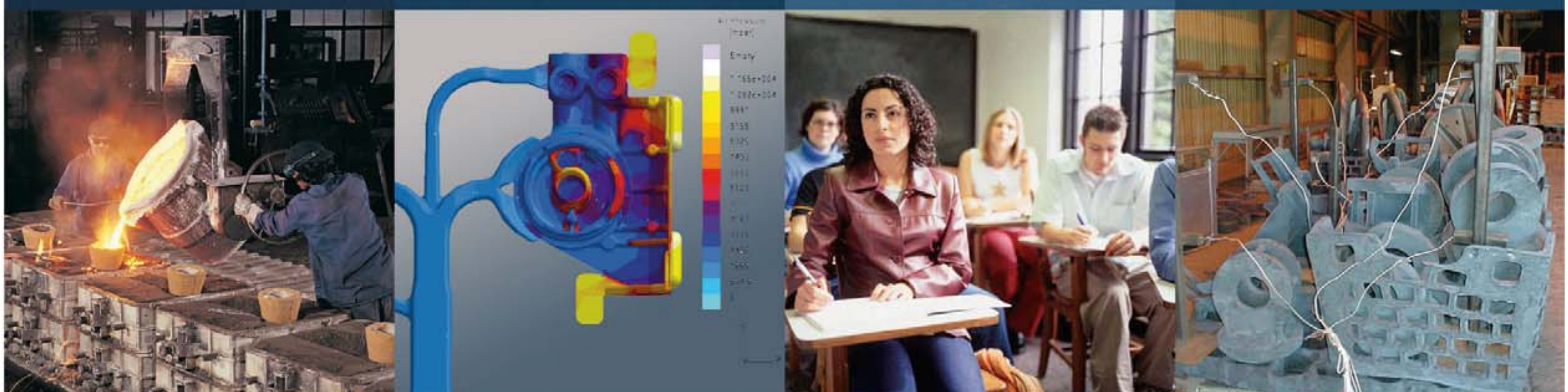
Implementation of Metal Casting Best Practices



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U.S. Department of Energy
Energy Efficiency and Renewable Energy
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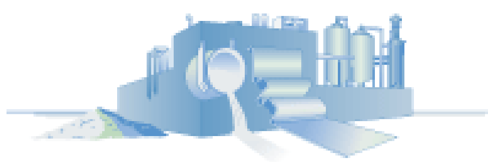
Prepared for ITP Metal Casting



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The final report was prepared by Robert Naranjo, Lee Schultz, Rajita Majumdar, Bill Choate, Ellen Glover, and Krista Jones of BCS, Incorporated. The cover was designed by Borys Mararytsya of BCS, Incorporated.

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Executive Summary

Since 1995 the U. S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), Industrial Technologies Program (ITP) Metal Casting Portfolio has funded research and development in cooperation with the metal casting industry to reduce its energy consumption and improve productivity. In addition, ITP's Technology Delivery subprogram provides a free energy evaluation service to the metal casters through its Industrial Assessment Centers (IACs) and a suite of free BestPractices software tools that focuses on implementing near-term energy-saving best practices.

To promote R&D needed by the industry, ITP has established excellent R&D partnerships with members of the Cast Metals Coalition—a consortium of the American Foundry Society (AFS), the North American Die Casting Association (NADCA), and the Steel Founders' Society of America (SFSA). However, a disparity remains between the availability of technologies and opportunities developed through ITP-supported research and the application of those research results in metal casting plants across the United States.[1] Furthermore, there is also a general lack of awareness within the metal casting industry of the free tools and services offered by the ITP Technology Delivery subprogram.

The project examined cases where metal casters had implemented ITP research results and detailed the benefits they received due to that implementation. In cases where casters had not implemented those results, the project examined the factors responsible for that lack of implementation. The project also informed metal casters of the free tools and service offered by the ITP Technology Delivery subprogram.

Industry Overview

According to the Cast Metals Coalition (CMC), the US metals industry is largely a small business industry. Eighty percent of U.S. metal casters employ fewer than 100 people. Fourteen percent employ 100-250 people and six percent employ more than 250 persons.[2] Cast metal components are used in the energy, automotive, aerospace, railroads, electronics, manufacturing, plumbing, construction and other industries. The casting industry ships approximately 13.8 million tons annually, valued in excess of $31.4 billion.[3]

The average metal caster had a pre-tax operating profit of 2.4% of sales in 2005. Energy costs for the industry were approximately 5-7 % of sales.[4] Thus, improving energy efficiency within the casting industry offers an opportunity to significantly improve the industry's low profit margins.

ITP-Industry Partnership Efforts: Energy Efficiency and Best Practices

The metal casting industry employs a variety of casting processes and alloys. Because the majority of metal casters are small businesses, they lack the resources to perform research on their own. Instead metal casters are collaborating with research consortia and public-private partnerships on R&D projects that are benefiting the industry overall. ITP's Metal Casting initiative supports these partnerships by providing cost-shared R&D funding to reduce the energy intensity of the metal casting industry. These partnerships are encouraged by ITP's Metal Casting Portfolio in collaboration with the CMC. [5]

ITP also offers free plant assessments as well as a variety of free software tools through its Technology Delivery subprogram to help metal casters reduce their energy consumption within the near term at little or no cost. The software tools enable metal casters to assess their process heating operations (melting, holding, and heat treatment), compressed air systems, and motor systems to identify energy-saving opportunities. These resources are:

- **Process Heating Assessment and Survey Tool (PHAST)**, a software application that helps metal casters identify opportunities for saving energy in process heating equipment such as melting furnaces, heat treatment furnaces, and holding furnaces. The PHAST application focuses on improvements for energy-intensive equipment; calculates potential energy savings; evaluates all areas in which energy is used, lost, or wasted; and constructs a detailed heat balance report.[6]
- **AirMaster+**: a software application that identifies energy-saving opportunities in compressed air systems throughout the casting operation. The software assesses compressed air systems and evaluates operational costs for various equipment configurations and system profiles. It estimates savings based on potential energy efficiency improvements and calculates the estimated payback periods.[7]
- **MotorMaster+**: a software application that identifies inefficient or oversized motors at metal casting facilities and computes the energy savings associated with replacing them with more energy-efficient or appropriately sized models.[8]
- **Industrial Assessment Centers** (IACs): DOE resources that offer free technical assistance to metal casters across the country. Teams of engineering faculty and students from more than 26 participating universities conduct one-day site visits to perform plant assessments. To date the centers have performed more than 360 assessments at metal casting facilities.[9]
- **Save Energy Now**: an initiative that helps industrial plants find effective ways to reduce energy use in steam and process heating systems so they can operate more efficiently and profitably, and to identify energy-saving opportunities for compressed air, fan, motor, and pumping systems. Through this program U.S. metal casters can apply for energy savings assessments performed by a team of professional energy efficiency experts.[10]

Methodology

Metal casting plants included in this project were nominated by the three participating technical societies (AFS, NADCA, and SFSA). Once the plants confirmed their interest, the assessment team contacted key individuals at each plant to schedule visits. Exhibit I illustrates the types of plants that participated. A visit centered on a group meeting with plant employees where the assessment team provided an overview of the assessment objectives and of the project, and of the free tools and services offered by ITP (BestPractices' MotorMaster+, AirMaster+, and PHAST tools). The overview was followed by a discussion of the implemented and non-implemented ITP Metal Casting portfolio funded research that pertained to their facility.

Typically, a representative from NADCA, AFS, or SFSA accompanied the assessment team on the site visit so they could provide additional insight into ITP research results. The meeting with plant employees was followed by a tour of the plant, which served as an overview of the facility. The assessment team would then reconvene the technical experts and plant personnel to review observations and to obtain information (e.g., scrap rate reductions, yield rate improvement) in order to complete the site evaluation. In addition, during this meeting the assessment team summarized comments regarding the tour and committed to addressing facility personnel requests regarding ITP.

Exhibit I
Metal Casting Facilities Visited

Casting Type	Alloy Type	Society
Air-Set/No-Bake Sand	Steel	SFSA
Air-Set/No-Bake Sand	Steel	SFSA
Die Casting	Aluminum-silicon (300 series), zinc-based	NADCA
High Pressure Die Casting	Aluminum A380	NADCA
Lost Foam	Aluminum A356 and A319	AFS
Shell mold, vacuum casting, permanent mold, air set nobake	Ductile iron, gray iron, heat resistant steels, corrosion resistant steels, high copper alloys	AFS
Lost Foam	Aluminum A356 and Gray Iron	AFS
Green Sand, Die Casting Permanent Mold, and Shell Modeling	Over 30 different aluminum alloys	AFS
Green Sand	Gray and Ductile Iron	AFS
Lost Foam, Die Casting, Investment Casting and Permanent Mold	Aluminum A356 and A319	AFS

After the plant visit, the assessment team sent a letter to the key contact at the plant recapping the site visit. The letter summarized issues observed during the plant tour that could help the plant become more efficient and competitive, which ranged from energy conservation to housekeeping.

Overall Assessment Observations

This project examined why the beneficial results of the CMC/ITP Metal Casting R&D projects were not being implemented broadly. Many of those results have been confirmed in both laboratoryand plant trials, yet many facilities have not taken advantage of them. The assessment team observed the following factors that can affect implementation:

- **Need for a Champion**: In this context, a champion is someone who understands the technology and the potential benefits of attempting its implementation even if the effort may fail, and who is vested in ensuring that the project is implemented to its fullest capability. The assessment team found that in cases where there was a champion at a plant for a given energy efficiency improvement, the project was implemented with great success.
- **Reluctance to Find the Root Cause**: Many metal casters were not committed to determining the root cause of imperfections in their products. Instead, they would accept a given level of imperfection and would simply incorporate the resulting expense into their pricing rather than trying to eliminate the root cause and reduce the imperfection rate.
- **Need for Business Case Analysis in Decision Making:** Technical staff did not know how to build a business case for evaluating and implementing energy-saving/productivity improvement processes and technologies.

- **Lack of Awareness of Free ITP Tools and Services:** The assessment team found that very few of the participating facilities were aware of the free tools and services offered by the ITP Technology Delivery subprogram.

Solutions to Lack of R&D Implementation

Several common factors that hinder the implementation of research results and perpetuate the lack of awareness of free ITP resources are not unique to the metal casting industry. These are common problems that can be changed thorough education and by incorporating some fundamental changes in management practices. The assessment team summarizes these solutions as:

- Using employee incentives;
- Quantifying metrics to measure the exact result or savings realized;
- Provide more clarification on the recommendations made by IAC;
- Increase outreach regarding and training on the tools and services offered by ITP;
- Provide metal casters with the tools needed to develop a business case to support a project implementation proposal.

Common Energy-Saving Solutions

A number of the energy-reducing solutions the assessment team recommended for all the facilities visited can be replicated among other metal casting facilities with little or no capital investment. They will reduce operating costs and thereby improve a facility's financial bottom line. They include:

Process Heating

- Optimize melting and heat treating operations; cover the furnace and maintain refractories; and install radiant panels in crucible furnaces.
- Shift operations to stack melters for their high efficiency and their improved operability and design.

Facility Maintenance

- Implement an energy management program.
- Eliminate leaks in compressed air systems;.
- Install energy-efficient lighting with better ballasts, high-efficiency bulbs, and occupancy sensors.
- Use cogged belts rather than the traditional smooth belts to drive components.
- Schedule energy-intensive processes to occur at non-peak load periods.
- Keep molten metal surfaces covered and optimize ladle heating practices.

Conclusion

The barriers to implementing the ITP Metal Casting R&D and BestPractices can be overcome. With the assistance of the ITP Metal Casting program, AFS, NADCA, and SFSA, the country's metal casters can reduce energy consumption and become more productive. Key conclusions from the project are:

- The industry can use incentives to encourage employees to undertake energy efficiency projects and not become complacent with a particular level of imperfection.

- Metal casters must investigate high scrap rates and energy bills to identify opportunities for process improvement, which will drive both industry and researchers to examine ways to reduce or eliminate the level of imperfections in cast products.
- The industry associations and ITP should provide metal casters with the tools and resources that will facilitate greater implementation of research. This includes providing more details on IAC recommendations and past success stories, training on BestPractices software tools, and resources for the technical staff to enable them to develop business cases for process improvements so that their management can make sound economic decisions on whether or not to implement a project.

Contents

1. Introduction

1.1 Background, Objectives, and Scope

The U.S. Department of Energy-Office of Energy Efficiency and Renewable Energy (DOE-EERE), Industrial Technologies Program (ITP) funds the Metal Casting research and development (R&D) portfolio through a cost-sharing partnership with the Cast Metals Coalition (CMC). CMC was formed by the metal casting technical societies to promote R&D needed by the industry and is composed of the American Foundry Society (AFS), the North American Die Casting Association (NADCA), and the Steel Founders' Society of America (SFSA). ITP also provides metal casters with comprehensive industrial energy assessments at no cost through its Industrial Assessment Centers (IACs), which focus on implementation of near-term energy-saving best practices. Through ITP's Metal Casting portfolio of research projects and IAC assessments, the U.S. metal casting industry has an opportunity to increase its profitability and productivity while simultaneously reducing energy consumption. The ITP Metal Casting portfolio has funded in excess of $50 million in research with an additional $60+ million in industrial cost sharing, and the IACs have performed over 300 plant-wide assessments for the industry to date.

These beneficial R&D partnerships have produced results that can increase metal casters' bottom lines, thus enhancing their ability to succeed in today's highly competitive global market. However, the technologies and opportunities developed have been found to be underutilized by the metal casting industry overall.[11] This is due to a reluctance to make facility and process changes for fear that they could disrupt production and have a negative effect on already small profit margins. Within the metal casting industry, plant personnel are more concerned with productivity and metallurgical quality than with energy savings. Thus, the industry has not taken full advantage of the variety of low-cost metal casting best practice software tools (i.e. design solidification software) available to help reduce energy consumption, even though application of these tools can also enhance productivity. Apparently, the industry has yet to comprehend fully how energy conservation can correlate with and enhance productivity and profitability.

This project addressed the disconnection between R&D tools and their industry acceptance by accomplishing the following objectives:

- Identify and quantify the extent to which the results of the Metal Casting R&D portfolio and the IAC recommendations have been implemented to date by metal casting facilities;
- Assess the impact that the research and recommendations, once implemented, have had on facility profitability;
- Determine the factors responsible for the lack of implementation of ITP research and IAC-recommended best practices in cases where implementation had not occurred; and
- Provide a comprehensive introduction to the suite of free ITP BestPractices software tools offered by the ITP BestPractices subprogram that can be used to assess metal casting process heating operations (melting, holding, and heat treatment), compressed air systems, and motor systems for potential energy-saving opportunities.

As part of this project, an assessment team from Eppich Technologies and BCS, Incorporated conducted best practices and technology assessments at 11 metal casting plants throughout the United States. The scope of these assessments included ferrous and nonferrous metal casters and a variety of casting processes, including sand, permanent mold, die casting, and lost foam. The assessment team sought out instances where research results and IAC recommendations had been implemented at these plants and documented a variety of case studies (see Appendix A). The case studies include actual plant testimonials as to how the R&D results implemented to date assisted facilities in improving their productivity and energy efficiency. Also during these assessments, the assessment team made observations and recommendations on facility and operational aspects that could improve the casting operations' bottom line. In addition, the assessment team provided each facility with copies of the free software tools offered by the BestPractices subprogram to enable them to analyze their own energy use.

1.2 Methodology

The assessment team investigated factors that have hindered large-scale application of low- to no-cost beneficial ITP resources available to the metal casting industry. The team considered incentives to encourage metal casters to adopt these technologies, and also explored cases where these practices and technologies have been incorporated into a metal caster's operations.

This project focused on the inexpensive technologies addressed in *Energy Use in Selected Metalcasting Facilities – 2003,* which addresses technologies developed through ITP Metal Casting R&D projects that have had promising plant trials, and IAC recommendations and best practices. Although the subject technologies can be implemented with little or no cost, they nevertheless can yield large energy and financial savings. Key recommendations at hand included:

Metal Casting Industry Recommendations: [12]

- Incorporate computer modeling in the design phase of a casting process, utilizing solidification and gating software.
- Apply the results of appropriate metal casting research.
- Utilize process control procedures to control variables, such as the temperature of molten metal while pouring, which has proven to reduce scrap without capital investment.
- Utilize ladle, trough, and furnace covers to maintain temperature.
- Implement fluxing technology to eliminate or reduce dross formation in aluminum and zinc casting operations.

General IAC Metal Casting Recommendations:[13]

- Utilize energy-efficient belts and other improved mechanisms.
- Utilize higher efficiency lamps and/or ballasts.
- Install compressor air intakes in coolest locations.
- Insulate bare equipment.
- Reduce compressed air pressure to the minimum required.

- Use waste heat from flue gases to preheat combustion air.
- Analyze flue gas for proper air/fuel ratio.
- Replace electric motors with fossil fuel engines where possible.
- Where electric motors must be used, use high-efficiency models.
- Use multiple speed motors or a variable frequency drive (VFD) for variable pump, blower, and compressor loads.

The assessment team, under the direction of the CMC, selected 11 metal casting facilities at which to perform assessments. Those plants were selected based on their implementation of ITP-funded research and their willingness to participate in this evaluation. Due to the diverse nature of the metal casting industry, the selected facilities differed in alloy, casting process, size, and melting method. The diverse range of facilities selected improved the team's ability to highlight the financial and energy benefits that ITP R&D results can offer the overall metal casting industry.[14]

Exhibit 1 characterizes the 11 foundries and die casters visited. During each plant visit, the assessment team evaluated whether the recommendations and technologies listed above had been incorporated into the facilities' daily operations. In cases where these technologies had not been incorporated, the team made suggestions as to how the recommendations could reduce a facility's energy consumption and improve its financial performance. The assessment team also informed each facility about the tools and services offered by the ITP BestPractices subprogram, in particular how those tools and services could help the facility to analyze and reduce its energy consumption.

Exhibit 1: Characterization of Participating Facilities

Alloy Type	Molding Process	Melting Method	Monthly Melt (tons)	Assessment-Sponsoring Society*
Steel	No-Bake Sand	Electric Arc	3,000	SFSA
Steel	No-Bake Sand	Electric Arc	1,000	SFSA
Aluminum (300 Series) and Zinc	Die Casting	Reverberatory	50	NADCA
Aluminum (A380 &A383)	Die Casting	Reverberatory	1,000	NADCA
Copper	Permanent Mold; No-Bake Sand	Reverberatory	125	AFS
Aluminum (300 Series)	Lost Foam	Reverberatory		AFS
Iron (Gray, Ductile)	Green Sand	Cupola		AFS
Iron (Gray and Ductile)	Green Sand	Cupola	4,200	AFS
Aluminum (300 Series)	Lost Foam	Reverberatory	150	AFS
Aluminum (30 different alloys)	Green Sand, Permanent Mold, Die Casting	Crucible	425	AFS
Aluminum	Lost Foam with Pressure	Reverberatory	1,700	AFS

* SFSA: Steel Founders' Society of America
NADCA: North American Die Casting Association
AFS: American Foundry Society

For more details on the assessment methodology, see Section 4 on page 16.

1.3 Report Organization

This report summarizes the observations and recommendations made throughout the 11 plant assessments. It includes an overview of the metal casting industry, followed by an overview and analysis of the ITP Best Practices tools and services that are applicable to the industry. It highlights how these tools and services can be accessed and used by metal casters. The report documents general recommendations that were commonly made by the assessment team throughout the project, and provides a case study of each facility visited (see Appendix A). The case studies are categorized by the type of casting operation employed: steel, die casting, lost foam, iron, and copper/aluminum foundries. Each case study provides a plant profile with details about its operation, general observations, and assessment of implemented ITP research projects. The case studies highlight the energy savings and financial paybacks that these plants received by incorporating R&D project results into their daily operations. For brevity, “Metal Casting R&D” refers to the ITP/CMC research collaborations throughout the remainder of this report.

2. Metal Casting Industry Overview

The metal casting industry produces both simple and complex parts that meet a wide variety of manufacturing needs. Nearly all manufactured goods contain one or more cast components, with major end uses being motor vehicles, defense equipment, power generation equipment, industrial machinery, construction materials, pipes and fittings, oil field machinery, farm equipment, railroad equipment, and other products vital to our economic growth and national security.

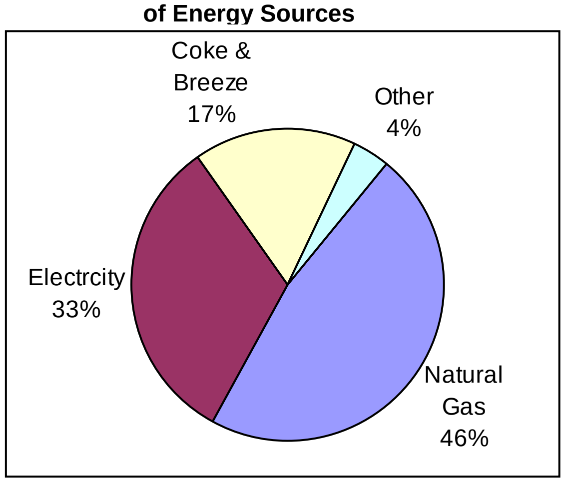
Although the industry utilizes many different processes and metals for casting, the basic metal casting process involves pouring or injecting molten metal into a mold or die containing a cavity of the desired shape. The most common process used for casting is green sand molding, accounting for approximately 60% of castings produced. Other methods include die casting, permanent mold casting, investment casting, lost foam casting, squeeze casting, and shell molding. Gray and ductile irons continue to comprise the greatest weight of casting shipments, followed by aluminum, steel, and copper. In addition, viable new markets are opening for magnesium, titanium, and other nonferrous alloys. For example, forecasters predict that magnesium shipments in the automotive sector will nearly double by 2008.[15]

Markets for both ferrous and non-ferrous castings are increasingly competitive, with casting customers placing greater emphasis on securing high-quality, light-weight, high-strength products at lower prices. Thus, the casting industry must continuously evolve and improve to remain competitive in today's market place.

