of 2014. An annual increase in the number of self-checkout stations was assumed to be 25% of the number of units in existence in the Fall of 2011. Therefore, the number of units assumed to exist within the US in the Fall of 2014 was 98,000. The net effective conversion costs resulting from corporate taxes of 20% are also shown in Table 4-9.

Table 4-9. Conversion Costs ($M) for Merchants

Coin Characteristic Changed	One-Cent Coin	5-Cent Coin	Dime Coin	Quarter Dollar Coin	Half Dollar Coin	Dollar Coin
Immediate Out-of-Pocket Expense in Fall 2014						
Diameter	14.1–28.4	14.1–28.4	14.1–28.4	14.1–28.4	1.6–3.4	1.6–3.4
Thickness	14.1–28.4	14.1–28.4	14.1–28.4	14.1–28.4	1.6–3.4	1.6–3.4
Weight	None	None	None	None	None	None
EMS	1.6–3.4	1.6–3.4	1.6–3.4	1.6–3.4	1.6–3.4	1.6–3.4
Final Cost Impact at 20% Corporate Tax Rate						
Diameter	11.3–22.7	11.3–22.7	11.3–22.7	11.3–22.7	1.3–2.7	1.3–2.7
Thickness	11.3–22.7	11.3–22.7	11.3–22.7	11.3–22.7	1.3–2.7	1.3–2.7
Weight	None	None	None	None	None	None
EMS	1.3–2.7	1.3–2.7	1.3–2.7	1.3–2.7	1.3–2.7	1.3–2.7

Changes to coin characteristics are defined as follows (relative to incumbent US circulating coins): diameter > 1% and thickness > 3%. EMS is more complex and requires a detailed analysis from each coin-processing equipment manufacturer to define when changes are required for their equipment.

4.5.10 Manufacturers of Commercial Coin-Handling Equipment

Discussions with representatives of manufacturers of commercial coin-handling equipment (as listed in Table 4-1), indicated that impacts to their industry would generally require mechanical system and/or EMS software/sensor upgrades to their equipment, depending upon the exact changes required to enable the handling of any new coins. All individuals from this stakeholder group interviewed for this study indicated an ability to adapt their product offerings to handle new coins. Of course necessary engineering design, development and validation efforts would have to be completed prior to releasing new products into the market place. Individuals from this stakeholder group indicated that they could be ready to handle new coins within 6 to 12 months after having sample coins in hand. Costs to conduct the development work would be recouped through higher product cost, through service calls to install the upgrades to their client hardware or through a combination of the two. As an engineering estimate, the total investment required by American-owned manufacturers of commercial coin-handling equipment to upgrade equipment to handle new coins would range from a low of approximately $500,000 (for simple EMS upgrades) to over $5M if coin sizes changed. Those manufacturers that produce passive units will, in most cases, not need to make any upgrades to their equipment if new coin sizes remained identical to incumbent US circulating coins. An exception would be the incorporation of aluminum alloys into the circulating coins. Aluminum alloy coins have been known to gall and weld together under the pressures and speeds of high-speed coin sorting/counting machines. The resulting damage potential would require some reengineering of these devices followed by installing the associated upgrades into fielded units.

Since such costs would be passed onto clients, the approach taken here to compute the conversion cost was to determine the cost associated with upgrading all known commercial coin-handling equipment resident throughout the US. Such an approach was assumed by CTC to represent the best measure of the conversion cost impact to US businesses and others who are dependent upon commercial coin-handling equipment. Detailed numerical values for this stakeholder group can be found in the section entitled "Manufacturers of Coin-Handling Equipment" in Appendix 4-C. Highlights include the following:

- Four types of equipment are common to commercial coin-handling:
    - High-speed coin sorters/counters
        - Estimated 30,000 units total in the US
        - Upgrades needed if either or both coin dimensions and/or EMS changed
    - Coin return kiosks
    - Passive sorters/counters
        - Estimated 250,000 units in the US
        - No upgrades needed unless coin dimensions are changed
    - Coin wrapping machines (which are discussed below in the section entitled "Coin and Currency Handlers/Armored-Car Operators").
- This stakeholder would require 6–12 months to prepare their equipment once samples coins are in hand.

With an estimated 30,000 high-speed active coin sorters/counters in the US, the total conversion costs to upgrade these machines across the US ranges from $1.05M to $2.55M; $1.05M was considered the most-probable conversion costs. These costs apply regardless of changes to coin dimensions, EMS and/or other characteristics and/or properties[100] typically used to validate coins in these high-speed active coin sorters/counters. These conversion costs apply to both the Fall of 2014 and the Fall of 2011 under the assumption that no change occurs in the number of units in service. The net effective conversion costs when corporate taxes of 20% are considered are between $0.84M and $2.04M with $0.84M being the most-probable conversion cost for these high-speed units. Self-serve coin return kiosks for sorting and counting coins are also included in the 30,000 unit totals mentioned above.

Added conversion costs for upgrades to accommodate processing of aluminum coins were identified by the manufacturers of high-speed coin sorters. Although the consensus was that introduction of aluminum coins would require changes to the current designs of high-speed sorters/counters, no specific cost details could be determined without an extensive engineering design review and analysis by the manufacturers of the high-speed coin sorters/counters. For purposes of this evaluation, an engineering estimate was made by CTC that changes to accommodate processing of aluminum coins would cost between $500 and $750 per machine, with a most-probable estimate of $600 per machine. Under these assumptions, the industry-wide conversion costs would be between $15M and $22.5M; $18M is the most-probable industry-wide conversion costs for aluminum coins of any one or more denomination(s).

There are an estimated 250,000 passive coin sorters/counters in the US; no change in their numbers was assumed through the Fall of 2014. Changes to coin materials or EMS (with no change in coin dimensions) would not require any equipment changes and therefore no conversion costs would be incurred for these machines. However, changes to coin dimensions would require between $25M and $125M to upgrade all passive coin sorters/counters in the US. The most-probable upgrade cost for passive coin sorter/counters with changes to coin dimensions is $62.5M. However, when the effect of corporate tax of 20% is considered, the net effective conversion costs are between $20M and $100M, with a most-probable value of $50M.

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[100] One exception occurs with aluminum-based coins. These coins have been known to cold weld together in high-speed sorters/counters. This situation can cause the machines to jam and/or cause permanent damage to the machine.

4.5.11 Vending Machine and Other Coin-Acceptor Manufacturers

The direct financial impact to the manufacturers of vending machines and other coin-acceptor manufacturers is small compared to the total upgrade costs required by the clients of these same manufacturers. Based upon interviews with a number of coin-processing equipment manufacturers, individual equipment manufacturers would require between $10,000 and $500,000 to prepare for a change over in their product line to accommodate an alternative generation of coins that would co-circulate with the incumbent circulating coins. In total for US-based coin-acceptor/sorter/counter manufacturers, the cost required to prepare for an alternative coin set is estimated by CTC to be a maximum of $10M. These costs would be passed along to the clients, in many cases through a software upload fee, service fees or through increases in product prices. These costs are accounted for in the various hardware and software conversion costs discussed in sections discussing other stakeholders.

The amount of time required for the coin-processing equipment manufacturers to get ready for release of alternative coins depends upon the types of changes that are made to the coins. If the alternative coin set differs in EMS from the incumbent coins and has identical dimensions to the incumbent coin set, then the typical manufacturer will require between six and 12 months upon receipt of alternative coin samples[101] to prepare for the alternative coin set. This would include designing and validating the new construction using pieces (either actual coins or nonsense pieces) to validate all changes to their hardware. However, if coin dimensions are changed, then several of the coin-processing equipment manufacturers have indicated that they would need up to two years to design and test new models to accept the alternative coin sets once the new coin dimensions were defined. Beyond the design and production changes, an additional 0 to 6 months would be required to field the upgrades to client units.

One of the large coin-acceptance equipment manufacturers interviewed for this outreach effort indicated that US-based acceptors made by their companies cannot correctly identify ferromagnetic-steel-based or other strongly ferromagnetic[102] materials. Introducing coins with strong ferromagnetism would require an approximate two-year development effort to design new sensors and/or to modify those that currently exist so that ferromagnetic coinage materials could be correctly identified. The total effort required to handle ferromagnetic coins could cost this American-owned company several million dollars.[103]

4.5.12 Depository Institutions

Management of coins owned by depository institutions[104] is typically contracted to armored-car operators. These depository institutions pass along the associated coin-management fees to their clients who wish to deposit or purchase coins; therefore, capturing the associated conversion

[101] Note that previous experience with changes to other country's coinage, the coin-processing equipment manufacturers are reluctant to initiate detailed product design changes until the new coins have been fixed in their dimensions, materials, material layer thicknesses and coin production processing. Alterations in these factors may require that the coin-processing equipment design team start over in their efforts to account for unintended consequences resulting from changes to any of these factors.

[102] Ferromagnetic materials are attracted to a magnet.

[103] A more precise value could only be given after a rigorous engineering pre-development analysis, which was well beyond the scope of the present study.

[104] As of June 28, 2012, the US had 7265 FDIC-insured institutions [16].

costs for depository institutions is best done by examining the impact to the armored-car operators.

Many depository institutions have in-house passive coin counting machines (for use by bank employees to count small quantities of coins [typically less than 1000 at a time]). No changes would be required for these machines (other than a potential removal of a screening magnet if steel-based coins are introduced into circulation) if alternative coins have the same dimensions (diameter and thickness) as the incumbent coins, regardless of any changes to coin weight or EMS. Should coin dimensions change, then these passive sorters would have to be modified or complimented with a new machine to accept two sets of coin dimensions. In addition, most institutions would also have to pre-sort coins into two groups of two differing dimensions. Although not likely to require any additional staff, this would increase the amount of time (by a few minutes) required to sort and count coins.

Very few (estimated by CTC to be less than 10%) depository institutions have publically accessible coin sorting/counting machines. The few machines that are available would have to be upgraded as a result of any alternative coins that differ in those characteristics used to recognize and validate coins. Costs to upgrade equipment used by depository institutions have been accounted for in the section entitled “Manufacturers of Commercial Coin-Handling Equipment” above.

On July 20, 2010, Ms. Louise L. Roseman, Director, Division of Reserve Bank Operations and Payment Systems testified to the Subcommittee on Domestic Monetary Policy and Technology, Committee on Financial Services, United States House of Representatives, Washington, D.C. In those remarks Ms. Roseman commented that “changing the metal content of pennies and nickels [i.e., one-cent and 5-cent coins], even if doing so changes the weight and electronic signature, would not have a material adverse effect on the operations of the Reserve Banks” [17]. The findings from this outreach effort are in agreement with this statement.

4.5.13 Coin and Currency Handlers/Armored-Car Operators

To understand the issues faced by this stakeholder group, several armored-car operators were interviewed and two coin terminals operated by commercial companies were visited to understand and quantify the issues that coin and currency handlers and armored-car operators would face as a result of changes to US circulating coins.

Detailed numerical values defining the impact to this stakeholder group resulting from changes to coins can be found in the section entitled “Coin and Currency Handlers/Armored-Car Operators” in Appendix 4-C. Highlights include the following:

- Armored-car carriers manage coins for large banks.
- Coins may be sorted, counted, wrapped and/or transported to/from clients by the armored-car carriers.

In general, the one-time cost to upgrade each of the high-speed coin-handling units used by this stakeholder group would be no more than $200 for EMS differences and not more than $500 for changes in coin dimensions. With an estimated four coin sorting/counting machines at each coin terminal and with a United States Mint estimated 200 Federal Reserve-contracted coin terminals in the US, the cost to the industry to upgrade machinery would be between $160,000 and

$400,000 to get ready for any coin changes. These costs are accounted for in the section above entitled “Manufacturers of Commercial Coin-Handling Equipment.”

If secondary separation is needed for all incoming coins (that is, incumbent and new coins) beyond the one-cent coin due to a difference in weight or dimensions of all coin denominations, then another full-time employee is likely to be required at each of the 200 coin terminals. This added employee would confirm the contents of 100% of the incoming containers and complete the extra handling of the co-circulating coins. These costs, which would be passed along to clients, are estimated to be $21M per year for the industry based upon changing coin weight and/or dimensions for all denominations greater than one cent. Either or both of these changes would lead to the need for approximately one additional full-time laborer at each coin terminal with an assumed fully burdened cost of $50 per hour. Smaller impacts would be expected if fewer than all coin denominations were changed in weight. No impact is expected with weight or dimensional changes to the one-cent coin, since these coins are not currently weighed by the majority of bulk-coin handlers to validate container contents. The other coin denominations would, however, require the following approximate annual increased costs[105] for handling as a result of differences between weights and/or dimensions of the incumbent and alternative coins:

- 5-cent coins: $3.75M
- Dime coins: $6.92M
- Quarter dollar coins: $9.20M
- Half dollar coins: $0.04M
- Dollar coins: $1.09M.

Some of these costs would be offset by a reduction in fuel and other handling costs if alternative coins were lighter than the legacy coins. In addition, lighter coins would allow for a larger quantity of coins to be transported prior to reaching weight limits on the delivery trucks; this could reduce the number of trips required for transporting coins. The exact value of these reduced costs is not known at this time. A more thorough assessment is required to quantify these cost savings, which are dependent upon the specific materials selected for new coins.

Changes to coins would also potentially impact the automated coin wrapping machines in common use by the coin and currency handlers/armored-car operators. If alternative circulating coins have identical dimensions to the incumbent circulating coins, then no changes would be required to the machines that automatically wrap coins. However, if coin dimensions changed by more than about 1% in either diameter or edge thickness, then modifications to the standard operating procedures and/or equipment used by the coin-wrapping stakeholders would have to be made. The infrastructure that is currently in place for wrapping coins would still support handling of coins of different dimensions; however, coins of like dimensions would have to be segregated and wrapped separately. Standard-dimensioned coin-transfer trays may no longer be wide enough to accommodate wrapped coins of today’s standard quantities if the stack height increased by more than approximately 5%. Upgrade costs forced by a change to coin dimensions for the estimated 5000 coin wrapping machines owned by coin and currency handlers/armored-car operators would require conversion costs of between $250,000 and $1.25M based upon an

[105] These individual denominations values were computed by first determining the percentage of each of these coins that enters a “typical” coin terminal. That percentage was then multiplied by the earlier total cost resulting from an expected one additional full-time employee if all coins (beyond the one-cent coin) were simultaneously changed in weight and/or dimensions.

assumed upgrade cost of between $50 and $250 per machine. With a most-probable cost estimate of $100 per machine to upgrade, the most-probable conversion costs would be $500,000 for the coin-wrapping element of the coin and currency handlers/armored-car operator stakeholder group. No changes in the numbers of these machines are assumed projecting forward to the Fall of 2014. Corporate tax of 20% would reduce the net effective conversion costs to between $200,000 and $1.0M, with the most-probable conversion costs being $400,000.

The Federal Reserve Cash Product Office (CPO) was contacted on several occasions. They pointed out that because the coin terminals act on behalf of the Federal Reserve Banks in handling mutual customer coin orders and deposits to/from the Federal Reserve, they are required to enforce the rules as defined in both the Federal Reserve Banks Cash Services Manual of Procedures [18] and Federal Reserve Banks Operating Circular Number 2 [19]. However, not all coin facilities operated by armored-car carriers are coin terminals. The CPO also indicated that if the weight of US coins was to be changed, initial weight verification could no longer be relied upon as the initial verification of coin deposits, and other solutions would need to be explored, such as handling and storage of wrapped coins rather than the current method of handling and storage, which is loose coins contained in bags of a given dollar amount for each coin denomination.

4.5.14 Blind and Visually-Impaired

As part of the outreach efforts and to understand issues associated with the 3.4M US citizens who are legally blind or visually-impaired [20], the National Federation of the Blind (NFB) was consulted on issues associated with the use of coins. The comments that were received were generally positive concerning the ability of the blind and visually-impaired to recognize and distinguish among the incumbent circulating coins minted in the US. While generally able to quickly distinguish coins by their current tactile features when a mixture of coin denominations is present, when handled in isolation from other coins, some difficulty still remains in distinguishing between some US coin denominations:

- The one-cent and 5-cent coins
- The quarter dollar and Susan B. Anthony dollar coins.

Both the one-cent and 5-cent coins have smooth edges; aside from dimensions, no other significant distinguishing tactile features are available to facilitate the identity of these coins to blind or visually-impaired individuals.

The similarity between the quarter dollar and the Susan B. Anthony dollar coin has been well documented [21]. Both have reeds along their edges and are of similar dimensions and color. The currently minted dollar coins have edge lettering, which is not widely distinguishable to the blind or visually impaired. The otherwise smooth edge is helpful in distinguishing today’s dollar coin from the quarter dollar coin. However, when asked to identify a quarter dollar coin whose reeds were worn off, neither of the two NFB individuals (both either blind or visually-impaired) who were interviewed in person for this outreach effort were able to confidently identify the coin’s denomination.

Given the difficulty tactilely distinguishing between the one-cent and 5-cent coins and between the quarter dollar (with worn reeds) and dollar coins, changes to the dimensions of circulating coins may be problematic for the blind and visually impaired without additional tactile features being included. Introducing new coins of differing dimensions than those of incumbent coins would likely increase the difficulty of discriminating through tactile means alone among what would then be a larger pool of circulating coins. Material changes in the construction of coins would generally not impact the visually impaired. However, changes that would result in large differences to the weight of coins, such as minting an aluminum coin, would be useful to the blind and visually-impaired in identifying the various coins in circulation.

The discussions with the NFB did not reveal any requirements for new investments to be made as a result of changes to US circulating coins. Therefore, no conversion costs were attributed to the blind and visually-impaired as a result of changes to US circulating coins as contemplated and discussed in the present study.

4.5.15 Public

While the population size of individuals that engage in hand-to-hand transactions of coins is greater in number than all other stakeholders, it was generally agreed by the project team (and informally by many of the individuals that were interviewed for the outreach efforts) that these individuals (which include nearly all US citizens over the age of about 10 years) would be able to quickly adapt to visual and tactile elements of any new coins and correctly identify the denomination of these coins. Therefore, no conversion costs were computed for the general public as it relates to the introduction of alternative US circulating coins.

Based upon comments received from a notice and opportunity for public comment that was posted by the United States Mint in the Federal Register [2], the public differs widely in their opinion about introducing alternative coins into circulation.

The cost to produce the one-cent and 5-cent coins has been well documented and discussed in the public media [22, 23]. However, many US citizens remain skeptical about an implication that lower-cost coins reflect runaway inflation or that such coins represent some attempt by the United States Government to devalue our country's assets. This thought was expressed in a report prepared by the Department of the Treasury in April 1980. "It is probable that the light weight of aluminum would be a negative factor in public acceptance. The light weight and less expensive material will be perceived by the public as further confirmation of the declining value of the Nation's coinage" [24]. Some citizens would welcome changes in, while others may react negatively to changes in the color of US coinage. Hoarding of legacy coins would likely increase upon public announcements declaring that changes to US coins are planned. To gain a more comprehensive awareness of and to obtain focused information about public opinion related to changes to US circulating coins, separate and focused public opinion polls are recommended to complement the findings of the present study. New Zealand was successful in gathering such data on public opinions prior to introducing their new coin set in mid-2006 [25, 26].

More specific replies received from the United States Mint's public call for comments [2] are discussed here. Responses were collected by the United States Mint. In total, 224 responses were shared with CTC. Sources of the feedback included private citizens, material suppliers, coin-processing equipment manufacturers and distributors, and associations that represent selected stakeholders. Of those expressing an opinion about the acceptability of changing the metallic composition of US circulating coins, 59 responses were in favor of making a change, while only 24 responses indicated that they do not support any change in US circulating coinage materials of construction. Comments that expressed individual desires for coin characteristics and/or properties, as they relate to the focus of the current study, included:

- Tarnish and corrosion resistance
- Pleasant and unique color with good visual appearance and lasting shine
- Aesthetically rich and sharp details
- Made of familiar metals with raw material supply stability and intrinsic metallic value
- Low-cost alternatives to save taxpayer money
- Have a distinctive ringing sound
- Be nontoxic with no leaching of constituent materials, be antifungal and have no sharp edges
- Not easily bent, be nick resistant, have high hardness and suitable density
- Does not cause excessive wear on coin-processing equipment
- Have reliable EMS properties that differ from commonly available materials
- Be easily recycled
- Be durable and portable
- Be resistant to counterfeiting
- Be compatible with existing manufacturing processes.

Suggested materials included:

- Nickel-plated zinc for the 5-cent coin
- Steel including copper-nickel-plated steel, stainless steel and Multi-Ply-plated steel
- Silver or gold
- Aluminum one-cent coin, aluminum-clad bronze, aluminum-bronze and copper-plated aluminum one-cent coin
- Nickel composite
- 90% rhodium/10% copper for a 20-dollar coin
- 90% palladium/10% copper dollar coin
- Bi-metallic coins
- 10% silver/90% cupronickel
- Titanium, magnesium, manganese, zinc and/or tin.

Other thoughts that were offered included:

- Mint a two-cent coin instead of one-cent coins
- Eliminate the one-cent coin
- Eliminate the 5-cent coin
- Eliminate the use of manganese in coinage
- Eliminate the one-dollar note in favor of a one-dollar coin (complement with a two-dollar note)
- Eliminate zinc (which was claimed to pose a danger to pets)
- Do not use aluminum
- Eliminate the half dollar coin
- Change all coins at the same time
- Mint even higher-denomination coins (five-dollar, ten-dollar and up through one-thousand-dollar coins)

- Put a hole in the coins (to reduce metal usage)
- Mint more half dollar coins
- Eliminate clad coins
- Drastically reduce the production of one-cent and 5-cent coins to coax hoarders to release their supply
- Shape coins (other than circular) to allow for quicker determination of their denomination
- Reduce coin dimensions
- Use round coins without ridges or knurls having even thickness all around and lays flat and is of heavy metal (not aluminum or plastic)
- Reduce the number of artistic designs used on coins
- Make all coins of a single metal.

Of note is the general opposition of the National Automatic Merchandising Association (NAMA) to circulating coins that are steel or plated steel in design [15]. NAMA cited the need for extensive upgrades to the coin acceptors for their members if steel-based circulating coins are introduced in the US. In addition, NAMA raised concern about potential problems with misvalidation of steel-based coins and difficulty in distinguishing such coins from the increasing number and availability of steel-based coins that are circulating throughout the world. NAMA recommended against the use of steel-based coins in high-denomination coins.

4.6 SUMMARY OF IMPACT TO STAKEHOLDERS FOR EACH METALLIC COMPOSITION-DENOMINATION CONSIDERED

The discussion above highlights the most significant impacts to all stakeholders considered in the present study. Changes to the US circulating coin set and any of several coin characteristics and/or properties used to process coins were considered. The major factors impacting coin stakeholders are visual and tactile recognition and automated methods to recognize, validate and otherwise process coins.

The composition and fundamental methods of manufacturing the 5-cent, dime, quarter dollar and half dollar coins have not changed since at least 1965. During that time many sophisticated automated coin-processing devices have been successfully developed and marketed. While the majority of modern coin-processing devices rely upon active sensor technology that can be easily reprogrammed to accept new coins, many other such older or passive devices, which mechanically validate a coin, rely upon physical properties and specific characteristics of US circulating coins that could change with alternative materials of construction.

Therefore, careful planning must be exercised in selecting alternative materials of construction when defining compositions of an alternative generation of US circulating coins, if in fact such a change is to be made. Given that inflation will inevitably overcome whatever attempts are made to keep coin manufacturing costs below the assigned face value of the coinage, changes will eventually be required to coins (and/or to their assigned face value) so that they can be minted and continue supporting commerce without creating an undue burden to taxpayers.

Tables 4-10 and 4-11 summarize the impacts discussed throughout this chapter and summarize the cost impact resulting from each of the materials/denominations that have been considered for the present alternative metals study. An indication of the relative impact to various stakeholders is presented for two different scenarios:

- Material change while maintaining the dimensions of incumbent circulating coins (Table 4-10)
- Coin dimensions change and accompany the material change (Table 4-11).

Three total conversion cost values are given in these tables:

- Low
- Most probable (Est)
- High.

These values bracket the expected conversion costs to the US stakeholders that are dependent upon coinage for commerce. The range of values accounts for sensitivities of the many factors that impact the stakeholders as discussed above in those sections that relate to each of the stakeholder groups identified in Tables 4-10 and 4-11.

In all cases, the assumed date of introducing alternative US coins into circulation is the Fall of 2014; this is also the date that all equipment upgrades or replacements were assumed to occur for all stakeholders. Introducing coins at a later date would generally result in a small reduction in the magnitude of the conversion costs as older automated units are replaced with units built around modern technology that allows for easier and less-expensive upgrades.

Commercially available equipment throughout the US from one of the major American-owned active coin-validation equipment manufacturers relies upon coin validation technology that is unable to read ferromagnetic-steel-based coins with all sensors (see the section below entitled "Validation of Nonsense Pieces"). This manufacturer indicated that using ferromagnetic-steel-based coins would require a complete replacement of all their currently fielded vending machine units (and selected others) throughout the US. The associated costs are reflected in Table 4-10 where one of every three coin validators for the vending industry was assumed to be replaced if ferromagnetic-steel-based coins (5-cent, dime and/or quarter dollar) are introduced into circulation.

One of the major manufacturers of active-coin validators for vending machines and other stakeholder equipment was able to distinguish between incumbent 5-cent coins and both 669z and G6 mod 5-cent nonsense pieces[106] (see the section below entitled "Validation of Nonsense Pieces"). Given the acceptance windows typically used for the US-based validators from this manufacturer, the majority of the US-based units would reject 669z and G6 mod 5-cent nonsense pieces. Although alloy and/or material processing changes could be completed to alter these alloys so that a later generation of nonsense pieces from these modified alloys would be indistinguishable from incumbent 5-cent coins, an assumption was made in this analysis that 5-cent coins made from either 669z or G6 mod alloys would require that all active vending machine validators from this manufacturer would require upgrading or replacement. Approximately one third of the US-based vending machine active coin validators would require this upgrade if 669z or G6 mod (in their current chemistry and processing conditions) were selected for the 5-cent coin.

[106] These two copper-based alloys were considered by some to be nearly seamless; if their compositions and/or processing routes were slightly altered, they may be found to be a seamless alloy option.

Table 4-10. Impact to Stakeholders: Maintain Incumbent Coin Dimensions and Change Material Composition of US Coins

Material	Denomination	Vending Machine Owners and Operators	Laundromat Owners and Operators	Pay Phone Owners and Operators	Municipal Parking Officials	Amusement Machine Owners and Operators	Gaming Machine Owners and Operators	Transit Officials	Car Wash Owners and Operators	Merchants	Manufacturers of Commercial Coin-Handling Equipment	Vending Machine and Other Coin-Acceptor Manufacturers	Depository Institutions	Coin and Currency Handlers/ Armored-Car Operators	Blind and Visually-Impaired	Public	Estimated Total Cost Impact in Fall 2014 Accounting for Net Effective Conversion Cost Associated with a 20% Corporate Tax ($M)		
																	Low	Est**	High
5052-H32 Aluminum	One-cent	■	■	■	●	▲	▲	■	▲	●	■	■	●	■	▲	■	52.3	55.2	59.3
CPS – Jarden		▲	▲	▲	▲	▲	▲	●	▲	▲	●	●	●	■	▲	▲	3.3	5.2	6.9
CPS – RM		▲	▲	▲	▲	▲	▲	●	▲	▲	●	●	●	■	▲	▲	3.3	5.2	6.9
302HQ SS		▲	▲	▲	▲	▲	▲	●	▲	▲	●	●	●	■	▲	▲	3.3	5.2	6.9
Surface-Modified Zinc		▲	▲	▲	▲	▲	▲	●	▲	▲	●	●	●	■	▲	●	3.3	5.2	6.9
NPS – RM	5-cent	■	▲	▲	●	▲	▲	●	▲	▲	●	■	●	■	▲	▲	444.9	531.5	915.8
Unplated 31157 (‡)		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	■	▲	●	8.8	11.3	13.7
MPS – RCM		■	▲	▲	●	▲	▲	●	▲	▲	●	■	●	■	▲	▲	444.9	531.5	915.8
Dura-White-Plated Zinc		■	▲	▲	●	▲	▲	■	▲	▲	●	●	●	■	▲	▲	247.6	277.4	619.3
669z		●	▲	▲	▲	▲	▲	▲	▲	▲	●	●	●	■	▲	▲	46.2	56.4	71.0
G6 Mod		●	▲	▲	▲	▲	▲	▲	▲	▲	●	●	●	■	▲	▲	46.2	56.4	71.0
302HQ SS		■	▲	▲	●	▲	▲	■	▲	▲	●	■	●	■	▲	▲	247.6	277.4	619.3
Surface-Modified Zinc		■	▲	▲	●	▲	▲	■	▲	▲	●	●	●	■	▲	●	247.6	277.4	619.3
302HQ Stainless Steel	10-cent	■	▲	▲	●	▲	▲	■	▲	▲	●	■	●	■	▲	▲	247.6	277.4	619.3
NPS – RM	25-cent	■	●	▲	●	●	■	■	■	▲	●	■	●	■	▲	▲	517.8	632.5	1042.8
MPS – RCM		■	●	▲	●	●	■	■	■	▲	●	■	●	■	▲	▲	517.8	632.5	1042.8
302HQ SS		■	●	▲	●	●	■	■	■	▲	●	■	●	■	▲	▲	318.3	375.6	743.1
669z-Clad C110 (‡) (†)		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	0.0	0.0	0.0
Dura-White 5Sn/12.4Cu*		■	●	▲	●	●	■	■	■	▲	●	■	●	■	▲	▲	318.3	375.6	743.1
Dura-White 7.7Sn/12.7Cu*		■	●	▲	●	●	■	■	■	▲	●	■	●	■	▲	▲	318.3	375.6	743.1
Dura-White 10.2Sn/11.2Cu*		■	●	▲	●	●	■	■	■	▲	●	■	●	■	▲	▲	318.3	375.6	743.1

Key: Level of Impact – ■: Significant; ●: Marginal; ▲: Minimal
M = million; CPS = copper-plated steel; RM = Royal Mint; SS = stainless steel; NPS = nickel-plated steel; MPS = Multi-Ply-plated steel; RCM = Royal Canadian Mint; Sn = tin; Cu = copper

* Dura-White-Plated Zinc

** Est = most probable; † = apparent seamless option; additional verification advised; ‡ = apparent EMS match with existing circulating coin; additional verification advised

Table 4-11. Impact to Stakeholders: Change Both Coin Dimensions and Material Composition of US Coins

Material	Denomination	Vending Machine Owners and Operators	Laundromat Owners and Operators	Pay Phone Owners and Operators	Municipal Parking Officials	Amusement Machine Owners and Operators	Gaming Machine Owners and Operators	Transit Officials	Car Wash Owners and Operators	Merchants	Manufacturers of Commercial Coin-Handling Equipment	Vending Machine and Other Coin-Acceptor Manufacturers	Depository Institutions	Coin and Currency Handlers/ Armored-Car Operators	Blind and Visually-Impaired	Public	Estimated Total Cost Impact in Fall 2014 Accounting for Net Effective Conversion Cost Associated with a 20% Corporate Tax ($M)		
																	Low	Est**	High
5052-H32 Aluminum	One-cent	■	■	■	●	▲	▲	■	▲	●	■	■	●	■	■	■	82.5	120.6	180.3
CPS – Jarden		▲	▲	▲	▲	▲	▲	■	▲	●	■	▲	●	■	■	●	33.5	70.6	127.9
CPS – RM		▲	▲	▲	▲	▲	▲	■	▲	●	■	▲	●	■	■	●	33.5	70.6	127.9
302HQ SS		▲	▲	▲	▲	▲	▲	■	▲	●	■	▲	●	■	■	●	33.5	70.6	127.9
Surface-Modified Zinc		▲	▲	▲	▲	▲	▲	■	▲	●	■	▲	●	■	■	■	33.5	70.6	127.9
NPS – RM	5-cent	■	▲	■	■	▲	▲	■	▲	●	■	■	●	■	●	●	826.0	1048.5	1590.6
Unplated 31157		■	▲	■	■	▲	▲	■	▲	●	■	■	●	■	●	●	826.0	1048.5	1590.6
MPS – RCM		■	▲	■	■	▲	▲	■	▲	●	■	■	●	■	●	●	826.0	1048.5	1590.6
Dura-White-Plated Zinc		■	▲	■	■	▲	▲	■	▲	●	■	■	●	■	●	●	826.0	1048.5	1590.6
669z		■	▲	■	■	▲	▲	■	▲	●	■	■	●	■	●	●	826.0	1048.5	1590.6
G6 Mod		■	▲	■	■	▲	▲	■	▲	●	■	■	●	■	●	●	826.0	1048.5	1590.6
302HQ SS		■	▲	■	■	▲	▲	■	▲	●	■	■	●	■	●	●	826.0	1048.5	1590.6
Surface-Modified Zinc		■	▲	■	■	▲	▲	■	▲	●	■	■	●	■	●	●	826.0	1048.5	1590.6
302HQ Stainless Steel	10-cent	■	▲	■	■	▲	▲	■	▲	●	■	■	■	■	●	●	826.0	1048.5	1590.6
NPS – RM	25-cent	■	■	■	■	■	■	■	■	●	■	■	■	■	●	●	1078.6	1445.1	2090.1
MPS – RCM		■	■	■	■	■	■	■	■	●	■	■	■	■	●	●	1078.6	1445.1	2090.1
302HQ Stainless Steel		■	■	■	■	■	■	■	■	●	■	■	■	■	●	●	1078.6	1445.1	2090.1
669z-Clad C110		■	■	■	■	■	■	■	■	●	■	■	■	■	●	●	1078.6	1445.1	2090.1
Dura-White 5Sn/12.4Cu*		■	■	■	■	■	■	■	■	●	■	■	■	■	●	●	1078.6	1445.1	2090.1
Dura-White 7.7Sn/12.7Cu*		■	■	■	■	■	■	■	■	●	■	■	■	■	●	●	1078.6	1445.1	2090.1
Dura-White 10.2Sn/11.2Cu*		■	■	■	■	■	■	■	■	●	■	■	■	■	●	●	1078.6	1445.1	2090.1

Key: Level of Impact – ■: Significant; ●: Marginal; ▲: Minimal
M = million; CPS = copper-plated steel; RM = Royal Mint; SS = stainless steel; NPS = nickel-plated steel; MPS = Multi-Ply-plated steel; RCM = Royal Canadian Mint; Sn = tin; Cu = copper

* Dura-White-Plated Zinc

** Est = most probable

4.7 OTHER FACTORS THAT COULD ALTER THE CONVERSION COSTS TO STAKEHOLDERS

The impact of changes to circulating coins to all stakeholder groups discussed above was based on several assumptions including the following.

- 100% of impacted coin-processing equipment will be upgraded.
- Equipment upgrades will be a focused activity rather than one completed when other opportunities (such as routine maintenance) present themselves.

Given coin-acceptance equipment manufacturers' experience related to the multi-year lag that vending and other equipment owners and operators had with upgrading their machines to accept the recently released and redesigned US $5 note from the Bureau of Engraving and Printing (BEP), a percentage of the current owners and operators will either refuse to upgrade their equipment to accept coins of new metallic construction or they will take advantage of other maintenance needs to complete equipment upgrades. These operating strategies would significantly reduce the conversion cost estimates defined above. However, it is difficult to predetermine the size of this impact. This thought is echoed by a report from HM Treasury when discussing the impact of recent changes to the materials of construction for the United Kingdom's 5-pence and 10-pence coins [4]. This reference expects that a significant number of machine owners will wait for up to 18 months or more to upgrade their equipment. Given that on average each year one-third of coin validators within the vending industry receives attention from a service technician, it is conceivable, that as many as 66% of the US coin acceptors could be upgraded without the attendant cost of a separate service fee.

4.8 VALIDATION OF NONSENSE PIECES

A fundamental element in the approach to defining alternative coinage materials centers around two competing financial aspects of the decision: selecting materials and manufacturing processes that either:

- Reduce costs to the United States Mint
- Minimize the impact (including conversion costs) to stakeholders, who are dependent upon coins to conduct commerce.

Striking the most favorable balance between these foci must be defined before final material selections can be made. In the present study, alternative material candidates were selected that represent one or the other of these foci. No metallic materials were found that can simultaneously accomplish both of these foci.

Coins that would seamlessly (or nearly seamless) circulate with incumbent coins would satisfy a focus on minimizing the impact to stakeholders. Other non-financially based factors must also be included when considering alternative material candidates for circulating coins, including an evaluation of the uniqueness of the characteristics and/or properties of alternative material candidates relative to other coins and common slugs available throughout the world.

To that end, nonsense pieces were tested to evaluate the consistency of their characteristics and properties with incumbent US circulating coins as determined by measuring the response of these nonsense pieces in existing automated coin-processing equipment. These drop tests were designed to provide confirmation of the intended characteristics and properties of proposed alternative material candidates. To validate the performance of each alternative material candidate, CTC procured samples (either in planchet, blank or strip form), produced blanks (as needed) and worked with the United States Mint to produce test pieces using nonsense dies.

Two sets of tests were completed. Nonsense pieces of alternative material candidates were struck at the United States Mint during an initial striking trial. Samples of these nonsense pieces were tested by SCAN COIN. This information was useful in eliminating some of the early alternative material candidates. After further development on selected alternative material candidates, a second striking trial was completed at the United States Mint in Philadelphia. The resulting nonsense pieces were then tested by three coin processing manufacturers: SCAN COIN, MEI and Coinco.[107] Each of these manufacturers relies upon different proprietary coin recognition technology and strategies. Therefore, limiting this initial evaluation to these manufacturers was expected to provide broad **initial** feedback on the suitability of the alternative material nonsense pieces to meet the objectives of Public Law 111-302.

4.8.1 Round One Testing

Round One alternative material nonsense pieces (one-cent, 5-cent and quarter dollar) were struck at the United States Mint in Philadelphia on December 13–15, 2011. Samples of these nonsense pieces, along with randomly selected circulated coins, were tested in a SCAN COIN SC4000 machine. Testing was completed on December 19, 2011. The EMS and coin dimensions were evaluated for each of the 15 alternative material nonsense piece designs. Except for one of the aluminized steel one-cent coin alternative material nonsense pieces (which had 10 total specimens), each alternative material-denomination combination included 40 specimens. The circulated coin lots included 100 coins for each denomination tested. These confirmation tests were led by SCAN COIN, Ashburn, Virginia and were supervised by CTC. The nonsense pieces were kept at room temperature (approximately 21 °C [70 °F]) for over one hour before the start of testing. Each set of nonsense pieces was passed through the SC4000 machine once and then each set of nonsense pieces was passed through the machine a second time in the same sequence as that used in the first pass through the machine. Each pass through the coin sorter/counter for any given set of nonsense pieces (or circulating coins) took approximately 30 seconds.

The following measurements were made for each nonsense piece and circulated coin:

- Diameter
- Thickness (an average of several readings)
- Inner electrical conductivity at low frequency
- Inner electrical conductivity at high frequency
- Inner magnetic permeability
- Outer electrical conductivity at low frequency
- Outer electrical conductivity at high frequency
- Outer magnetic permeability.

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[107] SCAN COIN, which has an American-based sales office, manufacturers high-speed coin sorting and counting equipment. MEI and Coinco, which are American owned, manufacture coin acceptors for vending machines and other devices. The project team recognizes that other coin-processing equipment manufacturers are resident in the US; CTC recommends that the United States Mint include comments from and have future alternative material nonsense pieces evaluated by additional automated coin-acceptance and coin-handling equipment manufacturers if the project is extended to include additional production development phases.

The nonsense pieces tested in the Round One confirmation tests included the following:

- One-cent nonsense pieces
  - Copper-plated steel
  - Aluminum alloy 5052-H32
  - Aluminized steel from Atlas
  - Aluminized steel from Ryerson
- 5-cent nonsense pieces
  - Dura-White-plated zinc (tin-plated zinc)
  - Multi-Ply-plated steel – lot# 11-137 (copper/nickel-plated steel)
  - Multi-Ply-plated steel – lot# 11-170 (copper/nickel-plated steel)
  - G6 mod (copper-based alloy)
  - 669z (copper-based alloy)
  - 430 stainless steel
  - 302HQ stainless steel
  - 302 stainless steel with altered annealing heat treatment
  - Nickel-plated 31157 (copper-based alloy)
- Quarter dollar nonsense pieces
  - Multi-Ply-plated steel
  - 669z-clad C110 (copper-based alloy clad on commercially pure copper alloy C110).

The electrical conductivity and magnetic permeability measurements are ratios of the measured value to a reference value used by SCAN COIN. Given the electronic sensors used by SCAN COIN, all individual parameters represent values that give relative magnitudes of local property rather than actual measured property values. For any given coin/nonsense piece, however, these reading are relatively as consistent as are the actual material properties and material distribution within each coin/nonsense piece. The resulting values for the US circulating coins were found to be consistent with readings that SCAN COIN has observed previously for US circulating coins. This was an indication that the SC4000 used for these tests was properly calibrated.

Some EMS properties for the 430 stainless steel 5-cent nonsense pieces were beyond the acceptable limits set at the factory for the SC4000 machine used for these tests. As a result, the machine would not permit these nonsense pieces to pass completely through the machine to obtain the above-mentioned properties. Should 430 stainless steel nonsense pieces be of interest for future tests, these software-defined property limits could be modified to allow 430 stainless steel nonsense pieces to be evaluated with an SC4000.

None of the one-cent nonsense pieces from Round One tests were found to have a similar electromagnetic signature to either pre-1982 or post-1982 one-cent US circulating coins. Three of the 5-cent nonsense pieces (G6 mod, 669z and 31157 [either unplated or nickel-plated]) were found to be indistinguishable from the incumbent cupronickel US 5-cent coins. Likewise, the 669z-clad C110 quarter dollar nonsense pieces closely matched the electromagnetic signature of the incumbent cupronickel-clad C110 US quarter dollar coin. All other alternative material nonsense pieces that were tested had a significantly different EMS than that of the corresponding incumbent US circulating coins.

4.8.2 Round Two Testing

A second round of coins was struck at the United States Mint in late March 2012. These nonsense pieces were tested by three manufacturers: two coin-acceptor and one coin-handling equipment manufacturers. Although each of the manufacturers measures coin dimensions and EMS, the specific technology to do so differs from one to another: the most significant difference being the EMS frequencies used to identify the metallic composition of the coins. These differences in sensor design (and in the software used to interpret the output signals) result in varying degrees of sensitivity to detect slight differences in material composition. To maintain anonymity among the three manufacturers, summary observations are provided without reference to specific manufacturers. Furthermore, each manufacturer indicated that details defined within their individual reports are proprietary. Since all three manufacturers have fielded units throughout the world, they necessarily must be able to tune each unit to accept alternative coins as they are introduced into circulation throughout the world. Consequently, each manufacturer used its own unique, preexisting product standard test methods to evaluate the alternative material nonsense pieces. Each manufacturer requested some details on the alternative material candidates being tested; to avoid inappropriately disclosing proprietary information on the composition or suppliers of these materials, the descriptions provided by CTC to these manufacturers were kept simple (such as [but not limited to] “aluminum alloy,” “plated steel,” “stainless steel,” “copper alloy,” “plated zinc” or “plated copper,” as appropriate).

In addition to the alternative material nonsense pieces, newly minted 2012 circulating coins, nonsense pieces made from the same materials as those used for circulating coins and randomly selected circulated coins of various mint dates were tested for each of the coin denominations evaluated. The circulated coins, which were randomly selected from coins in public use, were used to form a baseline from which the nonsense pieces could be compared. Nonsense pieces made from the same material as circulating coins, but with the nonsense image,[108] were compared to the newly minted 2012 coins to determine if any detectable difference could be determined between the coins/nonsense pieces struck with the two different images.

Since all three coin-processing manufacturers found no detectable difference among the newly minted 2012 coins, nonsense pieces struck on incumbent material and randomly selected circulated coins, CTC was confident that any detectable differences between the alternative material nonsense pieces and the circulated coins could be attributed to material differences and not the differences in the struck image between the nonsense pieces and circulating coins. Note that all nonsense pieces made from alternative material candidates were struck with nonsense dies.

The nonsense pieces tested for Round Two verification tests included the following:

- One-cent coins
  - Newly minted 2012
  - Circulated pre-1982
  - Circulated post-1982

[108] These nonsense pieces had scrambled lettering throughout, an image of Martha Washington on the obverse and another image on the reverse. The United States Mint has used similar images for previous experimental evaluations. These images were designed to have features that mimic those of circulating coins to test the striking characteristics of the proposed alternative material candidates.

        - Incumbent material with nonsense dies
        - Aluminum alloy 5052-H32
        - Copper-plated steel from JPZ
        - Copper-plated steel from RM
        - 302HQ stainless steel
- 5-cent coins
    - Newly minted 2012
    - Circulated
    - Incumbent material with nonsense dies
    - Nickel-plated steel
    - Unplated 31157
    - Multi-Ply-plated steel
    - Dura-White-plated zinc
    - 669z
    - G6 mod
    - 302HQ stainless steel
- Quarter dollar coins
    - Newly minted 2012
    - Circulated
    - Incumbent material with nonsense dies
    - Nickel-plated steel
    - Multi-Ply-plated steel
    - 669z-clad C110
    - Dura-White-plated zinc
        - 5-micron plating
        - 8-micron plating
        - 10-micron plating.

4.8.2.1 One-Cent Nonsense Pieces

All three coin-processing equipment manufacturers drew similar conclusions about the one-cent coin alternative material candidates. Because of the differences in material construction, the pre-1982 one-cent coins have a different signature than that of the post-1982 one-cent coins. This situation is typically accommodated in active coin-processing software by allowing for two separate entries into the coin-property database; any coin that meets either of the two sets of characteristics and properties in these databases is accepted as a one-cent coin.

Both the newly minted 2012 one-cent coins and the one-cent nonsense pieces of the incumbent post-1982 one-cent coin material provided signatures that were indistinguishable from the post-1982 circulated one-cent coins. In other words, those three sets of coins would validate as a one-cent coin in all coin acceptors/sorters/counters used in the present evaluation.

All other one-cent nonsense pieces that were tested had signatures that differed from either of the two US one-cent circulating coins (i.e., pre-1982 one-cent coins, which were made of a mono-layer of a copper alloy and post-1982 one-cent coins made of copper-plated zinc). The two copper-plated steel nonsense pieces had similar signatures to each other; however, a detailed assessment of the signals showed that these two nonsense pieces could be distinguished from each other by some, but not all, coin-handling equipment. The copper-plated steel nonsense pieces had similar characteristics and/or properties to the greatest number of foreign coins or common slugs available throughout the world. The stainless steel nonsense pieces had the smallest range of values for each of the measurements used to validate the one-cent nonsense pieces.[109] In addition, the stainless steel one-cent nonsense pieces had the fewest number of coins with similar characteristics to other known coins throughout the world. However, stainless steel is a commonly available material and can be easily frauded in automated coin-processing equipment through use of simple stainless steel disks. Furthermore, the color and size of one-cent stainless steel coins may result in confusion with the incumbent US dime coin.

As a low-denomination coin, security is not a major concern for the US one-cent coin. Therefore, other factors should take precedence over fraud for this coin according to the three coin-processing equipment manufacturers. Placing lower emphasis on coin security for this low-denomination coin is also consistent with coin design strategies outlined in The WVA Coin Design Handbook [5]; it is also consistent with a previously stated position of the United States Mint [24].