Energy Use

The metal casting industry consumed 257 trillion Btu in 2002,[16] with 165 trillion Btu accounted for by metal casters categorized under NAICS 3315[*] and 92 trillion Btu by captive foundries.[†] This represents more than a 21% decrease in the industry's energy consumption as compared to 328 trillion Btu consumed in 1998.[17] This decline reflects a 26.6% reduction in the total shipment tonnage from 1998 to 2002, which occurred when a number of foundries went out of business.

Exhibit 2: Metal Casting Industry Distribution of Energy Sources



Source: U.S. Department of Energy, Energy Information Administration, 2002 Manufacturers Energy Consumption, Table N1.2 "First Use of Energy for All Purposes," NAICS 3315; 331511; 331521; 331524

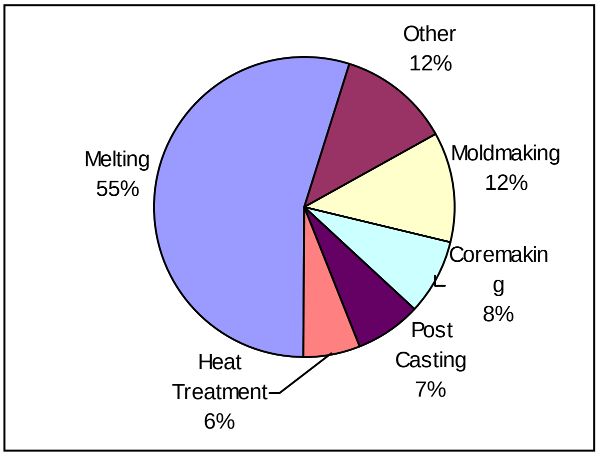
The metal casting industry utilizes a variety of fuels and electricity to meet its energy needs (Exhibit 2). In 2002, 46% of the industry's energy was provided by natural gas and 33% by electricity. Coke provided 17% of the industry's

[*] **NAICS 3315 Foundries:** This industry group comprises establishments primarily engaged in pouring molten metal into molds or dies to form castings. Establishments making castings and further manufacturing, such as machining or assembling, a specific manufactured product are classified in the industry of the finished product.
[†] See Glossary (page 91)

energy needs, primarily to the large iron foundries that utilize the coke both as a fuel for melting and as a source of carbon.[18]

The major energy-consuming processes in metal casting include melting metal, core making, heat treating, and post-casting operations. Exhibit 3 illustrates the distribution of the process energy cost within these operations, with melting representing 55% of the total.[19] The industry spent $1.4 billion in 2004 on purchased fuels and electricity, equaling approximately 11% of the material costs and 5% of the value of the shipments. Energy costs were highest in ferrous foundries where they averaged 12% of material costs and 5% of the value of shipments. They were lowest in nonferrous foundries that were not related to aluminum where they averaged 8% of the material costs and 3% of the value of shipments.[20]

Exhibit 3: Distribution of Casting Process Energy Costs



Source: U.S. Department of Energy, Office of Industrial Technologies, Metal Casting Industry of the Future, *Energy and Environmental Profile of the U.S. Metal Casting Industry*, Washington DC 1999. pg. 10/

Market Overview

In 2004, there were approximately 2,480 metal casting facilities[21] located throughout the United States, employing approximately 161,000 people.[22] Although the industry is widely dispersed throughout, six states account for over 60% of all shipments: Alabama (14.3%), Ohio (12.8%), Indiana (11.1%), Wisconsin (11.1%), Illinois (7.3%), and Michigan (7.2%).[23] A majority of metal casters are small businesses, with 80% employing fewer than 100 people, 14% between 100 and 250 people, and 6% more than 250 people.[24] These small businesses are vital to the economic well being of their local communities.

The metal casting industry has declined significantly since the early 1980s. In 1982, there were 4,100 metal casters in the U.S. with a capacity of 23 million tons per year output. The number of facilities has since dropped to approximately 2,380 in 2005. A substantial part of the decline in the number of facilities is due to the trend of consolidation of smaller ownerships. Fewer and larger facilities are starting to produce and ship a majority of the tonnage. During the period 1982 to 2004, the capacity of the industry declined by 22.3%, while the number of metal casters decreased by 40%.[25]

3. ITP-Industry Partnership Efforts: Energy Efficiency and Best Practices

Everyday tasks such as turning on a light, starting a car, or using a computer would not have been possible without metal casting. The metal casting industry has been integral to U.S. growth and has helped the U.S. become the world benchmark in fields such as manufacturing, science, medicine, and aerospace. The industry is diverse, employing a variety of casting processes and alloys. Since the majority of metal casters are small businesses, they lack the resources to perform high-risk, high-impact research on their own. Instead, they participate in research consortia and public-private partnerships. These collaborations are proving to be successful methods for performing research for the industry overall.

The Metal Casting R&D initiative supports these partnerships by providing cost-shared R&D funding to improve the energy intensity of the metal casting industry. These partnerships are encouraged by ITP Metal Casting in collaboration with the CMC. The ITP Metal Casting portfolio emphasizes university-based research, tapping the technical and knowledge resource of our nation's educational institutions and encouraging young students to enter the industry. Furthermore, the partnership encourages strong industry involvement to ensure direct application of research results and provides evidence as to the importance of cost-shared research partnerships.

ITP also provides a variety of free software tools and services through its BestPractices initiative to help metal casters reduce their energy consumption within the near term at little or no cost. Metal casters can use these tools and services to assess their process heating operations (melting, holding, and heat treatment), compressed air systems, motor systems, and other operations to identify energy-saving opportunities. These tools and services have a proven track record of helping metal casters identify no- and low-cost practices, retrofits, and upgrades to existing processes to save energy and money.

The ITP-funded energy efficiency R&D technologies and BestPractices tools and services beneficial to metal casters are described below.

3.1 R&D of Energy-Efficient Technologies

The Metal Casting R&D strategy is designed to encourage government-industry partnership in the energy-intensive metal casting industry. This strategy fostered industry partnerships, such as CMC, and created the driving force for the industry to develop long-term visions and roadmaps. The vision documents assist in developing goals for the future of the casting industry, while roadmaps provide an outline of the R&D needed to achieve the vision goals. The ITP Metal Casting Vision and Roadmap documents, along with in-depth analysis of energy use in the industry, form the basis for open and competitive solicitations for pre-competitive R&D that addresses both the energy efficiency goals outlined in the *National Energy Policy*, as well as industry research priorities.

As a result of this strategy, ITP has provided over $50 million in support of metal casting research, with an additional $60+ million provided by industry cost sharing since the portfolio's inception in 1990. This funding has supported projects that have developed computer-based modeling tools and advanced sensors, provided methods for reducing machining requirements, and led to a greater understanding of material properties and performance. The funding also has accelerated innovative casting processes, such as lost foam, which has been implemented at large automotive and marine equipment companies as well as in smaller specialty casting shops.

Currently, the Metal Casting R&D portfolio is divided into two categories: Advanced Melting and Innovative Casting. Research in the Advanced Melting category is developing new melting practices and/or new design methodologies that will improve the energy efficiency of melting and save costs for metal casters. Research in this area is improving melt efficiency, reducing metal transfer heat loss, reducing revert, and improving mold yield. The Innovative Casting research category consists of projects that advance energy-efficient casting processes and practices to increase mold yield and reduce scrap. The projects in this area are developing accurate simulation tools; enhancing the ability to produce thin-wall, high-performance castings; producing real-time sensors and controls; making improvements in rapid prototyping; and expanding the knowledge base of various material properties and performances.

3.2 ITP Best Practices

Increasing the energy efficiency of the metal casting industry is a long-term challenge, but with the tools and resources of ITP's BestPractices initiative, metal casters can start saving today. BestPractices works with the metal casting industry and other industrial sectors to implement energy management practices. The program provides metal casters with a number of software tools that plant personnel can use to analyze process heating as well as compressed air and motor systems, using plant-specific data to identify energy-saving opportunities. These tools can be downloaded for free from the ITP BestPractices software website (http://www1.eere.energy.gov/industry/bestpractices/software.html). Furthermore, DOE stresses training on these tools since using them requires a thorough understanding of system dynamics. Qualified specialists offer such training and can be located through the BestPractices training website (http://www1.eere.energy.gov/industry/bestpractices/training.html).

ITP BestPractices also offers several services whereby a team of students or energy professionals performs plant assessments to assist metal casters in identifying energy-saving and process improvement opportunities. These tools and services have a proven track record of helping metal casters to increase energy efficiency and reduce costs. *However, during this project, none of the facilities that underwent assessments were aware of these free tools and services*.

Following is a description of the major BestPractices tools and services beneficial to metal casters:

1. Process Heating Assessment and Survey Tool (PHAST)

Melting and heat treatment operations in the metal casting industry account for 55% and 6%, respectively, of the process energy cost.[26] The thermal efficiency of individual components within an overall process heating system can vary significantly. Exhibit 4 compares the efficiency and the melt loss of the various types of furnaces the industry employs. **A**s the Exhibit reveals, the efficiency of melting operations can vary from 7% (gas crucible, lower end) to 76% (induction, aluminum, upper end). These widely varying thermal efficiencies combined with high energy costs imply that casters should be able to identify many opportunities to improve furnace operations and thus generate significant energy (and cost) savings.

Exhibit 4: Efficiency and Melt Loss for Different Die Casting Furnaces

Melting Furnace	Common Use	Melt Loss	Thermal Efficiency
Cupola	Iron	3-12%	40-50%
Electric Arc	Steel	5-8%	35-45%
Immersion	Zinc	N/A	63-67%
Electric Reverberatory	Aluminum	1-2%	59-76%
	Zinc	2-3%	59-76%
Gas Crucible	Aluminum	4-6%	7-19%
	Magnesium	4-6%	7-19%
Gas Reverberatory	Aluminum	3-5%	30-45%
	Zinc	4-7%	32-40%
Gas Stack Melter	Aluminum	1-2%	40-45%
Induction	Aluminum	0.75-1.25%	59-76%
	Copper-Base	2-3%	50-70%
	Magnesium	2-3%	59-76%
	Iron	1-2%	50-70%
	Steel	2-3%	50-70%

Source: Schwam D., Wallace J.F. and Wannasin J. "Energy Efficiency of Aluminum Melting in Die Casting Operations", CastExpo, St. Louis, April 2005, Presentation T-072.

The ITP BestPractices portfolio offers the Process Heating Assessment and Survey Tool (PHAST), a software application that can aid metal casters in identifying opportunities for saving energy in process heating equipment such as melting furnaces, heat treatment furnaces, and holding furnaces. PHAST provides plant personnel with the tools to survey furnaces and to produce a report that identifies ways to increase the energy efficiency of individual pieces of equipment throughout the entire heating process. Metal casters can assess equipment performance under varying operating conditions by changing the input parameter values used by PHAST.

The PHAST application offers three major benefits to metal casters:

- **Focuses Improvements on Energy-Intensive Equipment –** Using the metal caster's specific heat input and furnace operating data, the application reports the quantity and cost of fuel and electricity that each piece of equipment uses annually.
- **Calculates Potential Energy Savings –** The application assesses energy-saving opportunities by comparing the performance of individual pieces of equipment under various operating conditions with that of a wide variety of retrofit technologies.
- **Identifies Energy Waste –** PHAST evaluates all areas in which energy is used, lost, or wasted and constructs a detailed heat balance report for melting, holding, and heat treatment furnaces.

All of the facilities that participated in this effort can benefit from PHAST and should have some of their staff trained on its use. The assessment team observed a number of obvious energy waste sources in each facility's melting operation, including a lack of furnace coverings, improperly sealed containers, and excessive refractory wear. Utilizing PHAST will highlight possible adjustments plants can make to and optimize their process heating systems, potentially saving thousands of dollars annually in energy costs.

The economic implications of process energy loss are substantial. Heat losses from uncovered furnaces and furnace sidewalls can be significant, costing the metal casters millions in unnecessarily high-energy bills. According to AFS, radiant heat loss from a molten aluminum surface can be sizeable, as illustrated in Exhibit 5. The optimal combination of refractory and insulation can reduce these losses and save metal casters considerable money. When one takes into account the furnace efficiency factor, which is as low as 8-10% for a crucible furnace, the true cost of this heat loss equates with 66,000 Btu/hr/ft^2. Thus, even assuming an electric furnace efficiency of perhaps 80%, the heat loss cost per square foot of uncovered molten aluminum is 8250 Btu/hr. Exhibit 6 summarizes the heat loss as a function of exterior surface temperature. Exhibit 7 provides the results of an illustrative calculation of the potential cost of energy loss based on a hypothetical gas-fired facility employing an electrically heated furnace.

Exhibit 5: Radiant Heat Loss from Molten Aluminum Surface

Aluminum Temperature (ºF)	Heat Loss (Btu/hr/ft^2)
1,300	6,600
1,400	9,300

Source: AFS, as presented in Cast Metals Institute course on Aluminum

Exhibit 6: Heat Loss from an Exterior Furnace Surface

Exterior Surface Temperature (ºF)	Heat Loss (Btu/hr/ft^2)
212	284
279	494
471	1,046

Source: Industrial Heating, November 2006, Page 36

Exhibit 7: Examples of Potential Cost of Energy Loss

Exterior Surface Temperature (ºF)	Heat Loss (Btu/hr/ft^2)	Annual Cost for Gas-Fired Furnace* (per ft^2)	Annual Cost for Electrical Furnace** (per ft^2)
Energy Loss from Furnace Shell Surface			
212	284	$41	$63
279	494	$72	$110
411	1046	$152	$233
Energy Loss from Uncovered Molten Aluminum Surface			
1300	6600	$957	$1472
1400	9300	$1348	$2074
Assumptions: ***** Natural gas costs – $10.00/million Btu; Operating hours – 8,700 hrs/yr; and Furnace efficiency – 60% ****** Electrical energy costs – $.07/Kwh; Operating hours – 8,700 hrs/yr; and Furnace efficiency – 80%			

2. AirMaster+

The metal casting industry uses large amounts of compressed air for powering tools to perform a variety of tasks, including blowing resin coated sand into core boxes and green sand into copes and drags, pneumatically transporting sand, operating pneumatic cylinders and molding machines, spraying die lubricant, and blowing loose flash from trim equipment. Compressed air use is higher in typical sand foundries than in die casting operations. The compressed air pressure at a foundry ranges from 95-110 pounds per square inch (psi). In most cases, temperature control is only necessary to ensure that the dew point of the compressed air is kept low enough so that condensation does not collect in the line. However, some core-making processes require air at a - 40° F dew point to prevent chemical reaction between the resin and the moisture in the sand and air.[27]

Improving compressed air systems offers an opportunity for metal casters to reduce their energy consumption and lower their costs. According to the *Energy Use in Selected Metalcasting Facilities – 2003* study, most compressed air system installations were the result of progressive growth needs and, thus, were often engineered poorly, were saturated with water, and exhibited numerous leaks. Furthermore, facilities often misapplied air in a variety of situations and selected air driers and other compressed air components based on initial capital cost rather than functionality, leading to poor operating efficiency.

AirMaster+, another free software tool offered by the ITP BestPractices portfolio, can help casters identify energy-saving opportunities in compressed air systems throughout the casting operation. Using plant-specific data, the tool assesses the compressed air systems and evaluates operational costs for various equipment configurations and system profiles. The tool estimates savings based on potential energy efficiency improvements and calculates the estimated payback periods.

AirMaster+ evaluates the energy-savings potential based on reduced air leaks, improved end-use efficiency, reduced system pressure, the use of unloading controls, adjusted cascading set points, the use of automatic sequencers, reduced run time, and the addition of a primary receiver. The tool includes a database of generic or industry-standard compressor specifications and creates an inventory specific to the individual metal caster's air system. Based on user-provided data, the tool simulates existing and modified compressed air system operations. It can model part-load system operations for an unlimited number of rotary screw, reciprocating, and centrifugal air compressors operating simultaneously with independent control strategies and schedules. The application also develops 24-hour metered airflow or power load profiles for each compressor, calculates lifecycle costs based on inputs of seasonal electric energy and demand charges, and tracks maintenance history for system components.

In 2002, a foundry located in California that specializes in centrifugal casting implemented the AIRMaster+ tool in assessing its compressed air systems. Two rotary screw compressors served the facility: a 100-horsepower (hp) unit and a 50-hp unit. Results from the analysis enabled the facility to replace the 100-hp and 50-hp compressor with a new 50-hp compressor and upgrade the compressor controls to increase the system's efficiency. The foundry then used the old 50-hp unit as a back up. Implementing the recommendations allowed the foundry to reduce its compressor capacity by 50%, resulting in annual compressed air energy savings of 242,000 kWh and an annual maintenance cost savings of $24,200. The implementation required the foundry to invest $38,000; however, the plant received a $10,000 incentive payment from the California Public Utilities Commission, reducing the total cost for the investment to $28,000 and its payback period for the foundry to 14 months.

A number of the facilities visited during this analysis could benefit from performing a detailed compressed air analysis of their operation using AirMaster+. The assessment team found that these plants had numerous air leaks, misapplications of air, and at times poorly engineered systems. Use of this tool helps metal casters optimize their compressed air systems and determine ways to reduce the total amount of compressed air required.

3. MotorMaster+

Motor-driven equipment plays an essential role and is a major expense in the metal casting industry. Whether a metal caster should repair or replace motors requires a thorough knowledge of efficiencies, maintenance histories, and costs. DOE's free MotorMaster+ software tool analyzes motor and motor system efficiency to help in making these decisions.

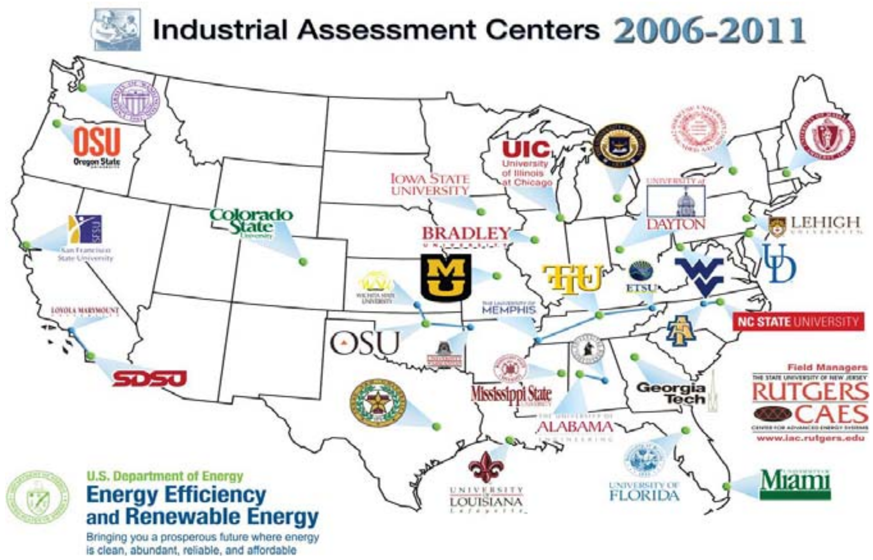
MotorMaster+ tool identifies inefficient or oversized motors at metal casting facilities and computes the energy savings associated with replacing them with more energy-efficient or appropriately sized models. In addition to facilitating repair and purchase decisions, the tool offers inventory management, maintenance logging, lifecycle costing, conservation analysis, savings evaluation, energy accounting, and environmental reporting. This suite of features can help metal casters comprehensively manage their electric motor systems.

The utility of MotorMaster+ was demonstrated at a major facility in Indiana that, based on MotorMaster+ analysis, replaced 125 motors with high-efficiency motors and saved $80,000 per year. The application also specified high-efficiency motors for new equipment purchases at the facility, yielding another $128,000 in annual savings.

4. Industrial Assessment Centers

Industrial Assessment Centers, or IACs, are DOE resources that offer free technical assistance to metal casters (Exhibit 9). To date, the IACs have performed more than 350 assessments at metal casting and die casting facilities across the country. A team of engineering faculty and students from one of more than 26 participating universities perform these assessments. The university-based teams conduct a one-day site visit to a subject plant, where students are equipped with data loggers to analyze the entire plant's operation, including the compressed air systems, furnaces, molten metal handling, and lighting.

Exhibit 9: Nationwide Locations of the IACs



Once an assessment is completed, the IAC team provides a detailed report of its analysis, findings, and recommendations to the plant within 60 days. On average, the implementation of actions recommended by the IAC results in an annual savings of $55,000 per plant. Exhibit 10 lists some of the recommendations made by the IACs to metal casters, their average implementation costs, and their resultant annual savings. To learn more about these and the Center locations, visit http://iac.rutgers.edu/database*.

Exhibit 10: Recent IAC Recommendations to Metal Casters

Facility Type	Yearly Energy Costs	Recommendation	Cost to Implement ($)	Annual Savings ($)	Payback Period (Yr)
Gray and Ductile Iron Foundry	$1,694,719	Automatic Grinding Stations	$250,000	$269,280	0.9
		Replace No. 2 Fuel Oil Furnace with an Electric Furnace	$40,000	$55,434	0.7
		Improve and Maintain the Insulating Dome Lids on Furnaces	$10,000	$52,852	0.2
		Repair Leaks in Compressed Air Lines	$2,484	$19,606	0.1
		Install an Air/Air Heat Exchanger to Retain Exhaust Air Heat	$150,000	$35,862	4.2
		Reduce Charging Time by Use of Gated Feeders	$50,000	$22,098	2.3
		Replace Drive Belts on Motors with Energy Efficient Cog Belts	$840	$864	1.0
Steel Investment Foundry	$2,171,872	Schedule Induction Melters to Reduce Peak Demand	$20,000	$41,580	0.5
		Convert Boiler Clave to Steam Heat	$15,605	$13,555	1.2
		Preheat Burnout Oven Combustion Air	$9,830	$5,980	1.6
		Retrofit Lighting Fixtures to High Efficiency Bulbs	$12,543	$4,977	2.5
		Turn Off Furnace Blowers During Cool Down	$1,039	$3,918	0.3
		Repair Compressed Air Leaks	$600	$3,228	0.2

* The IAC database contains hundreds of assessments where hundreds of recommendations from previous assessments are stored. Exhibit 10 displays a select few of those recommendations.

		Insulate Condensation Tank	$550	$910	0.6
Steel Foundry	$2,440,059	Reduce Compressed Air Leaks	$779	$9,964	0.1
		Reduce Compressed Air Pressure	$25	$2,291	0
		Install Screw Compressor	$136,000	$58,932	2.3
		Install High Efficiency Lighting	$0	$1,061	0
		Install Electronic Ballast and t-8 Lamps	$8,950	$1,976	4.5
		Install Occupancy Sensors	$2,261	$677	3.3
		Install High Efficiency Motors	$1,356	$1,748	0.8
Aluminum Foundry	$1,582,653	Reduce Compressed Air Pressure	$25	$1,405	0
		Reduce Compressed Air Leaks	$474	$5,625	0.1
		Install High Efficiency Motors	$866	$866	1.0
		Install Electronic Ballasts and T-8	$6,232	$2,387	2.6
		Install High Efficiency Lighting	$3,807	$5,647	0.7
		Install Occupancy Sensors	$1,729	$918	1.9
		Insulate Melt Furnace	$12,275	$11,767	1.0
		Insulate Heat Treatment Furnaces	$6,902	$8,410	0.8
		Insulate Ingot Preheat Box	$198	$1,907	0.2
Aluminum Die Casting		Investigate the Possibility of Alternative Electric Rate Schedule	$0	$12,973	0
		Install Economizers on the Existing Pad-mounted Units	$2,400	$3,034	0.8
		Insulate the Gas Kilns	$3,782	$7,575	0.5
		Implement A Regular Maintenance Program to Eliminate Air Leaks	$535	$6,211	0.1
		Install Adequate Compressed Air Storage	$3,690	$2,882	1.3
		Replace T12 Fluorescent Lighting with T8 Fluorescent Lighting	$5,444	$763	7.1
		Retrofit Exit Signs With LED Kits	$745	$464	1.6
		Replace Mercury Vapor With Metal Halide	$1,846	$550	3.4
Nonferrous Die-Castings, Except Aluminum	$534,927	Install Compact Florescent Bulbs	$540	$319	1.7
		Replace Existing Ballasts	$3,402	$872	3.9
		High Efficient Motors	$1,517	$599	2.5
		Install High Efficiency Fixtures	$26,880	$7,681	3.5
		Reduces Paint Booth Operating Time	$100	$3,393	0
		Insulate Molding Pots	$1,300	$2,891	0.4
Copper Foundry	$287,756	Install Occupancy Sensors	$1,000	$455	2.2
		Repair Air Leaks	$600	$4,249	0.1
		Recover Exhaust Heat	$6,000	$4,332	1.4
		Add Insulation to Side of Furnace	$2,228	$1,824	1.3
		Add Insulated Furnace Cover	$1,324	$3,029	0.4
		Install Waste Gas Evaporator	$7,313	$9,120	0.8
Nonferrous Foundry	124,803	Reduce Compressed Air Leaks	$30	$18,950	0
		Reduce Compressed Air Pressure	$30	$294	0.1
		Install High Efficiency Lighting	$3,755	$519	7.2
		Install High Efficiency Air Conditioners	$8,550	$2,428	3.5
		Install High Efficiency Replacement Motors as Existing Motors Fail	$89	$216	0.4
		Delamp Unnecessary Lighting	$49	$209	0.2
		Use Synthetic Lubricants for Compressor	$3,231	$420	7.7

Plants that may be eligible for an IAC assessment include small- to medium-sized manufacturing plants falling under Standard Industrial Classification (SIC) Codes 20-39. The plant should be located within 150 miles of an IAC-participating university and have:

- gross annual sales below $100 million,
- fewer than 500 employees at the site,
- an annual utility bill of more than $100,000 and less than $2 million, and
- no in-house professional staff to perform such an assessment.

Both plant managers and students benefit from the IAC assessments. Students receive exposure and training in the areas of industrial assessment and management techniques for energy systems. IAC participation generates interest among these students in careers and opportunities in the metal casting industry, which is critical to maintaining a competitive edge in the global market. The IACs train more than 250 students each year.

Rutgers University's Center for Advanced Energy Systems (CAES) maintains a comprehensive database on more than 13,000 assessments conducted by the IACs and over 100,000 recommendations made to date (http://iac.rutgers.edu/database).

5. Save Energy Now

Save Energy Now is an initiative that is part of a national campaign, "Easy Ways to Save Energy," announced by the U.S. Secretary of Energy in 2005. The campaign aims to assist U.S. industrial and government entities in reducing energy use, to support achieving national goals for energy security, and to educate the public about simple but effective energy choices. Save Energy Now is helping industrial plants find effective ways to reduce energy use in steam and process heating systems so they can operate more efficiently and profitably. This initiative is also addressing energy-saving opportunities for compressed air, fan, motor, and pumping systems.

Save Energy Now assistance is available to companies, states, utilities, and other industry groups. Thus, the U.S. metal casters can avail themselves of a service that involves energy savings assessment performed by a team of professional energy efficiency experts for the nation's large, energy-intensive plants. These large energy users are selected through a competitive solicitation process.

The initiative also makes available phone consultations for technical assistance provided by experts at the EERE Information Center. The Center offers numerous assistance activities, such as training, Web cast events, and workshops regarding the use of BestPractices analysis tools and ways to improve energy efficiency and productivity throughout the plant.

Finally, the initiative provides manufacturers with free access to its extensive portfolio of helpful information including tip sheets, case studies, and handbooks.

Additional information about the Save Energy Now initiative and how companies can access its services is available at www.eere.energy.gov/industry/saveenergynow/.

6. Other BestPractices Services

ITP's BestPractices initiative also offers system-wide and component-specific training programs throughout the United States, as well as training on the BestPractices software tools available for a nominal fee. In addition, it makes available a wide spectrum of publications, ranging from articles on industrial energy management, industry sourcebooks, and case studies narrating real energy-saving success stories. These resources are available for free at ITP BestPractices website, www.eere.energy.gov/industry/bestpractices.

4. Methodology for Assessing Industrial Implementation of ITP Technologies and BestPractices Tools

The three metal casting societies that comprise the CMC (i.e., AFS, NADCA, and SFSA) initially nominated the metal casting facilities that participated in this project. The nominating society took the initial step to arrange site visits by contacting the key personnel and soliciting their participation. Once the society received confirmation of a company's willingness to participate, the assessment team again contacted the key individual(s) at the facility to schedule the visit.

The assessment team employed the same general methodology at each site visit. The key contact at the facility would assemble the appropriate facility personnel with whom the team would meet, which typically included a plant manager, plant engineer, energy manager, and technical staff member. A representative from NADCA, AFS, or SFSA usually accompanied the assessment team on the site visit so they could provide additional insight into implemented R&D results. The site visits would begin promptly in the morning with a face-to-face meeting of the assessment team and all necessary plant personnel. At this meeting, the assessment team would provide an overview of the assessment objectives and of the overall project. The assessment team would then provide an overview of the free tools and services offered by ITP, followed by followed by a discussion of the implemented and non-implemented CMC and ITP Metal Casting-funded research that pertained to their facility. Facilities that the societies suggested tended to have participated in a number of past CMC and ITP-funded metal casting projects, and had implemented the results to some extent.

As part of the overview of the free tools and services offered by ITP, the assessment team focused on the BestPractices' MotorMaster+, AirMaster+, and PHAST tools which are felt to be the most relevant to the metal casting operations of all the BestPractices tools. The assessment team distributed copies of the software and descriptive fact sheets, and emphasized the need for training on the use of the tools. Also, the assessment team summarized the free services offered by the IACs, provided a listing of the 10 most recent IAC assessments that were in the same NAICS code as the facility being visited, and supplied contact information for the nearest IAC in their region. Furthermore, facilities that met the size criterion were encouraged to apply for a Save Energy Now (SEN) assessment.

Following the overview, the assessment team would then engage in dialogue with the facility team on the level of BestPractices implementation that had occurred at the facility. Based on a descriptive list given to them on projects relevant to their operation, the plant personnel would discuss whether they had integrated relevant R&D results into their operations and would describe the benefits they had realized through such integration. If integration had not occurred, plant personnel would explain why. If a lack of familiarity with the project was the reason, the society representative would provide some detail on the R&D, the results obtained, and potential applicability of those results to the subject facility.

After this initial meeting, the assessment team would then take a several-hour tour of the plant accompanied by plant personnel. The objectives of this tour were to observe which practices had been implemented and to evaluate the general “state-of-the-plant.” During this tour, the assessment team would note obvious wastes of energy, such as lack of furnace coverings, compressed air leaks, and unnecessary lighting. The tour was not intended to convey a thorough understanding of facility operations but to provide the team with an overview of the facility.

After the tour, the assessment team and facility team reassembled to go over the observations made during the plant tour. At this meeting, the team requested from plant management specific metrics regarding research result implementation. These metrics generally centered around scrap rate reductions, yield rate improvement, and cost savings realized by the plant from best practices implementation. In addition, during this meeting, the assessment team provided a summary of comments regarding the tour and committed to addressing facility personnel requests regarding ITP tools and projects with which they were unfamiliar. This included locating relevant reports for plant personnel or sending information on how to apply for a SEN assessment.

The assessment team concluded the plant visit by sending a letter recapping the site visit to the key contact at the plant. The letter presented a brief summary of issues observed during the plant tour that could help the plant become more efficient and competitive. These issues ranged from energy conservation to housekeeping. The letter also included a list of action items that each member of the assessment team and the facility team would address. Once the letter was sent, the assessment team followed up with plant personnel via telephone until the desired metrics were obtained or it was determined that the metrics could not be provided. No facilities were revisited to determine if there was any action that resulted directly from the facility assessment.

5. Overall Assessment Observations

Although the site visits uncovered some examples where Metal Casting R&D results had been adopted, in general implementation and quantification of research results was found to be poor. Therefore, a major focus of this project involved examining the reasons for the lack of implementation of the beneficial results of the Metal Casting R&D projects. Many of those projects have been proven in both laboratoryand plant trials, yet many facilities do not take advantage of their beneficial findings. The following section provides a synopsis of general observations made by the assessment team that may have afected implementation. Appendix A provides detailed case studies of each facility assessed for industry "Best Practices" and identifies areas for their potential improvement.

5.1 Need for a Champion

During the 11 assessments conducted as part of this project, the assessment team observed a number of industry best practices implemented in the various facilities, yet also noted a number of areas that required attention and needed improvement. One factor that affected Best Practices implementation was observed to be the presence or absence of a "champion" at the facility for a given technology or for energy efficiency in general. A champion, who understands the technology and the potential benefits of trying to successfully implement it even if the effort may fail, is vested in ensuring that the project is implemented to its fullest capability. In cases where there was a champion at the plant for a given energy efficiency improvement, it was implemented with great success.

For example, at Steel Foundry-2 (page 52), the Foundry Manager of Technical Services has been an excellent champion for a variety of Metal Casting R&D projects and saw potential financial and productivity gains from them. The Manager specifically recognized the benefits that could be gained from implementing the shroud pouring process and determined that the potential payback outweighed the risk and inconvenience of the trial-and-error process needed to get the technology to function properly in his production line. Additionally, the Foundry Manager has been a proactive champion, not just waiting for a technology advancement to appear, but instead actively searching through resources to find solutions that he can implement. He attends the technical sessions offered by SFSA and engages researchers on projects that he feels can be beneficial to his operation. He volunteers time and staff to test the research out in his facility.

The assessment team found that when there was a lack of implementation or understanding at a facility, it was accompanied by the absence of a champion. Even very simple and low-cost solutions, such as covering a furnace or sealing a furnace door, were not implemented. In fact, throughout this project, numerous casters were found to have their furnaces uncovered, thus allowing heat to escape and dross to form. This action cost them in both wasted energy and wasted material costs. Champions can be created within a facility by instituting incentives and by assigning a lead or a team to take charge in reducing energy consumption.

5.2 Reluctance in Investigation for Root Cause

A commonly observed aspect during this analysis was that many foundries and die casters were not committed to determining the root cause of the imperfections in their products or in the facility used for their production. Due to the economic pressures of the competitive metal casting industry, many casters solely focus on shipping products fast rather than on minimizing number of imperfections. In general, the metal caster will incorporate the expense of the imperfections into their cost structure rather than exploring opportunities to reduce or eliminate these expenses. There is a willingness to accept high level of imperfections, which creates a culture of complying with mediocrity. While this phenomenon does not always occur throughout an entire plant, it was frequently observed in specific areas of a plant. One case that exemplified this phenomenon was the extremely high scrap rate on a particular part produced at Die Casting Facility-2 (page 42). This plant had an internal scrap rate of over 20% on a particular casting. Thus, in order to produce 100 good castings, the facility had to produce 125 castings overall. The facility had five die casting machines working round the clock to produce this casting, which meant that one machine each day was essentially dedicated to producing scrap castings. This part is a legacy part that was designed 10 to 15 years ago. Initially the facility had examined ways to reduce the scrap rate of this part. However, they abandoned searching for a permanent remedy after several failed efforts. Die Casting Facility-2 accepted the flawed process and instead incorporated the expense of this scrap rate into their cost of doing business. Eppich Technologies when visiting another die caster who had reduced its internal scrap rate from 35% to 25% noted a similar instance. Having achieved this drop, the facility was content with the improved performance and abandoned efforts for further scrap reduction. Thus, a 25% scrap level became acceptable. These examples are two extreme cases. Nonetheless, these types of practices will greatly jeopardize a plant’s ability to compete in the long run.

Some facilities were found to seek solutions in some areas but ignore problems in others. For example, at Die Casting Facility-1 (page 36), management implemented a number of industry best practices and incorporated a number of Metal Casting R&D project results into their operation. The facility was at the cutting edge of implementing fatigue-resistant die materials due to their participation in critical plant trials performed by a university and funded by the Metal Casting R&D portfolio. The facility widely publicized this effort and has become an advocate for the research results. Yet the facility tended to overlook some simple housekeeping improvements, such as ignoring the need to keep their furnace openings sealed. A significant amount of hydraulic oil was observed on the floor and considerable heat was being lost through furnace openings. Preliminary calculations showed that the heat loss was approaching their profit of approximately $1 million in sales. There seemed a willingness to accept these inefficiencies and factors within the melting department. However, in other departments, such as machining operations, housekeeping was exceptional. This shows the lack of departmental champions or commitment by plant management to hold all of the departments to a common standard.

Committing to the investigation and elimination of root causes has improved product reliability, competitiveness, and the financial bottom line at Aluminum Casting Facility-1 (page 75). This facility participated in a research program, *Improvements in Efficiency of Melting for Die Casting*, conducted by a team from Case Western Reserve University with cost-share funding from Metal Casting R&D. During their site visit, the team from Case Western took metal samples and measurements from various points in the facility's melting operation to check the metal quality. They found that the die casting dip wells contained four times the amount of oxides as compared to the induction furnace. To increase product quality, these oxides needed to be eliminated prior to having the metal enter the die cavity. Initially the facility's management thought that Case Western's findings were a mistake or a misreading, and they enlisted a second opinion from an independent metal casting consulting firm. The results were identical to Case Western's research findings. The consulting group recommended that the facility change from a double square-head degasser to a single circular-head degasser, which would virtually eliminate the oxides. Based on the two consistent observations, Aluminum Casting Facility-1 implemented this approach throughout its operation and it was endorsed by the highest level of management.

Facilities that have sought to identify and address the root causes of their problems have experienced improvements in product quality and enjoyed an increase in profits. Die Casting Facility-2 could save considerable energy and dollars by focusing on eliminating scrap on the legacy part but instead they simply internalized the scrap cost into their routine cost structure. Aluminum Casting Facility-1 questioned the oxide level initially yet did not discount those findings. They took the time and effort to determine the root cause, even enlisting a second opinion, so they could implement an effective solution. This approach at Aluminum Casting Facility-1 was prevalent in all of their operations.

5.3 Need for Business Case Analysis in Decision Making

A common problem identified by the assessment team was a lack of knowledge on the part of plant technical staff to build a business case for evaluating and implementing energy-saving/productivity improvement processes and technologies. Furthermore, there was often a communication breakdown between the management and the technical staff, with the technical staff members considering themselves to be solely responsible for technical issues and not part of the management process. This non-integrated approach to plant operation impedes achieving optimal working conditions at the facilities. Much of the lack of Metal Casting R&D project implementation has not been due to a lack of understanding the benefits of the research but rather the inability of many of the technically oriented personnel (e.g., metallurgists, engineers) to convey to management the short- and long-term paybacks on various energy efficiency technologies.

Iron Foundry-2 (page 62) employs a highly trained technical staff to run the facility. It has some of the best metallurgists and young engineers in the industry and they understand the science behind many of the Metal Casting R&D projects. However, the staff has difficulty in communicating with upper management to explain the potential financial benefits that implementing the results of those projects could offer. Even when implementation had occurred, the assessment team found that the facility was not tracking financial benefits and thus was unable to demonstrate the efficacy of technologies in improving facility performance. There is an urgent need at this facility to implement a model for such analyses, and to communicate their results to the decision-making management.

This issue is not unique to Iron Foundry-2. It was prevalent throughout the project. Virtually every plant that participated in this effort was using computer modeling, both for solidification and flow analysis. However, when asked for specific data on the impact of these tools on their bottom line, no information was available. Every facility knew it had improved yield, scrap, and/or fatigue life, yet had no quantified estimate of the financial impact of these improvements. The energy savings, timeliness to market, and productivity cost savings were unknown. Therefore, it is difficult to communicate to corporate management the positive effect of these technologies and thus get their support for future projects. *Building good business cases around these implemented projects is critical to surviving in today's casting industry*.

Lost Foam Facility-1 (page 66) understands the importance of detailing the savings associated with the implementation of the Metal Casting R&D. This facility was able to provide metrics associated with the savings attributed to their two main casting lines: engines and blocks. They understood the impact of this research on their scrap and energy savings, including natural gas and electricity consumption. Management knew why research implementation was important and understood the benefits of supporting the Lost Foam Consortium.

Steel Foundries-1 and -2 (pages 46 and 52) had detailed metrics associated with the economic importance of shroud pouring in their operations. They understood how it benefits their productivity and process flow throughout the plant by improving their pouring, machining, and finishing operations. They also recognized the impact that this process would have on customer satisfaction and the importance of this practice in retaining customers.

An inability to develop a sound business case is also an issue in the industry when it comes to proposing a new project. Since most of the technical staff lacks the expertise to build a business case, it hinders research, the BestPractices program, and new technology implementation. For example, almost all of the die casting, lost foam, and aluminum facilities in this project utilized reverberatory furnaces for their melting needs. These furnaces have a low efficiency (20 to 25%), high oxidation rate, and large space requirements. Yet the facilities use these furnaces because they do provide a large reservoir of molten metal that ensures a steady and reliable supply to the casting process. However, stack melters provide an alternative that can improve energy efficiency significantly. Stack melters have an efficiency of 40 to 50%, double that of a typical reverberatory furnace. These facilities need to build the business case for the suitability of the stack furnace, examining the cost of natural gas at today's prices and estimated future prices rather than simply focusing on the up-front costs of the equipment and the historical prices of natural gas.

5.4 Lack of Awareness of Free ITP Tools and Services

One of the objectives of this project was to gauge industry awareness of the free tools and services offered by the ITP Technology Delivery subprogram. This subprogram provides no-cost assessments through the IAC and Save Energy Now initiatives, and also offers free tools to analyze energy consumption in melting, compressed air, and motor systems. Very few of the participating facilities were aware of these free tools and services, indicating a need for a more comprehensive outreach and communication effort to disseminate information on these tools and services to the metal casting industry. Publishing articles in trade magazines such as *Modern Casting* or *Die Casting Engineer* and conducting training on the suite of BestPractices tools at the Metalcasting Congress and other industry meetings are means by which the industry can become familiar with the ITP resources.

6. Solutions to Lack of R&D Implementation

Many of the common factors that hinder the implementation of research results and perpetuate the lack of awareness of free ITP resources available are not unique to the foundry industry. These are common problems that can be overcome both thorough education and outreach and by incorporating some fundamental changes in the management practices.