Plated-steel coins were therefore the recommended material of choice by two of the coin-processing equipment manufacturers. The third manufacturer, however, noted that ferromagnetic-steel-based (plated or otherwise) coins could not be recognized by their US-based sensors. Ferromagnetic-steel-based coins would create a significant validation and security issue for this manufacturer. Therefore, they were not in favor of moving to any ferromagnetic-steel-based materials for any coin denomination.

The aluminum alloy 5052-H32 nonsense pieces caused operational problems for the two coin-acceptance manufacturers. While only a few aluminum one-cent nonsense pieces jammed one of the coin acceptors tested by one of the manufacturers, these aluminum nonsense pieces consistently jammed the other manufacturer's devices. Although no particular difficulties were reported during testing of the aluminum one-cent nonsense pieces in the coin-handling manufacturer's tests, all three manufacturers warned against the use of aluminum in coinage. Specific problems beyond jamming of the mechanisms included concerns about the larger variability in electromagnetic properties of aluminum (relative to more traditional coinage materials including cupronickel) and a common problem of aluminum coins galling and cold welding in high-speed sorters/counters. As reported by these manufacturers (and consistent with comments made by several stakeholders during one-on-one interviews), when coins cold weld, they often cause permanent damage to coin-processing machines. Although cold welding is unlikely to occur in coin validators (since the coins do not rub across each other at high speeds and forces) and even though one-cent coins are rarely accepted by coin validators, insertion of one-cent coins is still attempted (and the coins promptly rejected and returned to the customer) for payment by unwitting customers. Due to its low density and low resulting inertia, an aluminum coin put into a coin acceptor could stall in the coin chute and if followed by other aluminum coins, could jam the machine beyond the ability of the coin return mechanism to flush the obstruction from the system [27]. This would temporarily disable the machine until maintenance was performed. According to one industry expert, the mean time between placing a maintenance call and the machine receiving the needed maintenance is four days. The machine is essentially disabled during this time. Furthermore, the owner of the machine must pay for a

[109] Small ranges are desired for validation parameters to increase fraud prevention in circulating coins.

maintenance call, which averages $75 per visit. Hence, the automated coin-acceptance and coin-handling communities strongly recommend against minting aluminum circulating coins (one-cent coins or otherwise).

4.8.2.2 5-Cent Nonsense Pieces

As with the one-cent nonsense pieces, newly minted 5-cent coins and nonsense pieces struck from incumbent 5-cent coin material were compared with a random sample of circulated 5-cent coins. All three of these coins/nonsense pieces were found to be indistinguishable from each other. Therefore, CTC concluded that any differences between the alternative material nonsense pieces and circulating coins, which form the baseline for the comparison, can be attributed solely to the materials of construction and the processing methods used to produce these nonsense pieces.

For two of the three coin-processing equipment manufacturers, unplated 31157, 669z and G6 mod monolithic nonsense pieces were indistinguishable from incumbent 5-cent coins. The third manufacturer found unplated 31157 to be indistinguishable from incumbent 5-cent coins; 669z had a low acceptance rate (meaning that it had similar, but not acceptably consistent characteristics and properties to the incumbent 5-cent coin); G6 mod was consistently distinguishable from and outside the acceptance windows defined for incumbent 5-cent coins for this third manufacturer. All three coin-processing equipment manufacturers noted that all other nonsense pieces had characteristics and/or properties that allowed ready discernment from incumbent 5-cent coins.

The two plated-steel nonsense pieces had unique signatures and could be easily distinguished from each other by two of the three manufacturers. However, for the third manufacturer, plated-ferromagnetic-steel-based coins would not register with their coin-acceptance sensors. Ferromagnetic-steel-based coins would require both hardware and software upgrades for fielded coin acceptors produced by this manufacturer. In general, the range in the signatures of the plated-steel nonsense pieces were wider than other nonsense pieces, meaning that these plated-steel coins would require wider acceptance windows[110] and would therefore be more susceptible to fraud.

The Dura-White-plated zinc 5-cent nonsense pieces were noteworthy for two reasons.

- They had a very narrow band of properties in at least two of the three manufacturer's products.
- They had the lowest number of potential signature matches by foreign coins and slugs.

Dura-White-plated zinc construction appears to offer the most secure 5-cent coin of any materials tested, including the incumbent 5-cent coin material. However, constructing coins of this material would require a substantial investment from the stakeholder communities to upgrade fielded coin-processing equipment to recognize this material construction.

[110] The industry defines acceptance windows as the range in measured characteristics that have been determined to match a given coin. When all measured values fall within each of the acceptance windows, then a coin is declared valid, its denomination accounted for and further actions taken within the coin-processing equipment.

4.8.2.3 Quarter Dollar Nonsense Pieces

The quarter dollar nonsense pieces were used as a test platform for dime, quarter and half dollar coins, assuming that all three of these coins will continue to be constructed of like materials and will continue to have a weight that is proportional to the coin's face value; this design philosophy is consistent with that of today for these three US circulating coins. In other words, results from the quarter dollar material tests are assumed to be directly transferrable to the dime and half dollar coins.

All three manufacturers were unable to distinguish between the newly minted 2012 quarter dollar coins, the circulated quarter dollar coins and the quarter dollar nonsense pieces made from cupronickel-clad C110 (the incumbent materials of construction for the quarter dollar coin). Therefore, CTC concluded that any differences between the measured properties for the alternative material nonsense pieces and the baseline circulated coins were strictly due to the materials of construction and production methods used to manufacture the nonsense pieces.

The 669z-clad C110 nonsense pieces were found by all three coin-processing equipment manufacturers to be indistinguishable from the circulated quarter dollar coins. Therefore, this coin construction shows promise to be seamless with the incumbent cupronickel-clad C110 dime/quarter dollar/half dollar coin construction.

All other quarter dollar nonsense pieces could be easily distinguished from incumbent US quarter dollar coins. Therefore, if used in future quarter dollar coins, the materials and manufacturing methods used to produce these other quarter dollar nonsense pieces would require an upgrade to all fielded active coin-processing equipment produced by the three manufacturers who conducted the validation tests. Although equipment from two of the manufacturers could easily be upgraded to accept plated-ferromagnetic-steel-based quarter dollar coins, the third manufacturer would be unable to do so with the sensors that are currently used in their fielded coin acceptors. The Dura-White-plated zinc quarter dollar nonsense pieces had the narrowest acceptance windows of all nonsense pieces that were evaluated; the three sets of Dura-White-plated zinc nonsense pieces (having plating thicknesses of 5, 8 and 10 microns, respectively) would offer a signature approximately as unique as the incumbent quarter dollar coin relative to other coins and slugs available throughout the world.

4.8.3 Comments about Validation Tests

Future validation testing involving a larger number and greater variety of coin-processing equipment manufacturers than were included in the present study should be completed prior to defining the final specifications of any new circulating coin materials of construction.

A broader sampling of coin-processing equipment manufacturers will ensure that alternative material coins will have the desired acceptance rate across these many products used by individuals across the United States that enable automated, unattended points-of-sale to support US commerce. These more-inclusive validation efforts, which are beyond the scope of the present study, include establishing the variability of material properties from multiple lots of coin materials and establishing the associated variability in finished coins through completion of simulated coin production runs each of approximately 1,000,000 test pieces for each material-denomination combination of continued interest.

Test pieces made at different times (rather than a single continuous production-like run) and under a variety of common production conditions should also be struck and tested to establish more realistic standard deviations in the characteristics and properties of nonsense pieces. Also, since coin acceptors must successfully operate in a wide variety of environmental conditions, future validation tests must also explore the impact of temperature, humidity, coin scratches, gouges, tarnish, corrosion and wear, slight bends in the coins and other stakeholder-defined test conditions. These conditions are also important in defining the boundaries of the acceptance windows used within coin-processing equipment.

4.9 SECURITY

A critical element in the design of coins is to ensure their security from those who would attempt to benefit from the production and/or use of low-cost substitutes that are accepted as legitimate articles. People/organizations capitalize on coin characteristics that are inexpensively duplicated so that the fraud[111] pieces pass for legitimate coins. In hand-to-hand transactions, the circulating coins need to have qualities that are quickly recognized as unique from counterfeit coins.[112] Therefore, the dimensions (diameter and thickness), image, weight, color and edge profile of counterfeit coins must bear some resemblance to the targeted coin. Laser scanning technology and computer-aided manufacturing technologies exist that allow fraudsters to inexpensively produce high-quality dies needed for producing counterfeit coins. In some instances, the quality of the counterfeit coins is so good that they are not easily and quickly detected even by experts in coinage [27]. In other instances, foreign coins having a lower value are pawned off on individuals who may not be familiar with local coins. This type of fraud often occurs in locations where tourists visit.

The methods used to fraud automated equipment include use of low-value foreign coins whose characteristics suitably match those of a higher-value local coin. In addition, slugs[113] are produced that may bear little or no visual similarity to an actual coin. Successful slugs must merely have characteristics and properties that fall within the acceptance windows for each of the characteristics and properties measured by the targeted coin-processing equipment.

4.9.1 Elements of a Secure Coin

The coin design community has developed several rules that are useful in increasing the security of coins. US circulating coins currently comply with most of these rules. Therefore, the US has a relatively low fraud problem with its coinage.

Rule # 1: Use multiple materials, especially for high-value coins.[114] Roll-clad materials are commonly used to satisfy this rule. Plated designs offer a lower-cost multiple-material option for many coins; however, plated coins are less secure than clad coins (see Rule #7 below). In other cases, bi-color coins are produced that have a small disk of one color joined to a washer-

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[111] As defined by The WVA Coin Design Handbook [5], the term "fraud coin" applies to a wide variety of invalid coins including counterfeits, slugs, foreign coins and tokens used to attempt to trick a person or machine.

[112] According to The WVA Coin Design Handbook [5], a counterfeit coin is one that is designed to look like a real coin. It is mainly intended to fool a victim during hand-to-hand transactions.

[113] The WVA Coin Design Handbook [5] defines slugs as a fraud coin that is designed to fool automated validation equipment.

[114] The threshold for defining a low-value versus a high-value coin is approximately at a quarter of a US dollar.

shaped outer ring having a color and material that differs from that of the inner disk (for example a bronze center disk inside a silver ring). Choosing materials that have a large difference in EMS in each portion of the bi-color coin allows coin-processing equipment to more securely validate coins through use of multiple-frequency sensors designed to test for type, location and thickness of each of the materials. Aside from the 5-cent coin, all incumbent US circulating coins are produced with multiple materials. Future high-value US circulating coins should continue to rely upon the use of multiple materials of construction. Such options are among the nonsense pieces struck by the United States Mint in support of the current study. However, a bi-color coin would require that the surface have clearly visible differences in color at different locations. For optimum security, each material should cover a significant portion of the face of the coin and each material should have a unique EMS signature. A coin of this design would necessitate upgrades to all EMS-based coin-processing equipment. The conversion cost to do so would be of similar magnitude to that defined in Section 4.5 from changes to coin EMS for each of the stakeholders. In addition, the production of bi-color coins requires additional process steps (including cutting the center piece and the ring-shape piece [assuming that the traditional concentric design is used], followed by assembly of these two pieces before striking). These added process steps would add additional cost to the production of coins.

Rule # 2: Ensure higher denomination coins are larger in dimensions than lower denomination coins when all are made of the same materials. This rule keeps fraudsters from machining the outer diameter or thinning any lower denomination coins to match the dimensions and other characteristics of higher denomination coins. A corollary to this rule is to ensure that both the dimensions and materials of construction of a given coin are not similar to coins of larger dimensions and similar materials of construction, but are of lower value from another country. The incumbent US circulating coins meet the conditions of this rule. CTC recommends maintaining this condition for future coins.

Rule # 3: Use high-value materials relative to the face value of the coin. Obviously the material selection should not result in coins whose intrinsic value exceeds its face value. Honoring this rule discourages production of fraud coins. With the exception of the 5-cent coin, incumbent US circulating coins meet this rule. The value of the various alternative material candidates evaluated in the present study meet this rule.

Rule # 4: Avoid coinage materials with similar electromagnetic properties to commonly available materials. Materials that are somewhat unique to coins and do not have widespread use in other applications in the dimensions and raw material forms common to coinage are encouraged, especially for high-denomination coins. Obviously, if the materials common to coins are readily available on the open market, fraudsters will have a ready supply of materials to support creation of fraud coins. Incumbent US circulating coins generally meet this rule. Monolithic 302HQ and 430 stainless steel and alloy 5052-H32 do not meet this rule; however, these material options were only considered for low value coins where security is not as critical. From a security perspective, these alloys are suitable only for low-denomination coins.

Rule # 5: Choose materials that have stable electromagnetic properties. Factors to consider to satisfy this rule include: 1) the effect of temperature on the electromagnetic properties, 2) the consistency of both the production processes used for producing the stock coinage materials and the processes used during minting of coins and 3) the stability of the electromagnetic properties during normal use of coins made from these materials (e.g., they are relatively constant with circulation wear and coin usage). Electromagnetic properties of materials are sensitive to changes in temperature. This is an important consideration for automated, unattended points-of-sale, especially vending, where machines are placed in environments that can range from –18 degrees Celsius (°C) to 65 °C (0 degrees Fahrenheit [°F] to 120 °F). The temperature of the coins themselves may be at even more extreme temperature conditions. Equipment specifications necessarily must allow for some performance variability from unit to unit to ensure economical production of coin-processing equipment. The variability permitted in materials and dimensions of the various constituents of coins must also be specified and minimized to the greatest extent practicable. The electromagnetic properties of some metallic materials, including most ferromagnetic steels and many aluminum alloys, are very sensitive to variations in their alloy chemistry even within their accepted chemical composition limits. Materials whose properties (especially those properties that are used to automatically validate coins) are easily altered, either through normal use or by readily-available methods should be avoided in coin construction. Coins made from materials that violate this rule require broad acceptance windows in the coin-processing equipment commonly used in vending machines, laundromat machines, car washes and the many other devices that rely upon automated coin validation. Broad acceptance windows encourage the development and use of fraud coins in these devices. Incumbent US circulating coins meet this rule. Of the candidate materials tested in this study, the steel-based (plated and stainless steel alloys) and the 5052-H32 aluminum alloy may fall short of meeting this rule; however, use of these materials in low-denomination coins may pose only a minor security risk. These materials are not likely secure options for high-value coins.

Rule # 6: Compare physical properties of contemplated coins to databases, which contain details of the world's coins. Such databases have been developed and used by mints and coin-processing equipment manufacturers throughout the world to compare the properties of coins during development and, as necessary, to aid in defining the best materials or other characteristics and/or properties of the coin to avoid duplication of features in preexisting circulating coins. These actions minimize the probability of fraud by the public or embarrassment on the part of the mint after release of new coins. The most comprehensive of these databases is located at the International Coin Registration Office currently operated by Monnaie de Paris in Paris, France. In addition, most manufacturers of coin-processing equipment have databases of common circulating coins and fraud coins throughout the world. While the databases from the coin-processing equipment manufacturers were consulted during Round Two validation tests, data from these databases remain highly proprietary and must necessarily remain secure. For these reasons, these databases were not shared with CTC.

Rule # 7: Use a thick outer layer of material for plated coins. <u>The WVA Coin Design Handbook</u> [5] recommends a 30-micron thickness (as measured at the centerline of the coin) for the plated material. This thickness is recommended for several reasons. First, it is sufficient to keep the plated layer from tearing during the stamping operation. Second, this thickness has been found to be sufficient to mitigate pitting corrosion and/or normal edge wear from exposing the under-lying core material. The EMS behavior of coins is greatly impacted when the underlying material is exposed potentially causing such coins to be misvalidated in coin processing equipment. Third, maintaining a sound outer layer typically keeps the coin from excessive corrosion. Fourth, normal face wear of coins will reduce the thickness of the outer layer of material. When this occurs and the thickness is less than 10 to 15 microns, the electromagnetic sensors, especially those operating at low frequencies, can no longer discriminate the coin from an uncoated blank of the same material as the core of the coin. Slugs of the core material may pass for coins when the acceptance windows include coins with such thin plating layers. Currently, the one-cent coin is the only US circulating coin that is plated. Its plating thickness, 8 microns, violates this rule; however, as a low-denomination coin, security is not a significant concern for the US one-cent coin. However, corroded one-cent coins, which have a green color, are not uncommon among the pool of US coins currently in circulation. None of the plated nonsense pieces evaluated in this study met this rule. Hence these nonsense pieces, though several were found to be economical to manufacture, are susceptible to large variation in EMS performance over their expected lifetime. Further testing is needed of worn nonsense pieces in coin-processing equipment to adequately quantify the impact of deviating from this rule by using such materials of construction.

Rule # 8: Ensure distinction between the denominations within a given coin set. The WVA Coin Design Handbook [5] recommends that all coins have a diameter between 17 and 30 millimeters (mm); an edge thickness between 1.7 and 2.8 mm and a weight between 2 and 12 grams. Edge design (smooth, reeds or lettered) and varying color among denominations can also add to coin security, especially for hand-to-hand transactions. The spread in dimensions among the various coins that make up a country's coin set should be easily distinguishable; at least 1 mm difference in diameter should exist between all coins. The incumbent US circulating coins meet this rule. CTC recommends maintaining size distinction between coins. Depending upon the materials selected for future coins, if in fact any changes are made, some color confusion could exist. It is generally recognized that color differences are preferred between the dime and one-cent coins; a color difference between the quarter dollar and dollar coins should also be maintained.

CTC's recommendations for alternative materials coinage that follow in later sections follow these rules developed by the coin design community for increasing the security of circulating coins.

4.9.2 Coin Security Issues of Importance for the Current Study

During Government fiscal year 2011, the United States Secret Service (USSS) received and assessed $5,491.25 worth of counterfeit coins that were used in financial transactions and passed to them by law enforcement and/or financial institutions. Although the actual amount of counterfeit US coins is not known, this small quantity is evidence of a low rate of counterfeit circulating coins in the US. Attempts to counterfeit rare coins notwithstanding, frauding US circulating coins is generally not worth the time and effort of fraudsters, since as several coin experts from coin-processing equipment manufacturers have noted in one-on-one interviews, "US coins are currently overdesigned, relative to security." The fraud rate for the British one-pound coin is estimated to be 3% of the total pound-coin population [28]. This fraud rate is high enough that the Royal Mint has considered withdrawing it from circulation and issuing a new coin of a different construction to replace it [28]. The primary reasons given for this high fraud rate are the high value of the coin (equal to 1.58 US dollars as of April 16, 2012 [9]) and its simple construction, which is a monolayer of nickel-brass alloy (70% copper, 24.5% zinc and 5.5% nickel) [29]. Design guides, as defined by the above eight rules, coupled with added guidance available in The WVA Coin Design Handbook [5], should be heeded in defining the construction of all future US circulating coins. The USSS also recommends that circulating coins be wear resistant, have highly consistent properties and low defect rates.

Application of the above eight rules, while not guaranteeing that fraud will not occur, will greatly reduce the risk of large quantities of fraudulent coins entering the circulating coin supply. Other precautions have been offered to increase the security of coins. Both ferromagnetic-steel-based and aluminum materials have been discouraged for use in coinage, except for low-denomination coins. EMS properties of these materials are more sensitive to temperature variations than more commonly used cupronickel (75% copper and 25% nickel) and other alloys found in incumbent US circulating coins. Thermomechanical processing and minor changes in alloying additions of steels can result in wide swings in EMS properties. Furthermore, with its ability to be magnetized, the effective EMS properties of a ferromagnetic-steel-based coin can change significantly over its otherwise useful lifetime.

Most countries do not expend significant resources attempting to protect low-denomination coins from fraud. It is rarely worth the fraudster's time, expense and risk to produce low-value fraudulent coins. As a result of inflation and the associated cost to produce coins, many mints and reserve banks, throughout the world have chosen to construct their low-denomination coins around a steel-based core. Given the increasing number of countries that have switched to steel-based coins, the opportunities are very limited for securely introducing new steel-based US circulating coins that offer unique EMS and other characteristics or properties from preexisting steel-based circulating coins from other countries.

Coin-processing equipment manufacturers have also identified a few other issues that can impact the size of acceptance windows on their devices. The magnitude of the impact of each of these conditions must be experimentally evaluated. Moisture can impact the sensor readings and must be taken into account during a comprehensive assessment of new coins by the device manufacturers. When present, moisture is often due to sweat. Dirt on the coin, especially if coupled with moisture, can impact the position of the coin with respect to the sensors and in turn alter the acceptance rate of coins. Tarnish, corrosion, scratches and wear are also known to impact coin acceptance rates in these devices. Another variable in coin validation is the natural randomness of the coin's position relative to the sensors as the coin passes through the coin-processing equipment. The design of the image on the coin can impact the acceptance rate within coin-processing equipment, as was noted by several manufacturers relative to the various images used on the 50 different state quarter dollar coins. Finally, typical lot-to-lot production variations also add to the width of acceptance windows required for circulating coins. Improved security in coins can be achieved by tightly controlling factors such as material specifications and production practices during production of materials delivered to the United States Mint along with the process steps taken by the United States Mint during coin production.

4.9.3 Future of Coin Security

Recent and ongoing research has been conducted throughout the world to develop additional security features for circulating coins. These efforts include the following:

- Image recognition under various lighting conditions
- Use of latent images that become visible at selected view angles
- Incorporation of radio frequency identification (RFID) tags

- Three-material coins, including tricolor coins, bicolor coins with a clad center piece and five-layer clad coins
- Laser etching of unique marks on individual coins that are later individually validated against a database of the associated information
- Coin embedded taggants developed by the RM that glow under certain harmless wavelengths of infrared (IR) radiation.

While various innovative security technologies may prove useful in future construction of US circulating coins, the infrastructure to take advantage of these features is still many years from being developed to a level that such feature can be used to robustly validate circulating coins. Also note that each of these technologies would add cost of an unknown magnitude to the production of circulating coins. CTC recommends that the United States Mint continue to track these technologies into the future and as they fit into United States Mint security strategies. The most promising of these technologies appear to be: 1) use of three-material construction and 2) use of embedded taggants.

4.10 ADDITIONAL REMARKS

Many of the stakeholders that were contacted for this outreach effort thanked the United States Mint and CTC for reaching out to obtain their input as the United States Mint moves forward with a potential change of materials in US circulating coins. Stakeholders, in general, have asked to remain informed about the progress of the effort as the process of introducing alternative materials into circulating coins moves forward; several stakeholders volunteered to test sample coins (or nonsense pieces) in their coin-processing equipment. These volunteers agreed to provide feedback to the United States Mint about their experiences and observations. Discussions with other mints and with coin development experts throughout the world have also confirmed the need to engage stakeholders early and often while in the process of developing new materials of construction for coinage. This sentiment is also echoed in The WVA Coin Design Handbook [5].

The Advanced Counterfeit Deterrence (ACD) Steering Committee, an interagency group devoted to ensuring the security of US currency, recommends policies related to currency. The ACD defines when the design of US notes will be changed [17]. When such a change is enacted, bill acceptors must be reprogrammed to recognize and accept the new note designs. Those stakeholders that accept both currency and coin payments, a common situation with vending and laundromat machines, may benefit from the Federal Reserve simultaneously introducing coins of alternative metallic construction into circulation with that of the next low-value (either $1 or $5 notes) currency design. Dialog between the BEP and the United States Mint to that end is recommended. Both currency- and coin-acceptance equipment upgrades could be made during a single service call if a simultaneous introduction of US currency could be coordinated. The overall impact to the effected stakeholders is expected to be reduced compared with two separate and uncoordinated releases of new notes and coins from the BEP and the United States Mint, respectively.

4.11 CONCLUSIONS – CHAPTER 4

1. For automated, unattended points-of-sale, the most important of the incumbent US circulating coins is the quarter dollar coin. Its use is pervasive throughout the many stakeholders that rely upon coins for commerce. Introduction of a non-seamless[115] quarter dollar coin into circulation would create the largest disruption among the US circulating coins to those stakeholders who rely upon automated, unattended point-of-sale transactions with coins.
2. The impact of introducing non-seamless 5-cent and dime coins into circulation, though less significant than that of introducing a non-seamless quarter dollar coin into circulation, is still significant to several stakeholders including, but not limited to, those that own and operate vending machines and parking meters.
3. One-cent coins are rarely accepted in automated, unattended points-of-sale devices. As a result, introduction of non-seamless one-cent coins into circulation will not have a significant impact on commerce; it will (except for an aluminum alloy) also require an investment of not more than $6.9M to impacted stakeholders to be able to successfully process these non-seamless one-cent coins.
4. Introduction of non-seamless dollar coins into circulation would have a modest financial impact to several stakeholders, especially those who own or operate laundromats, vending machines, gaming machines, parking meters, car washes and armored cars.
5. Half dollar coins are not widely recognized nor accepted for payment in automated systems. If non-seamless half dollar coins were introduced into circulation, the impact to the few affected business owners would be marginal. However, given the very limited number of US half dollar coins currently in circulation, the impact to commerce is expected to be of little consequence.
6. Ferromagnetic materials (i.e., those that would be attracted to a magnetic) would be very problematic for one American-owned manufacturer of coin-processing equipment. Use of such coinage materials would require a major upgrade of their client coin-processing equipment (at a cost of approximately $250M). In addition, this manufacturer would have to undergo a major redesign and retooling for its product line to accommodate the EMS characteristics of ferromagnetic materials and how they interact with their sensors.
7. The one-time conversion costs to the stakeholders assessed in this study as a result of changes to coin dimensions, including either diameter or thickness, for the dollar, quarter dollar, dime and/or 5-cent coins would dwarf any savings realized by the United States Mint in producing such newly dimensioned coins. The total conversion costs across all stakeholder groups resulting from changes to the quarter dollar coin dimensions was estimated to be between $1.08B to $2.09B, with $1.45B being the most probable conversion costs as a result of dimensional changes to the quarter dollar coin. The impact resulting from changes to the dimensions of the dime and/or the 5-cent coins would be approximately 80% of that for the quarter dollar coin, while changes to the dimensions of the one-cent coin would cost stakeholders approximately 5% of that for the quarter dollar

[115] Non-seamless in these conclusions refers to any change in coin characteristics and/or properties, including dimensions, EMS and/or weight that necessitate changes to stakeholder equipment, software and/or operational procedures for successfully validating, handling and managing coins. A seamless option would not require such changes.

coin. These impacts are significantly greater than the annual cost savings to the United States Mint as defined in the Cost Trends Analysis Chapter.

8. The conversion costs associated with a change in EMS (without any change to coin dimensions [diameter and thickness]) of coinage was considerable more complex than that for a change in coin dimensions. Based upon testing by a limited number of coin-processing equipment manufacturers, only one of the material-denomination combinations evaluated in this study was found to potentially be a seamless option for the quarter dollar coin: copper alloy 669z clad on commercially pure copper alloy C110. All other material-denomination combinations were found to require some costs for stakeholders to upgrade their equipment to accept coins of these alternative materials. Alloy 669z along with copper alloys G6 mod and unplated 31157 were found to be nearly seamless as 5-cent coin materials. However, density differences between all three of these alloys and the incumbent cupronickel 5-cent alloy would require a one-time upgrade cost between $8.8M and $71M. Other non-ferromagnetic material options having a different EMS from incumbent coins were projected to cost between $277M and $375M for the various stakeholders to prepare for the new coins. Ferromagnetic materials (including most steel-based materials) would require an estimated $531M to $632M for conversion by stakeholders to be prepared for coins of this construction.
9. Due to the weight difference between each of the various material-denomination combinations studied and their corresponding incumbent coin, an increase in annual operating costs would be required of those who handle large quantities of coins. Each incoming container of coins would have to be counted and the estimated processing cost, accumulated across all coin terminals in the US, would be as follows (one-cent coins are not currently counted):
    a. 5-cent coins: $3.75M
    b. Dime coins: $6.92M
    c. Quarter dollar coins: $9.20M
    d. Half dollar coins: $0.04M
    e. Dollar coins: $1.09M.
10. Aluminum-based coins have been known to create operational problems and/or permanent equipment damage with many types of coin-processing equipment including that used for unattended points-of-sale and those used to sort/count coins. Several mints, national reserve banks and manufacturers of coin-processing equipment strongly recommend against minting coins made of aluminum alloys. This includes plated and clad material coins with aluminum on the surface.
11. Most stakeholders have asked for between 12 and 18 month to prepare themselves and their clients for any changes to US circulating coins once they have sample coins available for testing, redesigning and upgrading their equipment and their products. This assumes that only EMS changes will be required and that no new coins are of a ferromagnetic material. If a ferromagnetic material is used in one or more of the 5-cent, dime, quarter dollar and/or the dollar coins, then collectively the coin-processing industry will require 30 months to prepare for introduction of such coins. Other countries have succeeded in making this transition after giving stakeholders 12 months to prepare for the introduction of alternative material coins; however, the size and complexity of the impacted US stakeholders is significantly greater than that for other countries. Therefore,

a longer time will be required for the US to prepare for introduction of non-seamless coins than that allowed by other countries.

12. For the vending machine owners and operators (and on a smaller scale pay phone owners and operators, municipal parking officials, transit officials, merchants and armored-car operators), the conversion costs associated with changes to any characteristic and/or property (especially dimensions and/or EMS) of one of the four most-widely vended US circulating coins (5-cent, dime, quarter dollar and dollar coins) is approximately equal to the financial impact of simultaneously changing two or more of these most-widely vended US circulating coins. Any time that a non-seamless coin (among these four denominations) is introduced into circulation, coin-processing equipment must be upgraded to recognize the new coin(s).
13. Additional public opinion about changes to US circulating coins is necessary to compliment the findings from the current study. This information would further elucidate remarks received from the open call for public opinion in the Federal Register on March 4, 2011 [2]. Direct and specific questions should be asked of a representative sample of US citizens on topics such as: a) the weight of coins, b) color of coins and c) level of support of changing US circulating coins to reduce taxpayer costs.

4.12 RECOMMENDATIONS – CHAPTER 4

1. The United States Mint should not introduce any new coins with dimensions that differ from the associated incumbent US circulating coins.
2. Aluminum should not be considered as a viable alloy for use in the construction of US circulating coins.
3. Ferromagnetic materials should not be considered for US circulating coins, except potentially for the one-cent coin.
4. As alternative materials of construction receive further development by the United States Mint, nonsense pieces or sample coins should be provided to a large number of coin-processing equipment manufacturers and to other appropriate organizations for testing and evaluation. Comments from these organizations related to potential changes in coin characteristics and/or properties should be considered by the United States Mint to increase the likelihood of a smooth introduction of alternative material coins into circulation.
5. Should the United States Mint decide to introduce coins of alternative material construction into circulation, regardless of whether or not the coins are expected to be seamless substitutes for incumbent circulating coins, the manufacturers of coin-processing equipment should be provided production samples of the final coin materials of construction at least 18 months (24 months if coin sizes are altered; 30 months if ferromagnetic materials are used) in advance of the expected release date for such alternative material coins. These samples are expected to be used to design and validate the necessary changes to the manufacturer's equipment and to prepare their clients for the release of the alternative circulating coins. After releasing final coin samples to these manufacturers, no changes should be made to the coin's production processing parameters, material specifications or finished coin specifications.
6. Should the United States Mint decide to introduce several denominations of non-seamless coins into circulation, then all such non-seamless coins should be introduced on or approximately on the same date. (As an preliminary engineering estimate, the span of

time should be no more than approximately 2 to 4 months between introducing the first and last of these new coins). Otherwise the industries that rely upon these coins will be forced to complete multiple equipment upgrades (corresponding to each of the separate releases of non-seamless coins), which will drive up the total conversion costs significantly beyond that noted in this study. Consistent with the previous recommendation, the United States Mint must make samples of all new coins available to the coin-processing equipment manufacturers at a time and pace that will allow equipment upgrades to be completed during a single release of their upgraded equipment.

7. Future validation testing involving a broader number and greater variety of coin-processing equipment manufacturers than used in the present study should be completed prior to defining the final specifications of any alternative material coins.
8. More-inclusive validation efforts must be completed to establish the variability of finished coins produced from multiple lots of coin materials. These efforts need to establish the associated variability in finished coin characteristics and properties through completion of simulated coin production runs each of approximately 1,000,000 nonsense pieces. Nonsense pieces made at different times and under a wide variety of typical processing conditions should also be produced and tested to establish more realistic standard deviations in the characteristics and properties of potential future circulating coins. These tests must also assess the impact to coin-processing equipment associated with realistic operational conditions including effects of temperature, humidity, tarnish, corrosion, coin scratches, gouges and wear, slight bends in the coins and other stakeholder-defined test conditions.
9. Conduct a public opinion survey using telephone or direct one-on-one interviews of US citizens to collect direct and specific data on changes to coins. The survey should consist of questions to determine the public's opinion about coin weight and color, and level of support for changing US circulating coins.

4.13 REFERENCES – CHAPTER 4

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4.14 APPENDICES – CHAPTER 4

4.14.1 Appendix 4-A: OMB-Approved Alternative Metals Study Outreach Questionnaires

4.14.1.1 Questionnaire for Coin Sorters

We Need Your Input.

Welcome to the United Stated Mint's survey designed to help us improve our products and services. The United States Mint has contracted with Concurrent Technologies Corporation (CTC) to conduct a study of Alternative Metals for Circulating coinage in support of Public Law 111-302. This survey is part of that study. **Your participation is in this survey is ENTIRELY VOLUNTARY and should take approximately 15 minutes of your time.**

According to the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB number. The valid OMB control number for this information is 1525-0012-0163.

A stakeholder group of importance to the U.S. Mint in this assessment is those who own and operate devices with coin sorters. As a result, we are seeking your quantitative input to help define the impact to your industry.

Please complete this brief confidential survey by October 15, 2011.

Click on the link below to participate. You can only complete the survey once and you will not be able to view other participants answers.

This survey is being conducted by Concurrent Technologies Corporation, a contractor to the U.S. Mint.

Questions may be forwarded to Michael L. Tims at 814-269-2515 or via e-mail to US_Mint_Survey-Sorters@ctc.com.

1. What is the approximate total number of coin sorters at your facility/facilities? [radio button selection]
   a. 1 to 5
   b. 6 to 20
   c. 21 to 50
   d. 51 or more
2. If available, please indicate the manufacturer, model and total number of each coin sorter in your inventory.
   a. _____
3. What is the total number of sites where your coin sorting machines reside?
   a. _____

4. Approximately, how frequently are your coin sorters serviced by a representative of the equipment manufacturer? [radio button selection]
    a. 3 or more times per year
    b. 2 times per year
    c. 1 time per year
    d. Once every two years
    e. Once every three years
    f. Other
5. How many coin sorters do you replace each year?
    a. _____
6. What is the approximate total number of coins sorted by your equipment per week?
    a. _____
7. How many labor-hours per week does your business require to sort coins?
    a. _____
8. Does your equipment also collect and sort tokens?
    a. Yes
        i. How many tokens are sorted per week?
            1. _____
        ii. How many token designs are currently in use at your facility?
            1. _____
    b. No
9. Of the total number of coin sorters that you have, how many count coins to determine quantity?
    a. _____
10. Of the total number of coin sorters that you have, how many weigh coins to determine quantity?
    a. _____
11. What impact (including cost per unit) would you face if any of the following coin properties were changed? [Radio Button Scale 1 to 10 + "unknown or N/A"]
    a. Diameter
    b. Thickness
    c. Weight
    d. Metallic content (such as ferro-magnetic metals)
    e. Color
    f. Gloss
    g. Hardness
    h. Electromagnetic signature

12. Please provide comments concerning potential changes to any of the above coin properties.
    a. _____
13. How many of your coin sorters have 4 or less bagging stations?
    a. _____
14. 5 bagging stations?
    a. _____
15. 6 bagging stations?
    a. _____
16. 7 bagging stations?
    a. _____
17. 8 bagging stations?
    a. _____
18. 9 bagging stations?
    a. _____
19. 10 or more bagging stations?
    a. _____
20. What is the total number of electronically-based sorters at your facility/facilities that are less than 6 years old?
    a. _____
21. Electronically-based sorters that are between 6 and 10 years old?
    a. _____
22. Electronically-based sorters that are greater than 10 years old?
    a. _____
23. What is the total number of mechanically-based sorters at your facility/facilities that are less than 6 years old? (Mechanical sorting coupled with electronic counting still count as mechanically-based sorters.)
    a. _____
24. Mechanically-based sorters that are between 6 and 10 years old? (Mechanical sorting coupled with electronic counting still count as mechanically-based sorters.)
    a. _____
25. Mechanically-based sorters that are greater than 10 years old? (Mechanical sorting coupled with electronic counting still count as mechanically-based sorters.)
    a. _____
26. What is the approximate number of coin sorters at your facility/facilities that accept pennies?
    a. _____
27. Nickels?
    a. _____

28. Dimes?
    a. _____
29. Quarters?
    a. _____
30. Half dollars?
    a. _____
31. Dollar coins?
    a. _____
32. Please list any comments that you have concerning a potential redesign of U.S. circulating coins.
    a. _____
33. Would you be willing to be contacted concerning follow-up questions to this survey?
    a. Yes
    b. No
34. Optional Information: Please list your name, company, address, phone number and e-mail address.
    a. _____

Thank you for taking the time to complete this survey. If you have any questions, please forward them to US_Mint_Survey-Sorters@ctc.com.

4.14.1.2 Questionnaire for Coin Acceptors

We Need Your Input.

Welcome to the United Stated Mint's survey designed to help us improve our products and services. The United States Mint has contracted with Concurrent Technologies Corporation (CTC) to conduct a study of Alternative Metals for Circulating coinage in support of Public Law 111-302. This survey is part of that study. **Your participation is in this survey is ENTIRELY VOLUNTARY and should take approximately 15 minutes of your time.**

According to the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB number. The valid OMB control number for this information is 1525-0012-0163.

A stakeholder group of importance to the U.S. Mint in this assessment is those who own and operate devices with coin acceptors (including, but not limited to, vending machines, automated car washes, parking meters, toll booths, Laundromats, and amusement and gaming machines). As a result, we are seeking your quantitative input to help define the impact to your industry.

Please complete this brief confidential survey by October 15, 2011.

Click on the link below marked *Respond to This Survey* to participate. Please have only one member of your company or organization complete this questionnaire.

This survey is being conducted by Concurrent Technologies Corporation, a contractor to the U.S. Mint.

Questions may be forwarded to Michael L. Tims at 814-269-2515 or via e-mail to US_Mint_Survey-Acceptors@ctc.com.

1. What is the approximate total number of coin acceptors at your business?
   a. _____
2. If available, please indicate the manufacturer, model and total number of coin acceptors in your inventory.
   a. _____
3. What is the approximate total number of coin acceptors at your business in the following areas?
   a. Food and beverage vending
      i. _____
   b. Other vending
      i. _____

c. Parking meters
    i. _____
d. Laundromat
    i. _____
e. Amusement and gaming
    i. _____
f. Toll booths
    i. _____
g. Automated car wash machines
    i. _____
h. Other (please specify number and use of any other coin acceptors)
    i. _____

4. What is the total number of sites where your coin acceptors reside?
    a. _____
5. Approximately, how frequently are your coin acceptors serviced by a representative of the equipment manufacturer? [radio button response]
    a. 3 or more times per year
    b. 2 times per year
    c. 1 time per year
    d. Once every two years
    e. Once every three years
    f. Other (please specify)
        i. _____
6. Approximately how many coin acceptors do you replace each year?
    a. _____
7. Does your equipment also accept tokens?
    a. Yes
        i. How many tokens are processed per week?
            1. _____
        ii. How many token designs are currently in use in your business?
            1. _____
    b. No
8. What is the approximate number of coins (and tokens) processed by your coin acceptors per week? (if possible, provide by denomination)
    a. Total
        i. _____
    b. Pennies
        i. _____
    c. Nickels
        i. _____

    d. Dimes
        i. _____
    e. Quarters
        i. _____
    f. Half dollars
        i. _____
    g. Dollar coins
        i. _____

9. Of your total coin acceptors, how many determine coin (and token) quantities by weight?
    a. _____
10. by stack height?
    a. _____
11. by counting?
    a. _____
12. What impact (including cost per unit) would you face if any of the following coin properties were changed? [Radio Buttons: Scale 1 to 10 + “Unknown or N/A”]
    a. Diameter
    b. Thickness
    c. Weight
    d. Metallic content (including ferro-magnetic metals)
    e. Color
    f. Gloss
    g. Hardness
    h. Electromagnetic signature
13. Please provide comments concerning potential changes to any of the above coin properties.
    a. _____
14. What is the total number of electronically-based coin acceptors at your facility/facilities that are less than 6 years old?
    a. _____
15. Electronically-based acceptors that are between 6 and 10 years old?
    a. _____
16. Electronically-based acceptors that are greater than 10 years old?
    a. _____
17. What is the total number of mechanically-based acceptors at your facility/facilities that are less than 6 years old?
    a. _____
18. Mechanically-based acceptors that are between 6 and 10 years old?
    a. _____

19. Mechanically-based acceptors that are greater than 10 years old?
    a. _____
20. What is the approximate number of coin acceptors in your business that accept Pennies?
    a. _____
21. Nickels?
    a. _____
22. Dimes?
    a. _____
23. Quarters?
    a. _____
24. Half dollars?
    a. _____
25. Dollar coins?
    a. _____
26. Please provide any comments that you have concerning a <u>potential</u> redesign of U.S. circulating coins.
    a. _____
27. Would you be willing to be contacted concerning follow-up questions to this survey?
    a. Yes
    b. No
28. Optional Information: Please list your name, company, address, phone number and e-mail address.
    a. _____

Thank you for taking the time to complete this survey. If you have any questions, please forward them to US_Mint_Survey-Acceptors@ctc.com.

4.14.1.3 Questionnaire for Cash Handlers/Armored Cars

We Need Your Input.

Welcome to the United Stated Mint's survey designed to help us improve our products and services. The United States Mint has contracted with Concurrent Technologies Corporation (CTC) to conduct a study of Alternative Metals for Circulating coinage in support of Public Law 111-302. This survey is part of that study. **Your participation is in this survey is ENTIRELY VOLUNTARY and should take approximately 15 minutes of your time.**

According to the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB number. The valid OMB control number for this information is 1525-0012-0163.

A stakeholder group of importance to the U.S. Mint in this assessment is those who handle cash by armored cars and other means. As a result, we are seeking your quantitative input to help define the impact to your industry.

Please complete this brief confidential survey by October 15, 2011.

Click on the link below to participate. You can only complete the survey once and you will not be able to view other participants answers.

This survey is being conducted by Concurrent Technologies Corporation, a contractor to the U.S. Mint.

Questions may be forwarded to Michael L. Tims at 814-269-2515 or via e-mail to US_Mint_Survey-Cash_Handlers@ctc.com.

1. What is the total number of coin-filled containers handled weekly by your company? [Radio button response]
    a. 100 or less
    b. 101 to 500
    c. 501 to 2,500
    d. 2,501 to 10,000
    e. 10,001 or more
2. Of the number of coin-filled containers handled weekly, how many have the quantity of their contents determined by the following methods?
    a. Counting
        i. _____
    b. Weight
        i. _____

c. Stack height
    i. _____
d. Other (Please specify the method and number of containers)
    i. _____

3. What is the approximate number of the following coins that you handle on a weekly basis?
    a. Penny
        i. _____
    b. Nickel
        i. _____
    c. Dime
        i. _____
    d. Quarter
        i. _____
    e. Half dollar
        i. _____
    f. Dollar coin
        i. _____
4. What impact (including cost per unit) would you face if any of the following coin properties were changed? [Radio button: Scale 1 to 10 + N/A]
    a. Diameter
    b. Thickness
    c. Weight
    d. Metallic content
    e. Electromagnetic signature
    f. Color
    g. Gloss
    h. Hardness
5. Please provide comments concerning potential changes to any of the above coin properties. Consider co-circulation of today's coins with newly designed coins having different properties.
    a. _____
6. The following four questions request information on coin sorting machines that rely upon electronic sensors to <u>sort</u> the coins (as opposed to those machines that strictly mechanically <u>sort</u> by coin size.) What is the total number of your machines that are less than 6 years old and sort coins using electronic sensors?
    a. _____
7. What is the total number of your machines that are between 6 and 10 years old and sort using electronic sensors?
    a. _____

8. What is the total number of your machines that are greater than 10 years old and sort using electronic sensors?
    a. _____
9. Approximately how frequently are your electronic sorting machines replaced?
    a. _____
10. What is the total number of mechanically-based coin handling devices at your facility/facilities that are less than 6 years old?
    a. _____
11. Total number of mechanically-based coin handling devices that are between 6 and 10 years old?
    a. _____
12. Total number of mechanically-based coin handling devices that are greater than 10 years old?
    a. _____
13. Approximately how frequently are your mechanically-based coin handling machines replaced?
    a. _____
14. Please list any comments that you have concerning a <u>potential</u> redesign of U.S. circulating coins.
    a. _____
15. Would you be willing to be contacted concerning follow-up questions to this survey?
    a. Yes
    b. No
16. Optional Information: Please list your name, company, address, phone number and e-mail address.
    a. _____

Thank you for taking the time to complete this survey. If you have any questions, please forward them to US_Mint_Survey-Cash_Handlers@ctc.com

4.14.2 Appendix 4-B: Summary Results of Questionnaire Input

4.14.2.1 Summary Information from Vending Stakeholders

Question 1: What is the approximate total number of coin acceptors at your business?
52,841 total coin acceptors from 47 responses
Mean: 1124 coin acceptor per response
High: 16,000
Low: 9

Question 2: If available, please indicate the manufacturer, model and total number of coin acceptors in your inventory.
Crane National
MEI (also known as Mars)
Coinco
Imonex
Conlux
Currenza

Question 3a: What is the approximate total number of coin acceptors at your business in the following areas? Food and beverage vending
52,446 total coin acceptors from 48 responses
Mean: 1093 coin acceptors per response
High: 16,000
Low: 9

Question 3b: What is the approximate total number of coin acceptors at your business in the following areas? Other vending
1286 total acceptors for 35 responses
28 responses of 0
Among those with response > 0:
Mean: 184
High: 1000
Low: 1

Question 3c: What is the approximate total number of coin acceptors at your business in the following areas? Parking meters
All responses were 0.

Question 3d: What is the approximate total number of coin acceptors at your business in the following areas? Laundromat
All responses were 0.

Question 3e: What is the approximate total number of coin acceptors at your business in the following areas? Amusement and gaming

495 total acceptors from 34 responses

- 32 responses of 0
- Among those with response > 0:
  - Mean: 248
  - High: 300
  - Low: 195

Question 3f: What is the approximate total number of coin acceptors at your business in the following areas? Toll booths

All responses were 0.

Question 3g: What is the approximate total number of coin acceptors at your business in the following areas? Automated car wash machines

All responses were 0.

Question 3h: What is the approximate total number of coin acceptors at your business in the following areas? Other (please specify number and use of any other coin acceptors)

1 response of dollar bill changers
1 response of counting room equipment

Question 4: What is the total number of sites where your coin acceptors reside?

18,808 total sites among 48 responses

- Mean: 392
- High: 4000
- Low: 1

Based upon totals from Questions 1 and 4

- Mean number of units per site: 2.81 (= 52,841 acceptors/18,808 sites)

Question 5: Approximately, how frequently are your coin acceptors serviced by a representative of the equipment manufacturer?