6.1 Offering Incentives Program to Employees

Organizational success at a metal casting facility depends upon its employees, and lack of recognition can lead to poor morale and disengagement by employees. Effectively motivating employees can create champions within a foundry or die casting facility to seek out solutions for correcting efficiency issues. A meaningful employee recognition and incentive program can drive commitment to seek and implement necessary steps to improve operational efficiency and help the metal caster succeed in today's competitive metal casting markets. Incentives should be provided to employees who seek out solutions to wasteful operations, such as air leaks and heat losses. This may involve simple solutions such as tagging and reporting air leaks to broader initiatives such as setting goals to reduce a facility's overall air use by a certain percentage within a specified timeframe.

Incentive programs should also encourage technical staff to undertake complex projects that will have a risk of failure yet offer a high potential payback in both monetary and corporate sustainability terms. Facilities can implement incentive programs to challenge technical staff to improve the efficiency of or to eliminate a particular process. A good example to highlight this point is the lack of implementation of shroud pouring at Steel Foundry-1 (page 46). This facility participated in the initial casting trials and demonstrated to the casting industry the impact that shroud pouring would have on improving casting quality and profitability. However, when the facility installed a new molding line, they did not incorporate the proper height requirements to accommodate the shroud process. The company may have avoided this impediment had they provided an incentive for a champion to determine a solution to successfully integrating the shroud process.

Employee incentives are a topic that many may consider old news, yet many companies still struggle to find ways to shift the behavior and attitude of their workers to increase productivity. Studies have shown that even the most simple incentive programs can be beneficial for both the employee and the corporation. Incentives can be simple, non-monetary rewards such as a better parking spot or an award, or they can take the form of a monetary bonus.

The Power of Empowerment: What the Experts Say and 16 Actionable Case Studies by Bill Ginnodo (editor) shows how leading companies improve the performance of employees and managers—as well as customer satisfaction, costs, competitiveness and the bottom line—by giving individuals and teams the power to take action.[28] Empowering the foundry workers to take action and improve energy consumption may lead many metal casters to lower energy consumption and lower energy costs, thus improving their financial bottom line.

A case to highlight the importance of incentive programs is Kingston Technology Company, Inc., a world leader in independent memory. Founded in 1987 with a single product offering, the single in-line memory module (SIMM), the company now offers more than 2,000 memory products that support devices ranging from computers, servers, to MP3 players, and cell phones. In 2005, their sales exceeded $3.0 billion.[29]

Kingston has employed a strong incentives program for their employees, suppliers, and distributors that has benefited the staff and brought positive press to the company. In 1995, Kingston joined the billion-dollar club with sales exceeding $1.3 billion. In celebration of its achievement, the company took out ads in the *Wall Street Journal*, *Orange County Register*, and *Los Angeles Times* thanking the employees and identifying each by name. The company also ran ads thanking their suppliers and distributors in trade publications and the *Wall Street Journal*.[30] Kingston recognized that this achievement would not have been possible without the hard work of their employees and everyone else in their supply and distribution chain. In December 1996, when Softbank® Corporation of Japan acquired 80% of Kingston for a total of $1.5 billion, the company executives allocated $100 million for employee bonuses, thus tangibly illustrating to their employees their important contribution to the success of the company. This generous bonus has hurt neither the company's bottom line nor its market share. In fact, Kingston announced in 2005, total revenues of $1.475 billion, and has maintained 16.75% of the world's market share for memory products, thus making them #1 in the world.[31]

While Kingston is an extreme example of the benefits realized by a corporation through an aggressive incentives program, it nevertheless demonstrates how success can derive from motivating employees. Metal casting companies could achieve significant savings by implementing best practices and eliminating waste. Foundries and die casters should seek to develop incentive programs that encourage their workers to reduce waste and energy, and increase productivity. Such programs will positively impact their financials bottom lines.

6.2 Tracking Impact of R&D Implementation

All of the metal casters that participated in this analysis had implemented or evaluated results from several Metal Casting R&D projects. Many of the casters spoke of the benefits realized through that implementation; however, few of them were able to quantify the exact effect or savings realized from the implementation. For example, throughout the project, all participants were modeling their castings for both flow and solidification, an outcome of research primarily supported by Metal Casting R&D. When the facilities were asked how the incorporation of this software improved their bottom line, they were unable to estimate the impact, although they all agreed on experiencing improved yield/scrap rates. The firms never gathered the data necessary to track and quantify the benefits of modeling. This made it difficult for management to gauge the success achieved through a given initiative or to determine whether or not to pursue future efforts.

However, not all of the facilities visited overlooked this vital step. Lost Foam Foundry-1 (page 66) tracks the impact of its implementation with detail. The facility was able to specify the extent of improvement in reducing scrap on the engine block heads and blocks that they produce through implementation of the results of the DOE-funded Lost Foam Consortium R&D, including the dollar value savings from reduced usage of material, natural gas, and electricity. The technical staff had the data available to quantify the potential benefit if the facility continued to provide the Lost Foam effort with both cash and in-kind support. Similar detailed impact analyses are necessary throughout the industry to determine what is effective commercially to aid in future decision-making processes.

6.3 Providing Explicit Case Studies on ITP Recommendations

As part of this effort, the team advised each facility as to specific recommendations that the IACs had made to similar casters over the years. That information was obtained from an IAC database, which can be searched by NAICS code. Making recommendations available to the industry is potentially important because it provides insight into energy-saving techniques that constitute practical, cost-effective solutions. However, the assessment team found that the level of detail on the IAC site often was inadequate to convey a detailed understanding of the exact nature of some recommendations or any insight into the means of their implementation.

For example, when visiting Die Casting Facility-2 (page 42), the assessment team provided facility staff with a list of recommendations from the 10 most recent IAC assessments conducted at aluminum die casting facilities. One of the recommendations made by the IAC was "Avoid Operating Aluminum Furnace on Low Fire." The IAC database indicated that this recommendation had an implementation cost of $120, while offering an estimated savings of $43,287. However, the plant personnel were unable to find any details as to what the recommendation actually entails (i.e., what is meant by "low fire"), thus hindering its implementation. Although this is not the case for all of the recommendations within the database, there is a lack of consistency in the depth of information explaining adequately the rationale behind some key recommendations.

Many of the facilities that participated in our project recommended building case studies that, while protecting the IAC-assessed facility's identity, can highlight the specific recommendations and the implemented results. These case studies should be clear and concise and be subjected to a professional review process by DOE and industry experts to ensure that the recommendations are realistic and practical. Furthermore, case studies should provide industry members with details to which they can relate to visualize the results they can anticipate for their plant.

Harvard Business School has been using the learning-by-case-study method because the faculty believes that it is one of the best methods for learning as it forces the reader to grapple with the kind of business dilemmas that others have faced and thus better understand the thought process underlying the decision they made. By redefining the way in which knowledge is dispensed and received, case studies enable individuals to visualize and relate to the case and its solution, instead of merely absorbing facts and theories. This facilitates their conceptualizing how the case applies to their operation and whether the solution in the case is applicable to their own situation.[32]

A step further in the same direction would be to document case studies that illustrate how the suite of BestPractices tools like the PHAST, AirMaster+, and MotorMaster+ has positively affected a metal casting operation. These cases should detail the experience of using a qualified specialist to assess plant operations using BestPractices tools and their ease of use. Publicizing such cases in trade journals will show industry members that these tools work and that their application can offer tangible benefits. Finally, ITP should also consider documenting cases that illustrate the benefits of implementing Metal Casting R&D projects results.

6.4 Increasing Outreach on BestPractices Tools and Services

Throughout the course of this project, the assessment team found little awareness among the metal casters interviewed of the free tools and services offered by ITP. Thus, the analysts concluded that more outreach is needed to publicize these services. To begin to address the lack of awareness, BCS, Incorporated and DOE published articles on these free tools and services in the April 2006 editions of both *Modern Casting* and *Die Casting LINKS*. Those articles were a first step in making the industry aware of these free tools and services, yet more effort is needed.

Training needs to be provided on the suite of BestPractices tools. The small-business nature of the metal casting industry means that it often lacks the financial resources to send staff to distant locations to attend BestPractices training. Instead, since they are more likely to send their employees to attend industry-specific events such as the Metalcasting Congress or local society chapter meetings, ITP should make an effort to offer training in conjunction with the major industry conferences. Some of the larger facilities (e.g., Lost Foam Facility-1 and Iron Foundry-2) were familiar with the tools and employees received training on their use. However, the size of these facilities and the financial resources available to them are not common throughout the industry.

6.5 Evaluating the Business Case for Implementation

A common observation throughout this project was that the technical staff at the facilities often had a good understanding of the Metal Casting R&D projects. Many of the technical personnel that met the assessment team participate extensively in the sponsoring society technical committees and in the annual technical conferences. These staff members have also worked closely with the primary investigators during the research projects' plant trials. Therefore, they clearly understand the science, although they have difficulty articulating the business advantage gained from implementing researched tools and practices.

A plausible solution for bridging this gap is for the technical societies or management of the foundries to develop a computerized template for building a business case to support a project implementation proposal. This template should be easy to follow, should not require an advanced degree in business or accounting to complete, and should be detailed enough so it does not overlook specific cost savings. It should also equate the savings with the amount of sales that would have to be achieved to realize the same financial benefit. By conducting this analysis, technical staff will be able to provide their management with the information needed to determine whether a project should proceed, and whether the project will positively affect the metal caster's bottom line.

For example, a template can be created for a paper analysis to determine whether the acquisition of process modeling software makes financial sense. The template would be designed to capture all pertinent variables, such as:

- Cost of:
  - The software package or license
  - The computer to run the application
  - Training on how to use the modeling application
  - The hourly rate or salary of the user
- Benefits deriving from reduced:
  - Lead-time due to the avoidance of a costly trail-and-error process
  - Man hours associated with the trail-and-error process
  - Metal cost associated with improved casting yield
  - Scrap rate

Developing quantitative estimates of costs and the dollar value of benefits will enable management to evaluate the potential financial return to the corporation of investments made in proposed energy efficiency improvement initiatives.

7. Common Energy-Saving Solutions

The assessment team found some energy-reducing solutions that may be commonly applicable among all the facilities visited. These included optimizing the melting operation and metal handling overall and implementing an energy management program to take advantage of easily achievable opportunities. These solutions should be replicable at metal casting facilities with little or no capital investment.

7.1 Optimizing Melting and Heat Treating Operations

The energy efficiency of any metal casting facility depends largely on the efficiency of its melting and heat treating operations. Combined, these two operations represent over 60% of the total process energy costs for a typical metal casting facility.[33] Therefore, any improvement in the energy efficiency of these operations will have a significant impact on a facility's bottom line. By implementing some simple operating practices and incorporating some cutting-edge melting equipment, metal casters can take advantage of such opportunities.

7.2 Covering the Furnace and Maintaining Refractories

Furnaces at many of the facilities visited as part of this analysis were found to be inadequately covered when melting or holding (and in some cases heat treating), have worn refractory material lining their furnaces, and be inadequately insulated. The practice of not keeping the furnaces covered was a result of oversight by employees and/or convenience (i.e., it enabled them to throw a charge into the furnace when needed). The worn refractory lining was primarily due to the harsh operating conditions and had reached the point where it needed repair. Not keeping the furnace covered and the refractory in optimal condition are major sources of inefficiency as they allow heat to escape from the furnace through a combination of radiation, conduction, and convection losses. These losses can account for 10 to 50% of total energy losses depending upon furnace design, operating practices, metals melted, and the source of energy used.[34] An improperly insulated furnace leads to additional conductive energy losses.

A simple step to minimize these excessive losses in melting and heat treating operations is to ensure that employees keep the furnaces properly sealed and open the lid only for charging and tapping the melt. Having a strict policy of keeping the furnace door closed is a no-cost solution to reducing energy consumption. Radiation losses from an uncovered bath can reach up to 130 kW per hour for an iron furnace with a 10-ton capacity.[35] Furthermore, the facility should monitor regularly the wear and tear on furnace refractory linings. Insofar as is possible, they should carry out repairs during the annual facility maintenance shutdown. Finally, they should utilize the optimal thickness of insulating material on the outer furnace shell. The U.S. Environmental Protection Agency (EPA) estimates that a properly maintained insulating system can improve thermal efficiency of heating equipment by as much as 50%.[36] DOE estimates that installing thermal insulation, maintaining the refractory lining, and keeping furnace lid properly covered can potentially have a payback period of one year or less in some industrial process heating applications.[37]

7.3 Examine Advanced Retrofitting Technologies

Many advances in retrofitting ferrous and nonferrous melting technologies can significantly reduce energy consumption in melting operations. Such technology advances include installing oxygen-enriched fuel combustion, preheating charge material, and recovering heat from flue gases can improve the efficiency in various steps in the melting operation. Exhibit 11 shows the estimated efficiency savings achievable by implementing these technologies. Furnace efficiency can increase from 25-30% by utilizing one or a combination of these technologies.

Exhibit 11: Estimated Efficiency Improvement from Retrofitting Technologies

Melting Technology	Estimated Efficiency Savings
Charge Preheating	5-10%
Air Preheating	10-20%
Operational Adjustments	0-30%
Oxygen Enrichment Technologies	1-40%

Source: Albany Research Center, *Improving Energy Efficiency in Aluminum Melting* presentation at 2005 Aluminum Portfolio Review

Employing oxygen-enriched fuel combustion has attracted substantial attention in the metal casting industry because of the increasing demand to reduce harmful emissions, in particular NO_x. These systems also improve the energy efficiency of a furnace because they decrease the electrical energy and increase the chemical energy. The energy efficiency improvement can be as high as 40%. However, oxygen in a furnace can also cause greater oxidation, especially in aluminum melting. Also, some foundries worry about wearing their furnace refractory at a higher rate due to the increased combustion rate. A metal caster should balance these competing effects and work with a burner manufacturer who knows how to design these systems optimally to obtain low NO_x emissions with minimal heat loss.[38]

Further efficiency improvements can occur in the melting and heat treating operation with the utilization of heat recovery methods. Recovering waste heat can improve efficiency by as much as 20%. Waste heat recovery devices simply transfer thermal energy from high-temperature effluent streams, such as furnace flue gases, to a lower-temperature input stream, such as incoming combustion air.[39] For example, preheating charge material is an important retrofit technology that has proven to save facilities between 5 to 10% in energy costs. Using the high-temperature off gas from the melting furnace to preheat the incoming scrap or ingot can reduce melting energy requirements for both ferrous and nonferrous operations. Scrap preheating in steel foundries has proven to reduce the energy for melting by 50-70 kWh per ton.[40] Besides improving energy efficiency, preheating will also remove moisture from the scrap or ingot, thus ensuring a cleaner melt.

More foundries should seek to improve the efficiency of their melt operation. During this project, the assessment team did not observe any facility using such retrofit technologies in its melting operation. The participants could have significantly lowered their energy bills by incorporating these retrofit technologies, many of which can work in conjunction with existing furnace technologies, thereby requiring less capital investment when compared with upgrading the entire melting facility.

7.4 Installing Radiant Panels in Crucible Furnaces

Crucible furnaces are an inexpensive melting method generally employed for melting small amounts of nonferrous metals, such as aluminum. The advantages of these furnaces are that they have low space requirements, avoid direct impingement of the flame on the metal, and limit heat loss by the refractory walls. They commonly are used as holding furnaces in die casting shops or for melting small amounts of metals in jobbing shops. They are simple to tap and charge, easy to clean, and enable the facility to rotate the number of alloys they can melt.[41] This was the case at Aluminum Casting Facility-2, which cast over 30 different alloys utilizing 42 natural gas-fired crucible furnaces to perform all of their melting (page 82).

A major drawback to these furnaces is that they are quite inefficient. The typical efficiency of a crucible furnace is low (i.e., 7 to 19%), with over 60% of the heat loss due to inefficient radiation.[42] Furthermore, these furnaces have a low melt rate and their available combustion space limits heat transfer.

One method for improving the efficiency of these furnaces is to install radiant panel linings, which combine a dense, high-alumina radiant panel with low thermal-mass insulation back-up materials. The design of these liners incorporates a series of raised nodules that create a high surface area to promote radiant energy transfer to the outer surface of the crucible. Backing up these radiant panels with a low thermal-conductivity refractory and insulating material reduces the heat loss through the sides of the furnace and increases the furnace's efficiency. These radiant liners require neither mixing nor drying which is required with traditional refractory liners that must be mixed with a cement like material. A benchmarking study by Case Western Reserve University found that these liners, in conjunction with an improved gas burner, increased efficiency in a natural-gas-fired crucible furnace from 8% to 16%. Engineers estimate that the panels themselves account for 50% of the improvement, and the remaining 50% is attributable to the improved burner. These panels cost approximately $4,000 per crucible. The assessment team recommends that foundries and die casters that employ crucible furnaces perform a cost/benefit analysis to consider installing radiant panels.

7.5 Shifting to Stack Melters

A stack melter is a modified reverberatory furnace that preheats the metal charge with waste heat gases. The efficiency of this enhanced furnace is significantly better than that of a typical reverberatory furnace because of its superior sealing and use of the waste heat to preheat the charge.

The charge is stacked above the hearth where flue gases heat and dry it prior to its entering the melting chamber. Preheating the charge minimizes the risk of an explosion occurring because it evaporates moisture that may build up on the charge. Preheating also reduces the cooling effect of charging cold metal into the molten bath of metal, thus reducing the energy used to maintain the molten bath.[43]

Stack melters offer higher efficiency and lower metal loss when compared with traditional reverberatory furnaces. A traditional reverberatory furnace has a thermal efficiency of 20-25%

with melt loss of 3-5%, where as a stack melter has a thermal efficiency of 40 to 50% with a melt loss of approximately 1%.[44] Actual plant data determined by a Metal Casting R&D project showed a reverberatory efficiency of 25% vs. 44% for a stack melter, with both furnaces installed at the same die casting operation. However, in the past, metal casters avoided stack melters because they required more labor and materials to maintain the refractory in the metal charging chamber. This is because charges enter the furnace from the top and the refractory lining at the bottom of the charging door suffers from repeated impact and excessive wear from the dropping charges. The cost of labor and materials for maintaining the refractory would typically offset some of the financial savings achieved by reduced energy consumption.[45] In addition, stack melters have been limited in the percentage of returns and ingot. They are unable to take advantage of lower cost, lower charge materials such as T-sows or RSI sows due to the stacking requirments of the charge.

However, in light of steeply rising natural gas costs and improvements in the stack melter design, metal casters should reexamine the cost effectiveness of these furnaces. Researchers at Case Western Reserve University that have benchmarked stack melters have documented their high efficiency and have noted their improved operability and design. Facility managers should perform a detailed cost analysis and determine whether these offer economic benefit for their operation.

7.6 Implementing an Energy Management Program

Foundry and die casting managers are always seeking ways to reduce costs without compromising the quality of the castings they produce. A good way of achieving this goal is to implement an energy management program to help improve their facility's bottom line in the face of rising energy costs. The plan should focus on low-cost, low-risk opportunities such as improving the efficiency of compressed air systems, lighting, and equipment belts. Another important element of the plan is the need to understand the rate schedule the facility has with the local utility and consider whether they can adjust their operating schedule to take advantage of non-peak load billing periods.

7.7 Eliminating Leaks in Compressed Air Systems

As previously mentioned, minimizing compressed air use and optimizing compressed air systems is an easy way to save energy. A single 1/16 inch diameter air leak in a compressed air system at 100 psi loses air at 6.5 cubic feet per minute. At a $.06/kWh rate, based on 24 hours/day operation, this can result in a cost of $633/year.[46] The assessment team noted numerous leaks at a number of the facilities visited during this project. These leaks caused the compressed air system to consume more energy to maintain adequate pressure. Implementing a tag and repair program can easily remedy this situation. Such a program can be designed to have employees use color tags to identify leak locations, and then, after-hours or during the weekend when the equipment is not operating, a team can repair each leak. In addition, after-hours or weekend periods offer an additional optimal time to perform leak detection since the peripheral noise associated with production is then absent. Furthermore, the repair team can note the weekend horsepower that is required to maintain pressure in the line. This will provide input as to the number of air leaks and the equipment that is using non-essential air.

7.8 Installing Energy-Efficient Lighting

Another simple activity a metal caster can perform to improve energy efficiency is to utilize energy-efficient ballasts, high-efficiency bulbs, and occupancy sensors in lighting systems. Although it may not make financial sense to replace all existing ballasts and bulbs at once, implementing a scheduled transition to more efficient equipment over time as existing equipment fails should be both feasible and beneficial.

One of the facilities visited during this effort also had lighting turned on in areas where there was no one working. In fact, that lighting illuminated areas where workers seldom go. Facilities should consider installing occupancy sensors in such situations. An occupancy sensor will activate the light only when a worker enters the area. These devices are inexpensive and simple to install.

7.9 Transitioning to Cogged Belts

Cogged belts are another simple item that a plant can incorporate into its energy plan. In belt-driven equipment, such as fans, it is best to use cogged belts rather than the traditional smooth belts. This is because the typical smooth belts slip and utilize more energy in turning the component. Utilizing cogged belts reduces slipping and improves the efficiency with which the component is turned, thus reducing its electrical demand. Although these belts are slightly more expensive than smooth belts, they both reduce energy consumption and last longer.

7.10 Scheduling Work during Non-Peak Power Rate Periods

Finally, a facility's energy management plan should incorporate scheduling energy-intensive processes to occur at the non-peak load periods. Performing such tasks at non-peak hours will reduce the demand on the local utility and allow the facility to take advantage of lower power rate charges. For example, many utilities will offer an overnight non-peak rate (e.g., from 9 p.m. to 7 a.m.), which could be $.02 per kWh less than the peak rate. Obviously, such varying rate structures make strategies such as performing melting during non-peak hours more cost effective.