48 responses

- 3 or more times per year: 6%
- 2 times per year: 4%
- 1 time per year: 15%
- Once every two years: 17%
- Once every three years: 19%
- Other: 40%

Question 6: Approximately how many coin acceptors do you replace each year?
1998 total replacements from 48 responses
Mean per response: 42
High response: 400
Low response: 0
Based upon totals from Questions 1 and 6
Mean ratio of acceptors replaced each year: 0.0378 (= 1998 acceptors replaced/52,841 total in field)

Question 7: Does your equipment also accept tokens?
48 responses
Yes: 27%
No: 73%

Questions 7a and 7b: How many tokens are processed per week? How many token designs are currently in use in your business?
Multitude of answers
High: 5000
Low: 0 (Comment: accept paper tokens)
Up to 7 different token designs accepted

Question 8a: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Total
37 responses
Mean: 73,664
High: 400,000
Lowest three responses: 0, 100, 200

Question 8b: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Pennies
35 responses
Total: 335
Mean: 9.57
High: 200
Low: 0 (86% of responses)

Question 8c: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Nickels
37 responses
Total: 278,193
Mean: 7519
High: 36,000
Lowest three responses: 0, 2, 50

Question 8d: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Dimes

37 responses

Total: 1,199,688
Mean: 32,424
Highest three responses: 600,000, 80,000, 50,000
Lowest three responses: 0, 10, 100

Question 8e: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Quarters

37 responses

Total: 1,889,172
Mean: 51,059
High: 350,000
Lowest three responses: 0, 80, 1000

Question 8f: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Half dollars

33 responses

Total: 1145
Mean: 35
High: 1000
Low: 0 (85% of responses)

Question 8g: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Dollar coins

37 responses

Total: 302,216
Mean: 8168
High: 60,000
Low: 0

Question 9: Of your total coin acceptors, how many determine coin (and token) quantities by weight?

36 responses

Total: 5457

Comment: given comments from coin-acceptor suppliers, some respondents were likely confused by question

Question 10: Of your total coin acceptors, how many determine coin (and token) quantities by stack height?

34 responses

Total: 11,092

Comment: after sending out survey, CTC realized that this question was likely misleading and the results were therefore considered invalid.

Question 11: Of your total coin acceptors, how many determine coin (and token) quantities by counting?
33 responses

Total: 30,382

Comment: after sending out survey, CTC realized that this question was likely misleading and the results were therefore considered invalid.

Question 12: What impact (including cost per unit) would you face if any of the following coin properties were changed? [Radio Buttons: Scale 1 to 10 + "Unknown or N/A"]
48 responses
Mean response is given for each of the following.

Diameter: 9.7
Thickness: 9.6
Weight: 9.0
Metallic Content: 9.4
Color: 2.1
Gloss: 2.5
Hardness: 4.9
Electromagnetic Signature: 8.9

Question 13: Please provide comments concerning potential changes to any of the above coin properties.
16 responses; significant responses follow.
"Would be too expensive."
"We would have to purchase new equipment."
"We would go out of business."
"Eliminate the penny. Eliminate the dollar bill."
"Existing coins are fine."
"I believe people would adapt to any changes."

Question 14: What is the total number of electronically-based coin acceptors at your facility/facilities that are less than 6 years old?
42 responses
20,333 total from all responses

Mean: 484
High: 8000
Low: 0

Question 15: Electronically-based acceptors that are between 6 and 10 years old?
42 responses
20,657 total from all responses

Mean: 492
High: 7500
Low: 0

Question 16: Electronically-based acceptors that are greater than 10 years old?
42 responses
6859 total from all responses

Mean: 163
High: 1400
Low: 0 (19% of responses)

Question 17: What is the total number of mechanically-based acceptors at your facility/facilities that are less than 6 years old?
39 responses
31 total from all responses

Mean: 0.79
High: 10
Low: 0 (69% of responses)

Question 18: Mechanically-based acceptors that are between 6 and 10 years old?
38 responses
14 total from all responses

Mean: 0.37
High: 3
Low: 0 (74% of responses)

Question 19: Mechanically-based acceptors that are greater than 10 years old?
40 responses
614 total from all responses

Mean: 15
High: 400
Low: 0 (73% of responses)

Question 20: What is the approximate number of coin acceptors in your business that accept pennies?
46 responses
7 total from all responses

Mean: 0.152
High: 4
Low: 0 (96% of responses)

From responses to Questions 1 and 20: percentage of acceptors that accept one-cent coins: 0.013%; note that after adjusting for some data anomalies the percentage was adjusted to 0.007%.

Question 21: What is the approximate number of coin acceptors in your business that accept nickels?
44 responses
49,028 total from all responses
Mean: 1114
High: 16,000
Low: 0
From responses to Questions 1 and 21: percentage of acceptors that accept 5-cent coins: 93%; note that after adjusting for some data anomalies the percentage was adjusted to 91%.

Question 22: What is the approximate number of coin acceptors in your business that accept dimes?
44 responses
49,028 total from all responses
Mean: 1114
High: 16,000
Low: 0
From responses to Questions 1 and 22: percentage of acceptors that accept dime coins: 93%; note that after adjusting for some data anomalies the percentage was adjusted to 91%.

Question 23: What is the approximate number of coin acceptors in your business that accept quarters?
44 responses
49,493 total from all responses
Mean: 1125
High: 16,000
Low: 3
From responses to Questions 1 and 23: percentage of acceptors that accept quarter dollar coins: 94%; note that after adjusting for some data anomalies the percentage was adjusted to 92%.

Question 24: What is the approximate number of coin acceptors in your business that accept half dollars?
39 responses
3595 total from all responses
Mean: 92
High: 1200
Low: 0 (74% of responses)
From responses to Questions 1 and 24: percentage of acceptors that accept half dollar coins: 6.8%; note that after adjusting for some data anomalies the percentage was adjusted to 6%.

Question 25: What is the approximate number of coin acceptors in your business that accept dollar coins?
45 responses
44,296 total from all responses

Mean: 984
High: 16,000
Low: 0

From responses to Questions 1 and 25: percentage of acceptors that accept dollar coins: 83%; note that after adjusting for some data anomalies the percentage was adjusted to 81%.

Question 26: Please provide any comments that you have concerning a potential redesign of U.S. circulating coins.
16 responses; significant responses follow.
"Increase dollar coin usage and ELIMINATE the paper $1!!"
"I appreciate the mint working with the vending industry on any possible changes to coin and paper currency."
"Any change that is compatible with our current equipment is fine."
"We put 70,000 dollar coins into circulation each week. It is essential in order to pay back someone who uses a 5 dollar bill."
"Please don't change anything."

Question 27: Would you be willing to be contacted concerning follow-up questions to this survey?
48 responses

Yes: 71%
No: 29%

Question 28: Optional Information: Please list your name, company, address, phone number and e-mail address.
Contact information supplied from selected respondents.

4.14.2.2 Summary Information from Laundromat Stakeholders

Question 1: What is the approximate total number of coin acceptors at your business?

10,371 total coin acceptors from 92 responses

Mean: 113 coin acceptor per response
High: 900
Low: 1

Question 2: If available, please indicate the manufacturer, model and total number of coin acceptors in your inventory.

ESD
Greenwald
Coinco
Nunzpruffer
IDX
Imonex
Hanke
MEI/Mars
Wasomat
Huebsch
Rowe
GE
Vendrite
Unimac
Drop Coin
Parker Engineering
Keltner
Set o Matic
Hamilton and Sunstrand
Rowe
SCAN COIN
Setomatic

Question 3a: What is the approximate total number of coin acceptors at your business in the following areas? Food and beverage vending

253 total coin acceptors from 85 responses

Mean: 2.98 coin acceptors per response
High: 32
Low: 0

Question 3b: What is the approximate total number of coin acceptors at your business in the following areas? Other vending

612 total acceptors for 66 responses

Mean: 9.3
High: 150
Low: 0

Question 3c: What is the approximate total number of coin acceptors at your business in the following areas? Parking meters
One response was 1; all others were 0.

Question 3d: What is the approximate total number of coin acceptors at your business in the following areas? Laundromat
3978 total acceptors for 90 responses
- Mean: 44.2
- High: 1260
- Low: 0

Question 3e: What is the approximate total number of coin acceptors at your business in the following areas? Amusement and gaming
281 total acceptors from 65 responses
- 38 responses of 0
- Among those with response > 0:
  - Mean: 10.4
  - High: 160
  - Low: 0

Question 3f: What is the approximate total number of coin acceptors at your business in the following areas? Tool booths
All responses were 0.

Question 3g: What is the approximate total number of coin acceptors at your business in the following areas? Automated car wash machines
116 total acceptors for 59 responses
- 52 responses of 0
- Among those with response > 0:
  - Mean: 16.6
  - High: 55
  - Low: 0

Question 3h: What is the approximate total number of coin acceptors at your business in the following areas? Other (please specify number and use of any other coin acceptors)
2 responses of dog wash
3 responses of vacuums
1 response of self-serve car wash
1 response of vending dispenser
1 response of changers

Question 4: What is the total number of sites where your coin acceptors reside?
480 total sites among 92 responses

Mean: 5.2
High: 114
Low: 1

Based upon totals from Questions 1 and 4

Mean number of units per site: 21.6 (= 10,371 acceptors/480 sites); note that after adjusting for some data anomalies the number was adjusted to 53 units per site.

Question 5: Approximately, how frequently are your coin acceptors serviced by a representative of the equipment manufacturer?
48 responses

3 or more times per year: 9%
2 times per year: 4%
1 time per year: 14%
Once every two years: 9%
Once every three years: 9%
Other: 55%

Question 6: Approximately how many coin acceptors do you replace each year?
870 total replacements from 92 responses

42 responses of 0
Among those with response > 0:
Mean per response: 17.4
High response: 600
Low response: 0

Based upon totals from Questions 1 and 6

Mean ratio of acceptors replaced each year: 0.084 (= 870 acceptors replaced/10,371 total in field)

Question 7: Does your equipment also accept tokens?
92 responses

Yes: 7%
No: 93%

Questions 7a and 7b: How many tokens are processed per week? How many token designs are currently in use in your business?
Multitude of answers

High: 5000
Low: 0 (Comment: only use “double D” tokens)
Up to 2 different token designs accepted

Question 8a: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Total

73 responses

- Total: 1,077,783
- Mean: 14,764
- High: 160,000
- Lowest three responses: 0, 100, 250

Question 8b: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Pennies

59 responses

- 56 responses of 0
- Among those with response > 0:
  - Total: 625
  - Mean: 208
  - High: 400
  - Low: 25

Question 8c: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Nickels

64 responses

- 29 responses of 0
- Among those with response > 0:
  - Total: 4589
  - Mean: 131
  - High: 1000
  - Low: 5

Question 8d: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Dimes

63 responses

- 24 responses of 0
- Among those with response > 0:
  - Total: 7335
  - Mean: 188
  - High: 1500
  - Low: 10

Question 8e: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Quarters

83 responses

- Total: 1,160,603
- Mean: 13,983
- High: 160,000
- Lowest three responses: 100, 250, 400

Question 8f: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Half dollars

55 responses: 54 responses of 0; one response of 10

Question 8g: What is the approximate number of coins (and tokens) processed by your coin acceptors per week? Dollar coins

58 responses

- 34 responses of 0
- Among those with response > 0:
  - Total: 32,076
  - Mean: 1336
  - High: 10,000
  - Low: 1

Question 9: Of your total coin acceptors, how many determine coin (and token) quantities by weight?

71 responses

- 49 responses of 0
- Among those with response > 0:
  - Total: 1353
  - Mean: 62
  - High: 131
  - Low: 3

Question 10: Of your total coin acceptors, how many determine coin (and token) quantities by stack height?

61 responses

- 51 responses of 0
- Among those with response > 0:
  - Total: 9674
  - Mean: 967
  - High: 5000
  - Low: 1

Question 11: Of your total coin acceptors, how many determine coin (and token) quantities by counting?

68 responses

- Total: 83,247

Comment: after sending out survey, CTC realized that this question was likely misleading and the results were therefore considered invalid.

Question 12: What impact (including cost per unit) would you face if any of the following coin properties were changed? [Radio Buttons: Scale 1 to 10 + "Unknown or N/A"]
48 responses
Mean response is given for each of the following.

- Diameter: 9.7
- Thickness: 9.7
- Weight: 8.5
- Metallic Content: 7.4
- Color: 3.0
- Gloss: 3.1
- Hardness: 3.8
- Electromagnetic Signature: 6.8

Question 13: Please provide comments concerning potential changes to any of the above coin properties.
39 responses; significant responses follow.
"Changing any of the basic qualities of coins, quarters in particular, would be VERY costly & likely would put us out of business."
"Just don't replace the paper dollar with a coin . . . since a huge portion of our income is with dollar bills."
"I do feel STRONGLY that the US Mint should eliminate the PAPER DOLLAR."
"My customers prefer coins over the card system."
"Change all coins or get rid of them entirely . . . Coins are a nuisance and don't have enough value to justify production in today's economy."
"Quarters are critical to my business."

Question 14: What is the total number of electronically-based coin acceptors at your facility/facilities that are less than 6 years old?
82 responses

- 26 responses of 0
- Among those with response > 0:
  - Total: 2549
  - Mean: 45.5
  - High: 300
  - Low: 2

Question 15: Electronically-based acceptors that are between 6 and 10 years old?
75 responses

- 27 responses of 0
- Among those with response > 0:
  - Total: 1362
  - Mean: 28
  - High: 173
  - Low: 1

Question 16: Electronically-based acceptors that are greater than 10 years old?
70 responses

43 responses of 0

Among those with response > 0:

Total: 1711

Mean: 63

High: 604

Low: 1

Question 17: What is the total number of mechanically-based acceptors at your facility/facilities that are less than 6 years old?
71 responses

43 responses of 0

Among those with response > 0:

Total: 386

Mean: 13.8

High: 30

Low: 1

Question 18: Mechanically-based acceptors that are between 6 and 10 years old?
65 responses

43 responses of 0

Among those with response > 0:

Total: 386

Mean: 17.5

High: 150

Low: 1

Question 19: Mechanically-based acceptors that are greater than 10 years old?
67 responses

38 responses of 0

Among those with response > 0:

Total: 383

Mean: 13.2

High: 82

Low: 1

Question 20: What is the approximate number of coin acceptors in your business that accept pennies?
77 responses
4 total from all responses
From responses to Questions 1 and 20: percentage of acceptors that accept one-cent coins: 0.039%.

Question 21: What is the approximate number of coin acceptors in your business that accept nickels?

79 responses

- 27 responses of 0
- Among those with response > 0:
  - Total: 221
  - Mean: 4.25
  - High: 20
  - Low: 1

From responses to Questions 1 and 21: percentage of acceptors that accept 5-cent coins: 2.1%.

Question 22: What is the approximate number of coin acceptors in your business that accept dimes?

79 responses

- 26 responses of 0
- Among those with response > 0:
  - Total: 226
  - Mean: 4.26
  - High: 20
  - Low: 1

From responses to Questions 1 and 22: percentage of acceptors that accept dime coins: 2.2%.

Question 23: What is the approximate number of coin acceptors in your business that accept quarters?

86 responses

- Total: 8241
- Mean: 96
- High: 800
- Low: 0

From responses to Questions 1 and 23: percentage of acceptors that accept quarter dollar coins: 79.5%.

Question 24: What is the approximate number of coin acceptors in your business that accept half dollars?

71 responses

- 64 responses of 0
- Among those with response > 0:
  - Total: 42
  - Mean: 6
  - High: 20
  - Low: 2

From responses to Questions 1 and 24: percentage of acceptors that accept half dollar coins: 0.4%.

Question 25: What is the approximate number of coin acceptors in your business that accept dollar coins?

77 responses

> 42 responses of 0
> Among those with response > 0:
>> Total: 1291
>> Mean: 37
>> High: 500
>> Low: 1

From responses to Questions 1 and 25: percentage of acceptors that accept dollar coins: 12.4%.

Question 26: Please provide any comments that you have concerning a <u>potential</u> redesign of U.S. circulating coins.

41 responses; significant responses follow.

"Don't mess with a good thing."

"It's a good idea if it is helping economy and country, business like should be able to take care of themselves by moving to latest equipments or probably credit card acceptance."

"ELIMINATE THE PAPER DOLLAR AND PENNIES."

"Quit wasting money on dollar coins!"

"Circulating and popularizing dollar coins would be enormously beneficial to laundromat owners."

"I only deal in quarters but they have to be the same diameter."

"Today, my laundromat is Dollar Coin Only (DCO). My customers have adapted to my 5 year change over from quarters to dollar coins."

"They must work in current vending units to be at all practical."

"Costs associated with this endeavor will result in staff reduction."

Question 27: Would you be willing to be contacted concerning follow-up questions to this survey?

89 responses

> Yes: 65%
> No: 35%

Question 28: Optional Information: Please list your name, company, address, phone number and e-mail address.

Contact information supplied from selected respondents.

4.14.3 Appendix 4-C: Detailed Stakeholder Data

4.14.3.1 Vending Machine Owners and Operators

In the US, there are approximately 5.3M food and beverage vending machines [1]. Approximately 200,000 vending machines[116] (the majority of which were manufactured before approximately 1986) are still in service that rely upon communication protocols that are no longer supported by the industry. For these latter vending machines to accept non-seamless coins they will require installation of a communications adaptor or they will have to be replaced in their entirety since changes to US circulating coin characteristics and/or properties cannot be directly accommodated by these machines.

Based upon the vending industry questionnaire results, the average vending machine site has 2.81 vending machines. More than 98% of the vending industry coin acceptors use active coin sorters (typically based upon EMS) to recognize coins and 84% of the vending industry coin acceptors in service are less than 10 years old (as of Fall 2011).

According to the questionnaire results, of the coins **collected** by vending machines:

- 53% are quarter dollar coins
- 31% are dime coins
- 8% are dollar coins
- 8% are 5-cent coins
- Far less than 0.1% is either one-cent or half dollar coins.

In terms of the distribution of coin denominations that are **recognized** by the coin acceptors in the vending industry:

- 92% recognize quarter dollar coins
- 91% recognize dime coins
- 91% recognize 5-cent coins
- 81% recognize dollar coins
- 6% recognize half dollar coins
- 0.007% recognize one-cent coins.

Approximately 8% of vending machines do not accept coins for payment. Presumably, they accept notes, tokens and/or non-cash payment methods such as credit/debit cards.

In terms of 2010 revenues, 85% of total vending sales came from operators whose individual annual vending revenue was at least $5M [1]. These operators are referred to in this report as large vending machine owners and operators; those operators with annual sales of less than $5M are referred to in this report as small vending machine owners and operators. The large vending machine owners and operators are generally big enough to have their own maintenance staff. Those that do are often able to install upgrades themselves at lower cost than that for small vending machine owners and operators who typically rely on third-party service centers for modifications or services to their equipment. In addition, large vending machine owners and operators would likely receive large-volume discounts for any hardware upgrades that would be

[116] Since these 200,000 machines are included in the 5.3M total vending machines, only 5.1M vending machines are assumed to use the modern communications protocol.

required to recognize alternative material coins. A 5% large-volume discount was assumed for large vending machine owners and operators.

Since 92% of the 5.1M vending machines recognize quarter dollar coins, a maximum of 4.692M vending machines would have to be upgraded if quarter dollar coin characteristics and/or properties changed. If changes are made to the characteristics and/or properties of either (or both) the 5-cent or dime coins without any changes to the characteristics and/or properties of the quarter dollar coin, then a maximum of 4.641M machines would require upgrades. Given the meager usage of and low recognition rate of one-cent and half dollar coins, the present analysis assumes that changes to either or both of these coins will not precipitate a need to upgrade coin acceptors used in vending machines should coin characteristics and/or properties of either of these coins change. Although alternative material changes to the dollar coin have not been fully experimentally investigated in this study, since the production of circulating dollar coins was suspended in December 2011 [2], the number of vending machines requiring upgrades strictly due to changes to the dollar coin, which are still accepted by 81% of vending machines, would be a maximum of 4.131M.

4.14.3.1.1 Large Vending Machine Owners and Operators

If the number of vending machines is scaled by total revenue, then 85% of the vending machines are owned and/or operated by large vending machine owners and operators. All coin acceptors (active or passive) older than 10 years were assumed to require full replacement at a discounted per unit cost between $142.50 and $237.50; $190.00 was assumed to be the most-probable cost per new coin acceptor. These values represent typical discounted costs for newly manufactured active coin acceptors across coin-acceptor manufacturers/retailers and commonly available models.[117]

For active coin acceptors between 6 and 10 years old assuming a change in EMS, but no change in coin dimensions, upgrades would consist primarily of software uploads or modifications; hardware replacement would not be required. Therefore, the projected upgrade costs were found to be between $25 and $42, where $25 represents the minimum labor or service fee to complete the upgrades while the $42 per unit value includes another 20 minutes of labor (at a fully burdened rate of $50 per hour) per unit beyond the low estimate of $25. The value selected as the most-probable cost for upgrading these units is $25.

Costs for upgrading active coin acceptors less than 6 years old were found to be between $17 and $25 per unit to reflect the cost range from various suppliers to upload software to these coin acceptors. A value of $25 per acceptor was selected as the most-probable value for the present analysis. All of these values assume that new coins remain the same dimensions as the incumbent coins. Changes to coin dimensions would require that all coin mechanisms be replaced.

[117] The most commonly quoted service fee for coin acceptor upgrades was $75 per site, where the average number of vending machines per site (from questionnaire results) is 2.81. Consequently, the service fee per machine is approximately $25 (i.e., $75 per site fee divided by 2.81 machines per site).

4.14.3.1.2 Small Vending Machine Owners and Operators

Small vending machine owners and operators control the remaining 15%, or 703,800, of the vending machines needing upgrades as a result of changes to quarter dollar coin characteristics. A total of 696,150 vending machines would require upgrades if changes were made only to the 5-cent and/or dime coins. No vending machine changes are assumed to be needed by the small vending machine owners and operators if changes were made to the one-cent or half dollar coins; and 619,650 vending machines would need to be upgraded if changes were introduced to the dollar coin. Small vending machine owners and operators rely on third-party providers to complete upgrades and maintenance to their vending machines. Service calls for completing third-party upgrades were estimated by the stakeholders to be between $50 and $75 per site.

To upgrade units manufactured prior to 2001, the following assumptions were made: $75 per site service call, three vending machines per site and hardware costs (between $150 and $250; $200 is the most probable hardware cost). Therefore replacement of coin-acceptor units would cost small vending machine owners and operators between $175 and $275 per unit. The most probable value used was $225 per vending machine.

Upgrades to coin-acceptor units installed between 2001 and 2006 typically can be either 1) taught to recognize coin characteristics and/or properties (either dimensions or EMS) that are different from the incumbent coins or 2) can be removed from the vending machine and sent to a service center for upgrades. Either of these scenarios would cost approximately $42 to $50 per unit based upon a $75 service fee split among three vending machines and between 20 and 30 minutes additional labor (at $50 per hour fully loaded) per machine. The most-probable scenario assumed was $42 per unit.

Estimates for upgrading units produced after 2006 range from $27 to $35 per unit based upon a $10 software upload fee applied to all machines and between $50 and $75 per site service fee to upload upgraded software; three vending machines per location was assumed. The most probable per unit upgrade cost for the post-2006 units was $27. Based upon the experience from the coin-acceptor manufacturers and the coin-acceptor service centers, the majority of small vending machine owners and operators will wait until maintenance on the coin acceptor is required before upgrades are requested. At that time these small vending machine owners and operators will have the new software uploaded for up to $10 per acceptor. This strategy will save the service fee that would otherwise be assessed to solely upload new software resulting from changes to coin characteristics and/or properties. However, the cost analysis assumed here does not account for small vending machine owners and operators taking advantage of such a scenario; all impacted coin accepters are assumed to be immediately replaced/upgraded.

4.14.3.2 Laundromat Owners and Operators

The laundromat industry differs from the vending industry in several respects. First, the average number of machines per site is 53 for laundromats, compared to 2.81 for vending. Secondly, the majority (98% by some estimates) of laundromat owners and operators performs their own maintenance and many of the units rely upon passive coin acceptors. Passive units include slides, whereby coins are placed into holding slots and after placing the required number and denomination of coins in these slots, the mechanism is slid into passive coin recognition hardware, which typically checks for coin diameter and thickness. The total number of laundromat machines in the US is estimated to be 5.1 million units based upon combined totals from public laundromats and those at college dormitories, hotels, apartment complexes and similar multi-housing facilities. The coin acceptors in this industry typically last approximately 10 to 15 years.

According to the questionnaire results from this stakeholder group, 82% of all laundromat coin acceptors are electronic-based (i.e., rely on active sensing to validate coins); the other 18% are passive. Of all laundromat coin acceptors, 63% are less than 10 years old.

One of the by-words in the laundromat industry is that the "quarter dollar coin is king." This is borne out from the questionnaire results, which showed that 96% of the coins collected from laundromat owners and operators are quarter dollar coins; 2.8% are dollar coins, while the other coin denominations account for less than 1% each.

Among all laundromats, 80% of the machines are equipped to accept quarter dollar coins; 12% of the machines accept dollar coins; 2% of them accept dime coins; 2% of them accept 5-cent coins; and less than 1% of laundromat machines accept either half dollar or one-cent coins. (Note that some of the respondents to the laundromat questionnaire indicated that other machines were present at their facilities, including vending machines. The reported totals for the one-cent, 5-cent, dime and half dollar coins are assumed to be associated with other products or services offered by the laundromat owners and operators.)

Therefore, for purposes of the current analysis, impacts to the laundromat stakeholders will be based strictly upon the use of quarter dollar and dollar coins. Approximately 20% of laundromat machines are designed to accept notes, tokens or non-cash payment options including credit/debit/customer loyalty cards. No known laundromat coin mechanisms[118] are designed to provide change. Therefore, coin mechanisms for the laundromat industry are simpler and less expensive than the units used by the vending industry.

Since "the quarter dollar coin is king," the main focus of the present analysis was on the impact associated with changes to the quarter dollar coin. Of course, changes to the dollar coin, in spite of the current suspension of its production as a circulating coin, must also be considered since many laundromats remain dependent upon the use of dollar coins. A few laundromats are "dollar only" establishments, meaning that the only coin accepted is the dollar coin.

The analysis conducted for the laundromat owners and operators assumed that all active coin acceptors manufactured before 2001 would require replacement with a new model costing between $125 and $150. The most-probable value is $135 for purchase of new active coin acceptors for laundromat use. New active coin acceptors would likely be installed by current maintenance staff as part of their daily activities. Therefore, under the low-cost estimate, no additional labor hours are assumed for installation of any new coin acceptors. Both the high-cost estimate and the most-probable cost estimates account for installation of each new coin acceptor to occur in 20 minutes. The cost of this labor (at an assumed fully burdened rate of $50 per hour) is accounted for in the high and most-probable cost calculations: for the high-cost estimate, all labor is assumed to be completed during overtime using existing staff or through

[118] A coin mechanism includes the coin acceptor plus any other mechanical features used to process coins. Coin mechanisms may include systems that move coins around, return invalid coins to the customer, store coins for later retrieval (to make change for example) or perform other mechanical functions to coins that are necessary for the proper operation of the machine.

hiring added staff, while for the most-probable cost estimate, half of the units were assumed to be installed during preexisting planned staff labor hours, while the other half would require extra labor hours at cost to the laundromat owners and operators.

Consistent with the acknowledgement of coin-acceptor manufacturers, the active units in the field that are between 6 and 10 years old (as of Fall 2011) could be taught to recognize new coins. The low-cost estimate for this activity assumes that the current laundromat staff completes this activity as part of their daily activities with no added cost to the laundromat owners and operators. The high-cost estimate assumes that these units can be taught to recognize the new quarter dollar and/or dollar coins in 15 minutes, while the most-probable cost estimate assumes that this can be completed in 10 minutes. In both cases, it was assumed that the teaching time represents additional labor beyond that currently budgeted for existing staff.

Uploading new software for active coin acceptors purchased after 2006 was assumed to require a $10 upload fee for all cost scenarios. The low-cost estimate for upgrading these coin acceptors included only the $10 upload fee and all labor required would be completed by existing staff within currently budgeted labor hours. For the high-cost estimate, it was assumed that each of the units could be upgraded in 15 minutes and that this would require labor beyond that currently budgeted for existing staff. The most-probable cost estimate assumed that half of the new coin acceptors could be installed with currently budgeted labor hours and the other half of the coin acceptors would be installed with labor hours beyond those currently budgeted for staff.

Passive units, including slides, which are prevalent in laundromats, rely on coin dimensions. Therefore, changes to the materials of construction of coins while maintaining incumbent coin dimensions will not impact these units. However, changes to coin dimensions will require replacement of these units. Passive units retail for between $50 and $100. The most-probable cost used in the present analysis was $75 per unit. The low-cost estimate assumes that replacement of passive coin acceptors—an estimated 15-minute task—will be made by preexisting staff as part of their normal activities. The high-cost estimates assume that replacements will require 15 minutes of labor per unit beyond that currently budgeted for existing staff. The most-probable cost estimate assumes that half of the replacements will be made with currently budgeted labor hours and the other half of the coin acceptors will be installed with labor hours beyond those currently budgeted for existing staff.

4.14.3.3 Pay Phone Owners and Operators

The US has approximately 425,000 public pay phones currently in service [3]. As a result of increased cell phone availability, the number of pay phones has dropped considerably since 2000 when over 2.0M pay phones were available in the US.

Approximately 85% of the installed pay phones rely upon passive coin-recognition technology. Coin diameter and thickness are carefully measured in these units. A counterbalance on a pivot within a cradle is used to validate coin weight. The pay phone industry was reluctant to indicate what tolerances in coin diameter, thickness and weight are acceptable to pay phones. To aid in addressing this issue, CTC acquired a popular pay phone coin mechanism to assess its dimensional and weight limits. Due to security concerns associated with providing these experimental results, this information (i.e., defining the acceptance windows), test results are not reported here. However, these findings were forwarded to the United States Mint. Changes to coin dimensions outside the associated acceptance window (among the 5-cent, dime and/or quarter dollar coins) would require that the mechanical coin acceptors be replaced at an estimated hardware cost of between $150 and $200 each; $175 was assumed as the most-probable cost. In all cost scenarios (low, high and most-probable) a $75 per site service fee was also assumed with two pay phones per site.

As an alternative to upgrading units, the pay phone owners and operators could accept only incumbent US circulating coins for payment. Passive coin acceptors cannot simply be replaced with active units in pay phones.

Active coin acceptors have been developed and are in use in approximately 15% of pay phones. These units carefully check a coin's dimensions and EMS; they can accept up to 14 different coin configurations. Upgraded software can be uploaded to these units for a service fee of approximately $75 per site. Some providers also charge a $10 fee to upload new software to a pay phone. These upgrades would be needed on active devices regardless of a change in EMS or coin dimensions. A $75 service fee per site, two phones per site and $10 software upload fee was assumed for all cost scenarios (low, high and most-probable) for changes to active coin acceptors in pay phones.

Pay phones typically only accept 5-cent, dime and/or quarter dollar coins. For this analysis, 100% of pay phones were assumed to accept quarter dollar coins, while only 90% of existing pay phones were assumed to accept 5-cent and dime coins in addition to quarter dollar coins. No evidence was found that suggests that any US pay phones accept one-cent, half dollar or dollar coins. Therefore, the analysis assumes that no conversion costs are required for pay phones from any changes to the one-cent, half dollar or dollar coins.

Change is not provided by pay phones; however, coins are held in escrow until the caller is connected with the other party. At that time the coins are released into the cash box. If no connection is made to the other party, then the inserted coins are returned to the caller.

4.14.3.4 Municipal Parking Officials

There are an estimated 2.0M parking meters in the US [4]. Legacy units, estimated at 10% of the total, rely upon the patron inserting a coin and then turning a crank that passes by several gates to passively validate the coin. Passive parking meter units evaluate diameter and thickness to determine the legitimacy of a coin. These remaining passive units are gradually being replaced with active coin validation technology that relies upon EMS and coin dimension detection technology that is similar to that used in vending machines.

Virtually 100% of parking meters accept quarter dollar coins for payment; an estimated 50% of parking meters also accept dime and 5-cent coins for payment. Only the active acceptors process dollar coins; approximately 50% of the active parking meter coin acceptors recognize dollar coins. From an Internet search to define the types of parking meters available in various major cities throughout the US, no fielded parking meters were found that accept one-cent coins and none were found that explicitly stated that they accept half dollar coins. No known parking meters return change.

In addition to coin payment options, many parking meters in use today allow for credit/debit card payment; some also allow for use of other cashless payment methods including payment through cell phone apps. Notes are not typically accepted by parking meters that service a single parking space. Many cities have installed kiosk stations that either service a specified group of parking locations or provide a validation pass for any parking spot within the jurisdiction of the associated parking authority. These kiosks typically accept multiple forms of payment including notes.

Should only the EMS of coins change, then none of the passive parking meter coin acceptors will be impacted. However, the active units would require new software uploads, which are assumed to cost $10 each. Software uploads for upgrading a large number of parking meters are expected to be made a rate of 6 to 12 per hour and require staff to work hours beyond their currently budgeted hours. The low-cost scenario assumes that current parking meter staff members complete the software upload in 5 minutes per meter. The high-cost scenario assumes a software upload every 10 minutes; while the most-probable cost scenario assumes a software upload every 7.5 minutes. A fully loaded labor rate of $50 per hour was assumed.

No known parking meters use coin weight as a validation parameter. Therefore, changes to coin weight (while keeping both EMS and dimensions consistent with incumbent coins) will have no known impact to parking meters.

Changes to coin dimensions will necessarily impact both passive and active coin acceptors. Such a change would require that passive units have their coin validator replaced. Although very sophisticated models, which accept credit cards, allow for cell phone payments and are solar powered, are on the market for upwards of $600 each; the assumption used for the present analysis is that simple coin drop units would be used to replace passive units.

These coin drop units retail for approximately $120 to $150 each. The most-probable cost was assumed to be $135 each. One industry expert indicated that these units can be replaced in 5 minutes or less. The low-cost scenario assumes that parking meter coin acceptors can be changed over in 5 minutes each. The high-cost scenario assumes that parking meter coin acceptors can be changed over in 10 minutes each; while the most-probable scenario assumes that parking meter coin acceptors can be changed over in 7.5 minutes each. Each scenario also assumes that all upgrades are completed during additional, currently unbudgeted hours at a fully burdened labor rate of $50 per hour.

Existing EMS-based units will also require upgraded software if coin dimensions change. The cost assumptions for changes to coin dimensions are the same as those for changes to coin EMS in parking meter coin acceptors.

4.14.3.5 Amusement Machine Owners and Operators

This stakeholder group, which has annual revenues of approximately $750M from coin-operated games and rides [5], includes games common to arcades and family entertainment centers (FECs). An estimated 1.7M coin acceptors are used by this stakeholder group, which is dominated by the quarter dollar coin and customized tokens for payment.[119] Changes to coins

[119] Actual percentages by denomination of coins collected were not found for this stakeholder group. In the few FECs visited by CTC during execution of this project, no US circulating coin other than the quarter dollar coin was accepted in any amusement machines. Based upon that limited exposure, it is assumed in this analysis that the only US circulating coin accepted in amusement machines is the quarter dollar coin.

other than the quarter dollar coin would not significantly impact this stakeholder group and are therefore not included in the present analysis.

Due to their simplicity of design, the majority of amusement machine coin validators are serviced by the owners or staff of the establishments that operate the equipment. Any upgrades would be completed by owners/staff of these businesses. Very few amusement machine owners and operators rely upon third-party suppliers for this type of service.

More than 70% of the coin validators used in amusement machines rely only on coin dimensions for validation. Of these, many coin acceptors use a removable magnet to sort out steel slugs. Some of the coin acceptors validate that coins are of metallic composition, although they do not attempt to validate the metal(s) used in the coin's construction. Therefore, changing the metallic composition, while maintaining the dimensions of the quarter dollar coin, would be minimally disruptive to the amusement stakeholders. A maximum of 30% of the amusement coin acceptors would require an upgrade if the quarter dollar coin's EMS was altered.

Given that the majority of the EMS-based coin acceptors used in the amusement industry can be taught to recognize coins having differing dimensions and/or EMS, the estimated cost impact to the owners and operators was based upon the labor to teach the units to recognize the alternative material coins.[120] For the present analysis, the low-cost estimate is based upon the FEC staff teaching the EMS-based coin acceptors as part of their daily activities. The high-cost estimate assumes that this function is completed in 10 minutes (only the alternative material quarter dollar coins would be required) and that this work is completed by currently unbudgeted staff hours at a fully loaded labor rate of $50 per hour. The most-probable scenario assumes that 50% of coin acceptors would be updated by existing staff as part of their daily activities; the other 50% would be upgraded with labor not currently budgeted for operating the FEC. Use of plated-steel coins would require the removal of magnets—a five-minute (or less) per machine task according to one of the amusement coin-validator manufacturers. Due to the limited amount of time required to remove any magnets, this task was assumed to be performed in its entirety by existing staff during currently budgeted work hours. Therefore, no cost impact for removal of magnets was assumed in the present analysis. Given that the amusement machine owners and operators "sell time" on their machines, the industry is not as vigilant as the vending industry to abate attempts at fraud.

This industry does not return change. Therefore, all coins are transferred directly to the cash box upon being accepted. Invalid coins are returned to the customer. Coins are also returned to the customer when the coin validator is temporarily incapacitated.

Co-circulation of two coins of differing dimensions would be problematic for this industry, whose coin acceptor infrastructure is heavily invested in quarter dollar coins of incumbent dimensions. Changing the dimensions of the quarter dollar coin would require that all passive coin acceptors be replaced with new models at a cost between $50 and $150. The most-probable cost assumed here was $100. Installation may be completed by existing staff during their typical

[120] Teaching these units to learn and accept the characteristics of new coins involves switching the unit to learn mode, dropping multiple coin through the device and saving the resulting sensor readings to the unit's database. This task typically takes less than 20 minutes. While ideally, all FEC machines would be upgraded before the release of new coins, completing the task within a few months after public release of new coins is not likely to significantly impact this stakeholder group.

daily activities, which is assumed for the low-cost estimate. For the high-cost estimate, 15 minutes of currently unbudgeted labor is assumed, while the most-probable cost estimate assumes a 15-minute per unit replacement effort and that 50% of the labor to complete upgrades is completed by employees as part of their normal work activities while the remaining 50% of the labor requires hours not currently budgeted by the amusement machine owners and operators.

4.14.3.6 Transit Officials – Public Transportation Fare Boxes

In the US, some 60,000 public buses are used by daily commuters, primarily in larger cities. Of these, 40,000 buses rely upon active coin-acceptance equipment (most use EMS detection methods); the remainder of the buses relies upon driver visual recognition and acceptance of the fare as it is dropped into a clear box. Most of the 40,000 active coin-acceptance devices can be quickly reprogrammed through a software upload to recognize coins having different dimensions and/or EMS from the incumbent coins.

Software uploads can be made from a small, dedicated computer with a USB connection. According to one industry expert, these uploads typically require about one minute to complete and the entire fleet of buses in any major US city can be upgraded in one weekend employing a handful of workers. This effort could be completed with existing staff without interruption to the operation of the buses. At 6 upgrades per hour, 8-hour shifts, fully loaded labor costs of $50 per hour and two days per person doing the upgrades, 18 persons could upgrade 1728 buses (approximately the number of public buses in Chicago, Illinois, which has a total of 1782 public buses [6]) over a two-day weekend. With an assumed software upload fee of $10 per bus, this would result in a total cost of $32,670 for the city of Chicago. New York City, which has 4373 public buses [7], would require a staff of 46 individuals working 16 hours each to upload the software to all buses. This would cost approximately $80,200 at a fully-burdened rate of $50 per hour and a $10 per bus software upload fee.

According to one industry expert, Chicago has approximately 2000 ticket vending machines, while New York City has approximately 3000 such machines. This averages less than one ticket vending machine for each public bus in these cities. Extrapolating these limited data to all 60,000 public buses across the United States, and doubling that to account for train, subway and other forms of public transportation, one arrives at a first-order approximation of 120,000 transit ticket vending machines in the US. The impact to these automated ticket vending units is included in the section above entitled Vending Machine Owners and Operators.

4.14.3.7 Car Wash Owners and Operators

This industry relies almost exclusively on quarter dollar coins, dollar coins and tokens. No change is provided by car wash coin mechanisms. Other forms of payment, including notes and credit/debit cards, are also accepted for payment. Changes to the one-cent, 5-cent, dime or half dollar coins will have no measurable impact to the car wash industry.

There are approximately 300,000 car wash coin-acceptor units throughout the United States. Several types of coin acceptors are used by this stakeholder group:

- Dimensions-only acceptors

- Sample coin comparators[121]
- EMS-based units.

The information gathered from various representatives of this stakeholder group showed significant discrepancies in terms of the numbers of fielded coin acceptors that exist within each of these coin-acceptor types. CTC's assessment of these discrepancies is that of the fielded units, 30% validate based upon coin dimensions only, 50% of the units are sample coin comparators and 20% of the coin acceptors are EMS-based units.

The dimensions-only units would not be impacted by a change to coin weight and/or EMS; however, they would require replacement if the quarter dollar and/or dollar coins were changed in dimensions. Replacement units would cost between $100 and $130 each; $120 was chosen as the most-probable cost.

Sample coin comparators that are designed to accept multiple coins can be reconfigured within 5 minutes to accept alternative material coins having differences in dimensions, weight and/or EMS. Sample coin comparators that are designed to accept single coins would have to be replaced with multiple-coin units if alternative coins have different dimensions, weight and/or EMS from the incumbent coins. Alternatively, owners of these units may choose to switch to token-based systems, which would allow continued use of single-"coin" units. For this analysis, it is assumed that 50% of the coin comparator units will be replaced if an alternative material quarter dollar and/or dollar coins were released into circulation that differs from incumbent coins in dimensions, weight and/or EMS. The purchase price for these multi-coin units is between $120 and $175; the most-probable cost was assumed to be $150.

EMS-based units can be quickly taught to recognize alternative coins. This task can be completed during existing work hours by existing staff of the car wash owners and operators.

Based upon provider feedback, car wash owners and operators were found to be very hands-on individuals, they would complete all upgrades using existing staff as part of their daily activities. Therefore, labor costs are assumed to be zero for all upgrades required by the car wash owners and operators.

4.14.3.8 Merchants

Four pieces of equipment common to merchants that could be impacted by changes to US circulating coins are automated coin sorters/counters, coin change makers, automated coin return kiosks, automated and self-checkout stations.

Nearly all of the coin sorters/counters used by merchants (to quickly and accurately count coins in cashier till drawers, to sum the cash on hand at the end of a business day or similar coin sorting/counting tasks) rely strictly upon coin dimensions for sorting/counting operations. Validation of the coins is assumed to have occurred at the time coins were accepted (typically in

[121] This type of coin acceptor relies upon use of a sample circulating coin (or token) to which all incoming coins are compared. By placing any desired coin or token into a designated holder (a task that takes less than 5 minutes), a new coin or token can be immediately used as the standard of acceptance. Units available on the market are typically designed to accept between one and three separate coins/tokens. Within the car wash industry, these units are often set up to accept quarter dollar coins, dollar coins and/or tokens. Co-circulated coins of any one denomination could be accommodated by two- or three-coin comparison-based coin validators.

hand-to-hand transactions) and placed into cashier till drawers or other coin collection units. Therefore, if coin dimensions remain the same as the incumbent US circulating coins, then no cost impact will be felt by merchants who use these passive coin sorting/counting devices. Costs required to accommodate changes to coin dimensions are discussed in and accounted for in the Manufacturers of Commercial Coin-Handling Equipment Section of this appendix.

Automated coin change makers will not be impacted by changes to any coin's materials of construction if the coin dimensions do not change. However, based upon input from one manufacturer of automated coin change makers, if the coin diameter is changed (by more than about 2%[122]), then these units will require mechanical upgrades. Upgrades to accommodate changes in coin diameters are estimated to be between $50 and $100 per unit for the estimated 250,000 units currently in the US. The most-probable cost was assumed to be $75 per unit. The analysis assumes that replacement of the new hardware for any change in coin dimensions would require a simple snap-in of new coin holders – a task that would merely require a new part be sent to each merchant. The new unit would then be attached in less than one minute. Therefore, no labor costs are accounted for in the present analysis. Changes to coin thickness will result in the quick coin count scales prevalent on these devices to become useless, especially with co-circulated coins having as much as a 1% difference in stack height. Significant changes[123] to coin thickness will also require mechanical changes to these devices. For purposes of determining the conversion costs of automated coin change makers required by a significant change to coin thickness, an engineering estimate was made. Costs were assumed to be between $50 and $100 per unit; $75 per unit was assumed as the most-probable cost.

Some local retailers use the services offered by coin return kiosks, like those offered by[124] Coinstar®, Money Machine™ (by Cummins Allison Corporation) and CoinCasher™ (by SCAN COIN), to allow customers to return their loose, unsorted coins. Upgrades to these devices are accounted for in the Manufacturers of Commercial Coin-Handling Equipment Section of this appendix.

A technology that has recently been gaining a foothold within the retail world is self-checkout stations having payment options that include the use of coins. These units use automated coin validators, which function in principal very much like the units used in vending machines or coin sorting/counting machines. If changes to dimensions and/or EMS were made to coins, these units would have to be upgraded in much the same manner as coin validators used in vending and other industries. A recent estimate claimed that 70,000 self-checkout lanes exist throughout North America [8]. Given their recent introduction in the retail space, and based upon input received from a few suppliers of this equipment, these units use technology that can be easily and quickly upgraded via a software upload to accept coins of different dimensions and/or EMS.

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[122] A reference was made to an acceptable diameter difference of a lower value in the section entitled "Additional Comments about Vending Machine Owners and Operators" in the body of this chapter. The value presented for automated coin change makers applies to the impact on automated coin change makers and is independent of the requirements of vending machines or other devices.

[123] The industry was not willing to commit to a specific value to define "a significant change in thickness" without a detailed engineering assessment. However, the industry did suggest that a 10% increase in stack height would be above the expected limit that would be acceptable with today's fielded automated change making equipment.

[124] These are examples only. Their listing here does not represent an endorsement of these products by either the United States Mint or CTC.

The present analysis assumes that 80% of the North American units are in the US for a total of 56,000 self-checkout units in the US; to upgrade for new coins these units require a per-site service fee of between $50 and $75; and three units exist per site. A $10 software upload may be changed by some providers. The high-cost and most-probable cost scenario is a $75 per site service fee and a $10 per unit software upload fee. The low-cost scenario assumes no software upload fee and a $50 per site service fee.

4.14.3.9 Manufacturers of Commercial Coin-Handling Equipment

Automated coin sorters/counters are used to quickly and accurately sort and/or count loose coins. Sorting and counting rates in excess of 10 coins per second are common in high-speed machines. They are the only practical tool to sort and/or count large quantities of coins. Industrial-scale machines, which can cost upwards of $70,000, are common at coin terminals and at central coin collection sites for transit authorities, vending machine enterprises, laundromats and other businesses that must sort and/or count hundreds of thousands or more coins per week. These industrial-scale machines typically use active sensors that inspect each piece for and sort coins by dimensions (diameter and thickness), EMS, edge profile (reeds, smooth or edge lettering) and potentially other characteristics.[125]

In addition, coin-accepting kiosks that sort and count coins can be found in grocery stores, bank lobbies and other public locations. These kiosks are used to collect loose change from the public in exchange for a receipt that can be given to a nearby attendant for cash or credit towards store purchases. Given their function, these devices must be upgraded and ready for any alternative coins in advance (an estimated 6- to 12-month effort) of the Federal Reserve Bank (FRB) releasing alternative coins into circulation.