Steel Foundry-2 (page 52) worked with its utility to determine the most cost-effective schedule for melting with its electric arc furnaces. It was determined that the foundry could take advantage of non-peak loads if it performed its melting from 9:00 p.m. to 9:00 a.m. The facility adjusted its production and labor schedules accordingly and began performing melting operations within the prescribed time. Moving to this schedule resulted in an annual savings of $250,000 on the facility's electricity bill. The cost to implement this change was minimal and primarily was associated with the need to rearrange production and labor schedules. There was no investment required in costly technology.

Although such scheduling changes offer a simple solution to reducing energy costs, it is important that the facility adhere to the period of the non-peak loads. If the foundry turns on its melters before the non-peak period, they will be charged the higher (i.e., peak) rate for the entire duration that the equipment is on. This practice has been witnessed in the field by Eppich Technologies, where the personnel in a melt shop were turning on their induction melting furnaces 10 minutes early to take advantage of an early labor break. This practice caused the facility to lose thousands of dollars each year because they were paying a much higher rate for their melting.

Developing an energy management plan that properly schedules energy-intensive processes to take advantage of non-peak load rates and proactively examines immediately achievable, low- or no-cost opportunities can save a metal caster several thousands of dollars a year in operating costs. Utilizing energy-efficient equipment can save money without affecting plant operations or interfering with the product quality. A good energy management plan will reduce operating costs and improve a facility's financial bottom line.

8. Conclusion

The ITP Metal Casting program, in R&D partnership with the Cast Metals Coalition (CMC), has funded the development of a number of technologies and practices that can lower the energy intensity of metal casting operations and improve their profit margins. ITP also offers casters free comprehensive energy assessments through ITP's regional Industrial Assessment Centers (IACs) and free software tools that provide customized analysis of a facility's process heating, compressed air, and motor systems to identify energy-saving opportunities. An assessment team of experts from Eppich Technologies and BCS, Incorporated conducted plant assessments at 11 selected metal casting facilities throughout the U.S. to seek out instances where plants had adopted research results developed by the Metal Casting R&D portfolio and IAC recommendations. In addition, the assessment team made observations and recommendations where implementing applicable R&D results could improve a plant's operations. Through one-day hands-on visits to the foundries, the assessment team identified some common factors at all participating facilities that hindered the adoption of technologies and practices by metal casters. The assessment team also provided some general solutions to the lack of implementation and common technical or operational solutions that metal casters could implement to save energy, increase productivity, and increase profitability.

As demonstrated in the case studies detailed in Appendix A, metal casters who have implemented the technologies, services, and practices provided by Metal Casting R&D, IACs, and the BestPractices subprogram have experienced significant improvements in their energy consumption, productivity, and bottom lines. However, even with the high level of implementation, the assessment team found inadequate use of several Metal Casting R&D technologies and BestPractices. The assessment team identified some common factors that hindered their utilization. These reasons included need for a champion, resistance to investigate the root cause of problems like high scrap rate, lack of awareness on resources available, and the need for business case analysis in decision making.

- **Need for a Champion –** One general commonality that caused the underutilization of these technologies and BestPractices tools was the need for a champion who would undertake the responsibility of ensuring that a project is implemented to the fullest capability. The assessment team noted at a number of participating facilities that the lack of implementation was due to a lack of a champion in that particular production area. Conversely, implemented projects did in fact have one or a group of employees who were their champions. The assessment team recommends that foundry management devise incentive programs that encourage employees to become champions and to seek out avenues to improve productivity and lower their facility's energy consumption.

- **Investigating the Root Cause –** Many casters solely focus on producing and shipping cast products rapidly and are willing to accept some level (usually minimal) of imperfections in those products. They incorporate the cost of such imperfections (e.g., higher-than-necessary scrap rates, product returns) into their cost structure when quoting jobs to potential customers. This implicit willingness to accept a certain level of imperfection in their castings hinders R&D implementation because the casters lack the drive to investigate the root cause for those imperfections and improve their production efficiency. Part of this is due to the lack of a champion for the cause of more efficient operation. This barrier can be overcome by not only providing incentives to employees to improve existing processes but also tracking the implementation of R&D work and trying to improve the current benchmark standard.

- **Lack of Awareness –** Another general commonality that caused the underutilization of these technologies and best practices tools was the lack of awareness of resources available. Very few casters knew of the free tools and services offered by ITP BestPractices. This indicated the need for more comprehensive outreach on these tools and services to the metal casting industry, and doing so through communication channels casters already utilize (e.g., CastExpo, the Metalcasting Congress, Steel Founder's T&O conference, and local chapters of technical societies) will facilitate their promotion and effectively educate the industry. Furthermore, ITP should work with the IACs to provide greater clarity on the recommendations IAC made during the foundry assessments they conducted; this will help metal casters to better understand the recommendations and replicate them into their facility.

- **Capability to Develop Business Case –** In the metal casting industry there are highly technical and knowledgeable personnel that understand the necessary science and metallurgy, but they lack the skills needed for making a business case for a given energy efficiency improvement. Typically, management will want to see a compelling argument made for any process change investment, and a properly developed business case can meet that critical need and support sound economic decisions. ITP and the CMC should consider developing a computerized template that the technical staff could utilize in developing a business case to support a project implementation proposal. By doing so, they will provide their management with the information needed to determine whether a project should be implemented and how that project will affect the corporate bottom line.

The barriers that prevent implementation of Metal Casting R&D and best practices can be overcome. The industry should examine how to structure incentives that encourage employees to undertake energy efficiency projects and should not become complacent with a particular level of imperfection. Metal casters should investigate high scrap rates and seek ways to eliminate or at least reduce the level of imperfections in cast products. It is important that both industry associations and ITP provide metal casters with the tools and resources that will facilitate greater implementation of research. This includes providing more details on IAC recommendations and past success stories, training on BestPractices software tools, and resources to the technical staff to enable them to develop business cases for process improvements so that their management can make sound economic decisions as to whether to implement a project. The assessment team believes that by addressing these gaps, the metal casting industry will utilize the low-cost technologies developed by Metal Casting R&D and more broadly implement the free BestPractices software tools.

Appendix A: Plant Assessment Case Studies

The BCS-Eppich Technologies assessment team visited 11 metal casting facilities to observe their operations for energy-saving processes in place and evaluate the extent of implementation of Metal Casting R&D and BestPractices tools. The case studies presented below detail the plant specifics, onsite observations, testimonials from plant personnel, and recommendations made by the assessment team for potential energy-saving opportunities identified at the facility. These case studies also highlight the energy savings and financial paybacks that these plants received by incorporating R&D results into their daily operations.

The cases are organized by the type of metal casting facility in the following order: die casting, steel, iron, lost foam, and copper/aluminum foundries.

A. Die Casting Plant-1

Plant Profile

This plant specializes in small volume, quick turn-around die cast products, filling orders for 300 to 500 die castings—a rare occurrence in the die casting industry. The facility produces both aluminum (300 series) and zinc die cast products for the automotive, defense, and household products markets. It operates 21 aluminum die casting machines that range in clamping capacity from 400 to 1,200 tons, and 15 zinc die casting machines that range in clamping capacity from 40 to 450 tons. The aluminum castings produced weigh up to 45 pounds in A360 alloy and up to 13 pounds for A380 alloy. For zinc castings, the plant produces #3 zinc castings, weighing up to 6 pounds.

The plant purchases its metal alloys in ingots and melts them on site. The alloys are melted in central reverberatory furnaces located throughout the plant. The molten metal is delivered to each die casting machine via a central launder system to ensure consistency in temperature. The facility has automated each die casting cell with automated ladles to enable shot-by-shot consistency in terms of weight and temperature. The plant has also implemented vacuum assist technology to reduce porosity and thus reduce the scrap.

The plant has put in place several systems to ensure production of quality castings. It implemented a Six Sigma analysis that uses statistical methods to identify the causes for defects and allows correction of identified issues. The plant has an onsite metrology laboratoryequipped with three measuring machines and spectrum analysis capability. In addition, the plant has been active in NADCA's research committees, allowing plant personnel to have access to cutting-edge technologies even before they are introduced to the industry as a whole.

Onsite Assessment

During the site visit, the plant's director of engineering and a plant engineer accompanied the assessment team. During the first half of the one-day visit, the assessment team received an overview of the plant operations from plant personnel in a face-to-face meeting. The overview described the current energy-saving actions implemented at the plant and the obvious waste problems encountered. The assessment team responded to the overview by providing the plant personnel with an overview of the suite of BestPractices tools and IAC services that are available at no charge. Plant personnel were unaware of these tools and services and expressed an interest not only in pursuing an IAC assessment but also in learning how to use and implement the PHAST, AirMaster+, and MotorMaster+ tools.

1. Implemented Best Practices

Compressed Air

Unlike most plants assessed, this facility is proactive in identifying compressed air leaks. The plant operates at 200 to 300 hp of compressed air, which is typical for a die casting operation. The plant has installed a sequencer to maintain its compressed air at approximately 82 psi, which it uses primarily to blow-clean dies and to operate air knives for the post-casting operations. The plant has invested in an ultrasonic leak detector that it uses as needed to locate system leaks in need of repair. The plant engineer, however, noted that the leak detector is not used as often as it should be. The assessment team ascertained that the only improvement that the facility could implement to improve its compressed air system is a simple control solenoid. The solenoid would enable the plant to control the compressed air flow to have it blow to the cutting knives only when needed, rather than having it blow continuously.

Waste Water Treatment

Plant personnel are also proactive in seeking ways to increase the facility's profit margin by improving operational efficiency and reducing waste. The plant's one concern at the time of the assessment was the high cost of disposing wastewater. Plant personnel revealed that they pay in excess of $22,000 a year to dispose of 48,000 gallons of wastewater comprising 90% water and 10% oil. According to the 2005 industry survey by NADCA and the *2005 Confidential Metalcasting Operational Cost Survey* conducted by Sapolsky Research Inc. for AFS and NADCA, the typical die caster either had a pre-tax profit of 2.87% of sales or a loss of 1.37%. Therefore, even a small saving can greatly affect the final profitability. To lessen its wastewater disposal costs, the plant was considering two general solutions: purchasing a Dissolved Air Flotation (DAF) system, and/or reducing the wastewater volume by installing an evaporation system. A DAF system employs gravity separation using air bubbles in the water to help float insoluble material (waste) to the surface where it can be skimmed off. The alternative evaporative wastewater management solution was estimated to offer a cost benefit when compared to purchasing a DAF. Although the plant would need to spend time and resources engineering and constructing the system, it would only have to pay for the disposal of the waste oil. The assessment team decided that evaporation might be the better solution because the plant could utilize the waste heat from its reverberatory furnaces to evaporate the water. This would utilize the energy that is otherwise being lost through the stack of the furnaces and, therefore, would be an energy-efficient solution to the wastewater problem. The plant personnel are currently performing the necessary engineering and cost analyses to implement an evaporative system.

Scrap Rate

The scrap rate at the plant ranges from 0% to 21% depending upon the complexity of the cast part, the design of the die, and the material used to construct the die. Although the plant does not design or develop its own tooling, it actively assists its vendor in designing the dies and selecting die materials. Currently, the plant management has incorporated a cost of 3% scrap rate into their pricing for new job orders. The plant engineer, however, estimates the plant’s average scrap rate to be closer to 5%. To reduce this gap in costing, the plant had to implement a corrective system to achieve better control of its scrap rate. Specifically, the plant has implemented a system to track the scrap produced at each machine. The system relies upon the die casting machine operators to track the scrap for their work shifts. After each shift, the scrap production numbers are entered into a corporate database and are analyzed to see if the rate of scrap generation was due to a failure in the casting machine, the design of the die, or failure of the die. The plant has also implemented an alarm system on each machine that activates if it detects three consecutive shots of scrap. This prevents the plant from operating a machine continuously as it develops scrap.

Another action the plant took to reduce its scrap level was integrating gas diffusers into its operations. The diffuser system fluxes metal to eliminate any contaminants that could potentially cause entrapped porosity in the casting. The implementation of this fluxing technology has helped eliminate porosity defects from castings and, as a result, reduced the plant’s overall scrap rate to the level factored in its pricing.

Even with the implementation of the gas diffuser and the system to monitor and track scrap, the plant still has room to make further improvements, and plant management and staff recognize this gap. They are examining other methods they can implement, such as performing solidification modeling on each casting produced to determine the optimal configuration of the die. Plant management is investigating the best modeling software to meets its facility’s needs, and is exploring the potential to incorporate technologies sponsored by NADCA into their operations.

Implemented R&D

The facility specializes in quick-turnaround orders, which is unique for the die casting industry where long lead times are typical due to the complications associated with designing proper tooling. Furthermore, the cost of typical die tooling makes short runs cost prohibitive and is generally only affordable with large orders. However, this facility has developed a niche for itself by filling orders for 300 to 500 parts, enjoying a competitive advantage in the market place to seize business opportunities that otherwise do not exist for a majority of die casters.

The facility was able to develop this specialty by incorporating some of the technology developments funded by the Metal Casting R&D portfolio and by paying attention to the layout of the die casting operation. The plant layout facilitates rapid change out of dies. This enables the facility to avoid wasting time waiting for a die to cool, thereby maintaining the die casting machine’s productivity.

Furthermore, the facility enlisted the assistance of NADCA and Case Western Reserve University to engage in rapid tooling activities and selection of proper die steels for its production needs. The utilization of Case Western die material studies led to significant improvement in die life at this facility. Case Western research showed that electro-slag re-melted H-13 steel with a modified chemistry exhibited a superior thermal fatigue resistance as compared to premium H-13 steel that has been the standard for casting dies. Die life is important because the more predictable the life of the steel, the more accurately the plant can estimate the costs of dies. Repairing and replacing dies is very costly in the die casting operation, involving not only the cost of the repair itself but also the additional loss in productivity while repairs are being performed. By working with NADCA and Case Western, the plant was able to select the appropriate die steel for the number of runs needed. The application of NADCA/Case Western research results also enabled this plant to use machine pre-hardened die materials to shorten its lead time and allow quick turnarounds on orders.

In-plant trials on a specific casting showed that extended die life was five to six times. Thus, the facility was able to keep up with increased demand and tight delivery schedules. Another trial on a different part increased die life from 200,000 shots to a new 300,000-shot level with reduced heat checking on critical surfaces. This improved die material could also be machined in the as-hardened condition, which, although it reduced the die life, also enabled the die caster to shorten delivery time and die costs on short orders where die life did not need to be optimized.

2. Areas of Improvement

Even with all of the proactive quality assurance measures the facility had implemented, this plant still has areas where it could implement further improvements to achieve benefits, in many cases with very little investment. Many of these recommendations involve simple ways to save resources that plant personnel often overlook in the greater interest of timely delivery on orders.

Furnace Coverings

The assessment team identified substantial energy losses in both the primary gas reverberatory melting furnaces and the electric holding furnaces, since none of them had covers. Operating uncovered furnaces appeared to be a routine, around the clock practice. An exposed square foot of furnace will loose approximately 6,600 Btu/hour at 1,300 ºF. At this facility, there were approximately 60 square feet of uncovered molten metal baths at temperatures ranging from 650 ºF (for zinc) and 1,300 ºF (for aluminum). The open furnaces will also lead to wide swings in pouring temperatures because of the lost energy and the plant operator’s tendency to allow metal baths to get excessively low before recharging. These large swings in pouring temperatures also cause more scrap to develop in die casting operations.

The assessment team recommended that the plant conduct and present to management a detailed analysis quantifying the costs associated with the energy losses resulting from the uncovered furnaces. It further suggested that the study include costs associated with purchasing insulated covers and calculate the payback on that investment.

Dross Management

Metal dealers and smelters may consider a container with any amount of dross to equate with a container of all dross, thus lowering the price at which the dealer/smelter purchases the metal. Such is the case at Die Casting Plant-1 where dross is collected in oil drums to be sent back to the smelter. However, these drums often also contain good alloy that, if recovered, could potentially save the plant money by optimizing the price paid for their returned metal. Thus, the assessment team recommended that the plant implement a drainage recovery system to recover metallic zinc from their dross. They also suggested that the plant investigate the feasibility of installing a dross spinner to assist them in the recovery process. Furthermore, the assessment team recommended that plant management meet with their metal providers and re-examine their contracts to understand better their policies and pricing on metal returns. This will enable the plant to develop a plan to optimize their financial incentives on returned metals.

Oil Leaks

Hydraulic and heater oil leaks can be costly for a die caster in terms of clean-up requirements, wasted oil, and employee safety. The assessment at this plant showed numerous oil leaks in the production facility. Each oil heater had a collection pan containing several inches of oil, and the die casting machine work areas had visible hydraulic oil on the floor and on the equipment. This situation was costing the plant approximately $72,000 per year, or $2,100 per machine. Again considering that die casters on average earn a 5% profit on their sales, the plant would need to sell $1,440,000 in die castings to offset this loss. Collateral costs to clean up the leaked oil are exacerbated if it mixes with water (see Waste Water Treatment Discussion for this facility), and oily surfaces are slippery, thereby constituting a hazard for workers.

The assessment team recommended that the plant implement an integrated housekeeping and maintenance plan to address the oil leakage issue. When visited, the plant was implementing a sector-by-sector plan wherein each manager was responsible for a specific area of the plant. This resulted in inequalities in the level of housekeeping and maintenance applied overall. For example, the machine shop was considerably more orderly than other areas of the plant. The team suggested that the plant implement a plan to provide incentives for all employees to keep their workstations clean and to identify and address oil leaks. This will reduce the costs associated with operating the die machines and will ensure a safe environment for the employees. This is an excellent example of where a champion is needed within the organization.

Stack Melter

This plant uses reverberatory furnaces to melt alloys. This is quite common throughout the die casting industry because reverberatory furnaces provide a large reservoir of molten metal, ensuring a steady and reliable supply to the die casting plant. These furnaces provide the advantages of being able to process high volumes of alloy with low maintenance cost. However, reverberatory furnaces also have several disadvantages: low efficiencies, high oxidation rates, and large floor space requirements. Their energy efficiency ranges from 20 to 25%, with energy lost mainly through the hot flue gases. In addition, as the molten metal contacts the furnace gases it forms slag/dross resulting in a melt loss rate of 3% to 5% in aluminum.[47]

The assessment team recommended that the plant perform a study to ascertain the costs and benefits of replacing their reverberatory furnaces with stack melters. Although this is very capital-intensive proposition, the assessment team felt that over time stack melters could provide significant cost reductions, especially if natural gas prices remain high.

A stack melter can be considered a modified reverberatory furnace wherein better furnace sealing and the use of flue gases to preheat the charge materials improves efficiency. The hot exhaust gases from the melting zone flow through the shaft to preheat the incoming charge, thus resulting in an energy efficiency of 40 to 50%,[48] which is a significant improvement over the 20 to 25% efficiency of the reverberatory furnaces currently installed at this facility.

3. Conclusion

This facility has utilized NADCA/government-sponsored research results to make significant improvements in its operation, especially in the area of die life. Implementation of other energy-saving practices, as identified by the BestPractices program and furnace/molten metal practices research, can also add to the facility's profitability without requiring significant capital investments. Installing more efficient melting equipment such as stack melters, although capital intensive, will add significant savings over time and is worth consideration to estimate benefits and payback period.

B. Die Casting Plant-2

Plant Profile

This die casting facility produces valve bodies, clutch housings, and stators for three major U.S. automobile manufacturers. The plant operates 3 shifts per day, 24 hours per day, 5 ½ days per week, and has 240+ hourly employees. The facility generates $34-$35 million in sales and produces castings ranging in size from 0.5 to 6 pounds. The facility has 36 die casting machines (including one vertical die casting machine), with typically 24 to 28 in operation during each shift. The plant also houses shot blast and machining operations within the facility.

The plant primarily casts A380 aluminum alloy but also casts a limited amount of A383 aluminum alloy. The facility receives its molten aluminum supply from a smelter twice a day and uses a launder system to deliver molten aluminum to each die casting machine. The monthly electric bill for the plant overall is approximately $48,000.

Tooling for this plant is designed at a corporate facility, which has complete control of the overall design process, although the production engineers are consulted when a new tool is designed. The plant itself repairs dies and currently runs computer models to evaluate dies that are showing problems (e.g., generating a high level of scrap or producing defective cast parts).

Onsite Assessment

During the first half of the one-day visit, the assessment team received overview of the plant's operation by plant personnel in a face-to-face meeting. A technical expert from NADCA assisted plant personnel by providing technical insights as needed. The plant personnel described their operations and explained particular areas where they were encountering problems. The assessment team then provided an overview of the suite of BestPractices tools and the IAC services that are available at no charge. Plant personnel were unaware of these tools and services, and expressed an interest in learning how to use and implement PHAST, AirMaster+ and MotorMaster+. They were also interested in the IAC services but were not sure if their plant exceeded the IAC's participant size limitation.

The plant views energy efficiency as an important focus area where improvements can improve its bottom line. At the time of the assessment, the plant engineer was under pressure from the corporate headquarters to reduce the facility's costs by 10%. The facility manager viewed energy conservation programs, such as the BestPractices tools and IAC assistance, as viable mechanisms for achieving that goal. The plant was rewinding motors rather than purchasing new ones, presuming that to be a cheaper option, but plant personnel were considering use of the MotorMaster+ tool to assist them in making such decisions. The plant also saw the benefit of having an assessment performed and viewed it as an easy contribution to achieving the targeted 10% cost reduction.