The most sophisticated models of these coin-handling machines sort coins by denomination, based upon their unique dimensions, EMS and whatever other characteristics and/or properties the specific machine is designed to measure. These machines can also sort coins by incumbent versus alternative coin construction when measured characteristics and/or properties differ between the two sets of coins. This ability could be useful if doing so would be beneficial for downstream processing of the coins.

Updates to the software/databases of these devices would be required as a result of changes to the EMS and/or dimensions (and/or potentially other characteristics or properties that may be [but rarely are] used for validation) of US circulating coins. These updates can be completed with a simple software push, which is assumed to cost $10 for each machine upgraded. A service call fee is also assumed for all upgrades. The cost of the upgrades was found to be between $50 and $75 per site. The low-cost and most-probable estimates, which would likely apply to fleet owners for upgrading machines during regular maintenance service calls was $50 per site and two machines per site; the high-cost estimate corresponds to a single machine residing at a remote location that requires a $75 service call.

Discussions with one user of coin wrapping equipment indicated that the cost to upgrade to enable handling of coins having new materials would be minimal or non-existent assuming that

[125] Manufacturers of high-speed sorting machines offer sorting technology that is rarely purchased by clients. This technology includes color recognition (a low-reliability technology) and other technologies whose fundamental measurements are proprietary.

no changes were made relative to incumbent coin dimensions. Changes to coin dimensions, however, would likely result in some required changes to the machines. One of the owners of coin wrapping equipment indicated that changes to coin dimensions (so long as new coins were no thicker than or larger in diameter than incumbent half dollar coins nor were they thinner or smaller in diameter than the incumbent dime coin) they could make adjustments on their machines to accommodate coin size changes without an appreciable cost to their operation. As a result, the present analysis does not include any upgrade costs for coin wrapping devices.

Another class of commercial coin sorting/counting equipment relies upon passive coin-recognition technology. Some of these passive designs also include a sensor whose sole purpose is to detect if a piece is metallic. Any piece not recognized as metallic is rejected as a legitimate coin. Some models also offer magnetic separation to ferret out steel-based slugs. Many more of these passive coin sorter/counter devices are in use than the active high-speed devices mentioned above. Passive coin sorters/counters, which typically retail for $1000 or less, are often used by merchants, car wash owners and operators, FECs and others to quickly count coins in till drawers, cash boxes and other containers; others who only deal with a few thousand coins per week would also find it useful to own and use a passive coin sorting/counting device. Validation of each coin is assumed to have occurred (typically during hand-to-hand transactions) prior to placing coins into passive sorters/counters. Most units also allow for a quick visual check of the coins prior to entering the sorting/counting machine. Therefore, sorting strictly by coin dimensions (diameter and thickness) provides a quick and economical method to process coins through these passive coin sorters/counters.

Assuming no change to coin dimensions, no modifications would be required for these passive coin sorters/counters regardless of changes to EMS, weight or other coin characteristics. These devices sort, count and direct all coins of given dimensions to the same container. However, if coin dimensions were changed, then extensive physical modifications would be required of passive coin sorters/counters. These modifications would typically cost between $100 and $500 per machine; $250 per machine was considered to be the most probable cost. Changes to coin dimensions would also require a two-step process to accommodate the larger number of coin dimensions between the incumbent and alternative sets of US circulating coins. This strategy was recommended by the Canadian Automatic Merchandising Association (CAMA) for their members as a result of the recently released Canadian $1 and $2 coins [9].

4.14.3.10 Coin and Currency Handlers/Armored-Car Operators

These stakeholders are generally contracted by large banks to manage the bank's coin inventories. In addition, some armored-car operators handle coin orders to and deposits from depository institutions on behalf of the FRB. These instances tend to exist where the customer base between the two organizations overlap. These coin terminal locations are authorized to hold coins owned by the FRB. The coins in stock at coin terminals are therefore the property of organizations other than the armored-car operators. Coins come into these facilities in a variety of forms:

- Loose coins of a specified denomination in bags whose contents have been counted to a pre-set dollar value
- Loose coins (either separated by denomination or mixed in denomination) in a variety of containers that do not hold a standard dollar amount of coins
- Wrapped

- Mixed with other forms of cash and tokens.

All FRB-owned coins must be stored and handled in loose bags of specific dollar values, depending on the denomination. Management of incoming coins varies depending upon corporate and/or local practices within any given coin facility. In some coin facilities, the contents of all incoming bags are verified by counting before the coins are passed along for additional processing. In other cases, when a customer deposits coins into FRB inventory, bags of pre-counted coins that have a well-established chain of custody and that have no obvious signs of tampering are weighed. If the weight of the bags falls within a tolerance defined by the Federal Reserve, the bags are accepted into FRB inventory on a "said-to-contain" basis and stored on metal racks. These coins may then be processed for payout to depository institutions at a later date. If differences are found during processing, they may be charged back to the depositor.

One of two methods is typically employed to deal with out-of-tolerance bags that are received. Some coin facilities do not accept out-of-tolerance bags and simply return unopened bags to the originator so that the originator can correct any deficiencies. In other cases, the bags are opened, the coins counted and the appropriate adjustments completed to the client's account to correct any deviation from the standard coin count of that bag. Should the client question any deviation, video tapes of the counting operation can be used as proof by the coin facility operator that no tampering occurred with customer coinage.

Mixed coins are first sorted and counted. Depending upon the immediate needs of the armored-car operator clients, loose coins can be counted and packaged in bags of a pre-determined dollar amount or they can be rolled into standard coin wrappers. In either case, piece count is used to ensure that an accurate number of coins is dispensed into each wrapper. Sorting, counting, bagging and wrapping are completed on automated machines. Sorting and counting are typically completed on the same machine. Coin denomination is typically further verified by dimensions in the coin wrapping machine. Foreign coins, slugs, mutilated coins and other objects are screened out at all stages of handling the coins. In some operations, the wrapping step is completed by resident employees; in other instances, third-party organizations provide the wrapping services.

Coin facility operators and armored car operators use commercial high-speed coin sorting/counting machines. In some instances, custom-designed and built machines are used that rely upon technologies that are similar to those used in commercial units. Coins of the same dimensions but with different EMS would require uploading the acceptance windows corresponding to the alternative coins when EMS is used as a sorting method. Changes to coin dimensions would require additional modifications to the equipment and/or to the manner in which coins are processed through coin facilities.

Changes to coin dimensions would generally require that a secondary sorting be completed for non-seamless co-circulated coins as discussed above in the section entitled "Manufacturers of Commercial Coin-Handling Equipment." Ferromagnetic-steel-based coins would require the elimination of a magnetic separator used on some units.

4.15 REFERENCES – APPENDIX 4-C

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4.15.1 Appendix 4-D: Estimate of the Number of US Coins in Circulation

4.15.1.1 Method # 1: Use of Estimated Total Value of Coins in Circulation

This method of estimating the number of coins in circulation assumes that the current distribution of coins in circulation is identical to the distribution in the number of coins minted by the United States Mint between the years 2000 and 2010. As reported on the United States Mint Web site, the United States Mint production of coins is shown in Table 4-D-1.

Table 4-D-1. Circulating Coin Production from the United States Mint

	Annual Production (number of coins of given denomination)					
Year	**One-Cent**	**5-Cent**	**Dime**	**Quarter Dollar**	**Half Dollar**	**Dollar**
2000	14,277,420,000	2,355,760,000	3,661,200,000	6,470,940,000	42,070,000	1,286,060,000
2001	10,334,590,000	1,303,380,000	2,782,390,000	4,806,980,000	40,700,000	133,410,000
2002	7,288,860,000	1,230,480,000	2,567,000,000	3,313,700,000	5,600,000	7,600,000
2003	6,848,000,000	824,880,000	2,072,000,000	2,280,400,000	5,000,000	6,160,000
2004	6,836,000,000	1,445,040,000	2,487,500,000	2,401,600,000	5,800,000	5,320,000
2005	7,700,050,000	1,741,200,000	2,835,500,000	3,013,600,000	7,300,000	5,040,000
2006	8,234,000,000	1,502,400,000	2,828,000,000	2,941,000,000	4,400,000	7,700,000
2007	7,401,200,000	1,197,840,000	2,089,500,000	2,796,640,000	6,500,000	950,670,000
2008	5,419,200,000	640,600,000	1,050,500,000	2,538,800,000	3,400,000	489,120,000
2009	2,354,000,000	86,640,000	146,000,000	533,920,000	3,800,000	423,640,000
2010	4,010,830,000	490,560,000	1,119,000,000	347,000,000	3,500,000	402,220,000
TOTAL	80,704,150,000	12,818,780,000	23,638,590,000	31,444,580,000	128,070,000	3,716,940,000
Percent of Total	52.94	8.41	15.51	20.63	0.08	2.44

Based upon the total estimated dollar value of US circulating coins currently in circulation from data prepared by the Financial Management Service of the United States Department of the Treasury,[126] the estimated dollar value of US circulating coins on June 30, 2011 was $36,361,263,077. In words, the total value of coins in circulation can be described as follows:

> Total value of circulating coins = SUM (Total number of coins in circulation X percentage of this denomination in circulation X value of this denomination). In mathematical terms, this can be expressed as:

where,

= total value of US circulating coins

j = one of the US coin denominations

[126] Ref.: September 2011 U.S. Currency and Coin Outstanding and in Circulation.

= total number of US coins in circulation

= percentage of denomination *j* of the total number of coins in circulation

= value of denomination *j*.

Since the total number of US circulating coins is a constant in the above equation, it can be factored out of the summation and the equation solved for the total number of US circulating coins as follows.

From the percentages listed at the bottom of Table 4-D-1 and the estimated values of US coins in circulation, the estimated number of coins can be computed from this equation. The estimated number of coins of any given denomination in circulation can be estimated by multiplying the percentage of the denomination ( ) by the total number of circulating coins ( ). The estimated numbers of US coins in circulation by denomination are shown in Table 4-D-2.

Table 4-D-2. Estimated Number of US Coins in Circulation – Based Upon Method # 1

Number of Coins (in billions)						
One Cent	**5 Cent**	**Dime**	**Quarter Dollar**	**Half Dollar**	**Dollar**	**TOTAL**
189.88	30.16	55.62	74.00	0.30	8.75	358.68

4.15.1.2 Method # 2: Scaling from Sample Set of Coins to Total Number of Coins in Circulation

The second analysis method used relies upon sorting a large sample of coins by year, and counting the number of coins in the sample for each of the years. The sample fraction by year is then projected to the whole population of circulating coins. For a perfect sample, the sample fraction for any given year is identical to the population fraction for that same year. Therefore, the only characteristic that remains (once the year-by-year fractions of the sample population are known) is the multiplication factor needed to scale from the sample size to the total population size. The method of determining this multiplication factor is discussed below.

The number of coins of a given denomination counted from the sample for a given year ( ) is and the total number of coins in the sample set is . In a similar definition, represents the number of coins in circulation for year and represents the total number of coins of a given denomination that is in circulation. Assuming that the sample distribution is identical to the distribution of coins in circulation, then the coin fraction by year is identical for each year.

Solving for yields.

The actual number of coins in circulation during any given year can also be expressed as

where,

= scaling factor, fraction of coins still in circulation relative to the total minted in year

= total number of coins minted in year .

At this point the values for are not known; however, the maximum value for any is 1.0. From the last two equations, the follow can be defined.

Solving for yields the following.

This last formula can be used to compute an estimate of the total number of coins in circulation for the given denomination. By computing an estimate for each year ( ), the actual number of coins in circulation is the minimum of these year-by-year estimates. This conclusion falls out since the scaling factors that yield larger total number of coins, must actually be less than 1.0. The actual fraction of coins in circulation for the year corresponding to the lowest value of , is assigned a value of 1.0 (or less) and the corrected scaling factors ( ) for all other years can then be determined by the following equation.

This computed scaling factor can then be used to determine the number of coins in circulation for any given year by multiplying it by the number of coins minted in that year. This method was followed by CTC using a large sample of coins for each of the following denominations: one-cent, 5-cent, dime and quarter dollar coins.

The sampling completed by CTC included 2536 one-cent coins, 2219 5-cent coins, 1288 dime coins and 1745 quarter dollar coins. The following curves show the fraction of coins in circulation after one additional factor is applied to the above method: reducing the value of the maximum value of by an engineering estimate of the actual anticipated maximum number of coins for that year. This estimate was arbitrarily made based upon the year in which the peak value of was observed for any given denomination and based upon how far above the neighboring years any given maximum value of was found to be. Values of 0.9, 1.0, 0.9 and 1.0 were selected for the one-cent, 5-cent, dime and quarter dollar coins, respectively. Figures 4-D-1 through 4-D-4 show the estimated fraction of coins in circulation by year since 1960 using this method.

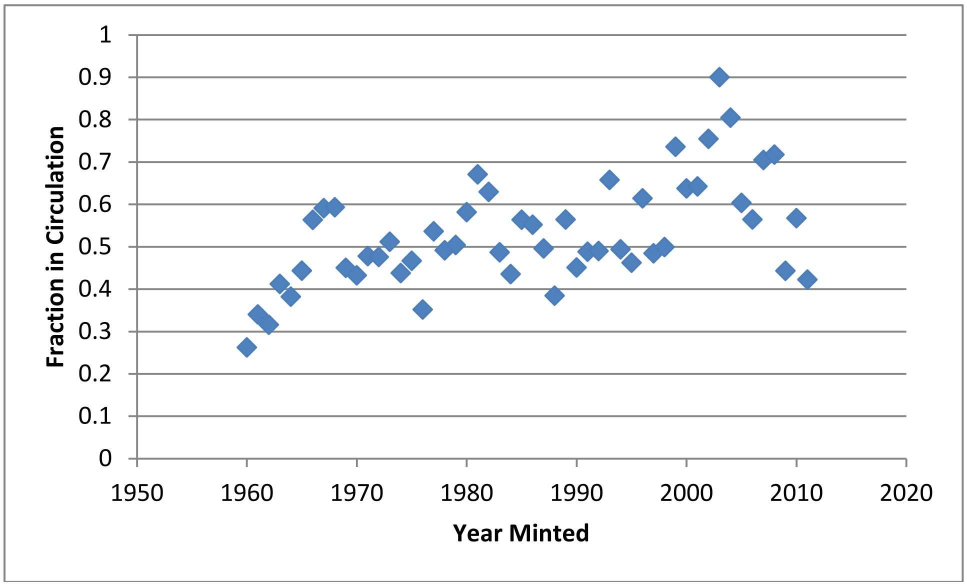

Figure 4-D-1. Estimated number of US one-cent coins in circulation.

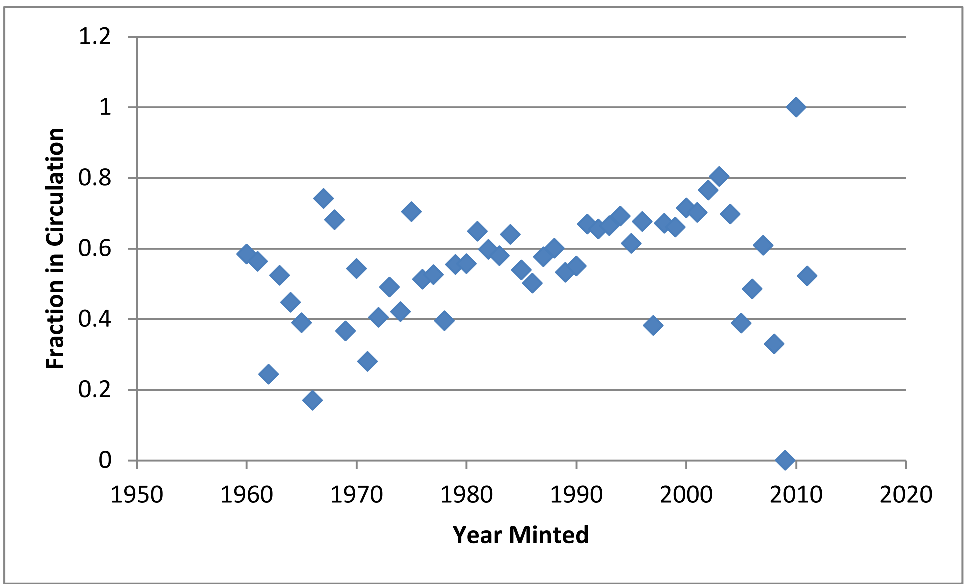

Figure 4-D-2. Estimated number of US 5-cent coins in circulation.

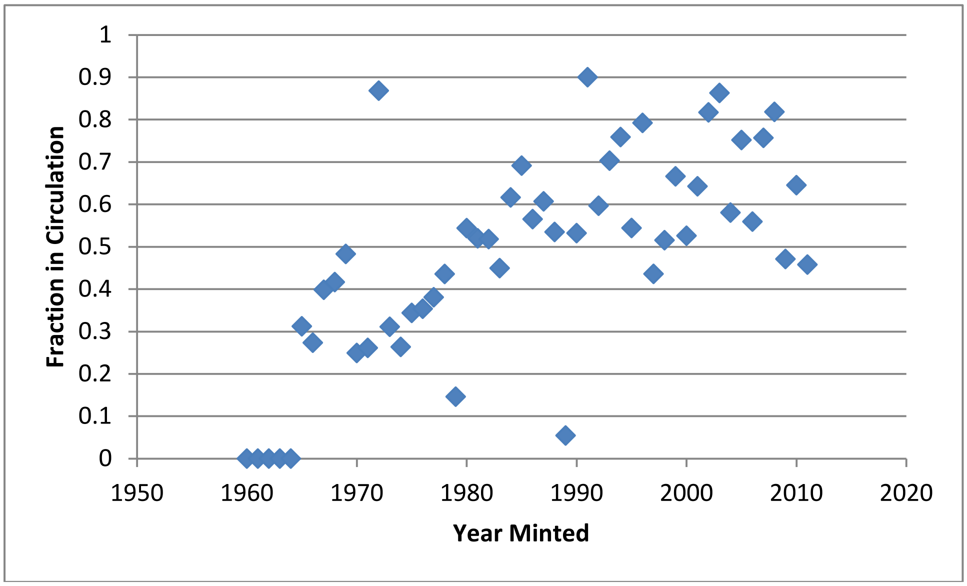

Figure 4-D-3. Estimated number of US dime coins in circulation.

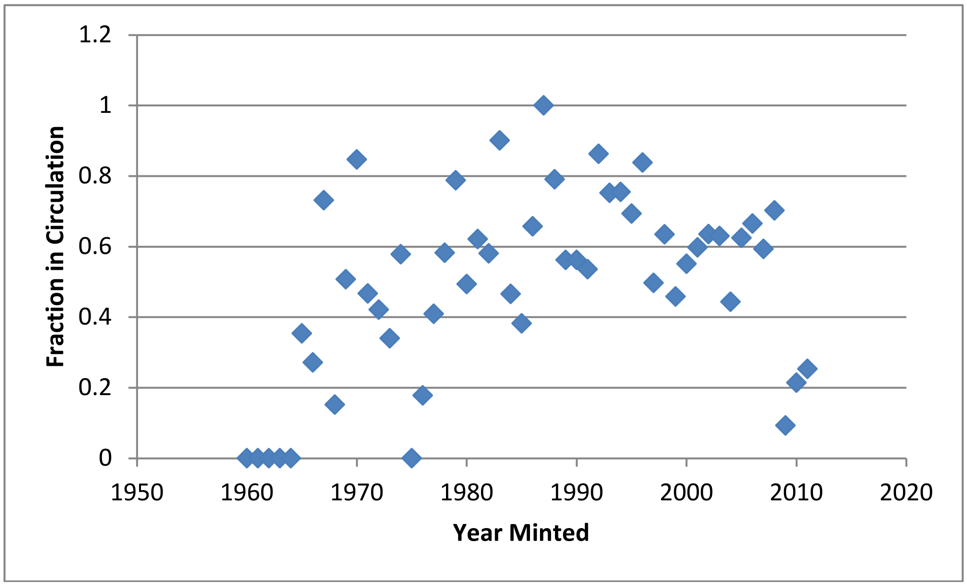

Figure 4-D-4. Estimated number of US quarter dollar coins in circulation.

Half dollar and dollar coins were not passed through this method, since these coins are in such low demand and CTC did not have confidence that they could get a representative sample of either of these coins. An additional factor was considered to account for US circulating coins that were minted prior to 1960, Canadian coins and mutilated coins. In these cases, the fraction of each of these coin types was computed relative to the total number of coins evaluated. This fraction was then multiplied by the total number of coins predicted to be in circulation from 1960 and beyond. This provided an estimate of these other coin types that also appear in circulation in the US.

Based upon the counted coins from the samples mentioned above, the total number of coins in circulation in the US is estimated by the above method as:

One-Cent: 240 billion
5-Cent: 29 billion
Dime: 44 billion
Quarter Dollar: 43 billion
Half Dollar: 0.3 billion (from Method # 1 above)
Dollar: 9 billion (from Method # 1 above)
Total: **366 billion**.

Many of these coins are not in active circulation on a daily basis. Many US citizens hoard coins in storage containers in their homes, automobiles, office desk drawers and other locations. Although no known data exist about the percentage of the above estimated 366B coins that are currently being hoarded, a study[127] completed for the Reserve Bank of New Zealand concluded that approximately 84% of all circulating New Zealand coins are in some type of storage. It is speculated that a similar fraction of US coins are being hoarded at any given time.

4.15.1.3 Conclusions – Appendix 4-D

The total coin count resulting from both methods is close to each other (< 2% difference).

Based upon the results of the above methods, the total number of US coins in circulation is estimated to be between 355 billion and 370 billion.

4.15.1.4 Improvements to the Implementation of Method # 2

A method to evaluate the sample size required to assure accuracy in a sample can be computed from the following equation:[128]

where,

$_R$ = sample size required
$_D$ = number of elements in the population (here, the total number of circulating coins of a given denomination)
$_c$ = estimated fraction of population, as a decimal (here, the fraction of circulating coins of a given year)
= precision desired, expressed as a decimal (value chosen here was 10% = 0.10)

[127] Antoinette Hastings, Alan Anderson and Josie Askin, "New Coin Requirements," Report prepared for the Reserve Bank of New Zealand, Reference Number O141300022, AC Nielsen, March 2006.
[128] How to Determine a Sample Size," Penn State Cooperative Extension, Program Evaluation, Tipsheet # 60, extension.psu.edu/evaluation/pdf/TS60.pdf.

= number of standard deviations required to reach desired confidence level (here, 1.96 was selected to achieve a 95% confidence level)

= estimated response rate, expressed as a decimal (here, 100% [= 1.0] was selected).

Given the typical fraction of coins for any given year and a desire to assure an accuracy of ±10% of the actual number of coins in circulation for any given year, this above equation was applied to the values found for each year and for each denomination from Method # 2. Ignoring the outliers in the list of values, the typical number of coins was computed to be 20,000 for each denomination to assure sound values at a 95% confidence level for each denomination and for each year. In other words, more accuracy and a higher level of statistical confidence in the results could be obtained in the CTC methodology if 20,000 randomly selected coins of any given denomination were sorted (by year), counted and the Method # 2 process applied to estimate the total number of coins in circulation in the US. Future estimates of the number of coins in circulation should rely upon 20,000 randomly selected coins of each denomination to obtain a more robust and accurate number of coins than the sample sizes used in the limited-effort CTC assessment discussed above.

Some other factors that should be used to improve on the implementation of the CTC method would be to pull all samples on the same date from a widely dispersed geographic location (preferably at least 10 sites throughout the US). In addition, some automated methods for determining the date of each coin would be useful to reduce the labor involved and the associated eye strain caused by reading 7500 coins twice (once to catalogue by year and a second time to confirm each selection).

5.0 PRODUCTION EFFICIENCY

5.1 INTRODUCTION

The Coin Modernization, Oversight, and Continuity Act of 2010 (Public Law 111-302), authorized the Secretary of the Treasury to review, research and develop new materials of construction for, improve the production efficiency of and report on the associated finding for production and use of current and alternative metallic material of construction for United States (US) circulating coinage. This chapter of the first biennial report to the United States Congress focuses on the findings from Concurrent Technologies Corporation (CTC) related to improving the production efficiency of circulating coins. The goal of the production efficiency efforts is well described by Section 3(c) of the language of the Act:

> Improved Production Efficiency.--In preparing and submitting the reports required under subsection (a), the Secretary of the Treasury shall include recommendations for changes in the methods of producing coins that would further reduce the costs to produce circulating coins, and include notes on the legislative changes that are necessary to achieve such goals.

The first part of this production efficiency effort involved investigating whether changes in production technology, in the machinery and methods used to produce patterned metal discs, could be expected to achieve cost savings. The United States Mint currently uses conventional stamping machinery to produce precisely detailed metal surfaces, with very tight quality control of each coin's diameter, edge thickness and weight. The United States Mint has shipped 5 to 14 billion (B) coins annually in the past five years.

Other industrial-scale metal shaping processes were evaluated to determine their capability to produce a metal piece with similar accuracy as that of current United States Mint production methods.[129] Each process was evaluated for its ability to reproduce surface details, hold dimensional tolerances and ultimately produce cost savings to the United States Mint.

In addition, surveys were taken of other producers of similar objects, including other mints around the world, and token and medal manufacturers, to see if production techniques were in use elsewhere that did not rely on traditional methods for producing circulating coins. Neither of these investigations revealed any superior production technology currently in use.

The second part of this production efficiency evaluation was a detailed study of circulating coin production by the United States Mints in Philadelphia and Denver. Differences in production practices between the two mints were investigated. In addition, scrap rates for coins, die life and production scheduling were studied. Meetings with relevant experts from the United States Mint were held to discuss production issues and explore possible means of facilitating production improvements. Several recommendations are discussed that are expected to improve the efficiency of the current production practices.

[129] Processes that are used for non-metallic materials were not considered, since the Coin Modernization, Oversight, and Continuity Act of 2010, Public Law 111-302 specifically limits consideration of potential coinage materials to metallic materials.

5.2 PRODUCTION TECHNOLOGY

5.2.1 Conventional Coining

The means of producing coins for circulation have not seen substantial changes since the introduction of steam-powered presses in 1788 [1] and knuckle or toggle presses, which replaced the slower screw presses beginning in the 1830s [2]. A knuckle press converts the continuous rotary motion of a flywheel into a back-and-forth linear motion, which is used to press the dies together on either sides of a piece of metal using a two-piece linkage that retracts and extends like a finger when the knuckle is bent or flattened, respectively. The continuing evolution of machine design has increased the speed and reliability of operations at mints, but the basic process steps are still used today for bulk production of coinage: rolling metal to a thin sheet, blanking[130] discs from the sheets, annealing the discs to soften the metal, cleaning the surfaces of the blanks, upsetting[131] the blank edges and coining between steel dies in a knuckle press.

5.2.2 New Technologies

The United States Mint facilities use presses that are capable of producing 750 coins per minute. The surface finish of newly produced circulating coins is very smooth, reproducing the finely polished surfaces of the coining dies. Meeting or exceeding these two criteria, relative to current circulating coin standards, represents a significant hurdle to overcome in order to successfully introduce any new process.

Various methods for creating finely-detailed metal surfaces were studied with the view of potentially replacing the traditional coin production processes in use today. A great deal of development has recently occurred in net and near-net-shape[132] production of metal objects. Alternative manufacturing processes were assessed in the present study based upon two principal criteria: 1) economics of producing coins at high rates of speed and 2) quality of resulting surface finish.

There are several casting technologies that have evolved over many years to produce accurately shaped small parts with fine details. In addition, there has been rapid development of new manufacturing techniques for producing net or near-net-shape, small, metal parts over the last several decades. Many of these techniques rely on computer controls to carefully manage the processes to ensure the production of consistency, high-quality parts. A discussion of each process capable of producing coin-sized objects follows.

5.2.3 Investment Casting

Investment casting is used to produce high-quality metallic parts. Based on the ancient lost wax process, investment molds are formed using liquid slurries of ceramic materials poured around patterns made of low-temperature-melting materials (such as wax or plastics) made in the shape of the desired object. Once the mold has dried, the wax/plastic is melted and drained out and the resulting mold is fired, like pottery, to harden it. The resulting mold has a precision cavity for molten metal to fill. After molten metal is poured into the mold and has cooled and solidified,

[130] Blanking is the process of mechanically punching small disks from flat sheet.
[131] Upsetting permanently deforms the edge of the blanks to gather metal near the rim for use in effectively filling the die during subsequent striking of the piece into a finished coin.
[132] Near-net-shape refers to processes that yield metal parts needing minimal machining after initial formation.

the mold is broken away to retrieve the finished metal casting. While this process can produce quite detailed parts, the surface finish is not comparable to fine machining; further finishing steps such as grinding, polishing or burnishing are usually required to obtain the highest quality surface finish. In addition, shrinkage of the hot metal reduces the dimensions of the cooled object and dimensional consistency similar to that of circulating coins is difficult to achieve on a consistent basis. The normal tolerance for dimensional stability is quoted at ± 0.010 inch per linear inch of material. With special care this can be improved to ± 0.005 inch per linear inch. This tolerance is larger than what is currently allowed (typically ± 0.1 mm [0.004 inch]) for US circulating coinage. A wide range of materials can be processed using this technique, especially if casting is conducted in a vacuum to avoid oxidation. However, due to the time and effort required to create the single-use molds, this is an expensive process for production of circulating coins.

5.2.4 Permanent Mold Casting

Permanent mold casting relies upon the use of reusable metal molds that are repeatedly cycled through mold fill, part cooling and solidification, part removal and mold cleaning. Mold filling is assisted by gravity; however, vacuum assistance is also sometime used. The molds must have a much higher melting point than the metal being cast. Mold surfaces are typically coated with a refractory material to protect the mold from heat and to avoid welding of the cast metal to the surface of the mold. Even so, the process has a high die wear rate, limiting die life to roughly 100 thousand (k) cycles. The refractory coating must be reapplied periodically, slowing the process. In addition, refractory coatings degrade both the quality of surface details and the dimensional tolerances otherwise achievable in a permanent metal mold. Using vacuum inside the mold reduces trapped gas in the solidified metal, reducing porosity in the finished parts. Dimensional tolerances, typically ± 0.015 mm per linear mm, are significantly greater than that required of US circulating coins.

5.2.5 Metal Injection Molding

Metal injection molding (MIM) began with experiments during the 1970s to produce metal parts using injection molding machines that had become highly successful at rapidly producing plastic parts. A mechanical screw forces a mixture of metal powders and specialized plastic binders through a heated chamber into a pair of sealed steel molds. After briefly allowing the material to cool and the binder to harden, the dies are separated and the cast pieces removed from the molds. The resultant material is then carefully heated in a furnace to burn out the binders and then sinter[133] the metal powders into a solid structure. For the production of small pieces like coins, the mold can be designed with many individual cavities arranged to produce a large number of individual pieces during each process cycle. The metal powder/binder mixture enters the mold and is distributed through feed lines to each of the part cavities. In so doing, dozens or hundreds of pieces can be produced with each process cycle. In metal injection molding, shrinkage is governed by the amount of binder used. The best dimensional stability achievable with the MIM process is said to be ± 0.003 mm per linear mm, good enough to match circulating coin specifications; however, more typical dimensional stability for MIM components is 0.015 mm per linear mm, which is too large relative to incumbent coin requirements. Surface finish can be

[133] Sintering is a process whereby solid metal powders fuse together at high-temperatures through diffusion of atoms between individual neighboring powder particles.

akin to that produced by sanding with medium grit paper. A wide variety of metals can be produced by this process. The initial feedstock consists of finely controlled powder materials (usually finer than 25 microns), which are expensive to produce and are several times more costly than the stock materials currently used by the United States Mint for volume production of circulating coins.

5.2.6 Die Casting

Die casting is a process whereby molten metal is rapidly forced into a metal mold. The primary differences between die casting and either metal injection molding or permanent mold casting is the speed with which the metal is introduced into the mold. Alloys produced by die casting have melting temperatures lower than that of the die material. Commonly die cast materials include zinc, aluminum, magnesium, lead and tin alloys. The best achievable dimensional tolerances and surface finishes are the same as those of metal injection molding. Production rates are a function of how quickly the metal solidifies, and these rates can be on the order of 10 seconds or less for small pieces that cool quickly. Typically small pieces like coins would be produced in dies having multiple part cavities; a trimming operation would be required to remove finished parts from the solidified metal remaining in the liquid metal delivery lines.

One problem with all multiple-mold-cavity processes is detecting when a single part cavity has failed in some way (perhaps due to a local crack or other type of flaw) and is producing defective parts. Although this would represent only a small percentage of the machine's output, sampling of a greater number of finished pieces would be required to identify defects and ensure final coin quality.

5.2.7 Semi-Solid Metalworking

Semi-solid metalworking (SSM) is a process developed beginning in the 1970s that is similar to metal injection molding or die casting. The primary differences are that binders are not used and the metal is partially (although not fully) melted prior to injection into the dies. In this process, the temperature of the metal feedstock is very carefully controlled between the solidus temperature (temperature at which the material first starts to melt) and liquidus temperature (temperature at which the metal first starts to solidify) so that the feedstock is in a highly viscous state. The semi-solid metal is forced into molds under pressure to create the desired shape. Although steel, copper alloys and other alloys having a high melting temperature have been successfully produced via SSM, the process is typically used for production of alloys like zinc (Zn), aluminum (Al) and magnesium (Mg), which have relatively low melting temperatures. This technique produces similarly fine casting details as MIM and die casting, but does not require special powder feedstock as with MIM. Dimensional tolerances are typically ± 0.002 mm per linear mm, and surface finish corresponds to a finely sanded surface, but is much less smooth than the surface of a typical coin. SSM can be adaptable to coin production of zinc-, magnesium- or aluminum-monolayer coins.

5.2.8 Production by Other Producers

CTC consulted with Schuler, a leading manufacturer of coining equipment. A Schuler representative stated that there are no short-term developments foreseen that would significantly impact current coinage processes.

A survey of mints around the world including the Royal Mint (RM) (in the United Kingdom [UK]), the Royal Canadian Mint (RCM), the Royal Australian Mint, the Royal Netherlands Mint, the Austrian Mint, the Paris Mint and the German Mint (Karlruhe) revealed that no world mint is using an alternative production method. Ten US producers of medals and tokens were surveyed; eight exclusively used the traditional striking press methods, one offered die cast medals using zinc alloys and one offered spin and die casting of pewter alloy, as well as traditional striking of a wider variety of metals. Casting processes are used for limited production, typically 100 to 10,000 pieces per run. Three UK-based commercial medal producers used striking exclusively. There is no indication from these surveys that there is an alternative production method that is being utilized anywhere around the world for high-speed coinage production other than the conventional coining process as discussed above in the Conventional Coining Section.

5.2.9 Production Technology Conclusions

Table 5-1 compares critical properties commonly cited for the potential process alternatives. All of the production techniques discussed above can produce thin discs with relatively fine surface details. However, none of them can produce surface finishes that approach the quality of the current coining process. Dimensional control is not as precise as current coin production methods in use at the United States Mint. Finally, of the commonly available machines for each of these processes, none is capable of 1) producing the rate of output expected of current coining presses or 2) reducing the cost of coinage production. In many cases the cost of the requisite metal feedstock is comparatively high, since controlled powders or high-purity materials must be used to achieve an acceptable result. While all of these processes are currently being used to produce high-value, difficult-to-machine parts, none of them is currently cost competitive with the coining process currently used at the United States Mint.

Table 5-1. Comparison of Critical Values for Various Net-Shape Production Processes

Process	Dimensional Tolerance (± mm per linear mm)	Surface Finish (microns RMS[134])	Production Rate (Pieces per Minute)	Possible Circulating Coin Alloys
Conventional Coining	0.002	127–254	750	all metals
Investment Casting	0.005	1270–3175	15	all metals
Permanent Mold Casting	0.015	3175–6350	75	aluminum, magnesium, copper
Metal Injection Molding	0.015	813–1600	150	aluminum, magnesium, zinc
Die Casting	0.003	813–1600	120	aluminum, zinc, magnesium
Semi-Solid Metalworking	0.002	813	150	aluminum, copper, magnesium, zinc

[134] Surface roughness is most frequently measured by averaging the deviations of the high and low points from an average position. RMS is the root mean squared average of deviations measured in microns.

5.3 IMPROVEMENTS IN CURRENT PRODUCTION PRACTICES

5.3.1 Review of Existing Processes in Use at the United States Mint

Documents provided by the United States Mint facilities at Denver and Philadelphia were used to establish a detailed understanding of the current production practices in use at these facilities. Subsequent discussions with staff from both facilities were useful in defining differences in experience, equipment and outcomes between the two facilities. In addition, possible means of improving current practices were discussed with production personnel and United States Mint headquarters personnel.

The overall production flow for the 5-cent, dime, quarter dollar and half dollar coins is the same. Coiled strip metal, received on pallets, feed the blanking presses. Blanks are stamped out of the strip in dedicated blanking machines (one machine for each denomination) to minimize changeover efforts. The resultant metal discs are fed through annealing furnaces that are arranged to process single denominations, largely to prevent mixing of materials and to reduce the possibility of wrong metal strikes.[135] The denomination-dedicated furnaces also allow tailoring of the furnace temperature to the kind and size of material being processed. The furnace interior is arranged as an Archimedes screw, so a continuous stream of blanks circulates through one end of the furnace, and exits the far end into a water bath to quench.[136] The annealed blanks are then sent through a cylindrical washer, cleaned and treated with a lubricant, and dried. The blanks then pass through upset mills to form a raised rim that assists filling the edge of the coin during striking.[137] Finally, the planchets are sent to presses where each is struck between steel dies inside a collar that defines the diameter of the finished coins. The tooling used for blanking produces many blanks per stroke, so that one blanking press feeds many stamping presses, each of which can only produce one coin at a time, although they do strike coins at very fast rates, up to 750 coins per minute.

The production flow for one-cent coins is considerably simpler, since the incoming copper-plated zinc material is supplied as ready-to-strike (RTS) planchets that arrive at the United States Mint in bulk in specially designed plastic carriers, each of which holds several thousand planchets. The carriers are positioned above receptor bins and a bottom access port opened to dispense planchets directly into the press feed conveyors. Thus the only operations carried out at the United States Mints in Philadelphia and Denver for one-cent coins is striking and bagging.

Dollar coin production is similar to the other strip materials, with three differences. Incoming coils are blanked then taken directly to upset mills for rimming. Dollar coins have a distinctively wide, non-reeded border to aid discrimination by the visually impaired. Dollar blanks are rimmed before anneal to produce a thick, more "dog boned" rim, making more metal available along the edge to fill the border. The brass material on the exterior of the dollar coins requires further cleaning, particularly at the upset rim, to produce clean coins. Following upsetting, the planchets are annealed and cleaned. At this point the dollar coin planchets are put in a more aggressive cleaning machine with stainless steel burnishing media, cleaning and anti-tarnish

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[135] If they enter circulation, wrong metal strikes are considered to be major error coins, which are highly desirable by coin collectors; but such situations are undesirable by United States Mint's standards.

[136] Rapid cooling facilitates handling and stops excessive growth of the metallic grains that could lead to unacceptable coin surfaces that resemble the surface of an orange.

[137] At this stage of production, the workpiece is referred to as a planchet.

chemicals: the planchets are then sent through pre-programmed wash cycles. Since other denominations are cleaned as unrimmed or flat blank, they do not require this more aggressive burnishing step. Dollar coin planchets are then sent to presses that discharge to dedicated conveyors for transport to special edge lettering machines where the dollar coins complete production.

Finished coins are delivered by conveyors to bagging stations. Each station has a battery of coin counters. All coins, with the exception of one-cent coins, are counted into large polypropylene bulk bags mounted on steel frame pallets, the bags are sealed and moved to holding areas ready for shipment to Federal Reserve Banks to fulfill their orders. In the case of one-cent coins at Philadelphia, the same bagging is used, but the bags are filled by weight, rather than count. Filling the one-cent coin bags to a specified weight simplifies the bagging process for these coins, which typically represent approximately half of all coins produced each year by the United States Mint.

5.3.2 Issues

5.3.2.1 Differences in Mint Facilities

The Denver facility occupies five different additions built up from the original 1904 site and currently occupies an entire city block in downtown Denver. Expansion space contiguous to the site is not available, and the current production facility is severely space constrained with many processes limited by these constraints. Primary work areas are constrained by a 5.4-meter (18-foot) ceiling height that limits the design of equipment that can be utilized. Annealing furnaces, in particular, take up considerable space. The annealing furnaces used at the Denver and Philadelphia facilities are different; annealing furnaces at the Philadelphia facility are too large for use in the Denver facility. Many operations at the Denver facility use batch material transfer between various process steps because there is insufficient space to either relocate primary equipment in a linear fashion or add conveyor equipment. For example, the Denver facility uses a skip hoist to get blanks out of the quench bath following annealing, whereas the Philadelphia facility has continuous conveyors that automatically transfer coins from quenching to cleaning operations. Coin lines feature automated conveyance between operations from start to finish in the Philadelphia facility; the only exception being the dollar coin line, where some manual transfers occur to accommodate additional processing.

Limited storage space at the Denver facility requires movement of material from the offsite warehouse to the production facility in ‘just in time’ fashion, whereas at current production levels, the Philadelphia facility has an approximately three-week (depending on daily production levels) storage capacity on site for raw materials. As another example of space limitation, the Philadelphia facility stores incoming coils face down on aluminum pallets and uses an upender table to upright and transfer the coils to uncoilers at the beginning of the production line. The Denver facility has to upright the coils at the warehouse and deliver them vertically to the minting area, where hoists are used to position them on the uncoilers. Keeping the coils face down on pallets permits the Philadelphia facility to use the down edge as a reference surface, which reduces damage during shipping and reduces the incident rate of several problems in blanking.

Given the differences in equipment layout, the Denver and Philadelphia facilities are nonetheless quite coordinated in their processes and approaches. Substantive differences between them are quite small. One example of coordination is the Denver facility's recent adoption of an improved blank lubricant pioneered at the Philadelphia facility. This process produces cleaner, more lubricious blanks improving fatigue die life.

There are two principal failure modes for dies used in producing circulating coinage, fatigue and wear. Fatigue die life is a measure of time until the die surface fractures or cracks due to repeated impacts and stresses imposed during striking. Surface die wear gradually erodes away fine details of the design and usually progresses slowly. Ideally, dies would be retired after the more gradual surface wear process. Reducing the incidence of fatigue failure, the most common failure mode for dies, would prolong average die life and reduce production costs.

Figure 5-1 shows the monthly die life for the obverse and reverse dies of circulating 5-cent coin production from the Denver and Philadelphia facilities. Die lives clearly improved as a result of using the improved striking lubricant.

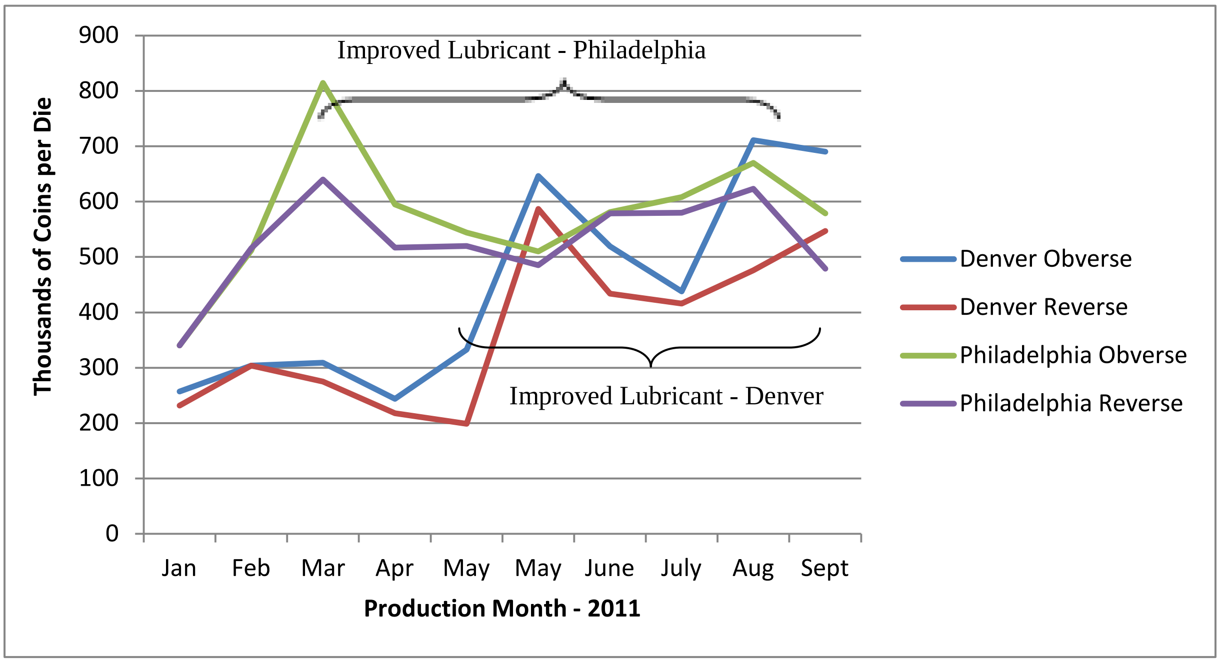

Figure 5-1. Die life with improved lubricant for 5-cent coins.

5.3.2.2 Coin Design and Die Life Considerations

One aspect of fatigue die failure that is not well understood is the influence of design features, such as the height of relief or abruptness of change from background to raised design features, on the propensity to accelerate fatigue. Higher striking loads are needed for some coin designs to produce acceptable fill of some details. Inevitably, higher striking loads lead to more rapid die failure, which requires a higher die replacement rate. Producing a sufficient number of striking dies, is not a substantial problem since the die-making process is quite efficient, but it does interfere with efficient production of the striking presses (with more frequent die [tooling] changes). A number of factors were identified to improve die life.

Until 2008, Janvier engraving machines were used to produce master dies. These engraving machines trace a spiral pattern over the die surface with a cutting tool. The inertia of the machinery limits the rate at which the cutting head can be moved in or out, and this acts to smooth the transition between high and low spots of the design. Subsequently an all-digital system was introduced using computer numerical control (CNC) milling machines that optimize material removal but may leave microscopically rougher surfaces. The new Research and Development (R&D) room at the Philadelphia facility will be able to investigate the effect of design on die life. The R&D room will be useful to evaluate new designs before production commences so adjustments can be made offline rather than during initial production runs.

Current design methodology rules are based on the "Engraver's Handbook," released January 16, 1987, that was compiled for very different production methods. To complement these rules, computer modeling (finite element analysis [FEA]) would be advantageous to predict more precise production response from any given coin design. After appropriate modeling validation, each design could be numerically simulated in advance of striking trials. These simulations would be useful in predicting coin fill, required striking loads, cyclic stresses that lead to die fatigue failure, die life, potential delamination and other die defects. This information could then be used to make alterations to the initial design such as the height of relief, the crown height of the die, taper angles, radii of intersecting surfaces and other geometric features to ensure that the final design provides the most favorable conditions for production efficiencies while also allowing for the greatest freedom in artistic expression in the finished designs. Ongoing collaboration between the artistic designers and numerical analysts is expected to lead to updated design guidelines for future coin design development.