1. Implemented Best Practices

Molten Metal Handling

Die Casting Plant-2 has an outstanding melt/metal handling system. As mentioned above, the plant receives its molten metal supply from its smelter twice a day. Delivered metal is held in a large reverberatory furnace from which it is transferred to a launder system that distributes it to the die casting machines. The metal goes through a filtration process prior to entering the covered launder system, thus reducing the amount of dross that goes through the system. The launder system keeps the molten metal at an optimal temperature and minimizes fluctuations in temperature when pouring which, if not controlled, can lead to high scrap rates and wasted processing energy.

The plant fluxes molten alloys to minimize the melt loss. It currently experiences a 2% melt loss, which is much lower than the industry average. The plant has also implemented a program to separate dross from metallics, saving $28,000 annually by receiving the optimal buy-back price for its dross and reducing the energy consumed in processing good metallic material with the dross.

They further reduce process inefficiencies by using computer monitoring of the molten metal handling throughout the operation, thereby enabling the plant to identify and correct problems as soon as they occur in the system. This optimal handling not only limits the amount of scrap produced at the plant from variations in pouring temperatures, but also provides for a safer working environment by reducing the number of employees that actually handle the molten alloy.

Simulation Modeling

Currently, the design facility at corporate headquarters provides complete tooling services for the plant. The facility runs simulation software on all new dies. These simulations primarily involve flow modeling, although the plant is beginning to run thermal models as well. The facility uses a variety of modeling software including CastView, Finite Element, Magma, and EKK.

The plant will occasionally run simulations if a new design poses a problem after it arrives at the plant. This allows the plant to troubleshoot the design of the die or the configurations of the gates and risers. Plant personnel employ the Magma software to perform this task as they find it to be the most accurate tool.

The modeling of all new dies and products has benefited both the plant and the corporation. The current internal scrap rate at the plant on new work is running at 2-3%, which is lower than the industry average of 4-5%.[49] This provides an obvious competitive advantage to the plant, since less time and effort spent controlling scrap translate directly into cost and energy savings.

Quality Control

The assessment team was impressed by the plant's quality control measures and attention to detail. The plant was very orderly and clean. It was apparent to the assessment team that management pays attention to the housekeeping and maintenance of the plant.

Since this plant serves the three big U.S. automobile manufacturers, it cannot afford to ship out any unacceptable castings. The plant has developed and implemented a quality control plan that has limited customer returns at 0.10% of its total castings shipped. The plant employs a thorough inspection progrm wherein computers monitor the entire casting process. The plant has the ability to trace a casting back to the melt in which it originated, the die casting machine that produced it, and the die casting operator. Each of the 36 die casting machines are monitored for temperature and shot parameters. If the system shows "red," the operator is notified and the casting is scrapped. This monitoring system enables the plant to shut down a machine immediately when scrap is produced, thereby reducing the amount of time, energy, and money wasted with a machine continuously producing scrap castings. The monitoring system also enables the plant to plan maintenance for periods when proper resources are available.

2. Areas of Improvement

Impeller Scrap

Despite the computer modeling of all of the new products and the implementation of a strong quality control program, Die Casting Plant-2 still experiences an abnormally high scrap rate on a transmission impeller. The part has an in-house scrap rate of over 20%, which means that the plant must produce 125 of these impellers in order to have 100 good parts shipped. The scrap is caused by "see through" holes in the impeller veins. When this scrap rate is factored into the total shipments of this casting facility, the in-house scrap rate rises significantly from 2-3% to as high as 15%. This is three times the industry average.

The transmission impeller is a legacy part that was designed about 10 or 15 years ago. The part weighs approximately 5 pounds and is made of A380 aluminum alloy. The plant ships 140,000 to 160,000 of these impellers each year. The plant runs this part on five machines continuously and the 20% scrap rate implies that one of the five machines is running merely to accommodate that high rate.

The assessment team recommended that the plant revisit the impeller design and enlist the help of NADCA and Ohio State University for assistance in optimizing the design. The plant agreed with the suggestion and NADCA is currently examining this part. The assessment team also recommended that the plant inspect its entire casting line for potential problems. The plant should run reduced pressure tests at the holding furnace to determine if there is any gas and/or dross variability causing the scrap. Finally, the assessment team recommended that the plant investigate the performance of new die materials such as Dievar* to determine if they can

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* Dievar is a commercially available chromium-molybdenum-vanadium alloyed hot work tool steel that provides good resistance to heat checking, gross cracking, hot wear and plastic deformation.

improve die life and reduce die maintenance. Plant personnel were not aware of the Metal Casting R&D work on the performance of this next generation of die materials.

Die Coatings/Die Materials

Currently, this plant uses Premium H13 die steel as the material for its dies. The plant was unaware of the ongoing research involving double-melted superior grade steels, which have shown significant improvement in die life and impact strength. The assessment team and NADCA agreed that the plant could benefit greatly from this research. The assessment team also advised the plant to become involved with some of the alternative coating processes. Currently, the plant uses the manually applied proprietary coating process, and they were unaware of NADCA work at the Colorado School of Mines on multiple material coatings. These coatings, along with the use of alternative steels, will enable this plant to improve its production rate, decrease downtime, and increase its profits.

3. Conclusion

Modeling plays a key role in the approach Die Casting Plant-2 uses to ensure maximum quality and productivity. However, plant personnel lacked a general awareness of the DOE BestPractices software/programs and the Metal Casting R&D research work on die materials and die coatings. Thus, there is a significant opportunity at the plant to implement the relevant technologies and reduce costs without making significant capital investments.

C. Steel Foundry-1

Plant Profile

Steel Foundry-1 is located in a rural community and employs almost 500 people. The size and location of this facility makes it a large part of the local economy. The facility specializes in producing carbon and low alloy, heavily cored steel castings primarily for the mining and construction market.

The facility designs and builds its patterns on site. First, they employ a variety of software to design the pattern that the pattern shop then builds from wood and coats to extend its life. The constructed pattern then moves to the molding lines. The facility has two molding lines, one for the construction of large molds, roughly 120” x 120”, and the other (an automated line) that produces patterns no larger than 63” x 96.5”. At these lines, molds are produced and coated and cores are inserted in preparation for the pour.

The plant performs all of its melting in three electric arc furnaces: one of 8-ton capacity, used primarily to melt ductile iron, and two of 20-ton capacity, used to melt steel scrap. The foundry has an excellent working relationship with its power supplier and uses the latest in power demand management and power monitoring equipment. Melting occurs at this facility depending upon the production schedule and the demand for molten metal. Bottom-pour ladles are used to pour the molten steel into the finished molds.

Once the casting is poured and cooled, the casting is shaken from its mold and transferred to the cleaning room. The plant maintains two cleaning rooms: one for castings under 4,000 pounds and the other for castings over 4,000 pounds. In the cleaning room, workers remove the gating and riser systems and weld the casting if any discontinuities exist. Depending upon the material specifications, the casting may also go to one of the 10 heat treatment ovens and quench tanks. The footprint of the cleaning department is quite large. Once a casting passes through the cleaning room, if necessary it can move to the machining room to be machined to meet customer’s specifications.

The facility maintains tight quality control of the metal it melts and the castings it produces. It has a state-of-the-art complex to perform chemical analysis, physical testing, hardness testing, and metallographic examination. Furthermore, the facility utilizes several tests to inspect the castings. At some point in the casting process, the casting goes through magnetic particle inspection to detect surface or near-surface abnormalities. The facility also performs dimensional checks on all new pattern equipment and sample parts, and performs periodic production audits. The facility has a radiographic inspection facility and develops/inspects the film onsite. Finally, several of the facility personnel have received training in ultrasonic testing.

Onsite Assessment

During the site visit, the plant’s management, designers, metallurgist, plant engineers, and floor management accompanied the assessment team. The first half of the one-day visit consisted of a face-to-face meeting wherein site management provided an overview of the plant operations and an evaluation of the extent to which Metal Casting R&D technologies and BestPractices programs have been implemented at the plant. The plant personnel described their current energy-saving measures and some of their obvious waste problems. Finally, the assessment team provided an overview of the suite of BestPractices tools and the IAC services that are available at no charge. The plant personnel were unaware of these tools and services, and they expressed interest not only in pursuing an IAC assessment but also in learning how to use and implement the PHAST, AirMaster+ and MotorMaster+ tools.

After this initial meeting, the assessment team took a tour through the entire plant and received a briefing from the head of each operational division. During this assessment, the assessment team noted some of the areas that already have benefited from DOE-funded R&D and as well as others where opportunities for further improvement still existed.

1. Implemented Best Practices

Modeling

Steel Foundry-1 is responsible for developing the appropriate feeding requirements for the castings they produce. The foundry uses the latest modeling and simulation software to analyze the coupled fluid flow and heat transfer during mold filling. They also use it to monitor solidification as castings cool. This modeling capability helps the foundry determine the optimum configuration of gates, risers, and chills.

The modeling tools used at the foundry incorporate the results of ITP-funded research conducted at the University of Iowa. That research developed new feeding rules for steel castings and unconventional yield improvement and defect reduction techniques. It developed a model to predict the formation of re-oxidation inclusions and shrinkage when pouring steel castings. By using this modeling capability, Steel Foundry-1 is able to predict where inclusions or shrinkage will occur and accordingly redesign the gating configuration to avoid the problem. Further, the foundry’s use of modeling has played a critical part in improving the fatigue life of its castings by avoiding microshrinkage in the critically stressed regions.

By investing in their modeling capability, the foundry has been able to reduce scrap and improve their casting yield. This capability has also saved the foundry significant amounts of money by improving its success rate on the first-test castings poured. This has proven to shorten the foundry’s lead-time to produce a casting and lower its production costs. Initially the foundry only modeled patterns of new jobs it received; however, due to the success that it has had, the foundry has gone back and modeled castings already were in production but that have a high scrap rate or have evidenced other problems. This effort has lowered the costs associated with producing steel castings and has improved the foundry’s overall quality.

Tracking of Casting Operation

Tracking casting operations can play a key role in helping a foundry identify the exact location of trouble spots in its operation, improving its productivity and, hence, its bottom line. Tracking also enables foundries to understand where areas of waste exist in their operation. Steel Foundry-1 has developed a process to track its castings from the shakeout operation through to product shipping. This system was under development during the assessment and was expected to come online a few months after the site visit.

The tracking system will enable the foundry to gather data on individual serialized parts so it can determine areas that need improvement. Prior to this system, the foundry's employees tracked this manually on a very small sample size, but the data were not adequate to allow tracking the costs associated with certain defects or tracking the savings achieved by reducing a specific defect in a casting. The new automated tracking system will provide the foundry with a much clearer understanding of its costs and, therefore, will constitute a far better tool for problem identification/correction and cost reduction.

The tracking system also will help measure improvements that derive from implementing new technologies. For example, all castings with "burn-in" and "burn-on" require extra processing steps for removal of contaminants. Burn-in is when the surface of the casting has sand adhering to it that cannot be removed other than by grinding. Burn-on is when large pieces of sand/metal are attached to the casting by metal ligaments, which can be removed by breaking, leaving a relatively clean cast surface. This extra processing step costs the facility considerable time and money. Some of the burn-in and burn-on can be chipped off, while other areas must be flame-washed or ground. Steel Foundry-1 has incorporated the Metal Casting R&D work at University of Missouri-Rolla to maintain the integrity of the coatings used in the sand and thereby reducing the amount of burn-in and burn-on. The foundry had realized an improvement by incorporating this work but had not quantified the effect such improvement had on its bottom line. With the help of the new tracking system, the foundry will be able to measure its success.

Process Flow Improvement

Many foundries suffer from poor facility design and large work-in-process inventories. The problem especially occurs in the casting finishing areas, which include blast cleaning, riser removal, grinding, welding, and heat treatment. The problem derives in part from the labor-intensive nature of the finishing process. Typically, finishing accounts for 50% of the cost of producing steel castings. Any decrease in this cost can improve a steel foundry's bottom line and provide it with a competitive advantage when compared to other steel foundries.

Steel Foundry-1 participated in two Metal Casting R&D projects conducted by the Iowa State University (ISU): *Re-Engineering Casting Production Systems* and *Reduction in Energy Consumption and Variability in Steel Castings*. These two projects addressed solutions and improvements in the areas of scheduling, inspection and re-work practices, plant layout, and material handling. Because of these studies and Steel Foundry-1's participation in them, the foundry has begun to work on redesigning the process flow in its cleaning room. It has relocated the blast at the end of its newest continuous heat treat furnace to eliminate the need for a fork lift to move castings from the continuous heat furnace to the blast, thus saving the facility fuel and labor costs.

Steel Foundry-1 continues to analyze its process flow in the cleaning room to identify projects that can reduce costs further, and the work performed by ISU has shown this foundry the benefits and payoffs by taking these incremental steps.

Shroud Pouring

The University of Alabama-Birmingham, funded by ITP Metal Casting, discovered that air entrainment during pouring and mold filling was a major source of oxygen that caused macro-inclusions in steel castings. The research in this project determined that one of the methods to remove the oxygen during pouring was the mechanical shrouding of the pouring stream. A ceramic shroud encloses the metal stream as it is poured and protects the molten steel as it passes from the bottom poured ladle to the mold.[50]

Steel Foundry-1 carried out significant trials utilizing this shrouding technique on four different castings. They melted steel for these experiments in 20-ton arc furnaces and transferred it to a bottom-pour ladle with a fire clay nozzle. The shroud fits over the ladle nozzle and attaches to the ladle. A seal between the shroud and ladle prevents air entrainment. The casting was equipped with a side riser that was large enough to allow insertion of the shroud and provided enough room below the bottom of the riser for a pouring well and impact pad in the mold. The shroud was inserted into the mold until it reached the proper depth, at which point the ladle filled the mold with the molten metal[51]

Exhibit A.1 summarizes the success of these trials on the four different castings. Implementing the shroud technique added an average of 1.5% to the casting yield, yet showed a 60-80% reduction in the amount of re-oxidation. The reduced “dirt” levels result from a reduction in cleaning room activities to weld repair castings.[52]

Exhibit A.1: Overall Level of “Dirt” Defects Found in Castings

(Measured as total length of defects in inches)

Method	Frame	Small Spindle	Medium Spindle	Large Spindle
Conventional Gating	86.25 in	16.10 in	12.03 in	15.85 in
Shrouded	12.67	6.41 in	8.30 in	5.56 in
% Improvement	**85%**	**60%**	**31%**	**65%**

The foundry performed a cost analysis after the trials to compare the cost of the additional materials (shroud) and the savings achieved, and found that they recover the extra cost associated with the shroud pouring technique by the reduction in molding cost. The improvement in casting quality showed a 25 to 40% reduction in the material and labor spent weld repairing the castings produced for these trials. The implementation of the shroud pouring technique proved to be successful at this foundry.[53]

Automated Molding Line

Steel Foundry-1 has installed an automated molding line that utilizes chemically bonded sand and produces flaskless molds. This state-of-the-art system includes sand preparation and mixing equipment, a fast loop molding compaction system, automated rollover/draw machine, water-based coating and drying equipment, and two automatic mold-closing machines. This system has the ability to produce molds at a rate of 10 per hour using the latest process controls.

This system is unique for a steel foundry. It enables the foundry to not only increase productivity but also reduce the scrap rate. It gave the foundry the ability to keep up with one of its customer's high demand without experiencing a disproportionate rise in its labor costs. In addition, because each mold is constructed under computer-monitored and computer-controlled steps, molds are formed under the same conditions, thereby ensuring consistency among molds. This automated system was a large capital investment for the facility, yet it has paid off by allowing the plant to retain an existing customer and to expand the volume of production for that customer at a reasonable cost.

2. Areas of Improvement

Even as proactive as Steel Foundry-1 is in using state-of-the-art technologies and techniques, there are still areas in which the foundry can further reduce its costs and energy consumption. The assessment team identified areas of opportunity where the plant can make changes, in many cases with very little investment. Many of the suggestions made involve simple steps that quite commonly are overlooked by steel casters because plant personnel are more concerned about getting castings delivered on time.

Compressed Air

Steel Foundry-1 has the potential to save thousands of dollars in energy costs by improving and optimizing its compressed air system. Many of the fixes could take place with little or no capital investment. For example, like many foundries, Steel Foundry-1 could implement some easy steps to reduce the number of compressed air leaks. The assessment team noted a number of leaks during the foundry tour. A single 1/16-inch diameter air leak can cost about $200 per year. The assessment team recommended that the foundry have a team of employees tag and repair existing air leaks over a weekend when peripheral noise from daily production will not interfere with the leak detection. Furthermore, the assessment team recommended that the facility should note the weekend horsepower used to maintain pressure in the line. This will provide input as to the quantity of air leaks and the equipment that is using non-essential air. The facility should identify and isolate any equipment that has non-operating air requirements.

Steel Foundry-1 could also improve its energy efficiency by utilizing the most efficient compressed air tools available. Currently, the facility utilizes air-powered stirrers in its coatings tanks. These stirrers use approximately four times the amount of energy as do electric stirrers. The assessment team recommended that the facility replace its air-powered stirrers with electric stirrers and estimated that the pay back for this replacement would occur in less than 2 years.

Energy Assessments

Overall the assessment team was satisfied with the facility's energy assessment practices. Steel Foundry-1 has undergone a number of energy audits and assessments that have enabled the plant to identify areas where it can improve its energy efficiency. The facility has completed the cost-effective process of purchasing new energy-efficient items and replacing older, less efficient equipment when the older equipment fails. For example, the facility replaced overhead lights with a higher efficiency variety as the existing bulbs failed, since it did not make economic sense to replace its functioning bulbs with higher efficiency bulbs.

The assessment team recommended that the facility analyze whether all of its overhead lighting is needed at all times and suggested that it consider minimizing bay lighting in favor of work-place lighting. The cost of one 400-watt light bulb burning around the clock at $.05/kWh is $175 per year. According to plant personnel, this facility has 1,000 overhead lights burning continuously. This means the foundry's total cost for overhead lights is $175,200 per year. By undertaking a program to use lighting only when needed, the foundry has the potential to achieve significant savings in its energy bills.

3. Conclusion

Steel Foundry-1 has successfully implemented the positive results from a number of DOE-sponsored projects and reported on those results in industry literature. Steel foundry 1 has implemented a number of technologies and practices that have reduced their energy efficiency and improved their bottom line. There are still areas that Steel Foundry 1 could improve upon, specifically in the compressed air and energy management area. These areas require little capital investment to address.

D. Steel Foundry-2

Plant Profile

Steel Foundry-2 is a large foundry that employs 100+ people. It produces large carbon and alloy steel castings for the mining, cement, and power generation industries. Their castings range in size from 500 to 100,000 pounds.

The process flow of the facility is typical for a steel foundry and begins in the design phase, where the facility designs the casting using the latest in computer modeling techniques. Once the foundry has designed the casting with the proper rigging system (e.g., gates, risers, chills), the design is sent to the pattern shop where the pattern is constructed.

Once the pattern is constructed, the facility proceeds to build the casting molds. The facility uses no-bake sand, specifically developed by the foundry, as their molding medium and a binder that produces no visible emissions. A computer controls the sand operation and determines the mixture and the number of patterns that need to produced. Also, the facility constructs large molds within pits to produce large castings. These large molds take approximately one week to build and command a rather large footprint within the facility. Due to the considerable time required in constructing the large molds, and the large quantity of metal poured into these pit molds, these molds are conservatively designed since any error could result in a large financial loss.

The facility uses two basic electric arc furnaces (capacities are 5 and 65 tons) for melting. They worked with their power utility to determine the most cost-effective time at which to melt, which proved to be the non-peak load hours from 9:00 p.m. to 9:00 a.m. Operating the plant on this schedule saved $250,000 per year on the electricity bill.

The facility transfers molten metal from the melting furnaces to a holding furnace and, when ready to pour on to large crane-driven ladles for pouring into the molds. After the castings have solidified in the molds, they are shaken out, cleaned, and machined. In some cases, castings also are heat treated.

Onsite Assessment

During the site visit, the assessment team was accompanied by a technical expert from the Steel Founders' Association of America (SFSA), the facility's foundry manager of technical services, an environmental engineer, and a manager of the pattern shop. During the morning, plant officials provided an overview of the plant operations and discussed with the assessment team the extent to which Metal Casting R&D had been implemented at the facility. Plant managers also provided an overview of measures they had implemented to combat rising energy costs. This was followed by the assessment team providing an overview of the suite of free software tools and services offered by ITP's BestPractices subprogram. The overview included informing plant managers as to the benefits they could attain by implementing the PHAST, AirMaster+, and MotorMaster+ tools. The assessment team also discussed with the plant personnel the savings that other steel foundries that were subjected to an IAC assessment had realized. As was common throughout this project, the facility was unaware of these tools and services and expressed an interest both in pursuing an IAC assessment and in learning about the suite of BestPractices tools.

After the morning meeting, the assessment team toured the facility with the foundry manager to observe first hand the implemented Metal Casting R&D results and to make recommendations on potential areas for additional improvement.

1. Implemented Best Practices

Plant Housekeeping

At Steel Foundry-2, the overall approach to efficiency and quality was impeccable. The plant was extremely clean and orderly. For example, metal chips were neatly collected in the machine shop. The foundry's management believes that maintaining a clean and orderly plant will translate into high-quality, cost-effective production. To that end, management made their employees responsible for the upkeep of their own work areas. This promoted a sense of ownership and pride for the employees and resulted in a safe and orderly workplace. The difference between this facility and other facilities is that from the top down, each area of operation was held to the same standard. One area of the shop did not supersede the other.