The complex process of producing working dies that strike coins starts from a two-dimensional drawing concept. Each step in the complex process introduces variations in topography that are not well understood. Figure 5-2 shows the range of tooling used to produce dies and coins. The master hub on the left is used to impress a master die, which in turn is impressed in a working hub, which is impressed in a working die, which is used to produce coins. The evolution of the artistic design details from digital maps through machining the master hub, then producing the master die, the working hubs and finally the working dies has not been followed in sufficient detail to understand exactly how each step modifies the original profile created by the sculptor-engraver.

Progressive strike studies are a good experimental method for determining how uniformly designs fill during production. Progressive strikes and investigation of changes in design details at various stages of the tooling process has been initiated by the United States Mint and should yield a better understanding of the entire designing/machining/striking interrelationship.

Arranged from left to right are the master hub, the master die, a working hub, a working die and a coin.

Figure 5-2. Tooling progression for making a coin.

The Philadelphia and Denver facilities frequently have different production experiences with the same coin design. Currently, all coin designs are modeled and digitized, or produced digitally. Master dies are prepared on digitally controlled milling machines at the Philadelphia facility. After heat treatment the master dies are used to impress an inverse of the design into another piece of heated die steel, the hub. After additional heat treatment, the hub is pressed into another steel piece to produce a working die that will be used in a coining press. Master dies are distributed to the Denver facility, which produces its own working hubs and dies. Despite using the same masters, the crown heights of dies and design heights of relief produced at the two facilities differ,[138] which has a measureable effect on coin fill. Further research into the reasons for this difference and its impact on die life, coin quality and production costs is warranted.

Consistently high one-cent coin die failure rates significantly affect overall production costs. Average die life in 2009 reached a low of approximately 300k strikes at both the Philadelphia and Denver facilities. Since one press produces roughly 300k coins in one 8-hour shift, this failure rate reduced production efficiencies and costs from historical trends. Note that one-cent coin die life from 2000 to 2008 averaged 1 million (M) hits, but that has fallen to under 500k from 2009 through 2011.

In the Philadelphia facility there are seven presses in one production cell for one-cent coins, and a single operator manages six or more presses at one time. Desired production rates rely on any six of the presses being in operation at any given time. Therefore, if one press is down for a die change or for some other reason, these production rates are not impacted. At the Denver facility, however, the production rates rely on all presses to be operational at all times; therefore, an increase in the frequency of die changes can be more disruptive. An average die life of 600k or

[138] 2011 ATB PM DM Progression Strike Results and Narrative (Oct 2011 Die Manufacturing Conf).pdf provided by the United States Mint.

more strikes (1M strikes or more for one-cent dies) would be beneficial for both sites. Denver facility engineers calculated that doubling the one-cent coin die life would save $2660/day for production rates equivalent to the monthly average at the Denver facility during 2011, i.e., 200M one-cent coins per month. Longer die life for other denominations was of lower importance to the production staff. The die life (as measured by the number of die strikes) is shorter for the other denominations; however, due to the smaller annual quantities produced, die life improvements for these other denominations would have less overall impact on production rates and production costs.

One area of potential future die research is the use of optimized physical vapor deposition (PVD) coatings for coining dies. Both the Royal Mint and the Royal Canadian Mint have developed such coatings; both of these mints contend that the coating improves die life in their operations. Chrome nitride PVD coatings have been used in the United States Mint since 2009 to improve die life of numismatic dies where wear is the major failure mode. A number of coining tests were conducted in 2010–2011 with chrome nitride PVD-coated circulating dies that demonstrated no significant improvement where fatigue is the primary mode of failure. Coining tests of specially formulated low coefficient of friction PVD coatings are scheduled for 2012, with the goal of improving fatigue die life. This is another area where better understanding of design features and die stresses could be used to develop a more scientific approach to improving production practices.

5.3.2.3 Material Change Implications

Annealing of 5-cent coins was identified as one of the most problematic production operations faced by the United States Mint. Annealing furnaces that operate at higher temperatures, as required for the incumbent 5-cent coin material, have been more prone to furnace component failures. Repairing the very large components of these furnaces is costly in both materials and lost production time. Coins are fed through the hot zone of the furnaces using an Archimedes screw retort that revolves internally. If the large retort cracks or fails, an unplanned change out becomes necessary, which disrupts production schedules for several weeks. One feature of the furnace design of the Seco Warwick units used at the Philadelphia facility that is particularly problematic is the use of a single large bearing at the base of the retort. The stress of the large retort cantilevered from this bearing makes it susceptible to premature failure. As a precaution, the externally mounted bearing is changed when the retort is replaced, since the down time is the same when changing a bearing on a retort. Five-cent blanks require a higher annealing temperature than other coins; 879 °C (1615 °F), or about 203 °C (365 °F) higher than the dime, quarter dollar, half dollar and dollar coins. The 5-cent coin requires a higher striking load than the other cupronickel-clad coins, adding additional cost.

Blanking for the cupronickel 5-cent coin is also difficult. More defective blanks with edge chips are seen for 5-cent coins than for other denominations. Blanking dies must be replaced more frequently as a result. At the Philadelphia facility, blanking dies are refurbished as follows: 5-cent coins after 3M strikes, dime coins after 10M strikes and quarter dollar coins after 8M strikes. At the Denver facility, blanking dies are refurbished as follows: 5-cent coins after 1.5M strikes and dime coins after 7M strikes. A material change for 5-cent coins that would result in lower annealing temperatures and more malleable material would increase production efficiency at many levels.

Stainless steels have the advantage of corrosion resistance, attractive silver-white luster and wear resistance, but die fatigue and price are concerns. Stainless steel coins have been used successfully in other nations. Grade 430 stainless steel strip was acquired for preliminary screening tests. Grade 430 stainless steel required too high striking load to be a viable candidate; therefore, a 302 stainless steel was used for subsequent testing. Stainless steels, despite the fact that they have an electrical conductivity that is about half that of cupronickel, were recommended for testing for the 5-cent coin. The ideal stainless steel for coinage would be non-ferromagnetic because coins made of this metal can be validated by all acceptors and to avoid steel slugs, have low flow stress[139] (i.e., result in low striking loads), have excellent corrosion resistance and be comprised to the greatest extent practical of elements that are not as expensive as nickel. Nickel and molybdenum contents should be low to reduce costs. Austenitic stainless steels (3xx series) are preferred because they are non-ferromagnetic and thereby are more likely to be accepted by a majority of fielded coin-processing equipment. Nitrogen (N) is the least-expensive austenite stabilizer; therefore, nitrogen-containing steels such as Enduramet 32 and 15-15LC were considered. However, nitrogen dramatically increases material flow stress but may also increase die fatigue. Nickel is among the best austenite stabilizers in steel, but its high cost is a big driver for minimizing nickel content. Silicon is an affordable austenite stabilizer and is present up to 1% in many stainless steels. Chromium is the lowest-cost hardener that maintains stainless behavior, but it induces a ferromagnetic signature. The ability of a stainless steel to be annealed to the lowest practical hardness would be an advantage for extending die life during coining.

5.3.2.4 Production Flow

Current production planning is to have a surge capacity of 18B coins/year to meet short-term demand for new coins from the Federal Reserve Banks; the current projected average demand in 2012 for new coins is only 9B coins/year. Figure 5-3 shows the monthly orders for all circulating coins (multiplied by 12 to scale to an equivalent annual production volume) compared with the total annual orders from 2001 through 2010. Clearly the number of coins produced has declined substantially over this time. In addition to this decline, there are large swings in coin orders from month to month.

[139] Flow stress is a measure of the force per unit area required to permanently deform a metal during forming operations.

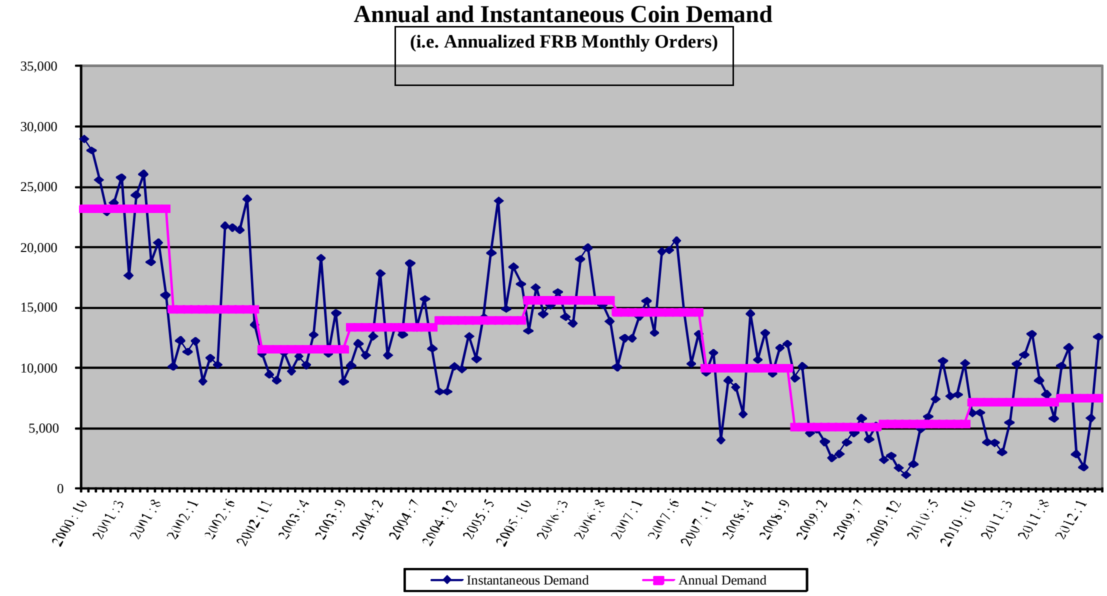

Figure 5-3. Monthly production targets compared with annual demand.

The demand for circulating coinage follows a regular annual pattern, with one high-demand period at the beginning of summer and a second in the fall of each year. Neither facility has a sufficient storage capacity to permit a more consistent week-by-week production rate throughout the year that would allow for building up coin inventories in anticipation of the peak coin demand periods.

Further complicating the management of coin production, orders from the Cash Product Office of the Federal Reserve are estimated one month in advance, but the actual quantity of coins ordered can still vary by as much as 30%. The actual number of coins required is not defined by the FRB until the finalization of the order as production actually begins. These shifting, short-term changes in coin demand impact the required installed machine capacity in addition to having an effect on staffing and the supply chain. The current coin production management requires excess production capacity, excess staff and excess raw material inventory so that each facility can quickly respond to the rapidly changing demand for circulating coins.

Greater finished coin storage capacity, controlled by the United States Mint, would be needed to level load production from month to month and allow more efficient planning, staffing and production capacity. The associated operating approach would yield a more consistent production pace and lower production costs with the coin storage accommodating short-term volatility in demand.

5.3.2.5 Lost Production

Some United States Mint production is lost as condemned product. This material includes anything that fails to meet in-process quality controls during production. Quality checks are performed after blanking, annealing, cleaning, upsetting and striking operations. If any errors are detected during any of these quality checks, entire batches of production may be condemned, and sent to recycling, even though only a small number of actual defects may be present. The costs of examining each potentially affected piece may be too high to justify sorting to pull out occasional defects. In some cases the impact of even one (1) off-quality coin getting into circulation creates too great a potentially negative impact to support sorting, which does not have a 100% success rate. Condemned scrap rates vary from year to year for each denomination. Based on production figures for the past five years, the mean condemned scrap rates of total production (excluding web scrap) vary from 1.3% for the one-cent coin, 8.6% for the 5-cent coin, 6.6% for the dime coin, 8.2% for the quarter dollar coin and 10.1% for the dollar coin; this condemned scrap was diverted to the recycling stream (see Appendix 5-A for Yearly Production/Scrap Rate Tables for each denomination). Scrap rates for one-cent coins are typically lower than for other denominations, largely because fewer operations are performed by the United States Mint. Blanking, cleaning and upsetting are performed at the planchet vendor and any scrap associated with these operations is not included in the one-cent total at the United States Mint.

Both the Philadelphia and Denver facilities have started to gather data for a detailed report on condemned pieces. From observations, there are very few rejects from the blanking operation. Condemned blanks mostly occur as a result of issues with annealing, burnishing or upsetting. Condemned struck pieces result most often from die-related problems such as piece out[140] and die crack defects. In several instances failures have caused one die to rotate during production resulting in misalignment of the images on the obverse and reverse of 5-cent coins; a large amount of material is condemned as a result of this situation. The rotation of dies produces a large amount of condemned material because 1) a misaligned coin is considered a major error coin, 2) these misaligned coins are co-mingled with otherwise acceptable coins produced on neighboring presses and 3) as explained below, sorting equipment is not 100% effective in removing these pieces. Once a defective coin is discovered, multiple bags and process hoppers are potentially contaminated. The detailed analysis of condemned pieces is expected to assist in identifying those processes that would benefit from instituting improved process controls.

One method for improving efficiency is to sift out and condemn defective pieces while reclaiming high-quality pieces from production lots known to contain some unacceptable pieces. A high-speed, automated inspection process would be needed to do this cost effectively. At the current technical maturity level, commercially available equipment to automatically complete such inspections on-line does not appear to be available. Considerable research may be needed to determine whether a cost-effective inspection technique could be developed and implemented for culling out defective pieces.

Another approach to reducing the amount of condemned production would be to loosen the quality criteria for acceptable circulating coinage. Currently any visible defect, such as possible staining from improper cleaning or a mark from a small crack in the die or misalignment of the obverse and reverse dies, is cause for rejection of all potentially affected batches of coins at any point in the production process. Given the difficulty in detecting such defects, and given the difficulty of tracking the exact time that any given piece completed a suspect process, detection of a defective piece typically impacts a substantial number of otherwise acceptable coins. Allowing small numbers of occasional mistakes to be released would enable a considerable

[140] A piece out defect occurs when a small piece of the die breaks off (typically do to a local fatigue failure) and alters the local shape of the struck image.

reclamation of mostly good production without impacting the commercial utility of circulating coinage while also reducing production costs at the United States Mint.

5.4 CONCLUSIONS – CHAPTER 5

CTC reviewed innovative production methods such as investment casting, MIM, semi-solid metalworking and others for possible use in the production of coins. The production methods used by other world mints (such as the RM, RCM, Paris Mint and others) were evaluated to determine if alternative methods of producing coins would further reduce the costs to produce circulating coins. No low-cost production methods were found that would allow circulating coinage to be produced in the volumes and quality specifications needed by the United States Mint. Therefore, current production techniques used by the United States Mint are quite efficient. The process for producing metal coins is substantially the same as it has been for years, but has undergone continuous improvement. Although some newer processes for producing volumes of small parts in other industries have been developed, such as plastic injection molding, no best practices and proven methods for forming metal were identified that could economically replace the highly evolved conventional processes used to produce high volumes of circulating coins. All other mints around the world use variants of the same process as those currently in use at the United States Mint.

From the standpoint of alternative material candidates, it is clear that a replacement for the 5-cent cupronickel alloy would benefit production efficiency. Reducing the annealing temperature needed to soften blanks for striking would both reduce energy usage and prolong the life of annealing furnace components. For all denominations, choosing materials that are readily coined at striking loads that are no greater than incumbent coin requirements is expected to maintain or improve die life from current levels.

A better understanding of the role of design and its impact on material flow during striking would be valuable in updating rules in the "Engraver's Handbook." This information could then be used to create images that improve die life relative to fatigue failure. The United States Mint has programs underway that will build a better understanding of this complex issue; the results from the Design for Manufacturability and Design Failure Mode and Effects Analysis studies should help develop optimal guidelines and procedures. Finally, either better inspection techniques or a greater tolerance for minor errors could reduce wastage due to condemnation.

While there may be many small changes that could and will be made to improve efficiency, CTC does not foresee any forthcoming means of markedly improving the production process of making coins. The same basic steps of blanking, annealing, upsetting, cleaning, drying and striking (along with the burnishing step for the dollar coin) should remain; however, the impact of using alternative metals for coinage could have significant effects on production efficiency. Should the 5-cent coin material be changed to one that can be annealed at lower temperatures, such as the copper-based alloys in the candidate list, there will be an immediate gain in production efficiency. Conversely, should an inherently hard material with high flow stress, such as stainless steel, be selected, reduced die life could be expected with an accompanying reduction in production efficiency.

5.5 REFERENCES – CHAPTER 5

1. http://www.sohomint.info/mantimeline.html, "Soho Mint – A World First!," May 2, 2012.

2. http://kmoddl.org/machinesandmechanisms/index.php/Diedrich_Uhlhorn, "Diedrich Uhlhorn," May 2, 2012.

5.6 APPENDICES – CHAPTER 5

5.6.1 Appendix 5-A: Summary of Total Condemned Scrap Rates per Denomination

Table 5-A-1. Total Condemned Scrap Rates per Denomination

FY	Denomination	One-cent	5-cent	Dime	Quarter Dollar	One Dollar	Total
2007	Production/Shipments	8,080,400,000	1,305,840,000	2,341,500,000	2,798,840,000	894,480,000	15,421,060,000
	Web Scrap	N/A	423,857,287	747,948,011	849,261,155	292,715,540	2,313,781,994
	Condemned	77,588,000	85,630,707	89,587,377	175,696,806	47,640,473	476,143,363
	Subtotal	**8,157,988,000**	**1,815,327,994**	**3,179,035,388**	**3,823,797,961**	**1,234,836,014**	**18,210,985,357**
	Subtotal without web scrap	**8,157,988,000**	**1,391,470,707**	**2,431,087,377**	**2,974,536,806**	**942,120,473**	**15,897,203,363**
	Web (%)	N/A	23.3	23.5	22.2	23.7	23.0
	COND (%)	1.0	4.7	2.8	4.6	3.9	2.6
	Cond/subtotal without web scrap (%)	1.0	6.2	3.7	5.9	5.1	3.0
2008	Production/ Shipments	5,162,800,000	630,480,000	978,500,000	2,546,000,000	460,540,000	9,778,320,000
	Web Scrap	N/A	190,360,202	278,980,159	725,820,811	138,600,000	1,333,761,172
	Condemned	56,034,000	91,655,556	81,931,217	232,855,737	78,317,913	540,794,423
	Subtotal	**5,218,834,000**	**912,495,758**	**1,339,411,376**	**3,504,676,549**	**677,457,913**	**11,652,875,595**
	Subtotal without web scrap	**5,218,834,000**	**722,135,556**	**1,060,431,217**	**2,778,855,737**	**538,857,913**	**10,319,114,423**
	Web (%)	N/A	20.9	20.8	20.7	20.5	20.7
	COND (%)	1.1	10.0	6.1	6.6	11.6	4.6
	Cond/subtotal without web scrap (%)	1.1	12.7	7.7	8.4	14.5	5.2
2009	Production/ Shipments	3,103,200,000	246,020,000	444,500,000	1,108,800,000	471,242,000	5,373,762,000
	Web Scrap	N/A	75,874,747	134,541,887	316,774,074	134,421,233	661,611,942
	Condemned	84,674,400	48,096,566	84,935,626	109,166,314	57,553,798	384,426,704
	Subtotal	**3,187,874,400**	**369,991,313**	**663,977,513**	**1,534,740,388**	**663,217,031**	**6,419,800,645**
	Subtotal without web scrap	**3,187,874,400**	**294,116,566**	**529,435,626**	**1,217,966,314**	**528,795,798**	**5,758,188,704**
	Web (%)		20.5	20.3	20.6	20.3	20.5
	COND (%)	2.7	13.0	12.8	7.1	8.7	6.0
	Cond/subtotal without web scrap (%)	2.7	16.4	16.0	9.0	10.9	6.7

Table 5-A-1. Total Condemned Scrap Rates per Denomination (continued)

FY	Denomination	One-cent	5-cent	Dime	Quarter Dollar	One Dollar	Total
2010	Production/Shipments	3,512,830,000	330,240,000	855,500,000	342,600,000	416,220,000	5,457,390,000
	Web Scrap	N/A	100,187,879	237,753,968	107,639,506	123,542,217	569,123,570
	Condemned	73,694,400	43,872,929	63,707,672	60,197,531	46,598,132	288,070,664
	Subtotal	**3,586,524,400**	**474,300,808**	**1,156,961,640**	**510,437,037**	**586,360,349**	**6,314,584,234**
	Subtotal without web scrap	**3,586,524,400**	**374,112,929**	**919,207,672**	**402,797,531**	**462,818,132**	**5,745,460,664**
	Web (%)	N/A	21.1	20.5	21.1	21.1	20.9
	COND (%)	2.1	9.3	5.5	11.8	7.9	4.6
	Cond/subtotal without web scrap (%)	2.1	11.7	6.9	14.9	10.1	5.0
2011	Production/ Shipments	4,628,140,000	953,040,000	1,475,500,000	316,800,000	326,900,000	7,700,380,000
	Web Scrap	N/A	266,502,626	434,126,984	99,095,414	93,579,452	893,304,477
	Condemned	34,239,200	56,376,768	107,645,944	60,889,771	58,868,555	318,020,237
	Subtotal	**4,662,379,200**	**1,275,919,394**	**2,017,272,928**	**476,785,185**	**479,348,007**	**8,911,704,714**
	Subtotal without web scrap	**4,662,379,200**	**1,009,416,768**	**1,583,145,944**	**377,689,771**	**385,768,555**	**8,018,400,237**
	Web (%)	N/A	20.9	21.5	20.8	19.5	21.0
	COND (%)	0.7	4.4	5.3	12.8	12.3	3.6
	Cond/subtotal without web scrap (%)	0.7	5.6	6.8	16.1	15.3	4.0
	Total condemned per year/total condemned year + shipments per year (%)	1.315	8.589	6.558	8.241	10.110	4.389

6.0 ENVIRONMENTAL ASSESSMENT

6.1 INTRODUCTION

This Environmental Assessment (EA) has been prepared by Concurrent Technologies Corporation (CTC) for the United States Mint and the Department of the Treasury in accordance with the National Environmental Policy Act (NEPA) of 1969 [1] and regulations implemented by the Council on Environmental Quality (CEQ) (40 Code of Federal Regulations [CFR] Parts 1500–1508), and Treasury Directive 75-02 (Department of the Treasury Environmental Quality Program) [2]. The CEQ was established under NEPA to ensure that federal agencies meet their obligations under the Act. *Regulations for Implementing Procedural Provisions of the NEPA* [27] (40 CFR Parts 1500–1508) specify that an EA should briefly provide sufficient evidence and analysis for determining whether to prepare an Environmental Impact Statement (EIS) or a Finding of No Significant Impact (FONSI); aid in an agency's compliance with NEPA when no EIS is necessary; and facilitate the preparation of an EIS when one is necessary. Treasury Directive 75-02 outlines the policy, standards and procedures for implementing NEPA at the Department of the Treasury. This EA analyzes the potential environmental impacts of implementing revisions to the composition of the materials used in circulating coin production in the United States. The coinage materials evaluation is being undertaken in accordance with the United States Congressional requirements outlined in the Coin Modernization, Oversight, and Continuity Act of 2010 (Public Law 111-302).

In accordance with 40 CFR §1506.6 – Public Involvement, Federal agencies must "provide public notice of . . . the availability of environmental documents so as to inform those persons and agencies who may be interested or affected." To allow for effective public review and comment, this EA must function as a standalone document. The EA cannot merely reference information contained in the other chapters of this report as those chapters will not be made available to the public along with the EA. Thus, the standalone nature of this EA requires that much of the information presented in other chapters of this report be repeated below to provide the proper background and context.

Furthermore, after providing the proper background and context, this EA assesses the potential impacts from the proposed action by subject area. The subject areas are those that are noted in the *Regulations for Implementing Procedural Provisions of the NEPA* and commonly assessed during the preparation of an EA, such as air quality, health and safety, transportation and socioeconomics. Each subject area is presented as an individual section with distinct subsections that address for that subject area the a) background and existing conditions, b) legal, regulatory and policy requirements, and c) environmental impacts.

A brief summary of the environmental impacts associated with the proposed action is provided in Table 6-1.

Table 6-1. Summary of Environmental Impacts

Resource	Environmental Impacts
Air Quality	There are no significant negative environmental impacts to air quality anticipated. None of the potential coin replacement options are expected to result in increased overall quantities of air pollutant emissions because none of them would require longer annealing times or additional steps in the coin production process. However, a potential reduction in the annealing temperature associated with the recommended copper-based alloy options for the 5-cent coin could result in increased concentrations of carbon monoxide (CO) being emitted from the annealing furnaces. Offsetting that potentiality, a combination of air emissions reduction efforts being undertaken by the United States Mint independent of the proposed action and the benefits associated with many of the potential coin composition options are anticipated to result in decreased air pollutant emissions from the coining process.
Water Use and Quality	There are no significant negative environmental impacts to water resources and quality anticipated. No increase in the amount of water used in the coining process is expected from the changes to coin composition under the recommended alloys or the other potential options because the water-using steps in the process, such as washing and pickling, will not change. However, any options that are currently delivered as coiled sheet and would be delivered as planchets would transfer the washing and pickling steps to the coinage material supplier. This would have a net-zero overall impact on both water usage amounts and wastewater discharges, but would reduce water usage amounts and wastewater discharges associated with the coining process at the United States Mint.
Solid Waste, Hazardous Waste, Hazardous Materials	The impacts to solid and hazardous wastes management associated with the proposed action are anticipated to be insignificant. Any differences in the quantities of hazardous materials used in the coining process would be negligible and would not be dependent on the proposed action because it does not involve the introduction of new hazardous materials or hazardous waste generating processes. Rather, the quantities would be driven solely by coin demand from the Federal Reserve Banks.
Health & Safety	The impacts to worker health and safety as a result of the proposed action, while ultimately dependent upon the alloys selected for the various coin denominations, are generally expected to be positive. With nickel exposure being the primary worker health and safety concern, all potential options contain significantly less or no nickel content than the incumbent denominations.
Transportation	Any environmental impacts related to transportation anticipated from the proposed action are expected to be insignificant due to the negligible, if any, change in the weight of the raw materials and scrap metal. If planchets are purchased in place of strip there may be a measureable improvement due to a reduction in transportation costs for scrap metal requiring transportation.
Energy Use	Any environmental impacts related to energy use anticipated from the proposed action are expected to be positive.

Table 6-1. Summary of Environmental Impacts (continued)

Resource	Environmental Impacts
Biological Resources	There are no significant environmental impacts to biological resources anticipated. The proposed action would utilize existing production operations within existing United States Mint and supplier facilities. No new activities with the potential to impact plants, animals or their habitats would be undertaken in order to carry out the proposed action.
Cultural Resources	There are no significant environmental impacts to cultural resources anticipated. The proposed action would utilize existing production operations within the manufacturing areas of existing United States Mint facilities in Philadelphia and Denver.
Socioeconomics	From a local standpoint, there will be no socioeconomic impacts, either positive or negative, to the immediate geographical area surrounding the United States Mint facilities in Philadelphia and Denver. From a national perspective, the socioeconomic impact of the proposed action will be greater, and negative financially, for the automated coin-processing business community, but the financial impacts are limited to that small subset of the population and, with the possible exception of a potential impact to coin terminal operators, will be relatively short-term in duration (approximately one to five years). Furthermore, the impacts from the recommended near-seamless copper-based alloys would be far less, and potentially non-existent, when compared to the non-seamless other potential options. For the United States Mint, and indirectly for American taxpayers, the proposed action will have a significant, long-term, financially positive impact.

6.2 PROJECT BACKGROUND

The United States Mint is a bureau of the Department of the Treasury (Treasury Department). Established in 1792, the United States Mint is the world's largest coin manufacturer. The mission of the United States Mint is to manufacture and distribute circulating coins, precious metal and collectible coins, and national medals to meet the needs of the United States. The United States Mint has approximately 1800 employees. The United States Mint's primary responsibility is to produce circulating coinage for the nation to conduct its trade and commerce. The United States Mint's other responsibilities are as follows:

- Distributing United States (US) coins to the Federal Reserve Banks and their branches
- Maintaining physical custody and protection of the nation's gold and silver assets
- Producing proof, uncirculated and commemorative coins, and medals for sale to the general public
- Manufacturing and selling platinum, gold and silver bullion coins.

The United States Mint owns four manufacturing facilities, which are located in Denver, Philadelphia, San Francisco and West Point. These facilities produce circulating coins, precious metal and collectible coins, and national medals.

In the Coin Modernization, Oversight, and Continuity Act of 2010, Congress called upon the Secretary of the Treasury to submit a biennial report to "the Committee on Financial Services of the House of Representatives and the Committee on Banking, Housing, and Urban Affairs of the Senate analyzing production costs for each circulating coin, cost trends for such production, and possible alternative metallic materials or technologies for the production of circulating coins." To develop the required report, the Treasury Department, and the United States Mint in particular, must conduct research and development into the production methods and the composition of the materials used in coin production in the United States. As directed by Congress, the overall goals of the research effort are to decrease coinage production and materials costs through increased production efficiency and/or materials composition revisions while ensuring fraud prevention and avoiding or mitigating any impacts to incumbent coinage material suppliers and stakeholders, such as vending machine owners or car wash operators, that would be affected by any change in the composition of circulating coins.

The United States Mint has only one major customer for circulating coinage, the Federal Reserve; shipping to about 240 locations. The Federal Reserve pays face value for coins. The United States Mint shipped approximately 7.4 billion (B) coins to the Federal Reserve in 2011, but has made more in years with a strong economy such as 2000 when 25B coins were struck. Approximately half of the coins struck are one-cent coins. The compositions of coins are designed in part to enable coins to readily go into existing recycling streams.

The overall production flow for the 5-cent, dime, quarter dollar and half dollar coins is the same. Metal strip is received on pallets in coils that feed the blanking presses. Coils weigh 1360 to 4550 kilograms (kg) (3000 to 10,000 pounds [lbs]). The starting strip is 330 millimeters (mm) (13 inches) wide and coins are blanked in a close-packed planar array with very little waste; up to 78 percent (%) of material is used. Blanks are produced out of the strip in dedicated machines (one machine for each denomination) to minimize changeover efforts and to avoid accidentally mixing up materials among the various denominations. The starting sheet is cold rolled to a hardened state to enable a sharp edge to develop during blanking. The resultant metal discs are fed through annealing furnaces, which are arranged to deal with single denominations, so that the furnace temperature can be tailored to the kind and size of material being processed. The furnaces at the United States Mint in Philadelphia are gas fired using an exothermic generator in which a natural gas-rich air mixture burns, water vapor is extracted, and a carbon monoxide-hydrogen reducing atmosphere is created to clean the blanks. Two of the five furnaces at the United States Mint in Denver also use exothermic gas for atmosphere, while the other three furnaces are older models that use natural gas for atmosphere. Depending on the furnace being used, the blanks are annealed at between 680 and 720 degrees Celsius (°C) (1265 and 1320 degrees Fahrenheit [°F]) for the dime, quarter dollar and half dollar blanks; between 870 and 930 °C (1600 and 1700 °F) for the 5-cent coin blanks; and 740 °C (1370 °F) for the dollar blanks. Annealing furnace capacity is 1360 kg per hour (kg/h) (3000 pounds/h [lb/h]) for the older models and 1820 kg/h (4000 lb/h) for the newer models.

The interiors of all of the furnaces are arranged as Archimedes screws, so a continuous stream of blanks is circulated through the furnaces and out the far end into a water bath to quench the blanks. (Rapid cooling is needed to keep the metal in a softened state.) The annealed blanks are then sent through a cylindrical washer, cleaned and treated with a lubricant, and dried.

The blanks are then upset, or rimmed, with the resulting workpiece called a planchet, which is ready for coining. The tooling used for blanking produces many blanks per stroke, so that one blanking press feeds multiple stamping presses, which can only produce one coin per strike, although they do operate at very fast rates, up to 750 strokes per minute. In the striking press, planchets are fed through a tube into a rotating holder that is akin to a revolver cylinder or fan blade. The holder receives a planchet, rotates to the striking position, where the coin is struck between steel dies inside a collar that defines the diameter of the finished coins, and then is moved out of position where it eventually falls into a collection basket.

The production flow for one-cent coins is considerably simpler, since the incoming copper-plated zinc material is supplied as ready-to-strike (RTS) planchets that arrive at the United States Mint in bulk in specially designed plastic carriers, each of which holds several thousand planchets. The carriers are positioned above receptor bins and a bottom access port opened to dispense one-cent planchets directly into the striking press feed conveyors. Thus the only processes carried out for one-cent coins at the United States Mints in Philadelphia and Denver are striking and bagging.

Dollar coin production is similar to the other strip materials, with three differences. Incoming coils are blanked then taken directly to upset mills for rimming. This is performed so that the thicker rims of dollar coins will be softened by annealing and thus made more amenable to striking. Heavily deformed metals become less malleable (known to engineers as "work hardening") so the upset edge becomes harder than the center of the blank. For lower denominations work hardening is not a significant problem in production. Following upsetting, the planchets are annealed and cleaned. At this point the dollar coin planchets are put in a more aggressive cleaning machine with stainless steel burnishing media and sent through pre-programmed wash cycles. The brass material on the exterior of the dollar coins requires further cleaning, particularly at the upset rim, to produce clean coins. Dollar coin planchets are then sent to presses that discharge to dedicated conveyors for transport to special edge lettering machines where the dollar coins complete production.

Selected coins are quality inspected. Finished coins are bagged in ballistic nylon bags that hold about 910 kg (2000 lb) of coins for the one-cent coin. The bags are housed in steel pallet frames to facilitate handling. One-cent bags are weighed in Philadelphia to determine coin count; a small discrepancy in actual piece count is accepted since the cost to conduct a piece count is greater than the magnitude of the potential discrepancy in the weight method. To the contrary, Denver counts one-cent coins to determine coin count. A summary of the steps for making coins is as follows:

- Blanking, annealing, quenching, washing/drying, upsetting, striking, bagging, (and weighing, for one-cent coins). The process for one-cent coins begins with the striking step.
- A media burnishing operation is used in place of washing to clean dollar planchets.
- A die lubricant is added to the wash bath so that a uniform amount of lubricant is applied to those planchets produced at the United States Mint facilities. This eliminates the need for in-press lubrication and reduces problems with dirt buildup and over lubrication that had been experienced with liquid delivery systems in the punching presses.

6.3 PROJECT LOCATIONS

The United States Mint has four manufacturing sites: Philadelphia and Denver, where circulating coinage is produced; and West Point and San Francisco where commemorative and bullion coinage is made. The United States Mint at Philadelphia, which also produces commemorative and numismatic[141] coins, is considered to be the largest coinage factory in the world and as of June 2012 works ten shifts per week in the circulating production area. All coin and medal design work is done at the United States Mint in Philadelphia. As they are the only locations where circulating coins are made, the United States Mint facilities in Philadelphia and Denver are the sole focus of this EA.

The Denver facility occupies five attached buildings built up from the original 1904 site and now occupies an entire city block at the corner of West Colfax Avenue and Delaware Street in downtown Denver, Colorado. There is no more expansion space contiguous to the site, and the current production facility is severely space constrained. Many processes are limited by these constraints. Ceilings of a height of 5.5 meters (m) (18 feet) in the primary work areas limit the type of equipment that can be used. Annealing furnaces, in particular, take up considerable space. The Denver facility also has limited storage space, averaging only a one-week backlog of raw materials, and moves material from warehouses in just-in-time fashion. In 2011, the Denver facility produced 4.2B circulating coins, including 2.5B one-cent coins, 540 million (M) 5-cent coins, 754M dime coins, 195M quarter dollar coins, 1.7M half dollar coins and 197.1M dollar coins. As of June 2012, the Denver Mint works ten shifts per week in the circulating production area.

The Philadelphia facility is located on Fifth Street between Arch Street and Race Street in downtown Philadelphia, Pennsylvania. Unlike Denver, Philadelphia has a 3-week storage capacity on site for raw materials, at current production levels. In 2011, the Philadelphia facility produced more than 3.9B circulating coins, including 2.4B one-cent coins, 450M 5-cent coins, 748M dime coins, 196M quarter dollar coins, 1.8M half dollar coins and 177.8M dollar coins.

6.4 PURPOSE OF AND NEED FOR THE PROPOSED ACTION

The purpose of the proposed action is to decrease US coinage production and materials costs through materials composition revisions and/or associated increased production efficiency while ensuring the continued security of US coinage and minimizing any impacts to coin-related stakeholders.

The cost to the United States Mint to make a one-cent or 5-cent coin significantly exceeds face value. The United States Mint's 2011 Annual Report indicated that it cost \$0.0241 to make the one-cent coin and \$0.1118 to make the 5-cent coin. In addition, the contributions to these costs of plant overhead, general and administrative (G&A), and distribution to the Federal Reserve total \$0.0107 for the one-cent coin and \$0.0322 for the 5-cent coin. Thus, it is impossible to achieve positive seigniorage[142] for the one-cent coin under the present indirect cost structure and allocation. Moreover, there is only \$0.0178 available for metal cost and all fabrication costs to make the 5-cent coin for parity.

The proposed action is necessary to address the issue of negative seigniorage and other production inefficiencies by:

- Identifying metals and concepts to reduce costs, considering fraud prevention

[141] Numismatic refers to high quality coins minted for collectors.
[142] Seigniorage is the difference between the face value of a coin and the total unit cost to produce it.

- Identifying coinage candidates for a seamless transition that minimizes conversion costs to upgrade any equipment or operations that would be impacted by new materials of construction in US circulating coins
- Making recommendations for improved production efficiency
- Ensuring minimal, if any, impacts to merchants, the vending community, producers and other parties that might be affected by a change in coinage.

Furthermore, the proposed action is needed to ensure compliance with Treasury Department policy, as outlined in Treasury Directive 75-09 [3], "to conduct business in a manner that protects human health and the environment, meets and exceeds the requirements of all applicable environmental laws, regulations, and Executive Orders, is sustainable, economically and fiscally sound, and ensures continuous improvement."

Finally, as noted above, the proposed action is also driven by the congressional requirements outlined in the Coin Modernization, Oversight, and Continuity Act of 2010.

The purpose of the EA is to describe the proposed action and the need for it; briefly describe the environmental impacts of, and alternatives to, the proposed action, including mitigation measures; list the agencies and persons consulted; and provide a brief analysis, based upon the above evidence, for determining whether to prepare an EIS or a FONSI. If, based on the information presented in the EA, it is determined that the impacts of the project will not have a significant environmental impact, then the EA will be used as the justification for a FONSI.

6.5 PROPOSED ACTION AND ALTERNATIVES

6.5.1 Introduction

As stated previously, as of March 2012 a negative seigniorage exists for both the one-cent coin and the 5-cent coin. To attempt to reduce the costs of coin production, CTC was awarded a competitively bid contract by the United States Mint to investigate various alternative compositions for all US circulating coins. As a baseline, the coins analyzed for potential compositional changes currently have the following compositions:[143]

- One-cent: copper-plated zinc (97.5%Zn-2.5%Cu)
- 5-cent: monolithic cupronickel (75%Cu-25%Ni)
- Dime: cupronickel-clad copper (91.67%Cu-8.33%Ni)
- Quarter dollar: cupronickel-clad copper (91.67%Cu-8.33%Ni)
- Half dollar: cupronickel-clad copper (91.67%Cu-8.33%Ni)
- Dollar: clad manganese-brass (88.5%Cu-6%Zn-3.5%Mn-2%Ni).[144]

The raw materials for the coins are supplied to the United States Mint in sheet form, with the exception of the materials for the one-cent coin, which as noted above, arrive as planchets. The suppliers of the alloys used to make the incumbent US coins are all located within in the continental United States. These existing producers include Jarden Zinc Products (JZP) in Greeneville, Tennessee for the one-cent coin, and Olin Brass in East Alton, Illinois and PMX

[143] Zn = zinc; Cu = copper; Ni = nickel; Mn = manganese.
[144] Note that the United States Mint suspended production of the dollar coin as a circulating coin in December 2011. As a result, this EA does not address the specific impacts associated with the dollar coin.

Industries, Inc. in Cedar Rapids, Iowa for the other five denominations. In addition to the producers of incumbent circulating coins, potential future suppliers of alloys (either directly or through license to an American metal producer) include, but are not in any way limited to, the Royal Canadian Mint (RCM), the Royal Mint (RM) in the United Kingdom (UK), Carpenter Technology in Reading, Pennsylvania, Alcoa in Pittsburgh, Pennsylvania, Aleris International in Beachwood, Ohio, and Constellium Aluminum in Ravenswood, West Virginia.

Using the Periodic Table of Elements and, coupled with London Metal Exchange and other sources of metal prices, iron (and steels), zinc and aluminum alloys were identified as the leading candidates to reduce the cost of coinage by replacing copper and nickel to varying degrees. To emphasize this important point, the alloys recommended were selected based in part on minimal adverse environmental impact. Candidates such as lead were eliminated before experimental work was undertaken. Several new elements are involved in the recommended compositions as alloying additions or are involved in plating. Candidates were selected for each circulating denomination. For the one-cent coin, low cost was the clear driver with security and ease of transition a minor concern because this denomination is not typically utilized in vending machines or for other non-attended automated points of sale. For all other denominations, metals and fabrication concepts were identified in two general categories: 1) potential for seamless transition with modest cost savings and 2) potential for significant cost savings with non-seamless, co-circulating coins. The candidates for seamless transition were designed to match the electromagnetic signature[145] (EMS) of the incumbent coin so disruption to the vending and coin-processing industries would be minimal. The candidates for non-seamless transition have an EMS that is different from that of the incumbent coin, but the candidates were designed to have an identifiable, unique EMS whenever possible.

6.5.2 No-Action Alternative

NEPA requires that a no-action alternative be considered as part of the environmental review process. Under the no-action alternative, the United States Mint would continue to produce coins that, depending on the coin, are more expensive to produce than their face value. In addition, by taking no action, the United States Mint would continue to use the same materials, equipment and processes that are currently in use. Additionally, under the no-action alternative, the United States Mint would not offer recommendations to the Congress for the near-term adoption of new compositional materials. It does not, however, preclude the United States Mint from continuing research and development into new coinage materials or production processes and making recommendations to the Congress to change the coinage materials in the future.

Congress, in the Coin Modernization, Oversight, and Continuity Act of 2010, authorizes the Secretary of the Treasury to conduct research and development into the production methods and the metallic composition of the materials used in coin production in the United States. The overall goals of the research effort are to decrease coinage production and materials costs through increased production efficiency or materials composition revisions while ensuring fraud

[145] Electromagnetic signature is understood in the industry to mean the electrical signal strength of a nearby electromagnetic sensor as a coin passes in close proximity to the sensor. The magnetic field in the vicinity of the emitting sensor, and therefore the electrical current in the EMS receiving sensor, changes as the coin passes by. The change in electrical signal strength is influenced by the materials of construction along with the thickness and distribution of materials within the coin. The signal strength and/or its decay rate are then used by software to validate the coin and determine its denomination.

prevention and avoiding or mitigating any effects to incumbent coinage material suppliers and businesses. The United States Mint has met the goals of the Act; the selection of the no–action alternative would merely recognize that, at the conclusion of the initial research effort, no new production efficiencies or material compositions were identified that would warrant a change at this time. A decision to opt for the no-action alternative also may be based on unmitigated or significant impacts on stakeholders such as commercial coin-handling equipment owners or coin and currency handlers.

In sum, selection of the no-action alternative would require a determination that, after considering all relevant factors, the best course of action would be to keep all of the incumbent coin compositions and manufacturing processes. Recognizing that future research and development may find proposals that will realize greater cost savings and environmental benefits than the proposed action, the no-action alternative remains a reasonable potential outcome of this effort and it has not been eliminated from consideration.

6.5.3 Alternatives Considered But Eliminated

The purpose of the proposed action is to decrease US coinage production and materials costs through materials composition revisions and/or increased production efficiency while minimizing impacts to coin-related stakeholder groups and ensuring the continued security of US coinage. As such, those materials and processes whose costs are too high, whose sources or supply chains are not secure, whose negative environmental impacts were significant or whose performance would not meet coinage standards regarding EMS, weight, feel, durability, appearance or manufacturability would be eliminated. Furthermore, the available alternatives were limited by the manner in which coinage is currently produced as well as security requirements.

6.5.3.1 Material Alternatives Considered But Eliminated

Very early in the project a number of potential elements were eliminated as potential constituents of an alternative coin composition for a variety of reasons; most often for their potentially negative environmental or health and safety impacts or their high costs. This early mitigation effort resulted in several potential constituents being eliminated for the reasons provided in Table 6-2.

Table 6-2. Eliminated Candidate Metallic Elements and Alloys for Coinage

Element Common Name	**Element Symbol**	**Reason for Elimination**
Beryllium	Be	Carcinogenic oxide to 3% of population; too expensive
Titanium	Ti	Too expensive
Vanadium	V	Too expensive
Zirconium	Zr	Too expensive
Niobium	Nb	Too expensive; for commemorative coins only
Cobalt	Co	Too expensive
Bismuth	Bi	Too expensive
Molybdenum	Mo	Expensive, but may be used as alloying addition in stainless steels
Silver	Ag	Too expensive; for bullion and commemorative coins only
Lead	Pb	Toxicity issues
Uranium	U	Radiation issues
Gold	Au	Too expensive; for bullion and commemorative coins only
Tungsten	W	Too expensive

In addition, the following potential coin compositions were considered and/or tested during the research phase of the project, but were eliminated for the reasons outlined below.

6.5.3.2 Aluminized Steel for the One-Cent Coin

This metallic material is steel cathodically protected by aluminum. This option was eliminated for the following reasons:

- Unacceptable color
- Load required to strike the coin would be too high
- Exposed edge could lead to corrosion issues
- Ferromagnetic (i.e., it is attracted to magnets and would not be recognized by a large number of coin-acceptance equipment).

6.5.3.3 Grade 430 Stainless Steel for the One-Cent Coin

Although this composition shows some encouraging future potential, this option was not recommended at the present time for the following reasons:

- Load required to strike the coin would be too high
- Excessive die fatigue is expected
- Ferromagnetic.

6.5.3.4 Grade 430 Stainless Steel for the 5-Cent Coin

This option was eliminated for the following reasons:

- Ferromagnetic (no EMS)
- It is not seamless
- The striking load would be too high
- Coining with this option would contribute to significantly increased die fatigue.

6.5.4 Production Method Alternatives Considered But Eliminated

Current production techniques used by the United States Mint are quite efficient. The process for producing metal coins is substantially the same as it has been for the past 75 years, but has undergone continuous improvement during that time. Although some newer processes for producing volumes of small parts have been developed since then, such as plastic injection molding for example, there are no proven ways to produce the volume and quality of metal stampings produced by the United States Mint in any more economic fashion. All other mints around the world use variants of the same processes, although the United States Mint is one of the world's largest producers of coined products. As a result, no significant production or equipment changes were considered as part of the proposed action. Instead, the focus was on cost-saving changes to the composition of the coins with any potential changes to production, such as eliminating blanking, annealing, upsetting and washing from the selection of an option supplied as a planchet rather than coiled sheet, being dependent on the alloy(s) selected.

6.6 PROPOSED ACTION

The proposed action involves compositional changes to the incumbent 5-cent, dime, quarter dollar and half dollar coins to reduce production costs while minimizing conversion costs, preventing fraud and minimizing or preventing impacts to the merchants, the vending community, producers and other parties that may be affected by a change in coinage. The proposed action includes a recommendation that no changes be made to the incumbent copper-plated zinc one-cent coin at this time. Under the proposed action, it is also recommended that the composition of the incumbent 5-cent coin be replaced with one of three copper-based options: 669z, G6 mod or unplated 31157. The proposed action also includes a recommendation to complete additional testing on copper-based alloy 669z-clad C110 copper for use in dime, quarter dollar and half dollar coins. Based upon testing completed in this study, quarter dollar nonsense pieces of this construction; showed evidence of being a seamless alternative to the incumbent quarter dollar coin. Development of G6 mod-clad C110 and/or unplated 31157-clad C110 may offer additional seamless options. However, the golden hue shown by the unplated 31157 alloy, if chosen as an outer clad material for the quarter dollar coin, may cause confusion with the incumbent golden dollar coin, although the dollar coin is not widely used in transactions. In addition to the recommended alloys, several other potential options are discussed, including Dura-White™-plated zinc, 302HQ stainless steel and Multi-Ply-plated steel. Note that, while not recommended under the proposed action, the no-action alternative also remains a potential outcome of this effort. Both the recommended alloys and the other potential options are assessed below.

6.6.1 One-Cent Coin

The lowest-cost option that is practical in the near term is the aluminum one-cent coin, with an aluminum (Al)-magnesium (Mg) alloy such as 5052-H32 being the leading candidate. It is possible to make a 5052-H32 one-cent coin for approximately $0.0074 excluding indirect cost allocations; using current total unit cost as of March 2012. The most-practical alternative to an aluminum alloy is to retain the copper-plated zinc one-cent coin.

If 5052-H32 was substituted for the incumbent copper-plated zinc-based one-cent coin, the elements comprising 5052-H32 are arguably less harmful to the environment and to worker health. Furthermore, while 5052-H32 will require blanking because it would be supplied in sheet form rather than as planchets, unlike other potential replacement options supplied in sheet form it is not expected to require the use of the annealing furnace. With all that said, however, the coin-processing equipment manufacturers (including coin acceptors, sorters and counters) and their clients have raised major objections to 5052-H32 based on the lower density of aluminum, its higher probability of jamming coin-acceptance equipment and coin-handling equipment, and its potential for cold welding to other aluminum coins resulting in permanent damage to high-speed coin sorters/counters.

The following alloys were identified as potentially meeting the goals of the proposed action with regard to the one-cent coin:

- 5052-H32 (Al-2.5Mg-0.25Cr[146]); aluminum 5052-H32 in sheet form from Aleris in the H32 heat treated condition.
- Copper-plated steel (25 microns [µm] Cu on low-carbon steel); copper-plated steel in planchet form from JZP
- Copper-plated steel (25 µm Cu on low-carbon steel); copper-plated steel in planchet form from the Royal Mint.

6.6.2 5-Cent Coin

For the 5-cent coin, options include both nearly seamless and non-seamless candidates. Nearly seamless alloys have an EMS match but may have slight weight differences from the incumbent coin. For nearly seamless alternatives, copper-based alloys such as 669z, G6 mod and unplated 31157 can each be used with a similar EMS and modest cost savings based on replacing nickel and copper with less expensive alloying elements. For non-seamless options, Multi-Ply-plated steel, non-magnetic stainless steel (302HQ) and Dura-White-plated zinc are also less expensive than the incumbent alloy used for the 5-cent coin. The only option for the 5-cent coin identified that could produce positive seigniorage is 430 stainless steel, or a similar ferritic stainless steel, with a significant cost savings over the incumbent cupronickel coin. At present, however, 430 stainless steel is not recommended because it produces increased die fatigue, has low coin fill characteristics during striking and has a ferromagnetic signature (i.e., it is attracted to a magnet) that would cause problems with some coin-acceptance equipment.

Annealing of 5-cent coins was clearly identified as the most problematic production operation at the United States Mint. Blanks of 5-cent coins require a separate higher-temperature annealing furnace from the other coin blanks. The furnace temperature must be set at 879 °C (1615 °F) or about 203 °C (365 °F) higher than the other blanks,[147] but even after this anneal the 5-cent planchets require a fairly high striking load to coin correctly, which further adds to production costs. Blanking for the cupronickel 5-cent coin is also hard on the blanking dies, causing more edge defects and chips than other denominations. Blanking dies for 5-cent coins are replaced far more often than for the other coin denominations. A change in the material used for 5-cent coins that would result in lower annealing temperatures would benefit production at many levels. The lower annealing temperatures would result in less energy use, longer furnace life and the

[146] Cr = chromium.
[147] The required furnace temperature for annealing the 5-cent coin is only 136 °C (245 °F) higher than that for the dollar coin.

potential for reduced quantities of combustion-related air emissions, although it should be noted that emissions concentrations could increase as a result of the temperature decrease.

The following alloys have been identified as potentially meeting the goals of the proposed action with regard to the 5-cent coin:

- Multi-Ply-plated steel (10 µm Ni on 23 µm Cu on 4 µm Ni on low-carbon steel); Multi-Ply-plated steel in planchet form from the RCM or a licensed domestic metal supplier
- Dura-White-plated zinc (3 µm tin [Sn] on 7 µm Cu on Zn); tin and copper on zinc in planchet form from JZP
- 669z (75Cu-10Zn-5Ni-10Mn); copper-based alloy with a lower nickel content than the incumbent 5-cent coin in sheet form from PMX Industries, Inc.
- G6 mod (65Cu-22Zn-10Ni-2Mn); copper-based alloy with a lower nickel content than the incumbent 5-cent coin in sheet form from Olin Brass
- Unplated 31157 (62Cu-31Zn-0.5Ni-6.5Mn); copper and zinc-based alloy with a low nickel content in planchet form from JPZ (through Olin Brass)
- 302HQ (Composition is company proprietary.); stainless steel in sheet form from Carpenter Technology
- aRMour™ nickel-plated steel (25 µm Ni on low-carbon steel); nickel-plated steel in planchet form from the Royal Mint or a licensed domestic metal supplier.

6.6.3 Dime, Quarter Dollar and Half Dollar Coins

Because the incumbent dime, quarter dollar and half dollar coins all share the same composition—roll-clad cupronickel to an alloy C110 (commercially pure copper) core—they will be addressed together. The quarter dollar is the most important coin to the vending industry and other stakeholders due to it being the most utilized US coin for unattended automated points of sale. Approximately 53% of the coins used in US vending machines and 96% of the coins used in laundromats are quarter dollars. Other industries, such as car washes and the amusement industry, also rely primarily upon quarter dollars. Seamless dime, quarter dollar and half dollar options are highly preferred. Near-seamless options include two of the three copper-based alloys identified for the 5-cent coin, 669z and G6 mod, roll clad to the incumbent C110 copper core. These alloys are projected to save between $0.0069 and $0.0067 per quarter dollar coin and $0.0065 to $0.0066 per dime coin using total unit costs as of March 2012. Unplated 31157 may also prove to be a viable near seamless option with additional development in alloy composition and/or processing, both of which have an impact on the properties of circulated coins. The G6 and 669z have a slight yellow cast while the unplated 31157 has a golden hue color. For non-seamless options, the plated candidates' Multi-Ply-plated steel and Dura-White-plated zinc are promising. These options offer a significant savings of $0.0286 and $0.0327 per quarter dollar coin, respectively; using total unit cost as of March 2012. Each has a tailored EMS that is unique, but different from that of the incumbent coins. These plated options have a silver-white color, are corrosion resistant, but will wear faster than roll-clad coins. Experience with wear of Multi-Ply-plated steel in other nations has generally been positive over their approximately 5–10-year service life to date. Dura-White-plated zinc is a relatively new development and less real-world wear data exists.

The following alloys have been identified as potentially meeting the goals of the proposed action with regard to the dime, quarter dollar and half dollar coins:

- aRMour nickel-plated steel (25 µm Ni on low-carbon steel); nickel-plated steel in planchet form from the Royal Mint or a domestically licensed metal supplier
- Multi-Ply-plated steel (10 µm Ni on 23 µm Cu on 4 µm Ni on low-carbon steel); Multi-Ply-plated steel in planchet form from the RCM or a domestically licensed metal supplier
- 302HQ (Composition is company proprietary.); stainless steel in sheet form from Carpenter Technology
- 669z-clad C110 (cladding layers are 75Cu-10Zn-5Ni-10Mn); clad-copper alloy with a lower nickel content than the incumbent dime, quarter dollar and half dollar coins in sheet form from PMX Industries, Inc.
- G6 mod-clad C110 (cladding layers are 65Cu-22Zn-10Ni-2Mn); clad-copper alloy with a lower nickel content than the incumbent dime, quarter dollar and half dollar coins in sheet form from Olin Brass
- Unplated 31157-clad C110 (cladding layers are 62Cu-31Zn-0.5Ni-6.5Mn); copper and zinc-based alloy with a low-nickel content in planchet form from JZP (through Olin Brass)
- Dura-White-plated zinc (5 µm Sn on 12 µm Cu on Zn); tin and copper on zinc in planchet form from JZP
- Dura-White-plated zinc (7.7 µm Sn on 12.7 µm Cu on Zn); tin and copper on zinc in planchet form from JZP
- Dura-White-plated zinc (10.2 µm Sn on 11.2 µm Cu on Zn); tin and copper on zinc in planchet form from JZP.

6.7 ENVIRONMENTAL ASSESSMENT

As the proposed action consists solely of modifying or introducing alternative materials and any industrial process modifications necessary to accommodate those materials within the existing facilities of the United States Mints in Denver and Philadelphia, the analysis of impacts in this EA is focused on the environmental conditions affected by these potential changes.

6.7.1 Air Quality

6.7.1.1 Background and Existing Conditions

The primary sources of air emissions from the coin manufacturing process are the exothermic gas generators and the annealing furnaces. The air pollutants emitted from these sources are carbon monoxide (CO) and nitrogen oxides (NOx). The United States Mints in Denver and Philadelphia have similar operations, with the difference being that Philadelphia's furnaces are slightly larger.

In Philadelphia, there are four annealing gas generators that burn natural gas with a deficiency of air to produce a gaseous product that is rich in CO. This annealing gas is sent to the five exothermic gas rotary furnaces that are used to anneal coin blanks, and prevents surface oxidation of the blanks during annealing. Typically 90% of the annealing gas produced by the generators is sent to the annealing furnaces where after passing through the furnace, the gas is combusted with the natural gas used to heat the furnace. The excess annealing gas is equivalent to 10% of the natural gas used by the generators and is treated in catalytic oxidizers.

There are five exothermic gas furnaces in Philadelphia. The gas is burned in the furnaces to externally heat a rotary cylindrical furnace in which coin blanks are annealed. The blanks are fed to the furnaces in 1820-kg (4000-lb) batches and have a residence time of approximately 45 minutes. Annealing gas rich in CO from the generators is injected into the rotary furnace to displace air and prevent surface oxidation of the blanks. The annealing gas is subsequently burned with additional natural gas to maintain a specified furnace temperature. The amount of additional natural gas required depends upon the desired furnace temperature and the frequency that blank coin batches are processed.

The annealing furnace operations in Denver are very similar to those in Philadelphia albeit with several differences. The United States Mint in Denver also has five furnaces; but while two are the more modern exothermic gas furnaces like those used in Philadelphia, the other three are older models that use natural gas that is partially combusted to create the proper annealing atmosphere. The exothermic gas and natural gas serve the same purpose in both types of furnaces. Both gases are introduced into the furnace to burn off any oxygen and prevent surface oxidation on the blanks. There are also four exothermic gas generators in Denver, but they are alternately operated in pairs to supply exothermic gas to the two exothermic gas furnaces.

In Denver's older-style furnaces, the blanks are fed to the furnaces in 1360-kg (3000-lb) batches and have a residence time of approximately 45 minutes. The newer, exothermic gas furnaces receive blanks in 1820-kg (4000-lb) batches and are also annealed for 45 minutes. The interiors of all of the furnaces in both locations are arranged as Archimedes screws, so a continuous stream of blanks is circulated through the furnaces, and out the far end into a water bath to quench them.

The United States Mint in Philadelphia currently holds a Title V Operating Permit for its air emissions [4]. Due to its low emissions rates for CO and NOx, however, the United States Mint in Philadelphia applied for a Synthetic Minor Operating Permit in March 2012. A synthetic minor source is an air pollution source that has the potential to emit (PTE) air pollutants in quantities at or above the major source threshold levels (which would typically require a Title V Operating Permit), but has accepted enforceable limitations to keep the emissions below such levels.

The United States Mint in Denver has similarly low emissions rates for CO and NOx, with emissions that are between 38 percent and 47 percent below the emissions limits allocated in their current air emissions construction permit [5] issued by the Colorado Department of Public Health and Environment Air Pollution Control Division.

The only other source of air pollutants is the cleaning operations for the blanking dies, which experience some losses of volatile organic compounds (VOCs) from the cleaning solvents used to maintain the dies. As with CO and NOx, VOC emissions from this source are significantly below the emissions limits in the current air permits for the respective facilities.

6.7.1.2 Legal, Regulatory and Policy Requirements

The Clean Air Act (CAA) [6] is the law that establishes the framework for protecting and improving the nation's air quality. Under the CAA, the US Environmental Protection Agency (EPA) issues implementing air quality regulations and the various states are responsible for enforcing those regulations.

Air quality is defined by ambient air concentrations of specific pollutants that may be harmful to the health and welfare of the general public. There are seven major pollutants of concern, called "criteria pollutants." The criteria pollutants are CO, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), particulate matter less than or equal to 10 microns in diameter (PM10), fine particulate matter less than or equal to 2.5 microns in diameter (PM2.5) and Pb. SO_2 and NO_2 are commonly referred to as sulfur oxides (SOx) and NOx, respectively. VOCs and NOx do not have established ambient standards, but are recognized and regulated as precursors to ozone. The US EPA has established primary and secondary National Ambient Air Quality Standards (NAAQS) for these pollutants. The primary NAAQS are health-based standards intended to protect public health. The secondary standards are intended to protect public welfare, including protection against damage to crops, vegetation, animals and buildings. US EPA requires each state to identify geographic areas that have attained the NAAQS for criteria pollutants. An area in which the levels of an air pollutant meet the primary NAAQS for that pollutant is designated an "attainment" area. If the emissions in an area exceed the primary standard for any air pollutant, the area is designated a "nonattainment" area for that pollutant. An area generally is in nonattainment for a pollutant if its NAAQS has been exceeded more than once per year. Because each of the criteria pollutants is measured separately, an area may be an attainment area for one pollutant and a nonattainment area for another at the same time. Former nonattainment areas that have attained the NAAQS are designated as maintenance areas. From the standpoint of an air emissions source, such as a United States Mint coin production facility, the importance and impact of these areas are reflected in the stringency of the air pollutant emissions limits in the facility's air permit. Facilities located in nonattainment areas will most often have stricter emissions limits in an attempt to bring the area into compliance with the NAAQS. Facilities in attainment areas will have emissions limits that are less strict, but still sufficient to prevent the area's air quality from deteriorating into nonattainment.

In addition, projects receiving Federal funds that would generate air emissions and are located in nonattainment areas must be assessed using the General Conformity Guidelines (40 CFR 93) [7]. These guidelines set emission thresholds (*de minimis* levels) for transportation and other Federal projects. If the emissions from an action exceed these thresholds, a conformity analysis must be performed to determine if emissions conform to the approved state requirements. If net annual emissions from a proposed project remain below applicable *de minimis* thresholds, a CAA Conformity Determination is not required.

Greenhouse gases (GHGs) trap heat in the atmosphere and are the result of natural processes as well as human activities. Scientific evidence points to GHG emissions from human activities as a contributing factor to increasing global temperatures over the past century. The most common GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), but hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride are also typically recognized as significant GHGs. Total GHG emissions from a source are most often reported as a CO_2 equivalent (CO_2e).

On a national scale, Federal agencies are addressing emissions of GHGs by reductions mandated in Executive Order (EO) 13514, *Federal Leadership in Environmental, Energy and Economic Performance* [8]. EO 13514 was enacted in October 2009 to address GHGs in detail, including GHG emissions inventory, reduction and reporting. EO 13514 established "an integrated strategy towards sustainability in the Federal Government" by requiring all Federal agencies to achieve a series of sustainability goals. EO 13514 requires all Federal agencies to achieve, among other sustainability goals, the following goals related to GHGs: reduce greenhouse gas emissions from direct activities (known as Scope 1 and 2 emissions), reduce GHG emissions from indirect activities (known as Scope 3 emissions), and measure and report GHG emissions from both direct and indirect activities. For purposes of EO 13514, GHGs include CO_2, CH_4, N_2O, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride. As defined in the EO, Scope 1 emissions are "direct greenhouse gas emissions from sources that are owned or controlled by the Federal agency," while Scope 2 emissions are "direct greenhouse gas emissions resulting from the generation of electricity, heat or steam purchased by a Federal agency." Scope 3 GHG emissions are the most difficult to track and quantify and include "greenhouse gas emissions from sources not owned or directly controlled by a Federal agency but related to agency activities such as vendor supply chains, delivery services, and employee travel and commuting."

The United States Mint fiscal year (FY) 2011 Strategic Sustainability Performance Plan (Sustainability Plan) identifies how the United States Mint will achieve each of the EO 13514 sustainability goals. While technically subject to, and included in, the Treasury Department's Strategic Sustainability Performance Plan, the United States Mint nonetheless crafted its own Sustainability Plan to focus attention on the goals and to help the Treasury Department meet the goals established in its Sustainability Plan. Consistent with the requirements of EO 13514, one of the primary sustainability goals of the United States Mint is the reduction of GHG emissions. The Treasury Department set goals of reducing Scope 1 and 2 GHG emissions 33 percent and Scope 3 GHG emissions 11 percent by FY2020 from a FY2008 baseline.

During FY2010, for example, the United States Mint reduced its Scope 1 and 2 GHG emissions by 20 percent and Scope 3 GHG emissions by 7.0 percent compared to FY2008 emissions levels. However, volatility in coin demand is one of the United States Mint's largest challenges because making more coins means consuming more energy, which generates more greenhouse gas. Likewise, a decrease in production reduces both energy consumption and GHG emissions.

6.7.1.3 Environmental Impacts

There are no significant negative environmental impacts to air quality anticipated from the proposed action. None of the alternative material candidates are expected to result in increased overall quantities of air pollutant emissions as none of them would require longer annealing times or additional steps in the coin production process. However, a potential reduction in the annealing temperature associated with the recommended copper-based options for the 5-cent coin could result in increased concentrations of CO being emitted from the annealing furnaces. Offsetting that potentiality, a combination of air emissions reduction efforts being undertaken by the United States Mint independent of the proposed action and the benefits associated with many of the alternative material candidates are anticipated to result in decreased air pollutant emissions from the coin-making processes in use at the United States Mint.

The City of Philadelphia is part of an area that is designated as a moderate nonattainment area for the 8-hour ozone standard. It is also within an area that is currently designated as nonattainment for the 1997 PM2.5 standard. On January 23, 2012, however, EPA issued a proposed rule stating that the agency has determined that the Philadelphia Area attained the 1997 annual PM2.5 NAAQS by its attainment date of April 5, 2010. The final determination regarding attainment of the 1997 PM2.5 NAAQS is pending, but does not impact the United States Mint because the facility's PM2.5 emissions are already very low (approximately 8.2 kg per year [kg/yr] [0.0090 tons per year]) and well within permitted limits.

As of September 27, 2010, all CO nonattainment areas were redesignated to maintenance areas. The City of Philadelphia, including high-traffic areas within the central business district and certain other high-traffic-density areas have been designated as a moderate CO maintenance area. Under the Philadelphia facility's recent Synthetic Minor Source Operating Permit application [9], potential emissions of CO from coin-making operations, especially from the annealing furnaces, would be reduced. Other CO emissions reductions are expected from several alternative material candidates, but these reductions are not specific to the Philadelphia facility and are discussed below.

Based on air quality data from 2005, 2006 and the first three quarters of 2007, the Denver area was designated nonattainment for the 8-hour ozone NAAQS, effective November 20, 2007. The Denver Metropolitan (Metro) Area is also a moderate maintenance area for the PM10 standard. In addition, the Denver-Boulder area, including the Denver Metro Area, is designated as a serious CO maintenance area.

In part because of strong resistance from coin-processing equipment owners, the proposed action involves no changes to the incumbent copper-plated zinc one-cent coin. Consequently, there is no adverse environmental impact from the proposed action associated with the one-cent coin. However, future changes to the one-cent coin that could result in slight cost improvements, such as reducing copper plating thickness, should be explored.

For the 5-cent coin, selection of any of the three recommended copper-based replacement options—669z, G6 mod or unplated 31157—would allow for annealing furnace temperatures that would be approximately 140 °C (250 °F) lower than the current temperature that could result in fewer combustion-related air emissions, as well as lower energy use and longer furnace life. It should be noted, however, that the lower operating temperature could impact flow patterns such as turbulence that may result in greater concentrations of CO emissions from the annealing furnaces. Given that both the United States Mint operations in Denver and in Philadelphia are located in CO maintenance areas, this possibility could affect the facilities' ability to meet the CO emissions limits in their respective air permits.

The incumbent 5-cent coin starts out in sheet form, so the options that would be delivered as planchets would eliminate air emissions from the blanking presses, annealing furnaces, washers and post-wash drying equipment at the United States Mint facilities. The air emissions from these operations would not be eliminated entirely, but would be transferred to the metals producers instead. These options include nickel-plated steel, unplated 31157, Multi-Ply-plated steel, 302HQ stainless steel and Dura-White-plated zinc. However, these options are not recommended at present although stainless steels show particular promise if flow stress can be decreased.

Similarly for the dime, quarter dollar and half dollar coins, the recommended copper-based replacement options, including 669z-clad C110 and G6 mod-clad C110 have lower nickel content than the incumbent coins, which would allow for slightly lower annealing temperatures and fewer NOx emissions from the annealing furnaces. Unplated 31157 clad on C110 may also prove to be a viable near seamless option after additional development in alloy composition and/or processing. Again, however, the lower operating temperature could impact flow patterns such as turbulence that may result in greater concentrations of CO emissions from the annealing furnaces. These options would be supplied as roll-clad strip, as is the case for the incumbent cupronickel-clad C110 for those denominations.

With regard to the CAA Conformity Determination, the requirements are not applicable to the proposed action as "the production of coins and currency" is specifically not covered in 40 CFR §93.153(c)(2)(x). The relevant text of the regulation is excerpted below.

§ 93.153 -- Applicability

…

(c) The requirements of this subpart shall not apply to the following Federal actions:

…

> (2) Actions which would result in no emissions increase or an increase in emissions that is clearly de minimis:

…

>> (x) Actions, such as the following, with respect to existing structures, properties, facilities and lands where future activities conducted will be similar in scope and operation to activities currently being conducted at the existing structures, properties, facilities, and lands; for example, … the production of coins and currency.

The quantity of Scope 1 and 2 GHG emissions that will be emitted from the United States Mints in Denver and Philadelphia as a result of the proposed action is not expected to exceed current levels and, depending on the alloy(s) selected, may be lower. This is because there are no new production processes or equipment being proposed that would contribute to increased GHG emissions. The reasons for anticipated reductions in GHG emissions are the same as for the other combustion-related air emissions discussed above.

There are several scenarios, however, in which Scope 1 and 2 GHG emissions would be reduced. If any of the recommended copper-based options with lower nickel content than the incumbent 5-cent coin, such as 669z, unplated 31157 or G6 mod, are selected to replace the composition of the incumbent 5-cent coin, then the annealing furnace could be operated at a temperature that is approximately 140 °C (250 °F) lower than the current temperature. In addition, as all denominations other than the one-cent coin are currently supplied as coiled sheet requiring blanking, the selection of an option that is supplied as a planchet, such as Dura-White-plated zinc or Multi-Ply-plated steel for the 5-cent, dime, quarter dollar or half dollar coins, would eliminate the Scope 1 and 2 GHG emissions associated with the blanking presses, annealing furnaces and post-wash drying for those denominations. Whether the selection of a ready-to-strike planchet option for the 5-cent, dime, quarter dollar or half dollar coins will result in increased Scope 3 emissions at the vendor is unclear, but in any event is not viewed as significant. Furthermore, as the United States Mint has stated previously, reductions in indirect GHG emissions are difficult because the United States Mint does not have operational control over its suppliers.

6.7.2 Water Resources and Quality

6.7.2.1 Background and Existing Conditions

Water use during the coin-making process has been significantly reduced in recent years. In FY2009, the United States Mint at Philadelphia completed a comprehensive energy and water evaluation and retro-commissioning. The water evaluation uncovered numerous water conservation measures that the United States Mint successfully implemented in FY2010. This reduced the facility's water consumption from 95M liters (25M gallons) in FY2007 to 73.8M liters (19.5M gallons) in FY2010. Water consumption at the United States Mint at Denver fell from 92.7M liters (24.5M gallons) in FY2007 to 50.7M liters (13.4M gallons) in FY2010, accounting for 76 percent of the overall 25 percent reduction in water consumption intensity. However, the primary reason for this drop in water usage was the reduction in coin demand caused by the economic recession. The United States Mint plans to continue its efforts to reduce water consumption in the years ahead in accordance with sustainability practices rather than solely relying on the water consumption reduction from decreased production.

Wastewater is generated during the production of circulating coins. The wastewater contains trace metals, including copper, zinc, nickel and iron; surfactants; and anti-tarnish chemicals. The primary source of wastewater from the coin-making processes comes from the post-annealing steps: quenching, washing and lubricating. Following annealing, the coins must be cooled and washed prior to upsetting. The United States Mint currently uses an environmentally benign citric acid/hydrogen peroxide solution to wash the blanks. The makeup of this solution is not expected to change under the proposed action. The quenching, washing and drying procedures for the United States Mints in Philadelphia and Denver are listed below.

Philadelphia

1. Quench: The blanks are quenched in "slippery water" (water with a Polyox resin additive, 227 grams [g] [8 ounces {oz}] per tank per day). Polyox resins are water-soluble (ethylene oxide) polymers used in the production of various industrial and consumer products. The slippery water keeps the blanks from sticking together. There is a continuous flow of blanks through the quench tank and into the wash chamber.
2. Wash: The blanks are pickled in a solution of AC-67 (citric acid), a surfactant and hydrogen peroxide, an oxidizer, in distilled water. Fresh solution is automatically mixed for each run. The blanks are then rinsed with fresh water.
3. Lubricate: The blanks are lubricated using Carboshield BTX and water. Carboshield BTX is a water-based proprietary product.
4. Dry: The blanks are dried using 71 °C (160 °F) heated air.

Denver

1. Quench: The blanks are quenched in slippery water (water with a Polyox resin additive, 227 g [8 oz] per tank per day). The blanks are batch-processed. In other words, they accumulate in a hopper and are then periodically transferred in large quantities for washing.
2. Wash: The blanks are pickled in a solution of cleaner burnishing compound (with the product name DW 5653) (1.02 kg [36 oz]) and citric acid (2.73 kg [96 oz]) in water (715-liters [189-gallon]) recirculating tank on lines 1, 2 and 3 and a (920-liter [243-gallon]

tank on lines 4 and 5) for 30 minutes. Pickle solutions are used for six to seven loads before replacement. The blanks are then rinsed with fresh water for four minutes.

3. Lubricate: The blanks are lubricated using 341 g (12 oz) of Carboshield BTX, an anti-tarnish product, for four minutes, then rinsed for two to four minutes with fresh water and drained.
4. Dry: The blanks are dried with air heated to 104–121 °C (220–250 °F).

In the United States Mint at Philadelphia, the existing on-site wastewater treatment system is located in the basement of the facility. The system uses physical and chemical treatment steps to remove the trace metal contaminants and adjust the pH.[148] The pre-treated water is then discharged to the Philadelphia Water Department sewer and subsequently into the City's Southeast Water Pollution Control Plant (SEWPCP) [10]. Waste solids generated during pretreatment at the United States Mint at Philadelphia are dewatered and disposed of in an approved landfill.

The United States Mint at Denver's wastewater pretreatment system is located in the sub-basement. It is a hydroxide pretreatment system with clarification, settling and solids separation. Process wastewaters from the annealing wash and rinse tanks and burnishing areas discharge to the pretreatment system. Wastewater goes from the clarifier to an 1140-liters (300-gallon) effluent holding tank and is pumped from there to one of two underground effluent tanks; each tank has a capacity of 30,300-liters (8000 gallons). The underground tanks discharge through a flow meter to record the volume of treated wastewater pumped to a monitoring point and then subsequently discharged to the Metro Wastewater Reclamation District's system [11]. The Denver facility's pretreatment operators have the opportunity to perform process control testing of the pretreated effluent before a tank is discharged. Each of the 30,300-liter (8000-gallon) effluent tanks can have the wastewater pumped back through the pretreatment system for further treatment, if necessary.

6.7.2.2 Legal, Regulatory and Policy Requirements

The Clean Water Act (CWA) [12] establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Under the CWA, it is unlawful for industrial facilities to discharge any pollutant to a publicly owned treatment works (POTW) without complying with EPA's General Pretreatment Regulations. The US EPA issued the General Pretreatment Regulations to implement pretreatment standards to control certain pollutants from industrial users, called prohibited discharges, that may pass through or interfere with POTW treatment processes or that may contaminate sewage sludge.

In addition, Categorical Pretreatment Standards limit the pollutant discharges to POTWs from specific process wastewaters of particular industrial categories. Such industries are called Categorical Industrial Users. The standards are promulgated by EPA in accordance with Section 307 of the Clean Water Act and are designated in the Effluent Guidelines & Limitations by the terms "Pretreatment Standards for Existing Sources (PSES)" and "Pretreatment Standards for New Sources (PSNS)".

[148] pH (potential hydrogen) is a measure of the acidity or basicity of an aqueous solution.

The manufacture of circulating coins in the Philadelphia and Denver facilities is regulated under a PSNS, specifically 40 CFR 468, Copper Forming Point Source Category, Subpart A, Copper Forming Subcategory, [40 CFR 468.15 (f), (h), (j), (k), (m), (o) and (p)], as well as the City of Philadelphia Water Department Regulations (PWDRs) and the requirements of the Denver Metro Wastewater Reclamation District. There are currently categorical pretreatment limits in place at the United States Mint facilities in both Denver and Philadelphia for the following pollutants: chromium, copper, lead, nickel, zinc and total toxic organics (TTOs). TTOs include numerous toxic organics (all of which are spelled out in the respective facility's pretreatment permit), but the limit applies to the sum of the concentrations of those pollutants on the list, which individually are found at a concentration greater than or equal to 0.01 milligrams per liter (mg/l). The wastewater discharges at both United States Mint facilities are currently well within the categorical pretreatment limits outlined in their respective permits.

EO 13514 requires all Federal agencies to achieve, among other sustainability goals, improved water use efficiency and management. Specifically, EO 13514 requires all Federal agencies to reduce their potable water consumption intensity by 2% annually through FY2020 from a FY2007 baseline. The United States Mint FY2011 Sustainability Plan identifies how the United States Mint will achieve each of the EO 13514 sustainability goals. An important sustainability goal of the United States Mint is reducing potable water use. In addition, Treasury Directive 75-04 [13] calls for reducing water consumption intensity by 2% annually, beginning in FY2008 and continuing through the end of FY2015, for a total of 16% reduction through the end of FY2015, using a baseline year of FY2007. Through FY2010, the United States Mint was able to reduce potable water consumption intensity by 25 percent over FY2007 use levels.

6.7.2.3 Environmental Impacts

There are no significant negative environmental impacts to water resources and quality anticipated from the proposed action. No increase in the amount of water used in the coin-making processes is expected from the changes to coin composition under the recommended alloys or the other potential options because the water-using steps in the process, such as washing and pickling, will not change. However, any options that are currently delivered as coiled sheet and would be delivered as planchets would transfer the washing and pickling steps to the coinage material supplier. This would have a net-zero overall impact on both water usage amounts and wastewater discharges, but would reduce water usage amounts and wastewater discharges associated with the coin-making processes at the United States Mint. As a result, the proposed action will not interfere with, and may assist, the United States Mint's ongoing water use reduction efforts under EO 13514, United States Mint Sustainability Plan [14], and Treasury Directive 75-04. In addition, the United States Mint would continue to use the citric acid/hydrogen peroxide solution to wash the blanks, so no new wash chemicals would be introduced into the process.

Additional categorical pretreatment limits may be created at the United States Mint facilities in both Denver and Philadelphia for certain metals present in some of the recommended and other potential replacement alloys, including aluminum, iron, tin and magnesium, as well as for elemental chromium (chromium(0)) and certain non-metal ingredients present in 302HQ stainless steel: silicon, sulfur and phosphorus. The wastewater pretreatment process for both facilities already involves physical and chemical treatment steps to remove the trace metal contaminants. So, unless the incumbent metals pretreatment process is ineffective for one or more of the alternative metals, the impact to wastewater discharges from those metals should be minimal. Should the United States Mint pursue further investigation of 302HQ stainless steel, controlled testing would need to be performed to determine the impact of the nonmetals (sulfur, silicone and phosphorous) on the United States Mint's ability to effectively treat any wastewater discharges associated with that alloy and to meet any additional categorical pretreatment limits that may be created as a result of its use. Grade 302HQ stainless steel is not a recommended alloy under this proposed action, but additional research, development and optimization of this alloy could allow for its future use in US circulating coinage.

A significant positive environmental and cost benefit could be expected from the proposed action. Current recommended copper-based replacement alloys for the 5-cent coin, including unplated 31157, 669z and G6 mod, and for the dime, quarter dollar and half dollar coins, including the 669z and G6 mod alloys each roll clad to C110, have lower nickel content than the incumbent coins. For example, the incumbent 5-cent coin contains 25 percent nickel, while the unplated 31157 option contains only 0.5 percent nickel; replacing it instead with less environmentally harmful alloys such as zinc and manganese. In addition, zinc and manganese are already being used in the manufacture of the Presidential and Native American dollar coins, so the wastewater pretreatment systems at the United States Mints in Denver and Philadelphia are already capable of treating these metals. Other potential options for the 5-cent coin, such as Dura-White-plated zinc, which uses tin and copper on zinc, eliminate nickel entirely. Tin in elemental form has low toxicity. The main area where tin has harmful effects is when it is bonded to organic molecules. The organic form of tin is not very biodegradable. However, if tin is used as an electroplated surface on coins, the tin-coated planchets would be provided to the United States Mint by the supplier, Jarden Zinc Products. Thus, minimal adverse environmental impact at the United States Mint is anticipated.

The only potential scenario in which water use and wastewater discharges could increase at the United States Mint facilities under the proposed action would involve the selection of a sheet-based option, such as aluminum alloy 5052-H32, for the one-cent coin. Because the incumbent one-cent coin is provided to the United States Mint in planchet form, a switch to a sheet-based option would require additional production steps, including washing, which would use more water and discharge more wastewater. However, any options that are currently delivered as planchets and would be delivered as coiled sheet would transfer the washing and pickling steps to the United States Mint. This would have a net-zero overall impact on both water usage amounts and wastewater discharges, but would increase water usage amounts and wastewater discharges associated with the coin-making processes at the United States Mint. This scenario is considered to be unlikely for the lightweight 5052-H32 option for the one-cent coin because it would cause major problems for the coin acceptor, sorting and counting industry stakeholders based on its higher probability of jamming coin-acceptor equipment and potentially permanently damaging high-speed coin-sorting and/or counting equipment. As noted above, the proposed action recommends retaining the incumbent copper-plated zinc one-cent coin.

6.7.3 Solid Waste, Hazardous Waste and Hazardous Materials

6.7.3.1 Background and Existing Conditions

This section analyzes existing hazardous materials use and solid and hazardous waste generation, storage and disposal.

The United States Mint has no control over the coin quantities to be produced in a given year. Coin quantities are determined by the Federal Reserve Banks. As a result, the quantity of solid and hazardous materials use and waste generation is proportional to, and dependent upon, the demand for coins from the Federal Reserve Banks. As an example, in FY2010, the United States Mint reduced its municipal solid waste disposal 22 percent to 910 tonnes (1000 tons) from 1160 tonnes (1275 tons) in FY2008. However, this was primarily caused by a reduction in the disposal of coin packaging materials caused by a decrease in demand for coins because of the economic recession. That said, because the United States Mint does not expect a drop in coin demand through FY2020, the United States Mint plans to continue its efforts to reduce its municipal solid waste disposal.

The amount of solid waste generated by the United States Mint coin-making operations in Philadelphia and Denver that is sent for disposal is significantly reduced by metal recycling. During the blanking process for coins, other than the one-cent coin (which arrives as a planchet), up to 78% of the sheet is used (depending on the coin), while all of the remaining sheet is returned for recycling.

Most of the non-recycled waste generated is non-hazardous and is shipped to “other landfills” for disposal. Other landfills are those landfills that are not authorized under Subtitle C of the Resource Conservation and Recovery Act (RCRA) [15] to accept hazardous wastes. These landfills are commonly referred to as non-hazardous waste landfills.

While the coin-making operations at the United States Mint facilities generate some hazardous wastes, the quantities are quite small and consist of wastes such as used coolant, solvent-containing rags, used oil and various types of batteries (all of which are recycled). In addition, the generation of these wastes is not tied to a particular coin or coin composition, so the proposed action is not expected to impact this area.

6.7.3.2 Legal, Regulatory and Policy Requirements

The Resource Conservation and Recovery Act of 1976 gives US EPA the authority under Subtitle C to control hazardous waste from “cradle-to-grave,” including the generation, transportation, treatment, storage and disposal of hazardous wastes.

RCRA also includes a framework for the management of non-hazardous solid wastes under Subtitle D. Subtitle D also covers certain hazardous wastes that are exempted from the Subtitle C regulations, including metal scrap. The Denver facility is a small-quantity generator of hazardous wastes and as such is subject to reduced requirements under RCRA.

The Emergency Planning and Community Right-to-Know Act (EPCRA) [16] established community awareness and annual reporting requirements for certain listed substances. Emissions, releases, transfers and waste management data for certain toxic chemicals listed under EPCRA Section 313 must be reported annually as part of the community right-to-know provisions (40 CFR Part 372). The EPA makes the data available to the public through the Toxics Release Inventory (TRI).

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) [17] established specific requirements for accidental releases of certain hazardous substances. Releases of CERCLA hazardous substances, in quantities equal to or greater than their reportable quantity (RQ), are subject to reporting to the National Response Center under CERCLA. Such releases are also subject to state and local reporting under Section 304 of EPCRA. CERCLA hazardous substances, and their reportable quantities, are listed in 40 CFR Part 302, Table 302.4. However, for metals listed under CERCLA, including chromium, copper, nickel and zinc, no reporting of releases of the solid form is required if the mean diameter of the pieces of the solid metal released is greater than 100 microns (0.004 inches).

Finally, among other sustainability goals, Section 2 of EO 13514 requires all Federal agencies to generally minimize the quantity of toxic and hazardous chemicals and materials acquired, used or disposed of, but does not dictate a specific numeric reduction goal.

6.7.3.3 Environmental Impacts

The impacts to solid and hazardous wastes management associated with the proposed action are anticipated to be insignificant. Any differences in the quantities of hazardous materials used in the coin-making processes would be negligible and would not be dependent on the proposed action because it does not involve the introduction of new hazardous materials or hazardous-waste generating processes. Rather, the quantities would be driven solely by coin demand from the Federal Reserve Banks. Appropriate and mature procedures for the handling, storage and disposal of hazardous materials and wastes would continue to be followed in Philadelphia and Denver in accordance with RCRA and other applicable federal, state and local regulations.

Depending on the composition of the selected alloy(s), the makeup of the solid wastes generated will likely change, but the RCRA requirements for management and disposal of those solid wastes will stay the same. United States Mint contracts with alloy suppliers dictate that all blanking wastes must be accepted by the supplier to prevent security lapses, so no new or additional solid wastes will be disposed of as a result of the proposed action. However, a change in the composition of the incumbent circulating coins could negatively impact the amount of money the United States Mint is able to recoup from its recycling efforts.

While the scrap from the recommended copper-based alloys would be recycled by the supplier to create the coiled sheet for alternative coins, other alloys may not be so easily recycled. Stainless steel or aluminum are fully recyclable, but may not be as valuable to the suppliers. Also, the Dura-White-plated zinc scrap cannot be used to make new Dura-White-plated planchets as the tin contained in it impedes its reusability for coin materials. However, brass and/or bronze foundries that will pay for, and recycle, Dura-White-plated zinc scrap have been identified, so that all of the scrap would be reused at some level and none of it would be disposed of in a landfill. As the value of the Dura-White-plated zinc scrap is considerably less than that of the recommended copper-based alloys, however, suppliers would likely want to negotiate a reduced price to accept Dura-White-plated zinc scrap. For Multi-Ply-plated steel, copper-plated steel and nickel-plated steel, the scrap is fully recyclable as steel scrap but would likely be valued only as steel as there is no proven economical way of separating the copper and nickel plating layers from the steel to recoup the value of those alloys. So, while all of the recommended and other potential options are fully recyclable, the overall cost of a given alloy will depend in part on how it is recycled and its scrap value, with the United States Mint likely recouping more of its materials costs from the recommended copper-based alloys, such as 669z, unplated 31157 or G6 mod, than from the other potential options such as Dura-White-plated zinc, aluminum, stainless steel or the plated-steel options.

Furthermore, as all denominations other than the one-cent coin are currently supplied as coiled sheet requiring blanking, the potential future selection of an option that is supplied as a planchet, such as Dura-White-plated zinc or Multi-Ply-plated steel for the 5-cent, dime, quarter dollar or half dollar coins, would eliminate the wastes associated with the blanking and washing processes at the United States Mint facilities. This would create an obvious environmental benefit for the United States Mint. It would obviously not eliminate those processes entirely; rather they would be transferred to the chosen supplier. The level of impact created would vary depending on the supplier, but the potential suppliers contacted during the development of this EA indicated there would be no significant impacts to their operations associated with the transfer of those processes to their respective facilities.

In addition, depending on the composition of the selected alloy(s), the two United States Mint coining facilities may be required to update their respective Spill Prevention Control and Countermeasures (SPCC) plans and Hazardous Waste Management Plans. This would be a one-time effort with little or no impact.

The United States Mints in both Denver and Philadelphia report off-site releases of the same four metals—copper, lead, manganese and nickel—annually as part of the TRI program under EPCRA. A very small percentage of those releases is sent to non-hazardous landfills, while an even smaller percentage is sent to their respective POTWs.[149] The vast majority of TRI off-site releases are sent for recycling. For example, for copper releases in 2010, the United States Mint in Philadelphia sent 71.4 kg (157 lb) to the POTW, 1350 kg (2980 lb) to a non-hazardous landfill and 1,672,261 kg (3,678,975 lb) for recycling. For another example, the United Stated Mint in Denver reported releases of manganese in 2010 in the following quantities: 19 kg (41 lb) to the POTW, 44 kg (97 lb) to a non-hazardous landfill and 46,040 kg (101,287 lb) for recycling. Of the new constituents present in the alloys under consideration in this proposed action, only aluminum (from 5052-H32) and chromium (from 302HQ) are required to be reported under EPCRA. Should one or both of those alloys be selected, the EPCRA-related impacts would be minimal because the United States Mint facilities are already submitting annual reports under EPCRA for the other covered substances. Should neither option be selected, then the EPCRA-related impacts would be nonexistent. In addition, United States Mint contracts with metal suppliers always include language requiring the suppliers to accept any web scrap and condemned material left over from the coin-making processes.

No impacts are anticipated as a result of the proposed action from a CERCLA standpoint because the alloy constituents are either not listed as CERCLA hazardous substances or are listed as solid metals with a diameter greater than 100 microns for which no reporting of releases is required.

6.7.4 Health and Safety

6.7.4.1 Background and Existing Conditions

The United States Mint has instituted several successful workplace safety programs and policies over the past three years the result of which have been injury and illness rates that are below

[149] Because metals are not destroyed by sewage treatment processes, amounts of metals and metal category compounds reported under the EPCRA TRI program are considered transfers to disposal or other releases.

industry standards. In FY2011, the recordable case rate was 2.74 injuries and illnesses per 100 full-time workers, an amount that is well below the industry standard of 6.3 per 100 [18].

The United States Mint has identified nickel as the only alloy currently used in circulating coins that presents a health and safety issue. Nickel allergy is caused by skin exposure to nickel. The symptoms are redness, swelling, blisters, itching and scaling. These symptoms are often caused by nickel-containing jewelry, watches, buttons and other items, but can also be caused by the handling of nickel-containing coins. In industrialized countries, nickel allergy is estimated to affect approximately 17 percent of women and 3 percent of men [19]. Nickel allergic persons may develop hand eczema that may become chronic. Recent research on nickel release and skin exposure clearly shows that nickel in coins may result in nickel allergy and hand eczema [19]. Those who handle coins professionally and consumers with nickel allergy are at particular risk. Prevention of nickel allergy and eczema requires that skin exposure to nickel is avoided or minimized.

At the United States Mint facilities in Denver and Philadelphia, there is an exposure to dust containing nickel at the upset mills as well as during the counting and bagging steps. While both of these operations have engineering controls installed to prevent exposure, the United States Mint has experienced cases of allergic contact dermatitis that are possibly due to exposure to nickel dust. Engineering controls involve physically changing a machine or work environment and are superior to personal protective equipment for protecting worker safety and health.

6.7.4.2 Legal, Regulatory and Policy Requirements

Any aspect of the project that creates a potential risk to human health and safety requires consideration under NEPA. This includes occupational hazards to workers as well as the exposure of the general public to conditions creating the risk of immediate injury or long-term health hazards.

The primary statute addressing occupational hazards is the Occupational Safety and Health Act of 1970 (OSH Act) [20]. Under Section 19 of the OSH Act[150] and Executive Order 12196 of February 26, 1980 [21], entitled *Occupational Safety and Health Programs for Federal Employees*, Federal agencies are generally subject to the requirements of the OSH Act and its implementing regulations promulgated by the Occupational Safety and Health Administration (OSHA). While Federal agencies are generally subject to OSHA requirements in the same manner as private sector entities, OSHA regulations specific to Federal agencies are found in 40 CFR Part 1960.

OSHA has established numerous general standards to protect worker safety and health, including those for communicating hazards to employees and for personal protective equipment, as well as industry-specific and chemical-specific standards. Even in areas where OSHA has not set forth a standard addressing a specific hazard, employers are responsible for complying with the OSH Act's "general duty" clause, which states that each employer "shall furnish . . . a place of employment which is free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees."[151]

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[150] 29 U.S.C. 668.
[151] OSH Act Section 5(a)(1).

Under its Air Contaminants Standards, OSHA has established Permissible Exposure Limits (PELs) for hundreds of hazardous substances. The PELs establish quantitative limits on the amount of a given regulated substance that a worker may be exposed to during an 8-hour shift.

6.7.4.3 Environmental Impacts

The impacts to worker health and safety as a result of the proposed action, while ultimately dependent upon the alloys selected for the various denominations, are generally expected to be positive.

The OSHA PELs for substances in the recommended alloys in particular as well as for the potential replacement options for the various denominations compare favorably. While all of the same alloys currently in the nation's circulating coins are present in one or more replacement options, the alloys with the most stringent PELs, copper and nickel, are present in much smaller percentages in the replacement options. The only exception is for recommended alloy 669z for the 5-cent coin, which contains a much lower percentage of nickel, but the same percentage of copper as the incumbent 5-cent coin. Tables 6-3 and 6-4 display the OSHA PELs for the alloys in the incumbent circulating coins and in the alternative material candidates, respectively.