Shroud Pouring

Steel Foundry-2 currently implements the results of the University of Alabama-Birmingham (UAB) Clean Steel Projects 1 through 5. Beginning in 1996, this foundry worked with experts from SFSA and UAB to perform casting trials for the research project. The research examined methods to remove oxygen during pouring with a mechanical ceramic shroud. Shroud pouring had been used previously at other facilities to pour steel into tundishes during continuous casting operations. This technology removes oxygen from the pouring stream in steel manufacture, so researchers from UAB were exploring its application in steel casting. UAB selected a number of castings on which to perform trials at Steel Foundry-2 to ensure that there was a significant quantity to provide statistically valid results and that the castings were of a design that could be poured with a shroud and that had a history of having oxide micro inclusions. Shroud pouring tests began once the castings were selected. Researchers noted that the shroud-poured castings were visually superior to those poured in the traditional way. Upon further inspection, they determined that inclusions were reduced significantly. The average number of inclusions for traditional gated castings is 10.8 per casting whereas the shroud-poured castings had 0.2 inclusions per casting. Furthermore, both the pourer and the crane operator found that lining up to a shroud was easier than with a pouring cup. In fact, pouring time was reduced by 7 seconds for each mold.

With these encouraging results, Steel Foundry-2 began to implement shroud pouring on its production line and has since experienced an overall cost savings of 14.5% as a result. The foundry implements shroud pouring on approximately half of the castings it produces. It has realized savings on the number of heats per year and has found that tool life has increased in subsequent machining operations. Exhibit A.2 illustrates the affect from implementing shroud pouring as experienced by Steel Foundry-2, as compared to using a conventional gating system.

Exhibit A.2: Shroud Pouring Affect on Facility Costs

Area of Impact	Impact on Operations
Gate Tile	100% Reduction
Molding Sand	13% Reduction
Yield	4% Increase
Molding Time	19% Reduction
Cleaning Time	14% Reduction
Shroud Cost	1% Addition
Impact Pad	1% Addition

As is obvious from Exhibit A.2, shroud pouring constitutes a successful improvement at Steel Foundry-2. It has been a win-win situation for both the foundry and its customers. The foundry has been able to improve efficiency and lower costs, while its customers receive a higher quality casting. Thus, participation in the Metal Casting R&D project was quite fruitful for Steel Foundry-2. The foundry manager attributed other steel foundries' lack of implementation of shroud pouring technology to their not risking the time and effort to get the process to work.

Modeling

Similar to Steel Foundry-1, Steel Foundry-2 also uses a modeling tool that has incorporated the work performed by the University of Iowa and funded by the Metal Casting R&D portfolio. The incorporation of the feeding rules and unconventional yield improvement and defect reduction techniques has led to an improvement in the casting yield at Steel Foundry-2. In fact, this foundry reported an 8% improvement in its entire facility yield rate from the impact of modeling. This is a significant saving in both materials and energy costs.

Prior to the incorporation of the rules and techniques developed by Iowa State University, Steel Foundry-2, like many other steel foundries, would overcompensate for risers by implementing the modulus process. Steel Foundry-2 would use this to provide feed metal to the casting during solidification to prevent holes or voids from forming. Once the foundry began to use the software tool based on ISU work, it began to reduce its rigging by optimizing the configuration and size of the rigging system. Steel Foundry-2 began to recognize the benefits of this approach almost immediately.

Currently, Steel Foundry-2 uses the work of ISU and models all of its new castings. With the success realized by the foundry from implementing modeling, it has gone back to model older products to seek additional improvement in their yield. The facility has become so proficient with the modeling software that typically the first casting poured is now sellable and the plant no longer needs to repeat samples to obtain a sound casting.

Optimizing Facility Layout

Foundry work involves various manual operations. The wide mix of products, particularly in the steel foundry industry, makes automation infeasible for many segments. In addition, many foundries suffer from poor facility design and large work-in-process (WIP) inventories. This is because as new technologies are developed, many foundries simply insert the technology into their plant where it fits rather than where it belongs in the overall workflow. Steel Foundry-2 was no exception to this industrial practice, and it began to work with The Iowa State University (ISU) to rectify inefficiencies, develop an improved plant layout, and reduce materials handling.

With support of the Metal Casting R&D portfolio and the cost share of Steel Foundry-2, ISU began to evaluate the foundry's layout. The ISU objectives were to provide Steel Foundry-2 with recommendations for re-engineering its layout and to identify ergonomic improvements. As a result of ISU's analysis and their suggested work in process material flow redesign, Steel Foundry-2 was able to cut 53 miles of wasted travel a year from within the plant. The ISU recommendations that the foundry implemented reduced the number of transfer stations from nine to six and affected approximately 50% of the products it produces.

The incorporation of the work done by ISU into Steel Foundry-2 has made the casting process more reliable for the foundry. This is because there is less handling of the products and operations are conducted in a much more continuous manner. According to the foundry management, this advantage assists them in meeting their delivery commitments efficiently.

2. Areas of Improvement

During the site visit, it was difficult to identify areas where Steel Foundry-2 could improve its operations and reduce the energy use. The common areas for improvement identified in this project at a number of plants were not applicable to this facility. There were no excessive air leaks, the facility was willing to test and implement research results that improved its bottom line, and the facility paid close attention to good housekeeping. However, there is one area in which the assessment team felt the foundry could make some changes to improve its energy efficiency and reduce costs.

Business Plan

Steel Foundry-2, like many other foundries, needs to devise a plan to overcome the dilemma between engineering and the purchasing department. The purchasing department at Steel Foundry-2 is mostly concerned with the cost of equipment, where as the engineering department wants the most efficient equipment. For example, when a motor needs to be replaced, the purchasing department will suggest replacing the broken motor with an older less efficient motor that the plant has in storage or rewinding/repairing the failed motor. This option saves the company money in the short term, yet will most likely result in higher electricity use at the plant. On the other hand, the engineering department's preferred decision is to purchase the most efficient and powerful motor, but that will incur a higher initial cost and may provide more horsepower than is needed.

It would benefit Steel Foundry-2 if it were to develop a long-term purchasing decision-making plan based on an analysis of both short-term and long-term costs and benefits of various purchasing options. Using the suite of BestPractices tools can further assist the staff at Steel Foundry-2 in making sound purchasing decisions. These tools can enable the purchasing and engineering departments to analyze the true costs of replacing a piece of equipment, such as a motor, with an older piece of equipment or with a new more efficient version. They can then present their quantitative findings to facility management for a final decision.

3. Conclusion

Steel Foundry-2 was considered by the assessment team to be the most proactive plant participating in this project. Foundry management paid close attention to details and had programs implemented for activities such as compressed air leak repair and high-efficiency lighting installation while maintaining a clean facility to minimize scrap and provide for a safe work place. The research implemented by Steel Foundry-2 has greatly improved its bottom line. The use of shroud pouring has reduced the facility's cost by approximately 14.5%. Incorporating the rules and techniques developed by the University of Iowa into the modeling software has improved the facility's yield rate by 8%. This is significant savings, especially in light of the total cost of foundry scrap and the effect of casting yield on profits.

Finally, the plant also retroactively reviewed its workflow and, with the assistance from Iowa State University, made changes so its process was more predictable and efficient with lesser chance of mistakes to occur. Steel Foundry-2 is a market leader in the steel casting industry, and it is because of its proactive measures, that it is able to maintain a competitive edge in the world market.

E. Iron Foundry-1

Plant Profile

Iron Foundry-1 is a large facility, occupying approximately 145,000 square feet on approximately two city blocks of land. The facility employs 200+ hourly employees. Castings produced at this foundry range in size from 1 to 110 pounds and are used in automotive, valve, and industrial machinery applications. The foundry produces either a gray iron base chemistry or a ductile base chemistry from a single water-cooled cupola at a rate of 15-20 tons/hour for 8-10 hours per day. The cupola uses a 1,000 ºF recuperative hot blast with oxygen injection.

Gray iron has a high percentage of carbon present in the form of flake graphite. Ductile iron has essentially the same carbon levels as gray iron along with a small amount of magnesium. The carbon in ductile iron thus forms into small spheres and produces a metal with good ductility, stiffness, strength, and shock resistance.[54] When producing gray iron, the iron leaves the cupola and goes directly into an induction holding furnace. During the weeks that the ductile iron base chemistry is being produced, the molten iron is desulphurized using a continuous lime-fluorspar porous plug ladle prior to being transferred to a ductile iron-specific induction holding furnace. Sulphur levels must be reduced from the typical 0.08% leaving the cupola to approximately 0.01% in order to economically produce ductile iron.

Before a mold is made, the facility models all new designs using AFS Solidcast and Flow Modeling/Novacast tools. The facility uses green sand as its molding medium. Sand is mulled in one of the two batch mullers with automatic control of compactability. For core making, the facility utilizes the shell, warm box, or cold box process depending on the economics and/or the core design. Compressed air is supplied from two 400 hp compressors with outside air intake. All air passes through refrigerated driers, which reduces the dew point to approximately +40º F. The air for the cold box process is dried to -40º F. Once the molds are poured and the castings are shaken out, the facility cleans the castings using one of the three shot blasting machines and then moves them to snag grinding and/or table grinding workstations.

Onsite Assessment

During the site visit, the facility's foundry manager accompanied the assessment team. The agenda for the site visit followed the same format as the others, beginning with a meeting in the morning for the assessment team to obtain an understanding of the research implemented at the facility and to provide an overview of the tools and services offered by the ITP BestPractices subprogram. As was common throughout this project, the facility was unaware of these tools and services, but expressed interest in pursuing both an IAC assessment and learning about the suite of BestPractices tools. After the morning meeting, the assessment team was guided on a tour of the facility by the foundry management to see the implemented R&D in action and also to make recommendations on potential areas for improvement.

1. Implemented Best Practices

Age Strengthening and Machinability of Iron

Researchers from the University of Missouri-Rolla (UMR) have worked to identify the age-strengthening mechanism in cast iron, quantify the parameters that control the process, measure properties, develop a predictive model, and quantify the relationship between aging and machinability. The mechanism and control of this phenomenon has not been conclusively determined. Yet initial research at UMR indicated that dissolved nitrogen may be the control mechanism. There was also an indication that these aging phenomena may favorably affect the machinability of gray cast iron. The ability to initiate and control this phenomenon could result in a significant improvement in casting mold yield, casting weight reduction, and possibly improved machining productivity. The reported 7-11% increase in strength would allow the production of higher carbon equivalent irons and a corresponding improvement in mold yield. The researchers found that aging not only improved tensile strength but that the machinability of cast iron also improves dramatically, especially when compared to “young”, one-day old iron. There is also the potential to reduce casting weight by producing higher-strength iron. This research concluded that a foundry could hold a casting for a period to increase its strength and lower its machining costs.

Iron Foundry-1 was skeptical of this research at first. Holding castings in inventory requires space and lower inventory turnover initially as more and more castings are stored. However, after running some tests, the foundry found that holding did in fact increase the strength and improve the machinability of their castings. At present, Iron Foundry-1 experiences an increase in tensile strength of approximately 10% because of allowing the castings to age. This has resulted in less concern in situations where the carbon equivalent is on the high side, which could jeopardize meeting minimum tensile requirements. Further evidence was provided to Iron Foundry-1 when it received complaints from customers about the difficulty of machining castings that were sent in as a rush order. At present, Iron Foundry-1 holds its castings for several days before shipping, many times at the request of its customers due to the problems they had experienced when machining “young castings.” This process has enabled Iron Foundry-1 to deliver high-quality castings that save its customers money on machining costs. Similar analysis can be made for gray iron and compacted graphite iron.

Thin Wall Iron Casting R&D

Today's foundries are confronted with a continuous demand to manufacture high-quality, cost-effective cast products. Those specializing in automotive castings have the added pressure of developing new processes and materials that reduce overall car weight to meet federally mandated fuel economy standards without sacrificing performance. In order to meet these needs, automakers have increasingly turned to lighter-weight materials, and castings continue to be a prime target. This explains why some ferrous castings markets have been lost in the past 15 years, as aluminum displaced cast iron for parts such as cylinder heads, engine blocks, and steering components. However, a closer examination actually reveals that ferrous castings are, in many cases, superior to – or at least competitive with – aluminum-based alloys. For instance, ductile iron is not only cheaper, but also superior to aluminum in many cases in terms of relative weight per unit of yield strength. European automakers have made significant progress in the replacement of aluminum castings with iron castings. However, for cast iron to regain the lost market from aluminum, it must be better engineered to achieve its full potential. Currently, iron castings cannot be routinely produced in sand molds with thickness less than 3 mm. With support from Metal Casting R&D, researchers from the University of Alabama began to develop the technology for producing commercial iron castings with mold wall thickness less than 3 mm. The project investigated both the metallurgical treatment required for molten iron and the mold and core-making techniques needed to reach the project goals.

Iron Foundry-1 participated in this research by running a number of casting trials at its facility, hoping to obtain technical knowledge ahead of its competitors and have an advantage of being able to produce the thin-wall castings. However, after the project was completed, Iron Foundry-1 found that the major factor affecting thin-wall mold design is that the mechanical engineering design software does not utilize the “tensile strength versus section thickness” parameter for gray iron. Instead, the design engineer enters a plugged figure (e.g., 30,000 psi) for the tensile input and the finite element analysis software only has that parameter with which to work and does not use the other much higher values for thinner sections. Although a new product line did not come out of this research for Iron Foundry-1, the plant personnel now have a good knowledge base and identified additional hurdles that need to be addressed. This can only help them improve as time progresses.

Modeling

Iron Foundry-1 actively models all new castings it produces using the AFS Solidcast and Flow Modeling/Noveacast software tools. Although the DOE-sponsored projects were not intended to create new software, the results of these individual projects nevertheless were incorporated into various commercial software applications such as AFS Solidcast and Flow Modeling/Noveacast. These applications enable the facility to conduct solidification and fluid flow simulations in order to determine the proper rigging system for the casting. Iron Foundry-1 personnel indicated that the implementation of these modeling tools has saved them both time and money by improving casting yield, lowering scrap, and avoiding costly trial and error test pours. The facility can get the design right the first time. During the site visit, the assessment team received good testimonials relating to the benefits derived from the modeling tools, yet the plant personnel were unable to quantify the level of improvement that modeling has had on their production, energy use, and bottom line.

2. Areas for Improvement

Iron Foundry-1 was determined to be a well-organized, well-engineered plant that produces high-quality products. The facility has been proactive and seeks ways to gain a technological competitive advantage by participating in a number of research programs funded by Metal Casting R&D. However, the assessment team identified certain operational aspects that the foundry could improve upon to manufacture its products more efficiently and of better quality.

Treating Sand

Iron Foundry-1 reclaims its green sand after the casting is shaken out. The used sand is returned to the sand muller, where additional clay, seacoal, water, and other additives are automatically added to the muller. Once this mulling occurs, the sand is returned to make additional molds. As of now, the used sand that is being returned to the muller is quite hot with temperatures ranging from 140-170ºF. This excessively high temperature leads to poor sand mulling and can also cause sand defects in the castings. Sand in excess of 135ºF in the mold creates extremely high humidity conditions in the mold cavity, and can thus cause degradation of the core and cause serious casting issues that will result in high scrap rates.

The assessment team recommended that Iron Foundry-1 consider implementing a system to cool the sand prior to its entering the muller. There are a variety of technologies that are available for this, including water-based systems, fluidized beds, and vacuum cooling systems. These systems generally utilize the cooling effect associated with the evaporation of water. The assessment team recommended that the vacuum cooling system be seriously explored because it removes the heat efficiently and has the least amount of environmental concerns. The vacuum sand cooling system relies on the vacuum-induced evaporation of water rather than air-flow-induced evaporation. Thus, a minimal amount of water-laden air needs to be handled in a dust collection system. These sand cooling systems are a large capital investment, yet they will reduce the scrap rate and will improve the overall productivity. The assessment team recommended that Foundry-1 perform a thorough cost analysis to determine the payback that can be achieved by implementing one of these systems.

Compressed Air

There were minimal air leaks observed in the foundry. However, the assessment team noted substantial over use of air at the blow-offs, which are used to remove loose sand from either the sand molds or the molding equipment. The assessment team suggested that Iron Foundry-1 re-evaluate the amount of air needed at the blow-offs and adjust/control the air accordingly to implement an easy cost control measure. For example, the blow-offs at one molding machine consisted of 6 to 8 nozzles that appeared to be ¼ inch in diameter. Estimating that a ¼ inch-diameter leak will cost about $1.00/hour, the cost on this line alone for six nozzles is about $6.00/operating hour or $300 per week, assuming 5 days a week, 10 hours per day. Summing this for other machines indicates a significantly large cost. There was also a sizable amount of air being used on the horizontal molding machine tail pulley.

Based on a full work year, becasue of the need to maintain pressure for 24hrs a day (i.e., 8,760 hours), and $0.05/kWh electricity cost, leaks or excessive air use costs are as follows:

Orifice (diameter)	Cost per Year
1/16 inch	$523
1/8 inch	$2,095
1/4 inch	$8,382

Cupola Modeling

The ITP Metal Casting and the Sensors and Automation programs funded a multi-year project to develop a computer model of the cupola operation to optimize this process for maximum energy efficiency. The project was carried further by S. Katz and Associates, Inc. with the help of a grant from the ITP I&I initiative. The computer model integrates charge metal process variables to predict furnace output based on given inputs. It contains improved algorithms describing SiC performance and has a user-friendly graphic interface. It can help iron foundries optimize operations and reduce energy consumption and greenhouse gas emissions.

The assessment team learned on the visit that Iron Foundry-1 had a beta version of the Cupola Model developed with funding from ITP, but never used it. The foundry had used the model owned by a cupola design/engineering firm when designing its current cupola. The assessment team recommended that Iron Foundry-1 use the Cupola Model software to analyze its cupola operations and optimize the system.

3. Conclusion

Iron Foundry-1 is a clean, well-run, and technologically current operation. The cupola production of both gray and ductile iron enables them to be a “one-stop” shop for their customers. One major problem observed by the assessment team was returning the sand to the muller operation at high temperature. Addressing this issue will reduce scrap, improve productivity, and save energy at Iron Foundry-1. The foundry also has the opportunity to achieve some energy savings with minimal investment by optimizing its compressed air system and reducing the air usage.

Other than these two issues, the facility was found to be operating efficienctly. The recuperative hot blast for the cupola operation is a significant energy saver because it offsets the use of natural gas. Traditionally, the recuperative systems in cupolas are natural gas fired, whereas this system uses the hot off-gas from the cupola as its energy source.

F. Iron Foundry-2

Plant Profile

Iron Foundry-2 is a large foundry that employs 2,000+ people. It produces gray iron castings primarily for the automotive sector; these include crank shafts and 8-cylinder, 6-cylinder, and 4-cylinder engine blocks. The facility ships approximately 300,000 tons of iron castings each year.

The facility has four steel, water-wall, unlined cupolas: two in operation and two used as back-ups. Three of these cupolas use coke as their primary energy source, while the fourth employs six plasma torches located in the tuyers. The facility is equipped with automated pouring lines and mold-making machinery. It uses green sand as the molding medium with as much reuse of the sand as possible. The facility has on site machining and finishing operations.

Iron Foundry-2 does not design or make its patterns but does repairs to them when needed and also performs some modeling to optimize the mold rigging. Its design and pattern making is performed by its corporate headquarters which uses state-of-the-art modeling and simulation software. The facility does have onsite metallurgy laboratory to ensure proper chemistry of its melt. It also inspects its castings to ensure that each meets customer requirements and specifications.

One operational aspect that stood out at this facility was its attention to detail and safety. The plant was extremely clean and well organized. Safety was tracked at each workstation. In fact, work safety is a top priority at this plant.

Onsite Assessment

The site visit followed the same format as the others with a morning session to review the implemented research results and best practices performed at the foundry. The meeting included a plant engineer, manufacturing engineer, casting development engineer, energy engineer, plant manager, and the assessment team from Eppich Technologies and BCS Incorporated. The assessment team provded plant personnel with an overview of the free tools and services offered by ITP BestPractices subprogram. The plant energy engineer was familiar with the AirMaster+ and MotorMaster tools and had received training on their use. The facility did not match the requirements for an IAC assessment because of its large physical size and revenues. Following the morning meeting, the assessment team toured the plant to see both the implemented best practices and to make recommendations as to how the facility may be able to further reduce its energy consumption.

1. Implemented Best Practices

Compressed Air

As noted in this project, many of the participating metal casters had an opportunity to reduce their energy consumption by analyzing and maximizing their compressed air systems. When touring facilities, the assessment team noted numerous leaks and misuse of compressed air, such as clearing a lunch table. However, Iron Foundry-2 already had achieved energy savings by optimizing its compressed air system and implementing a program to repair leaks.

The compressed air capacity at Iron Foundry-2 is 12,000 hp operated at 5,800 cfm. Plant personnel believe that theoretically they could operate on 9,000 hp. The plant has implemented a policy for its employees to tag any leaks for immediate repair. Also, the foundry energy manager is familiar with the AirMaster+ and had received training on the tool from a DOE qualified specialist. The energy manager has run the tool on the system at the plant and has made changes to the system when approved by foundry management. AirMaster+ enables the energy manager to build the case for foundry management to make decisions by showing the potential cost savings from a reduction in energy use.