Table 6-3. OSHA PELs for Alloys in Incumbent Circulating Coins

Metal Alloy	**OSHA PEL**
Copper (Cu)	
• Fume (as Cu)	0.1 milligrams per cubic meter (mg/m^3) of air as an 8-hour TWA[1]
• Dusts and mists (as Cu)	1 mg/m^3 as an 8-hour TWA
Manganese (Mn)	
• Manganese compounds (as Mn)	5 mg/m^3 as a ceiling limit
• Manganese fume (as Mn)	5 mg/m^3 as a ceiling limit
Nickel, metal and insoluble compounds (as Ni)	1 mg/m^3 as an 8-hour TWA
Zinc	
• Zinc oxide fume	5 mg/m^3 as an 8-hour TWA
• Zinc oxide	
o Total dust	15 mg/m^3 as an 8-hour TWA
o Respirable fraction[2]	5 mg/m^3 as an 8-hour TWA

[1] TWA = time-weighted average
[2] According to OSHA, respirable dust is the fraction of airborne dust that passes a size-selecting device having the following characteristics: 2.0 nanometers of dust have a 90% passing selector, 3.5 nanometers have a 50% passing selector and 10.0 nanometers of dust have a 0% passing selector.

Table 6-4. OSHA PELs for Recommended Alloys and Other Alternative Material Candidates to Circulating Coins

Metal Alloy	OSHA PEL
Copper (Cu)	
• Fume (as Cu)	0.1 milligrams per cubic meter (mg/m^3) of air as an 8-hour TWA[1]
• Dusts and mists (as Cu)	1 mg/m^3 as an 8-hour TWA
Manganese (Mn)	
• Manganese compounds (as Mn)	5 mg/m^3 as a ceiling limit
• Manganese fume (as Mn)	5 mg/m^3 as a ceiling limit
Nickel, metal and insoluble compounds (as Ni)	1 mg/m^3 as an 8-hour TWA
Zinc	
• Zinc oxide fume	5 mg/m^3 as an 8-hour TWA
• Zinc oxide	
o Total dust	15 mg/m^3 as an 8-hour TWA
o Respirable fraction[2]	5 mg/m^3 as an 8-hour TWA
Alternative Material Candidates and Ingredients	
Iron oxide (Fume)	10 mg/m^3 as an 8-hour TWA
Tin (Sn)	
• Metal	None
• Inorganic compounds (except oxides) (as Sn)	2 mg/m^3 as an 8-hour TWA
• Organic compounds (as Sn)	0.1 mg/m^3 as an 8-hour TWA
Aluminum metal (as Al)	
• Total dust	15 mg/m^3 as an 8-hour TWA
• Respirable fraction	5 mg/m^3 as an 8-hour TWA
Magnesium oxide fume	
• Total particulate	15 mg/m^3 as an 8-hour TWA
Silicon	
• Total dust	15 mg/m^3 as an 8-hour TWA
• Respirable fraction	5 mg/m^3 as an 8-hour TWA
Phosphorus (yellow)	0.1 mg/m^3 as an 8-hour TWA
Chromium metal and insoluble salts (as Cr)	1 mg/m^3 as an 8-hour TWA

[1] TWA = time-weighted average

[2] According to OSHA, respirable dust is the fraction of airborne dust that passes a size-selecting device having the following characteristics: 2.0 nanometers of dust have a 90% passing selector, 3.5 nanometers have a 50% passing selector and 10.0 nanometers of dust have a 0% passing selector.

Of the alloys used in the incumbent circulating coins, nickel is the only one identified by the United States Mint as a potential health and safety concern. The incumbent 5-cent coin is 25 percent nickel, while the incumbent dime, quarter dollar and half dollar coins are 8.33% nickel. There is no nickel in the one-cent coin. The concern is based on previous cases of allergic contact dermatitis that are possibly due to exposure to nickel dust at the upset mills as well as during the counting and bagging steps. Under the proposed action, the recommended alloys identified for the 5-cent coin involve significantly less nickel than what is found in the incumbent coin. For example, the unplated 31157 option contains only 0.5% nickel and the 669z option only 5% nickel; both replacing it instead with less harmful alloys such as zinc and manganese. Other alternative material candidates for the 5-cent coin have either less nickel or, in the case of Dura-White-plated zinc, which uses tin and copper on zinc, eliminate nickel entirely.

For the dime, quarter dollar and half dollar coins, the recommended alloys—G6 mod-clad C110 and 669z-clad C110— have a total nickel content that is at least 60% less than the incumbent coins. G6 mod-clad C110 offers a reduction in the total amount of nickel from 8.33% to 3.33%, while 669z-clad C110 would consist of only 1.66% total nickel. On the other hand, 302HQ stainless steel has a slightly higher percentage of total nickel (at approximately 9%) than the incumbent coins of the same denomination.

Unlike the recommended alloys or other potential options, certain non-metal ingredients—silicon, sulfur and phosphorus—are present in 302HQ stainless steel. The presence of these constituents, particularly phosphorus due to its low PEL, may require the United States Mint to conduct testing to determine employee exposure levels; the result of which could be the need for additional engineering controls or personal protective equipment to reduce exposure. Note also that chromium is present in the 302HQ stainless steel option for the 5-cent, dime, quarter dollar and half dollar coins. The form of chromium present, however, is ferrochromium, which is the chromium(0) form used for making steel. Hexavalent and trivalent chromium, chromium(VI) and chromium(III), respectively, are used for chrome plating and are much more strictly regulated not only by OSHA, but by the US EPA and certain states. The inclusion of chromium(0) in the 302HQ stainless steel option, while different from incumbent alloys, is not anticipated to create additional health and safety risks. But, again, additional employee exposure testing may be necessary. In any event, the 302HQ stainless steel option is not currently recommended under the proposed action. However, additional research, development and optimization of 302HQ stainless steel could allow for its future use in US circulating coinage.

6.7.5 Transportation

6.7.5.1 Background and Existing Conditions

Transportation refers to the use of roads as affected by the proposed action. The United States Mints in Denver and Philadelphia regularly receive shipments of raw materials for coins, both planchets and coiled strip, weighing substantial amounts. In addition, the United States Mint facilities in both cities ship large quantities of metal scrap for recycling. Neither shipment is considered to be hazardous.

In 2010, the United States Mint in Philadelphia sent over 1.7M kg (3.8M lb) of scrap metal, such as copper, nickel and manganese, for recycling. In the same year, the United States Mint in Denver shipped nearly 1.8M kg (4M lb) of scrap metal for recycling. In addition, in FY2011, the United States Mint shipped 7.4B circulating coins, an increase from FY2009 when only 5.2B coins were shipped, but far less than the FY2000 peak of 27B circulating coins shipped.

6.7.5.2 Legal, Regulatory and Policy Requirements

The transportation of heavy materials is subject to Department of Transportation (DOT) requirements and to federal, state and local regulation of weights on public roads. The regulations of the Federal Motor Carrier Safety Administration, a division of DOT, apply to the shipping company and not to the entity receiving or offering shipments. In addition, the supplies of metal alloys for coining, the circulating coins, and the metal scrap generated by the coining process are not considered to be hazardous under the Pipeline and Hazardous Materials Safety Administration's (PHMSA's) Hazardous Materials Regulations (HMRs) that govern shipments of hazardous substances.

6.7.5.3 Environmental Impacts

Any environmental impacts related to transportation anticipated from the proposed action are expected to be insignificant, but if anything, will be positive based on a potential reduction in weight of the raw materials, circulating coins and scrap metal. As shipments of the metal alloys for coin making, new circulating coins and the metal scrap generated by the coining process are not considered to be hazardous under PHMSA's HMR, there are no environmental consequences from a hazardous materials transport standpoint that would result from the proposed action.

The low density of metals such as magnesium and aluminum alloys potentially identified for the one-cent coin is an advantage from a transportation standpoint compared to the incumbent zinc-based one-cent coin. The lighter-weight coins would result in less fuel usage and therefore would be less expensive to transport in large quantities.

Although an aluminum one-cent coin is currently the lowest-weight and lowest-cost option from a transportation point of view, the coin-processing industry has raised major objections based on the lower density of aluminum and its higher probability of jamming coin-processing equipment and potentially permanently damaging high-speed coin-sorting and counting equipment. Consequently, an aluminum one-cent coin, while potentially viable in the future, is presently not recommended under the proposed action.

Because the weights of the other potential replacement alloys for the 5-cent, dime, quarter dollar and half dollar coins are all comparable to the incumbent circulating coins of the same denomination, no significant impacts to transportation are expected from the proposed action.

6.7.6 Energy Use

6.7.6.1 Background and Existing Conditions

Coin production can be a relatively energy intensive effort, relying as it does on sizeable and powerful coining machinery and furnaces. The United States Mints at Denver and Philadelphia must use significant amounts of electricity and steam to successfully manufacture the various coin denominations. Paying for that electricity and steam is an obvious and substantial cost burden and any efforts to reduce that burden through the introduction of more sustainable practices and coin materials could represent not only a significant cost savings, but a positive environmental benefit as well.

The United States Mint has begun to incorporate sustainability into its operations and culture, per EO 13514, the Department of the Treasury's Strategic Sustainability Performance Plan and other legal drivers. Sustainability projects that reduce the United States Mint's energy use during coin production should result in a corresponding reduction in costs.

The United States Mint facilities in both Denver and Philadelphia recently went to two shifts per day instead of three shifts per day. This plan went into effect in June 2012 and will allow production to be shut down completely from Friday through Sunday, saving considerable energy.

In addition, an energy audit was conducted in FY2009 (see page 19 of Reference 14) at the Philadelphia facility. As a result of the audit, a steam generation plant is under consideration to install onsite and save costs associated with offsite steam generation.

In FY2010, the United States Mint successfully concluded a Power Purchasing Agreement to supply the United States Mint at Denver with wind energy for all of its electricity use. As a result, the Denver facility now uses 100% sustainable energy. In addition, in FY2009, the United States Mint at Philadelphia completed a comprehensive energy and water evaluation and retro-commissioning. The retro-commissioning uncovered 21 energy conservation measures. In FY2010, the United States Mint at Philadelphia closed out 11 of these measures for a total energy savings of 2,022,180 kilowatt-hours (kWh) of electricity and 3563M kg (7839M lb) of steam compared to FY2008 levels.

These sustainability projects have the added social benefits of reducing air pollution, water pollution, solid waste and greenhouse gas emissions.

6.7.6.2 Legal, Regulatory and Policy Requirements

EO 13514, *Federal Leadership in Environmental, Energy and Economic Performance* established "an integrated strategy towards sustainability in the Federal Government" by requiring all Federal agencies to achieve a series of sustainability goals. EO 13514 adds to and extends the sustainability requirements of the Energy Policy Act of 2005 (EPAct), EO 13423, and the Energy Independence and Security Act of 2007 (EISA). One of the primary stated goals of EO 13514 is to increase energy efficiency.

The United States Mint FY2011 Strategic Sustainability Performance Plan (Sustainability Plan) identifies how the United States Mint will achieve each of the EO 13514 sustainability goals. The Sustainability Plan targets reductions in energy use as part of its approach to reducing GHG emissions and notes that Section 431 of EISA requires Federal agencies to reduce the energy intensity of their buildings by 3% annually through FY2015 from a FY2003 baseline.

Under Treasury Directive 75-04: Energy Management Program, it is the policy of the Department of the Treasury to improve energy efficiency of agency facilities, on a gross square foot basis, 3% annually through the end of FY2015 or 30% by 2015 compared to FY2003 baseline year, thereby reducing production costs as well as GHG and other emissions.

6.7.6.3 Environmental Impacts

Any environmental impacts related to energy use anticipated from the proposed action are expected to be positive.

A change in the material used for the 5-cent coin that would result in lower annealing temperatures and more malleable material would benefit production energy use at many levels. If any of the recommended copper-based options with lower nickel content than the incumbent 5-cent coin, namely 669z, unplated 31157 or G6 mod, are selected to replace the composition of the incumbent 5-cent coin, then the annealing furnace could be operated at a temperature that is approximately 140 °C (250 °F) lower than the current temperature thereby reducing the amount of annealing gas and electricity used to operate the furnace.

In addition, as all denominations other than the one-cent coin are currently supplied as coiled sheet requiring blanking, the selection of an option that is supplied as a planchet, such as Dura-White-plated zinc, for the 5-cent, dime, quarter dollar or half dollar coins would eliminate the energy used by the United States Mint to operate the blanking presses, annealing furnaces, upsetting, washers and post-wash drying equipment for those denominations. A substantial savings in the United States Mint's energy costs would result.

It is not recommended under this proposed action, but a potential scenario in which energy use could increase would involve the selection of coiled sheet-based option, such as 5052-H32, for the one-cent coin. As the incumbent one-cent coin is provided to the United States Mint in planchet form, switching to a sheet-based option would require additional production steps, including blanking, washing, drying and upsetting which would necessarily require more energy use at the United States Mint. The overall effective energy usage would transfer from the current suppliers to the United States Mint. This would have a net-zero overall impact on energy usage, but would increase energy usage associated with the coin-making processes at the United States Mint; however, a final accounting would depend upon whether one of the energy saving options for the 5-cent coin is selected. With that said, this scenario is considered to be unlikely because the potential use of 5052-H32 for the one-cent coin would cause major problems for the coin-processing stakeholders based on the lower density of aluminum and its higher probability of jamming coin-acceptance equipment and the potential permanent damage that would be caused to high-speed automated equipment commonly used to sort and/or count coins.

The proposed action currently recommends keeping the incumbent copper-plated zinc one-cent coin that is supplied as a planchet, moving to one of the nearly seamless copper-based alternatives (669z, G6 mod or unplated 31157) for the 5-cent coin and moving to one of the nearly seamless copper-based alternatives (669z or G6 mod) roll clad to the incumbent C110 copper core for the dime, quarter dollar and half dollar coins. Unplated 31157 may also prove to be a viable near seamless option after additional development of composition and/or processing. (Again, nearly seamless alloys have an EMS match, but may have slight weight differences from the incumbent coin.) Taking these actions would, for the reasons outlined above, result in a reduction in energy use and an environmental benefit.

6.7.7 Biological Resources

6.7.7.1 Background and Existing Conditions

Biological resources include native and naturalized plants and animals and their habitats.

6.7.7.2 Legal, Regulatory and Policy Requirements

The goal of the Endangered Species Act (ESA) of 1973 [22] is to protect threatened and endangered species of animals and plants, and their habitats. Under the ESA, Federal agencies must avoid "takings" of threatened and endangered species or adversely affecting the critical habitats that are essential to their survival. Proponents of Federal actions are required to consult with the US Fish and Wildlife Service (USFWS) or the National Marine Fisheries Service (NMFS) when any threatened or endangered species may be impacted by a proposed action. In most cases, the USFWS is responsible for land and freshwater species while NMFS is responsible for marine species.

6.7.7.3 Environmental Impacts

There are no significant environmental impacts to biological resources anticipated from the proposed action. The proposed action would utilize existing production operations within existing United States Mint and coinage material supplier facilities. No new activities with the potential to impact plants, animals or their habitats would be undertaken in order to carry out the proposed action.

6.7.8 Cultural Resources

6.7.8.1 Background and Existing Conditions

Impacts to cultural resources can be direct or indirect and affect the integrity of the historic property and can adversely affect those characteristics that cause a property to be listed, or eligible for listing, on the National Register of Historic Places (NRHP). Direct impacts include physical impacts to all types of historic properties. They also include visual impacts to the setting of historic districts, buildings, structures and objects where setting is an important aspect of their integrity. Indirect impacts are those that change the accessibility, usage or economic viability of the historic property.

Cultural resources that are listed in the NRHP are termed "historic properties." Historic properties can include both prehistoric (prior to European contact) and historic (post-European contact) sites, buildings, structures, districts and objects. All historic properties within a project area constitute the affected environment for cultural resources.

All current coin-making activities occur within the physical boundaries of the United States Mint facilities in Philadelphia and Denver. While the Denver facility has been on the NRHP since 1972, the Philadelphia facility is housed in a relatively new structure that is not on the NRHP.

6.7.8.2 Legal, Regulatory and Policy Requirements

Two Federal acts establish requirements for assessing impacts to cultural resources: the National Historic Preservation Act (NHPA) of 1966 [23] and Archeological Resource Protection Act (ARPA) of 1979 [24]. Section 106 of the NHPA requires Federal agencies to take into account the direct and indirect effects of a proposed action on historic properties. ARPA protects archaeological resources found on Federal and Tribal lands from disturbance and establishes permitting standards for the excavation of archaeological sites. ARPA only applies if archaeological sites on Federal or Tribal lands will be excavated or if artifacts are going to be collected from those sites.

The NHPA created a formal national policy for historic preservation and defined historic preservation as the protection, rehabilitation, restoration and reconstruction of districts, sites, buildings, structures and objects significant in American history, architecture, archaeology or engineering. Section 106 of the Act requires Federal agencies to take into account the effects of the proposed action on any district, site, building, monument, deposit, structure or object, listed in or determined eligible for listing in the NRHP.

To assure compliance with the NHPA and the Advisory Council on Historic Preservation regulations (36 CFR Part 800), the United States Mint must follow Treasury Directive 75-01 [25], *Department of the Treasury Historic Preservation Program*. Treasury Directive 75-01 outlines the policies and procedures to protect the architectural integrity of all Treasury buildings, the original designs and sculptures associated with the grounds, and the historic Treasury collections of objects, such as furniture, furnishings and arts.

6.7.8.3 Environmental Impacts

There are no significant environmental impacts to cultural resources anticipated from the proposed action. The proposed action would utilize existing production operations within the manufacturing areas of existing United States Mint facilities in Philadelphia and Denver.

6.7.9 Socioeconomics

6.7.9.1 Background and Existing Conditions

Socioeconomics include the basic attributes and resources associated with the human environment, particularly economic activity. Economic activity typically encompasses employment, personal income and industrial growth. Socioeconomic impacts are typically described in terms of their locality, duration, intensity and whether they would be beneficial or adverse.

The composition and other physical characteristics of the incumbent circulating coins have not changed in decades. As a result, the various stakeholders whose businesses and livelihoods rely heavily upon the use of coins, such as laundromats, parking authorities, car washes and the vending industry have built or purchased machinery or systems designed to identify and accept the incumbent circulating coins. For instance, there are approximately 300,000 car wash coin-acceptor units and about 5,300,000 vending machines throughout the United States. Some of these units are old and may not be able to be re-engineered to accept a change in a given coin's characteristics and/or properties, while others are quite new and would merely require a one-time reprogramming of the software in the machine. Because of the wide variety in age and technology of the nation's coin-processing equipment, the potential financial impact to each stakeholder group resulting from a change in the composition or other physical characteristics of the incumbent circulating coins would vary widely as well.

6.7.9.2 Legal, Regulatory and Policy Requirements

The implementing regulations for NEPA state that the interrelation of "economic or social and natural or physical environmental effects" is typically part of the NEPA assessment process. Furthermore, when assessing whether a proposed action will have a significant impact or effect on the environment, the CEQ regulations require that a wide range of effects be taken into account. These effects include "ecological, . . . , aesthetic, historic, cultural, economic, social or health, whether direct, indirect or cumulative."[152]

While the analysis of socioeconomic impacts is an important aspect of the NEPA process, they are not the driving force behind the law and must be analyzed in the context of the proposed action as a whole. NEPA requires the preparation of an EIS when a major Federal action will have a significant impact upon the human environment. The CEQ regulations clearly state, however, that "*Human environment* shall be interpreted comprehensively to include the natural and physical environment and the relationship of people with that environment. . . . This means

[152] 40 CFR 1508.8.

that economic or social effects are not intended by themselves to require preparation of an environmental impact statement."[153]

6.7.9.3 Environmental Impacts

From a local standpoint, there will be no socioeconomic impacts, either positive or negative, to the immediate geographical area surrounding the United States Mint facilities in Philadelphia and Denver resulting from the proposed action. From a national perspective, the socioeconomic impact of the proposed action will be greater, and negative financially, for the automated coin-processing business community, but the financial impacts are limited to that small subset of the population and, with the possible exception of a potential ongoing impact to coin terminal operators, will be relatively short-term in duration (approximately one to five years). For the United States Mint, and indirectly for American taxpayers, the proposed action will have a significant, long-term, financially positive impact.

The proposed action involves recommending that alternative, copper-based or other metallic materials be used in future US circulating coins. As noted above, materials that are less expensive than those used in the construction of today's US circulating coins are available. These materials include various alloys containing copper, nickel, steel, stainless steel, zinc, tin and aluminum. As a result of the differences in physical properties of these alternative materials and the metallic materials used in the manufacture of incumbent US circulating coins, several issues may arise that would impact various segments of the impacted stakeholder groups. For example, the density of aluminum is approximately 30 percent that of the cupronickel (75% copper, 25% nickel) used in the incumbent 5-cent coin. A direct material substitution of aluminum for the 5-cent coin would result in a significant weight difference between the incumbent and alternative options. This difference impacts the coin-processing community and others that rely upon coin weight to identify the quantity of coins in a given container. To compensate for such a difference in density, other factors must be considered, especially as they relate to the automated devices used to recognize coins when co-circulating coins of differing construction.

The physical changes that could result from a change in the composition of the one-cent, 5-cent, dime, quarter dollar and half dollar coins include weight, EMS (for the non-seamless other potential options only), color, gloss and hardness. The stakeholder groups that could be impacted by these physical changes include the vending industry, laundromats, car washes, merchants (i.e., retail establishments), armored-car carriers, parking authorities (with coin-operated parking meters), public transportation authorities, amusement and gaming establishments, pay phone owners, coin-processing equipment manufacturers, owners of coin sorters and counters, and the blind and visually impaired. The physical changes that would have the most significant negative impact on these stakeholder groups, changes to diameter and thickness, will not be undertaken as part of the proposed action in order to completely avoid those significantly greater negative impacts.

While the population of individuals that engage in hand-to-hand transactions is greater in number than all other stakeholders, it was assumed that individuals would be able to quickly adapt to the visual and tactile clues in any alternative coins. Therefore, no cost or impact to the general

[153] 40 CFR 1508.14.

public was formally computed and any socioeconomic impacts to the general public are not expected to be significant.

Separate, comprehensive analyses of each stakeholder group that may be impacted from the proposed action were conducted. While the details are not appropriately included in this EA, it is clear from the analyses that the vending and laundromat industries would be the stakeholders most impacted by changes to circulating coins that result in coins that are not seamless with incumbent circulating coins. The proposed action recommends copper-based alloys that are nearly seamless with the incumbent circulating coins thereby significantly limiting or potentially eliminating impacts to the stakeholder groups. Nearly seamless coin options have an EMS match, but may have slight weight differences from the incumbent coin. Other industries would also be impacted depending upon the specific coin characteristics that are changed. The potential changes and their associated impacts are discussed below. It should be emphasized, however, that the discussed impacts are primarily associated with the non-seamless alternative material candidates that are not recommended under the proposed action.

6.7.9.3.1 Stakeholders that May be Impacted by Changes to Any Denomination

While many stakeholders would be primarily or solely impacted by a physical or compositional change to the quarter dollar coin, certain stakeholders may be equally impacted by changes to any denomination. These stakeholders include commercial coin-handling equipment owners, retail merchants, depository institutions, armored-car operators, and coin and currency handlers.

6.7.9.3.1.1 Commercial Coin-Handling Equipment Owners

Automated coin sorters/counters are used to quickly and accurately sort and/or count loose coins. They are the only practical tool to sort and/or count large quantities of coins. Industrial-scale machines, which can cost upwards of $70,000, are common at coin terminals and at central coin collection sites for transit authorities, vending machine enterprises, laundromats and other businesses that must sort and/or count hundreds of thousands or more coins per week. In addition, coin-accepting kiosks that sort and count coins can be found in grocery stores, bank lobbies and other public locations. The most sophisticated of these machines could sort coins by denomination and by incumbent versus alternative materials of construction. Updates to the databases of these devices would be required as a result of changes to the EMS and/or other features typically used to validate US circulating coins in these active[154] high-speed machines. These updates can be completed with a simple software push. With an estimated 30,000 high-speed active coin sorters/counters in the US, the total conversion costs to upgrade these machines across the US range from $0.84M to $2.04M with $0.84M being the most-probable conversion cost.

Another class of commercial coin processing equipment relies upon passive[155] coin recognition technology. Many more of these passive coin sorter/counter devices are in use than the active high-speed devices mentioned above. Validation of each coin is assumed to have occurred prior to entry into passive coin sorters/counters. Therefore, sorting strictly by coin size (diameter and thickness) provides a quick and economical manner to process coins. Because the proposed

[154] An active coin acceptor/sorter/counter relies upon measurements of coin characteristics, such as EMS, made with electronic sensors. Software is then used to interpret these signals to validate or reject a coin.
[155] Passive coin acceptors rely on coin size, and in some rare instances weight, to validate or reject a coin.

action involves no change to coin size, no modifications would be required for the passive coin sorters/counters and no significant impact is expected.

6.7.9.3.1.2 Retail Merchants

Retail operations, such as grocery stores, increasingly offer self-checkout stations having payment options that include the use of coins. A recent estimate claimed that 70,000 of these units exist throughout North America and it is assumed that 80 percent of them are in the United States. Given the growth of these units, an estimated 98,000 are expected to be in operation at the time of any potential introduction into circulation of candidate coins. These units use coin validators, which function in principle very much like the units used in vending machines. If non-seamless changes were made to any of the US circulating coins, these units would have to be upgraded. Given their relatively recent introduction in the retail space, however, these units use technology that can be easily and quickly upgraded to accept alternative coins via a software upload. As a result, the total cost to retail merchants to upgrade their self-checkout payment stations as a result of an EMS change to the one-cent, 5-cent, dime, quarter dollar, half dollar or dollar coins or any combination of those coins is estimated to be between $1.31M and $2.74M with $2.74M being the most-probable conversion cost.

In addition, it was assumed that retail cashiers would quickly learn to recognize and validate any coins made of alternative materials. Therefore, hand-to-hand transactions are not expected to create any measurable burden to merchants.

6.7.9.3.1.3 Depository Institutions

Management of coins by depository institutions is typically contracted to armored-car carriers. Many of these depository institutions pass along the associated fees to their clients who wish to deposit or purchase coins. Many depository institutions have in-house passive coin counting machines (for use by bank employees for counting small quantities of coins). No changes would be required for these machines (other than a potential removal of a screening magnet if steel-based coins are introduced) if coins of an alternative construction were of the same dimensions (diameter and thickness) as the incumbent coins, regardless of any changes to coin weight or metal composition. As the proposed action involves no change to coin dimensions, no modifications would be required for these passive coin counting machines and no significant impact to depository institutions is expected.

6.7.9.3.1.4 Coin and Currency Handlers/Armored-Car Operators

Armored-car operators and commercial coin terminals are generally contracted by large banks to manage their coin inventories. In addition, they help to manage coins on behalf of the Federal Reserve Banks (FRBs). Many of the coins owned by the FRBs are housed in these privately-run coin terminals. These organizations use commercial coin sorting/counting machines. In some instances, custom-designed and built machines are used that rely upon similar technology to that in use in commercial units. Changes to coin materials would require a reprogramming of the acceptance windows[156] for the impacted coins. Steel-based coins may require the elimination of a magnetic separator on some units.

[156] Acceptance windows represent the upper and lower limits of measured values (including, but not necessarily limited to, EMS, diameter and thickness) used by coin-processing equipment to valid or reject a coin.

In general, the cost to upgrade these units would be no more than $200 for EMS differences in the coins; other changes could result in costs upwards of $500 per machine at coin terminals. With an estimated four coin sorting/counting machines at each coin terminal and with a United States Mint-estimated 200 Federal Reserve-contracted coin terminals in the US, the cost to the industry to upgrade machinery would be between $160,000 and $400,000 to get ready for coin changes. If secondary separation is needed and alternative material coins have a different weight than the incumbent coins, then another employee is likely to be required at each of the 200 coin terminals if all coin denominations beyond the one-cent coin[157] are changed in weight from the incumbent coins. This added employee would confirm the contents of 100% of the incoming containers and complete the extra handling of the coins. The estimated increase in annual costs associated with circulating individual denominations with differing weights from incumbent coins is:

- 5-cent coins: $3.75M
- Dime coins: $6.92M
- Quarter dollar coins: $9.20M
- Half dollar coins: $0.04M
- Dollar coins: $1.09M.

Some of these costs would be offset by a reduction in fuel and other handling costs if alternative coins are lighter than the incumbent coins.

6.7.9.3.2 Stakeholders that May be Impacted by Changes to the 5-Cent, Dime, Quarter Dollar Coins or a Combination Thereof

6.7.9.3.2.1 Vending Machine Owners and Operators

Of the stakeholder groups assessed as part of the proposed action, the vending industry has the largest number of potentially impacted machines and the largest number of individual sites where impacted machines reside. The potential financial impact to this stakeholder group is the largest of all groups considered. In the United States, there are 5.3M vending machines. Approximately 8% of vending machines do not accept coins for payment. Presumably, they accept notes, tokens and/or non-cash payment methods such as credit and debit cards. Since a maximum of 92% of the US vending machines recognize coins, 4.876M machines would have to be upgraded if coin characteristics and/or properties changed for the 5-cent, dime or quarter dollar coins or a combination of those coins. In addition, some vending machines (especially those placed in service before approximately 1986) may have to be replaced in their entirety or be retrofitted with special communication adaptors since these machines use electronic interfaces that are no longer supported by the industry. Changes to US circulating coin characteristics and/or properties can no longer be directly accommodated by these old machines.

According to survey estimates, more than 98% of the vending machine coin acceptors use active coin sorters to recognize coins and 84% of the coin acceptors in service are less than 10 years old. Of the coins collected by vending machines, 53% are quarter dollar coins, 31% are dime coins and only 8% are 5-cent coins. The cost of upgrades to coin acceptors used in vending machines for all of these coins would be approximately the same as that for any one of them.

[157] One-cent coins in circulation today differ in weight depending upon their mint date. One-cent coins minted prior to 1982 weigh 3.11 grams; post-1982 one-cent coins weight 2.50 grams. Therefore, methods already exist to deal with coin weight differences for mixed quantities of one-cent coins.

Note that over 90% of vending machines recognize 5-cent, dime and quarter dollar coins. In contrast, only 6% of vending machines recognize half dollar coins and only 0.007% recognizes one-cent coins, so any changes to those denominations would have little or no measurable impact on the vending industry.

The majority of vending machines are owned by larger organizations (those whose annual revenue exceeds $5M) that are equipped to complete their own maintenance. The remaining 15% of vending machines needing upgrades as a result of changes to coin characteristics and/or properties are owned by smaller-sized companies and would likely be serviced by a third-party provider. Costs per machine to upgrade vending machines would be higher for those companies using third-party providers. Taking into account numerous other factors, the estimated total conversion costs to the vending industry to upgrade its machines is highly dependent upon the precise alloys selected for any or all denominations that are changed. Quarter dollar coins made of 669z-clad C110 are expected to be seamless and therefore would require no conversion costs if introduced into circulation. Use of copper-based alloy unplated 31157 for the 5-cent coin would require an estimated conversion cost of $11.3M to the vending industry; copper-based alloys G6 mod and 669z for the 5-cent coin would require an estimated conversion cost of $56.4M. Changes to the materials of construction for any combination of the 5-cent, dime and/or quarter dollar coins would require the following conversion costs for the given materials: Dura-White-plated zinc and 302HQ stainless steel would require an estimated $257M; plated-steel would require an estimated $514M.

In 2010, the vending industry had annual revenue of approximately $42.2B. Assuming that the industry-wide average vend price is between $1 and $2 per item, this represents approximately 21B to 42B vends each year. Assuming that the average vend price was increased by five cents per vend (i.e., between 2.5% and 5% of current totals), then the industry could be fully paid back in less than one year.

Finally, the bulk vending industry is comprised of 2.0M machines that dispense loose candy, gum balls, nuts, capsules and small rubber balls (among other items). These units are commonly found in shopping malls and in the entryways of restaurants. In virtually all such devices, coin dimensions are the only characteristics validated within these machines; in some instances, only coin diameter is validated. Because coin dimensions are the only defining parameters for the bulk vending industry and changes in coin dimensions are not part of the proposed action, any changes to coin compositions will not impact this industry.

6.7.9.3.2.2 Municipal Parking

There is an estimated 2.0M parking meters in the United States. Legacy units, estimated at 10% of the total, typically evaluate only the coin diameter to determine the legitimacy of a coin. No known parking meters use coin weight as a validation parameter. Therefore, changes to coin weight (while keeping EMS consistent with incumbent coins) will have no known impact to parking meters. While virtually 100% of parking meters accept quarter dollar coins for payment, only about 50% accept dime and 5-cent coins; a minority accepts dollar coins for payment. Modern parking meters rely upon more sophisticated coin validation methods, including use of EMS. In addition to coin payment options, many parking meters sold today allow for credit/debit card payment. The impact to this stakeholder group from a change in coin EMS is estimated to be $21.1M to $27.3M ($24.2M is the most-probable cost.) if quarter dollar coins are included in any combination of new coins released into circulation. If no EMS changes are made to quarter dollar coins, but EMS changes are made to either or both of the 5-cent and dime coins, then the conversion costs are 50% of these values. Note that these costs are not cumulative across denominations, unless the associated coins are introduced into circulation on dates that differ by more than approximately six months and thereby require a series of equipment upgrades—one for each new coin introduction.

6.7.9.3.2.3 Pay Phones

The majority of the 425,000 pay phones in the US rely upon coin dimensions for validation. Others can be upgraded through an onsite software push to accept alternative coin construction. Pay phones typically only accept 5-cent, dime and/or quarter dollar coins. Some only accept quarter dollar coins. The conversion cost to the pay phone industry is estimated to be between $1.20M to $1.70M with $1.70M being the most-probable cost.

6.7.9.3.3 Stakeholders that May be Impacted by Changes to the One-Cent Coin

Many industries and stakeholder groups do not rely in any significant measure upon the one-cent coin for commerce. As a result, changes to the one-cent coin will have no measurable impact on these groups, which include the vending, laundromat, amusement, gaming, pay phone and car wash industries, all of which rely almost entirely on other coin denominations.

6.7.9.3.3.1 Blind and Visually Impaired Persons

For the blind and visually impaired, material changes in the construction of one-cent coins (such as changing to a plated-steel coin) would generally not have any impact. Changes that would result in large differences to the weight of coins, however, such as minting an aluminum one-cent coin, would have a positive benefit for blind and visually impaired persons in distinguishing the various coins.

6.7.9.3.3.2 Transit Officials

The conversion cost (estimated at $1.18M) to bus fare boxes from an alternative one-cent coin construction appears to be minimal. The one-cent coin is rarely used in the payment of bus fares. In addition, most buses in the US rely upon automated active coin-recognition systems (using EMS detection methods); the remainder of the buses relies upon driver visual recognition and acceptance of the fare as it is dropped into a clear box, some of which are equipped to automatically validate only the diameter of the coins. Most of the automated systems can be quickly reprogrammed to recognize additional coins. Software uploads, which typically require about one minute, can be made from a small, dedicated portable computer.

Systems are in place to collect and accept coins at most facilities that have automated toll collection mechanisms. Such systems are common along turnpikes, toll roads, toll bridges and other motorized transportation systems. Coins are accepted for payment; however, one-cent coins are not accepted for payment by approximately 50% of the automated systems as a result of the processing time required to handle large sums of one-cent coins. Therefore, any change to the one-cent coin will not have a significant impact on tollway collection units; conversion costs are estimated to be $100,000.

6.7.9.3.4 Stakeholders that May be Impacted by Changes to the Quarter Dollar Coin

6.7.9.3.4.1 Laundromats

The total number of laundromat machines in the United States is estimated to be 5.1M based upon combined estimated totals from the Coin Laundry Association and the Multi-Housing Laundry Association. Laundromats rely almost entirely on quarter dollar coins—96 percent of all coins collected—so changes to the quarter dollar coin would have a large impact to this stakeholder group. Approximately 80% of laundromat machines accept coins, while the others accept other forms of payment including notes, tokens, customer cards and credit/debit cards. Based on 80% of laundromat machines accepting coins, estimated financial impacts to this stakeholder group from a compositional change to the quarter dollar coin are estimated to be $48.2M to $89.4M (and up to $153.7M if the diameter and/or thickness changed—changes not recommended in this proposed action).

The typical turns per day (TPDs), i.e., number of times in a typical day that each machine is used, for laundromat equipment is between three and eight. If the average price to use a machine is raised by 25 cents (consistent with the industry's heavy reliance on the quarter dollar coin), then the time required to pay back the investment required to upgrade to alternative US circulating coins is estimated to be between 5 and 40 days.

6.7.9.3.4.2 Amusement

This stakeholder group is dominated by the quarter dollar coin and customized token payment. Changes to other coins would not significantly impact this stakeholder group. More than 70 percent of the coin validators used in amusement machines relies only on coin size for validation. Since a change in coin size is not part of the proposed action, a maximum of 30 percent of the amusement industry would be impacted by a change in the EMS of the quarter dollar coin. Given that the majority of the coin acceptors used in this industry can either accept new validation software or be taught to recognize alternative coin designs, the estimated impact to this stakeholder group would be between $0 and $3.4M for an alternative quarter dollar coin.

6.7.9.3.4.3 Gaming

This industry has recently invested heavily in machines that no longer require or accept circulating coins to operate. Fewer than 5% of gaming machines in operation accept any sort of circulating coins. Today, casinos largely depend upon payment cards and tokens. Small games of chance are typically dependent upon notes or other forms of payment. Rarely do machines that accept coins recognize one-cent or 5-cent coins. Those that recognize quarter dollar and/or dollar coins are of an older design that is no longer manufactured and are not well supported. As a result, the impact of the proposed action on this stakeholder group is expected to be relatively small, most probably about $800,000 for a change in the EMS of the quarter dollar coin.

6.7.9.3.4.4 Car Washes

There are approximately 300,000 car wash coin-acceptor units throughout the United States. Of the fielded units, it is estimated that 30 percent validate based upon coin dimensions only, 50 percent of the units are sample coin comparators and 20 percent of the coin acceptors are EMS-based units. The dimensions-only units would not be impacted by a change to coin weight and/or EMS. Sample coin comparators that are designed to accept multiple coins can within 5 minutes be reconfigured to accept alternative coins having differences in weight and/or EMS. Sample coin comparators that are designed to accept single coins would have to be replaced with multiple-coin units if alternative coins have different weight and/or EMS from the incumbent coins. EMS-based units can be taught to recognize alternative coins. This task can be completed by existing staff of the car wash owners and operators.

This industry relies almost exclusively on quarter dollar coins, dollar coins and tokens. Other forms of payment, including notes and credit/debit cards, are also accepted. Changes to the one-cent, 5-cent, dime or half dollar coins will have no measurable impact to the car wash industry. Impacts associated with changes to the EMS of quarter dollar coins will impact approximately 70% of all car wash coin-comparator units currently in use. The total financial impact to the car wash industry is estimated to be between $7.2M and $10.5M as a result of changes to the EMS and/or weight of quarter dollar coins.

6.7.9.3.5 Potential Impacts to the United States Mint

A switch to one of the alternative material candidates for the one-cent coin typically would result in a negative financial impact. The only exception is the potential use of aluminum (Al) alloy 5052-H32, which is anticipated to save about $19.2M per year using March 2012 metal costs. However, the coin-processing industry has raised major objections to 5052-H32 based on the low density of aluminum and its higher probability of jamming coin-processing equipment and potentially permanently damaging high-speed automated coin-sorting and counting equipment. The next lowest-cost, practical alternative to an Al alloy, and the recommendation of this proposed action, is to retain the incumbent copper-plated zinc one-cent coin. Some additional cost savings may be realized by making a design that is easier to mint. The other one-cent coin options are estimated to cost (based upon March 2012 metal prices) between $12M more per year for the copper-plated steel in sheet form to nearly $22M more per year for the copper-plated steel in planchet form.

For nearly seamless alternatives to the 5-cent coin with an EMS match, copper-based alloys 669z, G6 mod and unplated 31157 can each be used with cost savings based on replacing nickel and copper with less expensive alloying elements. The non-seamless options, including Multi-Ply-plated steel, stainless steel such as 302HQ and Dura-White-plated zinc, would produce metal cost savings greater than the copper-based alloys. The estimated overall annual cost savings to the United States Mint from selecting one of these non-seamless options for the 5-cent coin ranges from $20.6M to $46.6M using March 2012 metals pricing.

Near-seamless options for the dime, quarter dollar and half dollar coins include two of the three copper-based alloys identified for the 5-cent coin (G6 mod or 669z) roll clad to the incumbent C110 copper core. Unplated 31157 may also prove to be a viable near seamless option after additional development in alloy composition and/or processing. These options are slightly less expensive than the incumbent quarter dollar coin. For non-seamless options, the plated candidates Multi-Ply-plated steel and Dura-White-plated zinc show greater savings, but Multi-Ply-plated steel coins would have lower security than the incumbent coin. Based on metal prices as of March 2012, these non-seamless options would save significantly more than the copper-based alloys. Estimated overall savings to the United States Mint from selecting one of these non-seamless options to replace the incumbent quarter dollar materials of construction range from $4.38M to $10.56M per year, using savings vs. March 2012 costs.

While the proposed action is expected to require a varying level of conversion costs, depending upon the specific actions taken, from the stakeholder groups as outlined above, the anticipated impact will be limited in duration (with the exception of the labor costs at coin terminals, which would be ongoing), scope (i.e., the small subset of the population represented by the stakeholders) and, depending on coins changed, intensity. Offsetting those negative financial impacts, however, are the direct financial benefits associated with United States Mint coin production that would be realized from the selection of any of the options for the 5-cent, dime, quarter dollar and half dollar coins. Indeed, certain options, such as nickel-plated 31157 or 302HQ stainless steel for the 5-cent coin, are expected to result in an annual production cost savings of over $11M over FY2011 production costs for the 5-cent coin. In addition, while not currently recommended, the Dura-White-plated zinc option for the 5-cent coin could save the United States Mint close to $52M over FY2011 costs. These are significant annual savings to the American taxpayer and these savings would be realized year after year.

Finally, while the financial impact to certain stakeholder groups could be relatively substantial in the short term, the CEQ regulations clearly state that "economic or social effects are not intended by themselves to require preparation of an environmental impact statement."

6.8 CARBONYL PROCESS

The carbonyl process is not part of the proposed action or any of the alternatives discussed in this EA, but it was briefly investigated during the course of this effort, so a concise summary of the process and the potential environmental impacts are included for reference.

The carbonyl process was invented in 1903 and deposits nickel, iron, cobalt and some other metals by a relatively low-temperature gaseous process; but also can extract these metals at near ambient temperatures. The carbonyl process exploits the ability of carbon monoxide (CO) to form compounds with many of the transition elements in Groups VIA to VIIIA of the Periodic Table of Elements. The process works particularly well for nickel and it is reversible. That is, nickel can be diffused from a substrate, or deposited onto a substrate depending upon processing temperature. The deposition system is approximately the size of a large oil delivery truck. To deposit nickel, a stream of nickel carbonyl flows in an enclosed chamber and the substrate to be deposited upon is heated to about 175 °C (347 °F). The nickel deposits on the surface releasing CO, which is recycled in a closed system.

Since the cost of the cupronickel coins has escalated sharply in recent decades, it was suggested that the carbonyl process be used to cost-effectively deposit nickel and nickel alloys on planchets of coins and to use the process for metal reclamation of worn coins or scrap. The process can coat nickel on any clean surface, so one issue would involve preparing a clean surface on the planchet or stamped coin. This typically would be done in a hydrogen-reducing atmosphere. The resulting coated coin would also need to be buffed to achieve the proper appearance.

While there are carbonyl reactors in operation, there are no known prototypes or commercial practices of using the carbonyl process to deposit nickel on substrates for use in the production of coins. As a result, feasibility studies and scale-up would be needed to assess and optimize the process for coins, define plant configuration and to minimize the processing and plant capital costs.

The potential benefits of the carbonyl process, other than its reversibility, include its relatively low operating costs and the ability to coat less expensive materials used in the core of coins.

From an environmental standpoint, however, the carbonyl process presents air emissions and worker health and safety issues. Both carbon monoxide and nickel carbonyl are regulated poisonous gases, so appropriate air pollution control equipment must be installed and more importantly, worker exposure assessments would need to be performed to determine the need for engineering controls and/or personal protective equipment to safeguard workers. Overall, extreme care must be exercised in building and operating carbonyl reactors.

The carbonyl process is currently commercially used by CVMR Corporation of Toronto, Ontario, Canada and Vale Metals in several nations including Canada, Germany, Great Britain and China.

6.9 CUMULATIVE IMPACTS

Cumulative impact is the collective effect on the environment that results from the incremental impact of the proposed action when added to other past, present and reasonably foreseeable future actions regardless of what agency or person undertakes such other actions. Cumulative impacts can result from individually minor, but collectively significant, actions taking place over a period of time.

US circulating coins are designed to be in circulation for 30 years. Historically, coin composition changes have occurred no more frequently than the 30-year time frame. While changes to circulating coins could occur on a more frequent basis in the future, the proposed action covered in this EA assumes a one-time change in the composition of the circulating coins produced by the United States Mint that will remain in circulation for 30 years. These compositional changes are expected to have environmental, health and safety, and financial benefits that increase over time. The potential reduction in nickel content for the 5-cent, dime, quarter dollar and half dollar coins would not only benefit United States Mint worker health, but US citizens nationwide that suffer from nickel allergies. Current annual coin production rates only amount to approximately 3% of the coins in circulation. So, while the full health benefits for United States Mint production line workers would be immediate for a change in the composition of coins, the benefit to Americans with nickel allergies would continue to increase for many years as the incumbent coins are replaced with the alternative versions.

The positive financial impacts of the proposed action will increase over time as well. The cost savings in coin production costs will be immediate, ongoing and will fluctuate slightly with raw materials costs. Even if non-seamless alternative coins are introduced, as the affected coin industry stakeholders replace or upgrade their respective equipment to accept the alternative coins, overall industry costs associated with the proposed action will decline as upgrades are completed. Once all impacted stakeholder groups have completed their upgrades, the net financial benefit to the US taxpayer will be fully realized.

6.10 REFERENCES – CHAPTER 6

1. National Environmental Policy Act (NEPA), as amended (42 U.S.C. 4321 *et seq*.).
2. Treasury Directive 75-02: Department of the Treasury Environmental Quality Program, September 25, 1990.
3. Treasury Directive 75-09: Environmental Management and Sustainability Program, July 01, 2008.
4. United States Mint Title V/ State Operating Permit V06-012, Issued by City of Philadelphia Department of Health – Air Management Services, effective April 18, 2007.
5. Colorado Department of Public Health and Environment Air Pollution Control Division Construction Permit NO: 00DE0180, excerpt.
6. Clean Air Act (CAA) (42 U.S.C. §§7401–7671q).
7. CAA General Conformity Guidelines (40 CFR 93).
8. Executive Order (EO) 13514, *Federal Leadership in Environmental, Energy and Economic Performance* (74 FR 52115, October 8, 2009).
9. City of Philadelphia Department of Health – Air Management Services Synthetic Minor Source Operating Permit Application, submitted by the United States Mint in Philadelphia, March 9, 2012.
10. United States Mint in Philadelphia Wastewater Treatment Permit USTROOOI0913WS, Issued by Philadelphia Water Department, December 13, 2010.
11. Metro Wastewater Reclamation District Wastewater Discharge Permit NO: 40-9, excerpt.
12. Clean Water Act (CWA) (33 U.S.C. §1251 *et seq*.).
13. Treasury Directive 75-04: Energy Management Program, December 31, 2008.
14. United States Mint FY 2011 Strategic Sustainability Performance Plan, April 22, 2011.
15. Resource Conservation and Recovery Act of 1976 (42 U.S.C. §6901 *et seq*.).
16. Emergency Planning and Community Right-to-Know Act (EPCRA) (42 U.S.C. §§11004–11049).
17. Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (42 U.S.C. §9601 *et seq*.).
18. United States Mint 2011 Annual Report, page 21.
19. Lidén, Carola, *Nickel Allergy and Coins,* Mint World Compendium, Issue 1, 2012, pp. 12–15.

20. Occupational Safety and Health Act (29 U.S.C. 651 *et seq*.).

21. Occupational Safety and Health Programs for Federal Employees, 45 Federal Register 12769, February 26, 1980.

22. Endangered Species Act (ESA) of 1973 (16 U.S.C. §§ 1531–1544).

23. National Historic Preservation Act (NHPA) of 1966 (16 U.S.C. §§470–470x-6).

24. Archeological Resource Protection Act (ARPA) of 1979 (16 U.S.C. §§470aa–470mm).

25. Treasury Directive 75-01: Department of the Treasury Historic Preservation Program, July 29, 2008.

26. *Audit of the United States Mint's Fiscal Years 2011 and 2010 Financial Statements*, Office of the Inspector General, Department of the Treasury, December 5, 2011.

27. *Regulations for Implementing Procedural Provisions of the NEPA* (40 CFR Parts 1500–1508).

6.11 LIST OF PERSONS CONTACTED

1. Chris Pilliod, Carpenter Technology, Reading, PA.

2. Mark Blizard, VP, Coinage Sales and Business Development, Jarden Zinc Products, Greeneville, TN.

3. Dr. Pete Robinson, Director, R&D, Olin Brass, East Alton, IL.

4. Richard Pratt, Director Marketing and R&D, PMX Industries, Inc., Cedar Rapids, IA.

5. Mike Philbrook, Constellium Aluminum, Ravenswood, WV.

6. Theresa Agugliaro, United States Mint, Manufacturing, Finance and Systems Support.

6.12 APPENDIX 6-A: CORRESPONDENCE AND PUBLIC COMMENTS

In accordance with 40 CFR §1506.6 – Public Involvement, Federal agencies must "provide public notice of . . . the availability of environmental documents so as to inform those persons and agencies who may be interested or affected." Appendix 6-A is currently a placeholder for future public comments on the proposed action or the EA itself should any be received.

7.0 CONCLUSIONS

As authorized by the Coin Modernization, Oversight, and Continuity Act of 2010 (Public Law 111-302) and consistent with United States Mint contract TM-HQ-11-C-0049, Concurrent Technologies Corporation (CTC) focused on accomplishing the following objectives during execution of this study:

- Reduce the costs to produce circulating coins
- Consider key stakeholders and, to the greatest extent possible, minimize conversion costs that would be necessary to accommodate significant changes to all circulating coins simultaneously
- Address critical performance attributes including physical, electromagnetic, mechanical and chemical properties

To accomplish the goals of this Act and the requirements of subchapter II of chapter 51 of title 31, Unites States Code elements of this study or factors to be considered included the following:

- Research and development (R&D) of metallic materials appropriate for coinage
- Testing of appropriate coinage metallic materials within or outside the Department of the Treasury
- Fraud prevention
- Ease of use and ability to co-circulate new coinage materials
- Analysis of production costs for each circulating coin; cost trends for such production
- Improved production efficiency
- Impacts on current and potential suppliers
- Environmental assessment
- Detailed recommendations for any appropriate changes to metallic content of circulating coins
- Recommendations for improved production efficiencies, changes in the methods of producing coins, that would further reduce the costs to produce circulating coins.

Based upon findings from efforts to meet these objectives, CTC offers the following conclusions to the Department of the Treasury and the United States Mint. The appropriate section of Public Law 111-302 is referenced in the brackets at the end of the title for each subsection below. A copy of Public Law 111-302 can be found in Appendix 1-A.

Please note: There are two types of alternative material candidates presented for each denomination: 1) potentially seamless candidates having approximately the same EMS and weight as the incumbent coin and 2) non-seamless (co-circulate) alternative candidates having a different, albeit unique, EMS and/or a different weight from the incumbent coin. The seamless alternative material candidates provide for a modest cost savings, whereas the non-seamless alternative material candidates result in larger cost savings to the United States Mint. Use of non-seamless alternative material candidates may result in significant conversion costs to upgrade coin-processing equipment.

7.1 POSSIBLE NEW MATERIALS [3(a)][158]

7.1.1 One-Cent Coin

Potential cost-effective alternative materials were evaluated as potential replacements for the incumbent copper-plated zinc (CPZ) one-cent coin, whose current composition is 97.5% Zn-2.5% Cu. The alternative metallic materials evaluated included: copper-plated steel, aluminum alloy 5052-H32, 302HQ and 430 stainless steels, aluminized steel and attractive oxide film deposited on a zinc substrate.

1. Accounting for the required additional high-temperature annealing step and the need for a thicker plating layer, copper-plated steel (CPS) one-cent coins (which would have the look and feel of incumbent one-cent coins) are nearly identical in total cost to produce as the incumbent CPZ one-cent coins. As March 2012, CPZ is slightly lower in cost than CPS. Of all the materials investigated, CPZ remains the most viable material for the one-cent coin.
2. In testing by coin-processing equipment manufacturers, the CPS one-cent nonsense pieces were found to have similar characteristics and/or properties to the greatest number of foreign coins or common slugs of all the one-cent materials tested.
3. Aluminum-based 5052-H32 one-cent coins were found to have lower per-unit costs than the incumbent one-cent coins; they also required the lowest striking load of all materials tested. However, aluminum nonsense test pieces were found to jam some commercial coin-acceptance equipment during testing. In addition, high-speed coin sorter/counter manufacturers have experienced permanent damage to their machines as a result of sorting/counting bulk quantities of aluminum coins from other countries; the aluminum coins fuse together under the speed and pressure of high-speed sorting and crash into sensitive internal components of these machines. Therefore, aluminum was found to be an unfavorable material for use in the one-cent or any other coin.
4. Sensors from coin-processing equipment used to validate coins showed a narrow range of values for 302HQ stainless steel nonsense pieces. These values were uncommon among the world's coinage, meaning that a 302HQ stainless steel one-cent coin would be easily sorted from most other coins throughout the world. However, 302 stainless steel is a commonly available material and coins made from it could be easily frauded in automated coin-processing equipment through use of simple stainless steel disks. Furthermore, the color and size of one-cent stainless steel coins may result in confusion with the incumbent US dime coin.
5. Grade 430 stainless steel was found to be ferromagnetic (i.e., drawn to a magnet) and require high striking loads. Furthermore, the expected unit cost of 430 stainless steel one-cent coins was not expected to be less than the incumbent one-cent coin. For these reasons, it was found to be unsuitable as a replacement material for CPZ.
6. Although per unit cost savings of approximately 10% are expected to accrue to the United States Mint with the production of one-cent coins from aluminized steel strip (i.e., aluminum-coated steel in strip form), issues with processing of such coins in high-speed coin sorting/counting equipment are expected; in addition, the exposed edges of aluminized steel coins would be subject to corrosion of the steel inner layer and an aluminum-colored one-cent coin would likely be confused with the dime coin.

[158] Denotes section of Public Law 111-302 (the Coin Modernization, Oversight, and Continuity Act of 2010)

Therefore, aluminized steel was found to be an unfavorable material for use in the one-cent coin.

7. Surface engineering of zinc or low-carbon steel for the one-cent coin (to obviate copper plating and its associated costs) may yield significant cost reduction in the cost of one-cent coins. However, the associated technology is immature and represents an area for long-term research. Inexpensive paints or colored particles on bare zinc covered with a wear resistant coating could considerably reduce costs to produce one-cent coins.

7.1.2 5-Cent Coin

Potential cost-effective alternative materials were evaluated as potential replacements for the incumbent cupronickel (75% Cu-25% Ni) 5-cent coin. These materials included: copper-based alloys 31157 (unplated and nickel-plated), 669z and G6 mod, nickel-plated steel, Multi-Ply-plated steel, Dura-White-plated zinc, 302HQ and 430 stainless steels, and surface-modified zinc. In addition, CPZ was considered, but was not tested, for the 5-cent coin.

1. None of the alternative material candidates were found to offer a total unit cost below face value.
2. Based upon validation testing completed in this study, the three copper-based alloys, unplated 31157, 669z and G6 mod, are notable for their similarity in electromagnetic signature (EMS) to the cupronickel alloy used in incumbent 5-cent coins (and as the outer layers of dime, quarter dollar and half dollar coins). These alloys offer annual savings to the United States Mint of $15.9 million (M) to $24.9M (using March 2012 costs and 2011 production rates). While savings would be achieved, unit cost would not be near or below face value of the 5-cent coin. The density of these copper-based alloys is between 93% and 97% that of cupronickel. This weight difference would require that existing fielded coin-processing machines incur conversion costs of between $11.7M and $58.6M. In addition, an estimated $3.75M annual increase in handling costs these costs would be borne by the armored-car carriers and coin facility operators. Also, 669z and G6 mod have a slightly yellow cast, while unplated 31157 has a golden hue. Further development of these alloys, including adjustments in chemistry and/or processing may yield EMS response (specifically electrical conductivity) and/or color that more closely matches those of the incumbent cupronickel 5-cent coins.
3. Although nickel-plated 31157 nonsense pieces had a similar color to the incumbent 5-cent coin, the expected production cost and weight difference would not justify its use as a replacement for incumbent coinage material.
4. Plated-steel material options (nickel-plated steel and Multi-Ply-plated steel) offer between $20.6M and $33.0M savings to the United States Mint for production of 5-cent coins (based upon March 2012 metal costs and production rates that match those of 2011). However, conversion costs for the several stakeholders that use coin-processing equipment was estimated at $531.5M. In addition, an annual cost of $3.75M by the coin-handling industry would be required as a result of the lower weight that each of these alternative materials would impart to the 5-cent coin. For these reasons plated-steel options do not appear to be viable for the 5-cent coin.
5. Dura-White-plated zinc and 302HQ stainless steel offered between $29.0M and $40.9M annual savings to the United States Mint (based upon March 2012 metal costs and production rates that match those of 2011). These candidate materials would require

$277.4M for conversion of US coin-processing equipment. Due to the lower density of these alloys, an annual cost of $3.75M by the coin-handling industry would be required to perform the additional handling of these materials.

6. Although 430 stainless steel was estimated to yield annual savings to the United States Mint of $46.6M for 5-cent coins (based upon March 2012 metal costs and production rates that match those of 2011), nonsense pieces of this alloy was found to be ferromagnetic. Consequently, such coins would require conversion costs of similar magnitude to that of plated-steel 5-cent coins. The 430 stainless steel nonsense pieces exhibited poor material flow during coining at maximum safe striking loads. For these reasons, 430 stainless steel does not appear to be a suitable material for 5-cent coins.
7. Surface-modified zinc 5-cent coins are options for future coin developments. The associated technology is not nearly mature enough to be applied in the next two to three years for the production of 5-cent coins.
8. Potential annual cost savings for a CPZ 5-cent coin were found to be $43.4M (based upon March 2012 metal costs and production rates that match those of 2011). (In effect a coin of this construction would be like a large version of the incumbent one-cent coin.) Coins of this construction would be different in color from incumbent 5-cent coins. Due to differences in EMS and weight, 5-cent coins made of CPZ would require conversion costs and an increase in annual coin-handling costs that are similar to Dura-White-plated zinc 5-cent coins. Prior to drawing a conclusion about the suitability of CPZ for 5-cent coins, samples should be produced, struck and evaluated for wear, corrosion and evaluation in commercial coin-processing equipment.

7.1.3 Dime, Quarter Dollar and Half Dollar Coins

Potential cost-effective alternative materials were evaluated as potential replacements for the incumbent cupronickel (75% Cu-25% Ni) clad pure copper alloy C110 dime, quarter dollar and half dollar denominations. These alloys included: 669z-clad C110, nickel-plated steel, Multi-Ply-plated steel, 302HQ stainless steel, Dura-White-plated zinc. In addition, copper alloys unplated 31157 and G6 mod were contemplated as clad materials for C110; however, samples of this construction were not tested since materials were not readily available.

1. Based upon validation testing completed in this study, quarter dollar nonsense pieces of copper-based alloy 669z clad to C110 copper showed evidence of being a seamless alternative to the incumbent quarter dollar coin. Given their similar materials of construction, these results are also expected to apply to the dime and half dollar coins. Annual savings to the United States Mint for dime and quarter dollar coins of 669z-clad C110 were estimated to be $6.1M using March 2012 costs at production volumes equal to that of 2011. Note that this clad construction (copper alloy 669z to C110) retains the costly copper core of the incumbent coin; furthermore, the clad material (i.e., 669z) has a propensity to develop a slight yellow cast.
2. Nickel-plated steel and Multi-Ply-plated steel would yield modest annual savings to the United States Mint: $6.4M and $9.2M, respectively (based upon March 2012 metal costs and production rates that match those of 2011). However, with conversion costs of $632.5M and an annual increase of $9.20M in coin handling costs by the coin-handling industry, these options do not appear to be viable alternative candidates for the quarter dollar coin.

3. Grade 302HQ quarter dollar nonsense pieces were produced and tested. Conversion costs for introduction of this alloy for the quarter dollar coin were estimated at $375.6M (based upon March 2012 metal costs and production rates that match those of 2011) as a result of its different EMS than the incumbent material. Due to the lower density of this alloy, an annual cost of $9.20M by the coin-handling industry would be required to perform the additional handling of these materials. Grade 302HQ, though not a suitable monolithic material for the quarter dollar coin, given its other attributes (discussed below), it may be suitable as a clad layer to C110 for future material development.
4. Although not physically tested as a potential replacement for the cupronickel cladding on the incumbent dime, quarter dollar or half dollar coins, two other copper-based alloys (G6 mod and unplated 31157), with electrical conductivity that were nearly identical to cupronickel, also show potential as alternative cladding materials for these denominations. Annual cost savings to the United States Mint were computed to be $5.9M and $9.3M using March 2012 costs at 2011 production levels for cladding made of G6 mod and unplated 31157 alloys, respectively. Both of these clad constructions rely upon the incumbent costly copper alloy C110 core. The G6 mod was found to develop a slight yellow cast color while the unplated 31157 develops a golden hue color.

7.1.4 Dollar Coin

For the incumbent clad manganese-brass for the Presidential Dollar and Native American Dollar coins (88.5% Cu-6% Zn-3.5% Mn-2% Ni) and Susan B. Anthony (Cu25%Ni clad to a copper core), cost saving alternative materials considered included: 88Cu-12Sn-Plated Zinc, C69250, Y42 and K474.

1. As it was deemed that revising the incumbent dollar coin material would have minimal impact to overall United States Mint costs, and, thus, this coin received a lower priority than the other denominations, alternatives to the dollar coin materials were only tested for steam corrosion. None of the dollar coin alternative material candidates improved upon the incumbent materials' steam corrosion characteristics.

7.1.5 General Materials Findings

1. After review of the Period Table of Elements, three elements stand out as possible cost-effective alternatives for coinage material; zinc, aluminum, iron (in the form of steel).
2. Steels have seen increasing use in coinage throughout the world, primarily for low-denomination coins.
3. No reliable method (other than actually making heats of material) was discovered that predicts the electrical conductivity and color of multi-component copper alloys, such as 669z, G6 mod or unplated 31157. Therefore, additional alloy (i.e., chemistry) and processing, including rolling practices and heat treatments, development is required to further refine these options as seamless alternative materials.
4. Based on poor coinability, steam corrosion and wear performance, aluminized steel was not considered a worthwhile candidate for further testing.
5. The high striking force required for 430 stainless steel and the substantial difficulty that a purely ferromagnetic material would pose to coin-processing equipment caused its removal from further consideration.

6. The plated-steel nonsense pieces exhibited a relatively large piece-to-piece variation in properties, which is commonly seen with plated-steel coins.
7. The Dura-White-plated zinc nonsense pieces had the most narrowly observed EMS readings of all materials-denominations combinations that were tested.
8. Stainless steels that have not been specifically developed to have very low strength/hardness, cannot be coined effectively under current conditions of die profile and equipment capability used by the United States Mint. Stainless steel alloy 302HQ planchets required excessive striking load. Austenitic stainless steel material may be developed into a suitable replacement material in a modified form that offers the potential for future consideration as a substitute for cupronickel, but it requires further development (including alloy composition, rolling practice and heat treatment) and testing before it could rationally be selected to replace the cupronickel used in the construction of incumbent clad circulating coins.

7.2 EASE OF USE AND ABILITY TO CO-CIRCULATE [2(b)(2)]

1. Public education would be required to inform the public about new materials of construction in the Nation's coinage, due to new materials creating a different appearance to coins, the conversion costs associated with hand-to-hand transactions is expected to be minimal and the public is expected to quickly adapt to any new materials of construction much like has been experienced by other countries that have recently introduced alternative materials for their coinage.
2. Maintaining incumbent coinage dimensions and edge design, along with maintaining approximately the same weight as incumbent coinage, will not negatively impact blind and visually impaired individuals.
3. With the exception of the one-cent coin (since the CPZ is the lowest cost option), bulk coin handlers would be negatively impacted by changes to the weight of coins since additional coin handling would be required to validate coin quantities if one or more denominations included coins of differing weights.
4. A number of alternative materials showed excellent wear and/or corrosion behavior when tested independently of other coinage materials. However, galvanic corrosion issues occur with some materials of construction when mixed and tested with incumbent materials of construction.

7.3 MINIMIZING CONVERSION COSTS [3(d)]

1. Vending machine owners and operators, along with the laundromat owners and operators were found to represent the two most significantly impacted stakeholder groups (in terms of total financial impact) if changes are made to the construction of circulating coins.
2. The conversion costs to coin-acceptance equipment are too large to justify changes to coin dimensions. The one-time conversion costs to stakeholders as a result of changes to coin dimensions, including either diameter or thickness, for the dollar, quarter dollar, dime and/or 5-cent coins would dwarf any savings realized by the United States Mint in producing such newly dimensioned coins. The total conversion costs across all stakeholder groups resulting from changes to coin dimensions was estimated by CTC to be between $1.08 billion (B) to $2.09B, with $1.45B being the most probable conversion costs as a result of dimensional changes to the quarter dollar coin.

3. The impact resulting from changes to the dimensions of the dime and/or the 5-cent coins would be approximately 80% of that for the quarter dollar coin, while changes to the dimensions of the one-cent coin would cost stakeholders approximately 5% of that for the quarter dollar coin.
4. Although the dollar coin is not widely used in circulation, assuming that all coin-acceptance equipment that currently accept dollar coins are upgraded to accept newly-dimensioned dollar coins, the conversion costs would be approximately 60% of that for the quarter dollar coin.
5. For automated, unattended points-of-sale, the most important of the incumbent US circulating coins is the quarter dollar coin. Its use is pervasive throughout the many stakeholders that rely upon coins for commerce. Introduction of a non-seamless quarter dollar coin into circulation would create the largest disruption to those stakeholders who rely upon automated, unattended point-of-sale transactions with coins. Assuming no change to coin dimensions, conversion costs for the various candidate materials ranged from $0 for 669z-clad C110 copper to $375.6M for all other non-ferromagnetic material candidates. Non-ferromagnetic materials are not magnetic and provide an EMS that is readable by current coin-processing equipment used in the US. Quarter dollar candidate materials that are ferromagnetic would require a $632.5M conversion cost. Ferromagnetic candidate materials include plated-steel, which includes nickel-plated steel and Multi-Ply-plated steel.
6. It is CTC's opinion, supported by comments made by several retailers who were interviewed for this outreach effort that the general public, and retail cashiers in particular, will quickly learn to recognize and visually validate coins made from new metallic materials of construction. Therefore, hand-to-hand transactions are not expected to create any measurable financial burden to merchants or to the general public.
7. Should changes be made to the materials of construction and/or dimensions for one or more US circulating coin, then all such coins should be introduced within a short period of time (nominally within a 2–4-month window of time). Doing so would require one upgrade, if needed, to the effected coin-acceptance equipment. On the other hand, introducing several coins of new material construction and/or dimensions into circulation over a significantly longer period of time would require a series of incremental upgrades, the effects of which would be far more costly and disruptive than introducing all coins at, or nearly at, the same time.

7.4 MATERIAL TESTS [2(a)(1)]

1. Standard United States Mint test protocols were used to estimate wear and corrosion effects on materials during circulation.
2. Additional validation testing must be completed for proposed materials of construction for circulating coins to quantify:
   - The variability of material properties from multiple lots of proposed materials of construction
   - The variability in finished coins through completion of simulated coin production runs each of at least 1,000,000 test pieces.

   Test pieces of any given denomination should be made at different times and under a variety of common production conditions. Samples of coins from each of these conditions should then be tested to establish a more robust understanding of how coins constructed of these materials will perform in circulation. These tests must also assess the impact of temperature, humidity, and coin scratches, gouges, tarnish, corrosion, wear and slight bends. Additional test conditions, if any, should be defined by the coin-acceptance equipment manufacturers.

3. For plated materials, the wear and corrosion rates differed depending upon whether the materials were tested in isolation or in combination with other coinage materials. Additional test protocols should be developed to quantify the wear and corrosion rate of coins/nonsense pieces of dissimilar materials co-circulating. The test protocol should consist of candidate materials and incumbent materials. Testing these materials simultaneously will provide more realistic conditions of coins in circulation.
4. Co-circulation with copper-based coins is of concern for the aluminum- and tin-plated candidate materials due to galvanic corrosion.
5. The wear test results should be taken as a qualitative indication of potential fitness of a candidate material, and small variations do not represent reproducible differences. No confident prediction of a service lifetime can be made based on the results of the United States Mint's wear test procedure.
6. From the tensile test results of the various materials tested, there does not seem to be a direct correlation between tensile properties and coining performance.
7. Although hardness may be a good discriminator for the quality of various lots of incumbent coinage materials, in the testing completed here hardness did not correlate with the relative performance of different materials in striking trials.

7.5 COST TRENDS FOR PRODUCTION [3(a)]

1. Using March 2012 metals prices defined on the London Metal Exchange, iron (and steels), zinc and aluminum alloys were identified as the leading alternative candidates to reduce the cost of coinage by replacing copper and nickel to varying degrees.
2. The large swings in coin orders from month to month have a negative impact on plant efficiency and overall costs.
3. Neither the United States Mint facility in Philadelphia nor the one in Denver has a sufficient storage capacity to permit a more consistent week-by-week production rate throughout the year that would allow for building up coin inventories in anticipation of the peak coin demand periods.
4. Further complicating the management of coin production, orders from the Cash Product Office of the Federal Reserve are estimated one month in advance, but the actual quantity of coins ordered can still vary by as much as 30%. The actual number of coins required is not defined by the Federal Reserve Banks until the finalization of the order as production actually begins. These shifting, short-term changes in coin demand impact the required installed machine capacity in addition to having an effect on staffing and the supply chain.
5. One method for improving efficiency is to sift out and condemn defective pieces while reclaiming high-quality pieces from production lots known to contain some unacceptable pieces. A high-speed, automated inspection process would be needed to accomplish this cost effectively. The United States Mint does possess two Proditec machines, but their capacity isn't great enough to accomplish this task. At the current technical maturity level, commercially available equipment to automatically complete such inspections on-line does not appear to be available. Considerable research may be needed to determine

whether a cost-effective inspection technique could be developed and implemented for culling out defective pieces.

6. No best practices and proven methods for forming metal were identified that could economically replace the highly evolved conventional processes used to produce high volumes of circulating coins.
7. Today, metal prices have moderated and seem to be slowly increasing, although it is difficult to predict long-term pricing trends amongst short-term volatility experienced in the metals market since the economic downturn that began in 2008. Nevertheless, there has been a fairly predictable trend in that the sequence in cost of metals does not seem to change and has been, from more to less costly in this order: nickel, copper, aluminum and zinc, and steel.

7.6 REDUCE THE COSTS TO PRODUCE CIRCULATING COINS [3(c)]

1. For the one-cent coin, the United States Mint's total indirect costs are greater than $0.01; positive seigniorage is impossible to obtain, at current indirect costs levels and under the same allocation methodology.
2. Copper-plated zinc (CPZ) and copper-plated steel (CPS) coins are nearly identical in total cost to produce. As of March 2012, CPZ is slightly lower in cost than CPS as current CPS production requires a greater copper plating thickness and more costly processing (including annealing). Material costs for the one-cent coin could be lower by using a monolithic material that does not require plating but has been surfaced modified to protect against corrosion and/or wear. Additional research would be required to determine if any suitable surface modification technologies could meet this objective.
3. For the 5-cent coin, the fixed United States Mint costs total just under $0.0322 and so obtaining positive seigniorage is very challenging. Several alternative material candidates offer significantly reduced costs in the production of these coins. The seamless alternative copper-based alloy candidates (669z, G6 mod and unplated 31157) provide up to a 35% total unit cost reduction compared to the 2011 cost of the incumbent 5-cent coin, reducing total unit costs but not to below parity.
4. Should the 5-cent material be changed to one that can be annealed at lower temperatures, such as the copper-based alloys G6 mod, unplated 31157 and 669z, there will be an immediate gain in production efficiency. Conversely, should an inherently hard material, such as stainless steel, be selected, reduced die life could be expected with an accompanying reduction in production efficiency.
5. Operational inefficiencies can be traced to the current and frequently changing production demands placed on the weekly production rate of circulating coins. These inefficiencies include overall circulating coin production capacity, which is approximately twice that required if production rates were level-loaded (i.e., consistent) throughout the year. During periods of low production rates, production staff may find themselves with idle periods, while during periods of high production rates, production staff may need to work overtime at a higher hourly rate. These large variations (a high-to-low ratio of up to 5 to 1) result in significant inefficiencies in the operation of the United States Mint production facilities.
6. Additional research to better understand the relationship between the fine details of a coin's artwork and its impact on material flow stress and die life during striking would be valuable. Improved understanding could be reflected in the "Engraver's Handbook."

This information may be attained through detailed observation of die failures and complemented with numerical simulations (FEA) and validation of the die filling process.

7. All industrial metals have exhibited a similar general cost trend in the commodities market that reflects overall global economic trends. There has been a fairly predictable trend in that the sequence in cost of metals does not seem to change and has been, from more to less costly in this order: nickel, copper, aluminum and zinc, and steel.
8. Progressive strike studies are a good experimental method for determining how uniformly designs fill during production. Progressive strikes and investigation of changes in design details at various stages of the tooling process has been initiated by the United States Mint and should yield a better understanding of the entire designing /machining/striking interrelationship.

7.7 POSSIBLE NEW TECHNOLOGIES FOR PRODUCTION OF CIRCULATING COINS [3(a)]

1. Current production techniques used by the United States Mint are quite efficient. The process for producing metal coins is substantially the same as it has been for years, but has undergone continuous improvement.
2. Although some newer processes for producing volume quantities of small parts in other industries have been developed, such as plastic injection molding, no best practices and proven methods for forming metal were identified that could economically replace the highly evolved conventional processes used to produce high volumes of circulating coins. All other mints around the world use variants of the same processes as those currently in use at the United States Mint.
3. Additional research to better understand the relationship between the fine details of a coin's artwork and its impact on material flow stress and die life during striking would be valuable. Improved understanding could be reflected in the "Engraver's Handbook." This information may be attained through detailed observation of die failures and complemented with numerical simulations (FEA) and validation of the die filling process.

7.8 FRAUD PREVENTION [3(e)]

1. For one-cent coins, which are rarely used in vending machine commerce, but are routinely processed through coin sorters and counters, security is not a significant issue due to their low value. These coins must feed reliably through coin sorting mechanisms and should not jam or misvalidate as another coin if mistakenly inserted into vending machines or other coin-validation devices intended to support unattended points-of-sale. Less costly metals, such as aluminum, which were tested in this study, are less dense/weigh less, and negatively impact coin handling equipment.
2. Although tested but not recommended at this time, Dura-White-plated zinc has a unique EMS and as such would be a highly secure material option for future coinage.
3. Plated-steel coins require substantially broader acceptance limits in automated coin-acceptance equipment, with significant impacts to coin sorting and counting, and would lead to less secure coin identification standards.
4. Clad materials provide a greater deterrent for high-value coins given the investment and technical expertise needed to produce clad coins, which increases production costs and makes it harder to simulate their EMS.

5. While advanced coin security features have been introduced by several mints, the coin-acceptance infrastructure to validate coins based upon these features remains undeveloped. However, the United States Mint should maintain its awareness of, and as warranted, participate in the development and implementation of, these technologies in the future. Coin-acceptance equipment manufacturers provide a broad and comprehensive set of tests to determine how secure individual coins are relative to circulating coins and common slugs available throughout the world.

7.9 POTENTIAL IMPACT ON CURRENT MATERIALS SUPPLIERS [2(b)(1)]

1. Current material suppliers of coinage materials to the United States Mint have proven ability to develop alternative metallic materials and are able to assist in defining chemical and/or processing changes to current alloys to achieve desired characteristics in coins. Alternative material candidates offered by these material suppliers were useful to the current study. Several were recommended for further assessment and validation as viable alternative materials. When considering the materials recommended, the current fabrication process and quantities sourced between suppliers may change for the copper based materials. For the 5-cent to be provided as a planchet, the additional production cost and any potential environmental impacts would be borne by the supplier.
2. The alternative candidate materials recommended for each denomination are produced by the current suppliers and are well within the capabilities of these suppliers to manufacture.
3. Metallic material producers not currently supplying materials to the United States Mint offered several viable co-circulate alternative material candidates that with further development offer significant savings to the United States Mint. Although these alternative materials would produce a non-seamless (co-circulate) alternative material candidates having a different, albeit unique, EMS and/or a different weight from the incumbent coin. Use of non-seamless alternative material candidates may result in significant conversion costs to upgrade coin-processing equipment. If these alternative materials are chosen for future coins, then the supplier base may have to be expanded.

7.10 ADDITIONAL CONCLUSIONS

1. Considering all of the significant requirements for coinage, the design and selection of a coinage alloy and the associated production methods is a complex, challenging task.
2. The US Public is likely to be more receptive of a new coin if its weight is similar to that of the coin it replaces.
3. The comments that were received were generally positive concerning the ability of the blind and visually-impaired to recognize and distinguish among the incumbent circulating coins minted in the US.
4. Based upon comments received from a notice and opportunity for public comment that was posted by the United States Mint in the Federal Register, the public differs widely in their opinion about their desire to introduce alternative coins into circulation.
5. To gain a more comprehensive awareness of and to obtain focused information about public opinion related to changes to US circulating coins, separate and focused public opinion polls would be useful to complement the findings of the present study.

6. The seamless or nearly seamless material candidates provide for a modest cost savings, whereas many of the non-seamless alternative candidates result in larger cost savings to the United States Mint.
7. Although the current study was successful in identifying several potential alternative material of construction for US circulating coins, more development, testing and evaluation must be completed prior to completion of a detailed specification for future coinage materials that would include “appropriate changes to the metallic content of circulating coins in such a form that the recommendations could be enacted into law as appropriate” [section 3(b) of Public Law 111-302].
8. Most stakeholders have asked for between 12 and 18 months to prepare themselves and their clients for any changes to US circulating coins once they have sample coins available for testing and upgrading their equipment and their products. Other countries have succeeded in making this transition after giving stakeholders 12 months to prepare for the introduction of alternative material coins; however, the size and complexity of the impacted US stakeholders is generally considered significantly greater than that for other countries. Therefore, a longer time of 18 months may be required than that allowed by other countries.
9. One-cent coins are rarely accepted in automated, unattended points-of-sale devices. As a result, introduction of non-seamless one-cent coins into circulation will not have a significant impact to those stakeholders that rely upon automated, unattended point-of-sale transactions with one-cent coins.
10. There are no significant negative environmental impacts to air quality anticipated from the proposed action. None of the potential coin replacement options are expected to result in increased overall quantities of air pollutant emissions as none of them would require longer annealing times or additional steps in the coin production process.
11. There are no significant negative environmental impacts to water resources and quality anticipated from the proposed action. No increase in the amount of water used in the coin-making processes is expected from the changes to coin composition under the recommended alloys or the other potential options because the water-using steps in the process, such as washing and pickling, will not change. The impacts to solid and hazardous wastes management associated with the proposed action are insignificant.
12. The impacts to worker health and safety as a result of the proposed action, while ultimately dependent upon the alloys selected for the various denominations, are generally expected to be positive.
13. Any environmental impacts related to transportation anticipated from the proposed action are expected to be insignificant due to the negligible, if any, change in the weight of the raw materials and scrap metal.
14. Any environmental impacts related to energy use anticipated from the proposed action are expected to be positive.
15. There are no significant environmental impacts to biological resources anticipated.
16. There are no significant environmental impacts to cultural resources anticipated.
17. Should the United States Mint pursue further investigation of 302HQ stainless steel, controlled testing would need to be performed to determine the impact of the nonmetals (sulfur, silicone and phosphorous) on the United States Mint’s ability to effectively treat any wastewater discharges associated with that alloy and to meet any additional categorical pretreatment limits that may be created as a result of its use.

18. Additional public opinion about changes to US circulating coins is necessary to compliment the findings from the current study. This information would further elucidate remarks received from the open call for public opinion in the Federal Register on March 4, 2011. Direct and specific questions should be asked of a representative sample of US citizens on topics such as: a) the weight of coins, b) color of coins and c) level of support of changing US circulating coins to reduce taxpayer costs.

8.0 RECOMMENDATIONS

Based upon the findings and conclusions from this study, CTC offers the following recommendations as required by the Coin Modernization, Oversight, and Continuity Act of 2010 (Public Law 111-302) Section 3(b).

Short term recommendations; present to 3 years

1. Relative to their associated incumbent denominations, maintain coin dimensions for all future coins regardless of their materials of construction.
2. At the time of this writing, CPZ is the most cost effective materials of construction for the one-cent coin. This construction should continue to be used for the one-cent coin until further research of a cost effective materials candidate is found.
3. Coin validation tests have shown that the copper-based alloys tested, unplated 31157, G6 mod and 669z are accepted as the incumbent 5-cent coin. These alloys provide a near seamless material option, although there is a weight difference between the copper-based and cupronickel alloys. The G6 mod and 669z have a slight yellow cast and the unplated 31157 has a golden hue color. Consideration should be given to copper-based alloys for further development as future 5-cent coin materials of construction.
4. Coin validation tests have shown that the copper-based alloys tested, 669z-clad C110 is accepted as the incumbent quarter-dollar coin. This alloy provides a seamless alternative material option, having a near identical weight to the cupronickel clad C110. (Note that bulk coin handlers would be impacted by change to the weight of quarter-dollar coins since additional coin handling would be required to separate incumbent coins from those made of alternative materials of construction.) Complete additional testing on copper-based alloy 669z-clad C110 copper for use in dime, quarter dollar and half dollar coins Development of G6 mod-clad C110 and/or unplated 31157-clad C110 may offer additional seamless options. The 669z-clad C110 and G6 mod-clad C110 have a slight yellow cast and the unplated 31157 has a golden hue color that may cause confusion with the golden dollar. CTC recommends that the United States Mint perform additional testing to quantify the level of public confusion that such color similarity may cause between quarter-dollar of these alternative material candidates and the incumbent dollar coins.
5. Complete additional, more-comprehensive validation tests on recommended materials, noted in points 3 and 4 above, of construction for circulating coins to quantify 1) the variability of material properties from multiple lots of proposed coin materials and 2) the variability in finished coins through completion of simulated coin production runs each of at least 1,000,000 test pieces. Test pieces of any given denomination should be made at different times and under a variety of common production conditions. Samples of coins from each of these test conditions should then be tested to establish more robust standard deviations in the characteristics to be expected from volume production of these coins. These tests must also assess the impact of temperature, humidity, and coin scratches, gouges, tarnish, corrosion, wear and slight bends. Coin-acceptance manufacturers and other stakeholders should be interviewed to determine if additional test conditions are warranted.

6. Should the United States Mint decide to introduce non-seamless coins (coins having EMS and weight different from the incumbent coins) into circulation, then introduce all such non-seamless coins on or approximately on the same date.
7. Complete future validation testing involving a larger number and greater variety of coin-processing equipment manufacturers than were included in the present study prior to defining the final specifications of any new circulating coin materials of construction. Act on the comments related to potential changes in properties and/or performance from these evaluators to increase the likelihood of a smooth introduction of alternative coins into circulation.
8. Provide manufacturers of automated coin-processing equipment samples of the final coins (made from the new materials of construction) at least 18 months in advance of the expected release date for introducing these coins into circulation.
9. Determine the impact of year-long level-loading of mint production rates to production costs. This evaluation should include the effects of excessive capacity and any costs to temporarily store larger quantities of struck coins during periods of relatively low demand for coins.
10. Production and headquarters engineers should be invited early in the process to evaluate and comment on the production implications of coin designs well before the completion of these designs. Design for easy, cost-effective manufacture should be weighted heavily in design selection. Furthermore, adequate time should be allotted to perform pre-production runs of new designs to enable adjustments to tooling and to eliminate causes of premature die failures and other potential problem areas.
11. Develop computer-based finite element models to accurately predict EMS values for alternative materials to reduce the time and expense needed for defining the materials and their distribution in future coins. In addition, computer-based finite element models should be developed, validated and used to predict metal and die response during upsetting and striking. Finite element models would also be useful to predict heat transfer and metallurgical changes to the metals during annealing that are expected to identify improved processing methods. Doing so will allow for additional improvements in the performance of these processes.
12. Additional test procedures should be developed to quantify the wear and corrosion rate of coins/nonsense pieces of dissimilar materials during co-circulating. The test procedure should consist of candidate materials and incumbent materials.
13. The United States Mint should consider pursuing additional R&D efforts on an ongoing basis so they are at the forefront of technologies related to United States Mint core business.
14. Conduct a public opinion survey using telephone or direct one-on-one interviews of US citizens to collect direct and specific data on changes to coins. The survey should consist of questions to determine the public's opinion about coin weight and color, and level of support for changing US circulating coins.

Long term recommendations; 3 years or more

15. The United States Mint should continue research and development (R&D) efforts on stainless steels as a potential alternative material for lower-denomination coins to increase cost effectiveness. Also, development of stainless steel alloys clad to C110 alloy

for higher denomination coinage to mimic the current electromagnetic signature (EMS) of the incumbent dime, quarter dollar and half dollar coins to avoid the need for upgrading coin-acceptance equipment, increase cost effectiveness and have the same appearance of the incumbent coins.

16. Consider future research on surface engineering of zinc or low-carbon steel to obviate the copper plating and its associated costs for the one-cent coin and reduce the costs for the 5-cent coin. For example, inexpensive paints or colored particles on bare zinc covered with a wear resistant coating could considerably reduce costs to produce one-cent coins.
17. A multi-year program should be undertaken to consider and thoroughly assess the carbonyl process, carefully weighing the potential coin production cost savings against the environmental safeguards required to handle the hazardous carbon monoxide and nickel carbonyl gases in the process.
18. Development of a copper-based high manganese content alloy should be completed. Based upon information in the open literature, this alloy may yield benefits such as lower materials costs while maintaining a similar color to the incumbent 5-cent coin.
19. The United States Mint should continue to track technologies to improve coin security in the future and as they fit into United States Mint security strategies. The most promising of these technologies appear to be: 1) use of three-material construction and 2) use of embedded taggants. Innovative security technologies may prove useful in future construction of US circulating coins, the infrastructure to take advantage of these features is still many years from being developed to a level that such feature can be used to robustly validate circulating coins.

9.0 APPENDIX A: ABBREVIATIONS AND ACRONYMS

A	Precision desired, expressed as a decimal
A	Annealing Costs
ACD	Advanced Counterfeit Deterrence
Ag	Silver
Al	Aluminum
ARPA	Archeological Resource Protection Act
Au	Gold
a	Degree to which a color is more red or more green
*a**	Degree to which a color is more red or more green
B	Billion
B	Blanking Costs
BEP	Bureau of Engraving and Printing
Be	Beryllium
Bi	Bismuth
b	Degree to which a color is more yellow or more blue
b	Bath size in dm^2
*b**	Degree to which a color is more yellow or more blue
C	Carbon
C	Total number of coins in the sample set
C_e	Equipment Cost
C_i	Number of coins of a given denomination counted for the sample of a given year
C_l	Labor Cost
C_m	Material Cost
C_t	Total Cost
CAA	Clean Air Act
CAMA	Canadian Automatic Merchandising Association
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CH_4	Methane
CIE	International Commission on Illumination
CNC	Computer Numerical Control
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	CO_2 Equivalent
Co	Cobalt
CPO	Federal Reserve Cash Product Office
CPS	Copper-Plated Steel
CPZ	Copper-Plated Zinc
Cr	Chromium
Cr^{+3}	Trivalent Chromium
Cr^{+6}	Hexavalent Chromium
CTC	Concurrent Technologies Corporation
Cu	Copper

CWA	Clean Water Act
cc	Cubic Centimeter
chromium(0)	Elemental Chromium
chromium(III)	Trivalent Chromium
chromium(VI)	Hexavalent Chromium
cm	Centimeter
DI	Deionized
Dist.	Distribution
DOT	Department of Transportation
d_m	Density
dm	Decimeter (i.e., 1/100th of a meter)
EA	Environmental Assessment
EDM	Electro-Discharge Machine
EH&S	Environmental Health & Safety
EIS	Environmental Impact Statement
EISA	Energy Independence and Security Act of 2007
EMS	Electromagnetic Signature
EO	Executive Order
EPA	Environmental Protection Agency
EPAct	Energy Policy Act of 2005
EPCRA	Emergency Planning and Community Right-to-Know Act
ESA	Endangered Species Act
Est	Most Probable
e.g.	Exempli gratia; for example
et seq.	And the following
F	Ferromagnetic
FDIC	Federal Deposit Insurance Corporation
FEC	Family Entertainment Center
Fe	Iron
FONSI	Finding of No Significant Impact
FRB	Federal Reserve Bank
FY	Fiscal Year
G	The color Gold
GHG	Greenhouse Gas
G&A	General & Administrative
g	Gram
HDPE	High-Density Polyethylene
HM	Her Majesty's
HMR	Hazardous Materials Regulation
h	Hour
IACS	International Annealed Copper Standard
Inc.	Incorporated
IR	Infrared
i	Given Year
i.e.	Id Est; That Is
j	One of the US Coin Denominations

JZP	Jarden Zinc Products
k	Thousand
kg	Kilogram (i.e., 1000 grams)
kgf	Kilogram Force
kHz	Thousand Hertz (i.e., thousand cycles per second)
ksi	Thousands of Pounds per Square Inch
kWh	Kilowatt-Hours
L	Lightness of a color
L^*	Lightness of a color
LME	London Metal Exchange
lb	Pound
lbs	Pounds
M	Million
MDB	Multi-Drop Bus
Metro	Metropolitan
Mg	Magnesium
MIM	Metal Injection Molding
Mn	Manganese
Mo	Molybdenum
MPS	Multi-Ply-Plated Steel
MRL	Manufacturing Readiness Level
Msi	Million Pounds per Square Inch
MT	Metric Ton (i.e., tonne)
m	Meter
m^3	Cubic meter
mg/l	Milligram per Liter
mg/m^3	Milligram per Cubic Meter
min	Minute
ml	Milliliter
mm	Millimeter
mod	Modified
N	Total number of United States circulating coins
N	Nitrogen
N_D	Total number of circulating coins of a given denomination
N_i	Number of coins minted in year
N_2O	Nitrous Oxide
N/A	Not Applicable
NAAQS	National Ambient Air Quality Standards
NAMA	National Automatic Merchandising Association
NaCl	Sodium Chloride
Na_2HPO_4	Sodium Phosphate
Nb	Niobium
NEPA	National Environmental Policy Act
NFB	National Federation of the Blind
NHPA	National Historic Preservation Act
Ni	Nickel

$Ni(CO)_4$	Nickel Carbonyl
NMFS	National Marine Fisheries Service
NO	Number
NOx	Nitrogen Oxides
NO_2	Nitrogen Dioxide
NPS	Nickel-Plated Steel
NRHP	National Register of Historic Places
n	Total number of coins of a given denomination that is in circulation
n_R	Sample size required
$n_{E,i}$	Estimated number of coins in circulation for year i
n_i	Number of coins in circulation for year i
O_3	Ozone
O/H	Overhead
Olin	Olin Brass
OMB	Office of Management and Budget
OSH Act	Occupational Safety and Health Act of 1970
OSHA	Occupational Safety and Health Administration
oz	Ounce
P	Planchet
P_c	Fraction of circulating coins of a given year
Pb	Lead
PEL	Permissible Exposure Limit
PHMSA	Pipeline and Hazardous Materials Safety Administration
PMX	PMX Industries, Inc.
PM10	Particulate Matter less than or equal to 10 microns in diameter
PM2.5	Fine Particulate Matter less than or equal to 2.5 microns in diameter
POTW	Publicly Owned Treatment Works
PSES	Pretreatment Standards for Existing Sources
PSNS	Pretreatment Standards for New Sources
PTE	Potential to Emit
PVD	Physical Vapor Deposition
PWDR	Philadelphia Water Department Regulation
p_n	Percentage of denomination of the total number of coins in circulation
p.	Page
p.a.	Per Annum
pH	Potential Hydrogen (a measure of the acidity or basicity of an aqueous solution)
psi	Pounds per Square Inch
R	Estimated response rate, expressed as a decimal
RBNZ	Reserve Bank of New Zealand
RCM	Royal Canadian Mint
RCRA	Resource Conservation and Recovery Act
RFID	Radio Frequency Identification
RH	Relative Humidity
RM	Royal Mint
RMS	Root Mean Squared
ROI	Return on Investment

RQ	Reportable Quantity
RTS	Ready-to-Strike
R&D	Research and Development
S	Strip
Sb	Antimony
SEWPCP	Southeast Water Pollution Control Plant
Si	Silicon
Sn	Tin
SOx	Sulfur Oxides
SO_2	Sulfur Dioxide
SPCC	Spill Prevention Control and Countermeasures
SS	Stainless Steel
SSM	Semi-Solid Metalworking
STS	Stainless Steel
s_i	Fraction of coins still in circulation relative to the total minted in year *i*
sic	sic erat scriptum (Latin "thus was it written")
T_b	Plating Time, in minutes
Ti	Titanium
TPD	Turns Per Day
TRI	Toxic Release Inventory
TTO	Total Toxic Organics
TWA	Time-Weighted Average
t	Thickness
t_a	Labor Time, in minutes
t_b	Specific Plating Time
tonne	Metric Ton (= 2204.6 pounds)
U	Uranium
U	Upsetting Costs
U.S.C.	United States Code
UK	United Kingdom
US	United States
USB	Universal Serial Bus
USD	United States Dollar
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USM	United States Mint
USM	United States Mint coin costs
USSS	United States Secret Service
UTS	Ultimate Tensile Strength
V	Vanadium
V	Total value of United States circulating coins
VOC	Volatile Organic Compound
v_n	Value of denomination *n*
vs.	Versus
W	Hourly Wages (with overhead)
W	Tungsten

W	The Color White
X	Multiplied
x	Multiplied
YG	The Color Yellow-Gold
yr	Year
Z	Number of standard deviations required to reach desired confidence level
Zn	Zinc
Zr	Zirconium
ZrO_2	Zirconium Oxide
3-D	Three Dimensional
µm	Micron (= 1 $x10^{-6}$ meters)
°C	Degrees Celsius
°F	Degrees Fahrenheit
%	Percent
£	British Pound
&	And
$	US Dollar
±	Plus/Minus
~	Approximately
¢	Cent
§	Section