Willingness to Experiment

Iron Foundry-2 is not risk averse. It is willing to examine technologies that will lower energy consumption, reduce costs, and improve productivity. The foundry agreed to evaluate the Cupola Model developed by S. Katz and Associates with funding from ITP and AFS. Foundry management invited S. Katz to demonstrate the model's capability on its cupolas and committed to investing in the model if it performed as advertised.

Another example of Iron Foundry-2's willingness to examine and test new technologies is its installation of a plasma-fired cupola. In an attempt to lower its energy bills and utilize loose borings as part of the charge, Iron Foundry-2 worked with its utility, the state, and Westinghouse Electric Corporation to demonstrate the use of plasma-fired cupola.

The idea behind this design was to increase the productivity of the cupola by as much as 60% by decoupling the combustion process from the total heat input to the cupola. Due to the high energy output of the plasma torches, the air blast velocity and penetration can be lower resulting in lower cost of air pollution controls and less dependency on premium coke. In fact, the technology can use smaller size anthracite coal without a negative effect on the melt rate or the composition. Since the conditions in this furnace are less reducing, the charge material can be thin and can include materials such as iron borings without oxidation loss of silicon. Iron Foundry-2 demonstrated that the technology could operate economically when melting up to 75% iron borings.[55] However, Iron Foundry-2 rarely operates this cupola and uses it primarily as a backup because it has half the melt rate as compared to the facility's other three cupolas. Nevertheless, this cupola provides the foundry with an alternative they can use when the cost of coke is too high.

The foundry management's open mindedness to experimenting with technologies to reduce energy consumption and lower operating costs gives them an advantage over their competitors. Even when projects are capital intensive, such as the plasma-fired cupola, the foundry has demonstrated that it is willing to take a risk. By taking this approach, Iron Foundry-2 has been able to remain competitive in the iron automotive castings market.

Working with the Utility

Iron Foundry-2 is a large energy user. They are on the ITP list of 5,000 top industrial energy consumers in the United States. Iron Foundry-2 has engaged its utility to examine methods by which it can reduce its energy consumption. The utility provided the facility with a full-time employee, who is paid by the utility, to identify and implement projects to reduce the foundry's energy intensity. This provides Iron Foundry-2 with an added resource that is able to focus on such projects, rather than pulling an individual from another job function to perform the energy conservation task.

Working with the utility has proven to be very useful to Iron Foundry-2. The utility representative has begun to audit the plant's energy use and has identified a number of energy-saving projects that are currently underway. The utility has demonstrated to Iron Foundry-2 that they are equally concerned with reducing energy intensity at the foundry in order to reduce the utility's total power load.

2. Areas of Improvement

Business Case Studies

Iron Foundry-2, like many other foundries, requires a maximum payback of 2.5 years when making changes to their operations. Engineering recommendations need to be backed with a detailed cost-savings analysis in order to secure purchasing department and senior-level management support. Yet it appeared to the assessment team that the engineers found performing business case analyses to be burdensome and not worth their time, resulting in shelving of many good ideas at this foundry.

The assessment team recommended that Iron Foundry-2 create a standard format for how to conduct business case analyses. The foundry should provide training to its engineering staff and department managers on how to develop a business case based on the standard format. This step would reduce the burden of having to develop a business case analysis for any engineering improvements, including energy conservation projects. Furthermore, by providing training to these individuals, they will gain insight into management's priorities.

Evaluate the Aging of Iron

Iron Foundry-2 personnel had dismissed the results of the work performed by the University of Missouri – Rolla (UMR) on the age strengthening of iron as invalid, based on their own test results that deviated from those of the UMR researchers. However, the assessment team determined that the foundry's in-house tests were based on the strength of the sample (not machinability), which flawed its analysis. The work done at UMR shows that machinability can change by as much as 15%, whereas strength only changes by approximately 10%.

The assessment team recommended that management take a sample of their production and run their own tests following the steps that UMR took. If Iron Foundry-2 can replicate these findings, the potential savings will be significant. Implementation of age strengthening has the potential to reduce machining time, increase casting yield, and reduce the weight of the castings produced. Some iron foundries have reported promising results by conducting their own tests and have implemented the process of holding iron castings for a period before they ship them. Their customers have reported an improvement in machinability; the success at these foundries warrants another look at this alternative by the Iron Foundry-2 staff.

3. Conclusion

Iron Foundry-2 was aware of the free tools and services offered by ITP. The facility has actively worked with the CMC and ITP and has sought out the results from the R&D efforts to improve its bottom line. The facility has been proactive in engaging their utility to improve their energy efficiency and lower their energy bills. The facility does not perform any modeling on site, and relies on its parent company's development laboratory to model all of the castings.

There were a few areas of improvement that the assessment team noted, the most critical being training their engineering staff on how to develop a business case or cost analysis for a given energy efficiency project. In addition, the facility staff was skeptical regarding the UMR results on aging of iron; the facility could potentially benefit from examining those research results and running its own trials.

G. Lost Foam Foundry-1

Plant Profile

Lost Foam Foundry-1 is a mid-sized facility, employing 100+ people and operating two shifts per day. It produces aluminum engine blocks and heads for 4-cylinder and 6-cylinder engines and ships approximately 12,000 tons of aluminum each year.

The facility was constructed in 2000, began producing in 2002, and was in full production by 2003. It is very spacious, clean, well-laid out, and highly automated. The foundry consists of four cells or operating lines. It has three reverberatory, natural gas-fired, dry hearth furnaces, two of which are in operation and the third remains stagnant because it is used as a back-up furnace. The foundry melts its aluminum on site and delivers the molten alloy to each cell via a launder system.

The foam patterns are constructed and steamed on site. They are dipped into a ceramic slurry using a robotic arm and then hung to dry. The dried patterns are transferred to a box by a robotic arm and placed on an engineered vibratory table which packs sand tightly around them. Following sand packing, the pattern moves down a line to a pouring station where an automated system pours molten metal into the down-sprue and a gating and riser system.

After pouring, the casting continues down the line where it is shaken out and a robotic arm removes the single gate and riser. The sand is reclaimed from the shakeout system; approximately 10% of it is disposed per year. The removed gates and risers fall into a collection basket where they go back into the furnace to be re-melted. Once the casting has cooled, it is inspected for quality. Because of the near net shape that lost foam provides, minimal machining is required.

A year prior to this project, Lost Foam Facility-1 averaged an 8% internal scrap rate on the heads and blocks it produced. This has since dropped to approximately 5%. Customer return at this facility is 0.35%. Quality of the castings is highly monitored, and the facility can trace each casting back to the time it was poured and to the batch in which it originated.

Onsite Assessment

The assessment of this facility followed the same format as the others, with a face-to-face meeting in the morning followed by a tour of the facility. During the morning meeting, the plant provided an overview of the Metal Casting R&D project results that it had implemented and the benefits experienced from these projects. The assessment team provided plant personnel with an overview of the suite of BestPractices tools and the services offered by the IACs. Plant management was familiar with the AirMaster+ and MotorMaster+, but had no familiarity with the IACs.

1. Implemented Best Practices

Active in the Lost Foam Consortium

ITP's Metal Casting portfolio has supported the Lost Foam Consortium (comprising of casting producers, foundry suppliers, and the American Foundry Society (AFS)), which was formed to develop a better understanding of the lost foam process. This cost-effective R&D partnership has been a catalyst for advancing the lost foam casting process. Consortium research is performed at the Lost Foam Technology Center at the University of Alabama – Birmingham, where R&D work has focused on developing advanced process controls, as well as a coating system to improve foam-related defects.

Lost Foam Foundry-1 is a participant in the Consortium and has benefited greatly from its research. Specifically, Lost Foam Foundry-1 and its parent company have gained a better understanding of the foam properties and the coating systems employed in the process. 80-75% of all the scrap produced at Lost Foam Foundry-1 occurred due to the foam. The research performed by the Lost Foam Consortium helped the foundry gain a critical understanding of and control over foam properties. This has systematically reduced casting defects from foam problems.

The coating technology work by the Lost Foam Consortium, particularly the high liquid expandable polystyrene (LEPS) saturation rate and high LEPS saturation capacity, led to a 6.5% reduction in scrap at the foundry for the inline 4-cylinder block castings. The scrap was caused by gas-porosity-related defects. Lost Foam Foundry-1 produces 2,100 block and head castings a day and operates 220 days per year. This amounts to a total of 462,000 aluminum lost foam engine blocks and heads per year. Thus, the annual 6.5% reduction in scrap represents a savings of 30,030 block castings a year for the facility (6.5% x 462,000 = 30,030).

Lost Foam Foundry-1 engineers demonstrated the impact of this scrap reduction by calculating the effected energy savings. The facility uses 83,747,280 kWh of electricity and 1,158,670 million cubic feet (mcf) of natural gas per year to produce lost foam block and head castings. This translates to 2.86×10^{11} Btu of electricity (1 kWh = 3412 Btu) and 1.16×10^{12} Btu of natural gas (1 mcf = 1,000,000 Btu). This yields consumption of 618,497 Btu of electricity ($2.86 \times 10^{11} \div 462{,}000$) and 2,507,944 Btu of natural gas per casting, totaling 3,126,441 Btu per casting.

Calculating energy savings from scrap reduction, the total amount of annual scrap was multiplied by the Btu/year consumption for a block and head casting ($30{,}030 \times 3{,}126{,}441 = 9.38 \times 10^{10}$ Btu/year). This amount was multiplied by 2/3 to correct for the metal differentials between a block casting and a head casting, ***yielding an annual savings of 6.26 x*** $\boldsymbol{10^{10}}$ ***Btu for the 6.5% reduction in block casting scrap***.

Another example of some of the benefits Lost Foam Foundry-1 described was the energy savings it realized by incorporating the work done by the Consortium on Expandable Polystyrene (EPS) beads, which lowers viscosity of the liquid EPS decomposition product. The incorporation of this work yielded a 0.85% reduction in scrap due to porosity and leak (folds) defects for the in-line 6-cylinder blocks it produces. Savings from this scrap reduction were calculated as follows:

Number of block castings produced per day = 1,750
Number of block castings produced/year = 1,750 blocks/day x 220 days/year
= 385,000 block castings/year

Scrap quantity reduced per year for 0.85% scrap reduction = 385,000 x 0.0085
= 3,272 block castings

	Energy Consumption[56] **(*Btu per pound of aluminum*)**
Electricity	3,810
Natural gas	6,354
Steam	1,343
Compressed Air	1,224
Delivered Molten Aluminum	3,100
Total energy consumed	**15,831 Btu/lb of aluminum**

Energy savings/yr from 0.85% reduction in scrap = 3,272 block castings x 130 lbs/casting x 15,831 Btu/lb = 6.73 x 10^9 Btu

Therefore, total yearly energy savings from 0.85% scrap reduction in block casting production is 6.73 x 10^9 Btu.

As demonstrated by these two calculations, the results of research performed at the Lost Foam Research Center at the University of Alabama – Birmingham are significant. Participating in the research has enabled the facility to incorporate cutting-edge developments directly into its operations. Lost Foam Foundry-1, therefore, has benefited substantially from this Metal Casting R&D, as shown by its energy-savings calculations, and this benefit will only improve with rising prices for natural gas and electricity.

Source of a Workforce

By participating in Metal Casting R&D efforts, such as the Lost Foam Consortium, Lost Foam Foundry-1 not only has benefited in terms of energy and financial savings but also in that it has gained a young, qualified workforce. Over the years, both the facility and its parent company had trouble in attracting young graduates to work in the foundry. However, the foundry manager and R&D director explained that more recently they hired a number of engineering students (both in undergraduate and advanced degree programs) who have participated in the ITP Metal Casting-funded research. This facility's management views the student participation in research efforts as a critical component in encouraging the students to join the metal casting industry. They believe that the involvement of students in these R&D projects provides the foundation for a well-trained and highly educated engineering work force for foundries.

Mitigating R&D Risk

One reason Lost Foam Foundry-1 has been an active participant in Metal Casting R&D is because it views program efforts as a means of mitigating its own R&D risks. Foundry management finds some of the projects funded by Metal Casting R&D as risky for investment and is hesitant to undertake such projects because they require a return on their R&D investment in 2.5 years or less. Lost Foam Foundry-1, therefore, finds value in taking the results of a number of the projects funded by Metal Casting R&D and using them as a foundation for its own research.

As one example of this strategy, Lost Foam Foundry-1 and its parent company worked with Arena-Flow to upgrade the computational fluid dynamic (CFD) tools for blowing and steaming EPS patterns. Industry experts estimate that poor patterns and coatings account for over 65% of all defects in the lost foam process that subsequently result in scrap castings. The EPS beads must flow through geometrically complex passages to fill a mold with a uniform packing density. The process of blowing beads is further complicated because of bead expansion caused by the residual heat in the mold. Arena-Flow developed a mathematical tool that allows the user to take an analytical approach to systematically designing EPS patterns. The tool extended an existing gas-particulate model to simulate air-driven bead blowing and use of pre-expanded beads for the mold, and the steaming of the beads to form the pattern. Because of this research, Arena-Flow released the initial bead blowing module in December 2001 and its second version in October 2002. The first release of the bead expansion module became available in December 2002.

Lost Foam Foundry-1 purchased the Arena-Flow software package to address manufacturing design issues as well as resolve bottlenecks. After many trials with the modules, the foundry found them to be only 20-30% accurate and, thus, used it only for troubleshooting casting problems. Nevertheless, the foundry found that the modules held promise. They began to work with Arena-Flow to expand the code and allowed Arena-Flow to gather data from their plant. Although the initial modules were not as accurate as plant management would have liked, the research demonstrated that the computational process worked and that the code could be expanded. If it were not for the investment made by Metal Casting R&D, private companies such as Lost Foam Foundry-1 could not spend the resources to develop the initial modules. ITP mitigated this risk and fostered further development by both Lost Foam Foundry-1 and Arena-Flow.

2. Areas of Improvement

Lost Foam Foundry-1 is a very modern facility. The plant is highly automated and is equipped with some cutting-edge technologies. The facility had a program in place to address obvious energy wastes such as compressed air leaks and energy-efficient lighting. The assessment team could only identify two areas for improvement at the plant: use of a stack melter and adding pressure to its castings.

Stack Melter

Like many plants melting aluminum alloys onsite that participated in the analysis, Lost Foam Foundry-1 uses natural-gas-fired reverberatory furnaces for its melting operations. As noted in the analysis of Die Casting Facility-1 (page 36), these furnaces have an efficiency that ranges from 20 to 25% because of high energy losses that occur through the flue gases. Additionally, the melt losses in reverberatory furnaces tend to be between 3 to 5% in aluminum.[57]

Since stack melters preheat the incoming charge with flue gas, they have a relatively high efficiency of 40 to 50%. Replacing the three reverberatory furnaces with stack melters will improve the facility's melting efficiency and reduce its natural gas use. Although this is a capital-intensive recommendation, in light of the rising price of natural gas the increased efficiency should make the economics of such replacement feasible. The assessment team recommended the plant to conduct a detailed cost/benefit study.

Casting Pressure

Personnel at this facility indicated that the lost foam casting process is limited by its inability to produce engine castings with the higher fatigue strength needed for the next generation of high horsepower/pound of lightweight engines. However, other research developments and modifications to the lost foam process have proven otherwise (see Aluminum Casting Facility-1 case study on page 75).

The team recommended that Lost Foam Facility-1 investigate the benefits of adding pressure to its casting process during the pouring phase. Adding pressure not only can reduce porosity defects but also increase the tensile strength of the castings. This can help the foundry in developing new, stronger aluminum engine blocks and heads capable of higher horsepower output.

3. Conclusion

ITP-sponsored research has contributed to the engineering success of the lost foam process and has encouraged students to enter the metal casting industry. Lost Foam Foundry-1 has utilized a number of the research results from the Lost Foam Consortium at the University of Alabama – Birmingham. Foundry management found the results of this work to benefit its manufacturing process and to help mitigate its risks. Participation in ITP-sponsored research has enabled Lost Foam Foundry-1 to lower its energy bills. The only major additional energy-saving opportunity identified by the assessment team at this facility was the replacement of reverberatory furnaces with more efficient stack melters (which was a common recommendation in this project for all aluminum facilities).

H. Lost Foam Facility-2

Plant Profile

Lost Foam Facility-2 is a new facility that produces A356 and A319 aluminum components for a variety of markets including automotive, marine, power generation, and original equipment manufacturers. The company has developed expertise in producing complex-geometry castings for niche markets such as snowmobiles and lawn mowers. The facility has been able to penetrate these markets by offering low-cost lost foam casting designs for parts that would traditionally be produced by machining or die casting.

The facility produces 2-3 million pounds of aluminum castings a year. The scrap rate at the facility is 1-2%, primarily due to defects in the foam pattern (e.g., dents). The shop operates one 8-hour shift per day for its pouring operation, and runs the pattern shop 24 hours per day, 4-5 days per week to keep up with the demand.

The facility fabricates its patterns on site using new bead blowing and mold-making machinery. The pattern process begins at the facility with the pre-expansion of polystyrene beads to a controlled density, following which the beads stabilize and reach a particular pentane level. Next, the beads are blown into an aluminum mold to create a foam pattern. The blown beads are then heated and steamed in order for them to expand and fuse together. Finally, the mold is cooled to stabilize the expanded beads that make up the pattern. The pattern is hung and subjected to a controlled atmosphere for up to six hours to shrink it to a stable controlled size. The pattern segments are glued together using a special adhesive, and multiple patterns are assembled into a tree or cluster.

The constructed patterns are dipped into refractory slurry to ensure a uniform evaporation of the pattern during the casting process and to prevent penetration of the foam by the molten aluminum. Once dipped, the patterns are dried in an oven. Dried patterns are placed into a flask and packed with mullite sand with the aid of vibration. The flask is then moved onto the automatic pouring line, where molten aluminum is poured directly into the foam cluster displacing the evaporated foam. Once cooled, the casting is shaken out, inspected, cleaned and finished.

Lost Foam Facility-2 performs all of its melting in two natural gas dry-hearth reverberatory furnaces. The facility purchases its alloys as large billets or “sows” rather than the typical ingot, and melts these onsite. The facility has two air compressors one 75-hp and the other 100-hp, both of which operate at 123 psi. The facility does reclaim its mullite sand, of which 10% is run through a fluidized bed. The footprint of the facility has extra capacity to accommodate future growth.

Onsite Assessment

The format of the one-day site visit was similar to the others, with a face-to-face meeting in the morning followed by a tour of the facility. The facility manager was familiar with the MotorMaster BestPractices tool; however, he was unfamiliar with the AirMaster+ and PHAST tools. Like many of the other facilities that participated in this project, Lost Foam Facility-2 was unaware of available IAC services. Since the facility was new, it had installed cutting-edge lost foam equipment and incorporated the results of Metal Casting R&D into its operation.

1. Implemented Best Practices

Starting with the Best

Lost Foam Facility-2 is a greenfield facility that only produces lost foam castings. During the development of the facility, its managers implemented many of the technologies and practices developed by ITP-funded research. The facility already had the newest technologies on its manufacturing line, making it difficult for the facility and the assessment team to evaluate the extent of implemented R&D's impact on the overall operation.

For example, Lost Foam-1 facility has only used mullite sand in its operation because of its low coefficient of thermal expansion, a quality that helps produce a better dimensional cast product with less thermal degradation than does silica sand. The University of Alabama – Birmingham and the Lost Foam Consortium has demonstrated the relative benefits of mullite. Learning about these developments prior to opening its door, this facility incorporated mullite into its operations from the outset. Likewise, the foundry incorporated the UAB coating tests into its operations. These practices and technologies control the facility's scrap rate at a mere 1-2% a year, whereas the industry average is 5%.

Furthermore, when constructing the facility its management considered which essential technologies would be needed to have a successful lost foam operation. The facility's single largest investment involved installing automated casting lines. Facility management viewed this technology as being critical to the success because it increased the facility's throughput. The facility also installed a state-of-the-art multiple pattern-making machine that enabled them to produce their own patterns. The company viewed this as a way to reduce its lead-time and implement a just-in-time manufacturing approach to its production. It also gave the company the ability to work more closely with its customers on the design of the casting.[58]

The facility managers have also used the Lost Foam Consortium as a source of knowledge on the advancements in lost foam process, and have even invited the University of Alabama scientists to perform research on site. According to the foundry managers, this has been a good way for them to offset the fact that they do not have an in-house R&D staff. Furthermore, the foundry finds it useful to learn from large lost foam producers such as GM.

With the benefit of starting with a greenfield operation, Lost Foam Facility-2 was able to develop a state-of-the-art lost foam facility. The scrap rate at this facility is well below the industry average, which allowed Lost Foam Facility-2 to develop a niche market by being a jobbing facility that can compete effectively for business to produce parts that otherwise would be produced via machining or die casting processes.

2. Areas for Improvement

Even though it is a state-of-the-art facility, the assessment team still identified areas for improvement at Lost Foam Facility-2 that management could pursue to achieve some energy and financial savings.

Ingot Size

Lost Foam Facility-2 purchases its alloys from a smelter. During the visit, the assessment team noted that the facility purchases pallets of large billets of aluminum alloys rather than the smaller ingots. These large billets are approximately the size of three normal size ingots. The facility purchases these larger sows because it saves them $0.05 per pound of aluminum as compared to the smaller ingots, which translates to a $50,000-savings for every 1 million pounds of the alloy purchased. However, the assessment team noted that these savings are eroded significantly by the extra energy purchased to melt the larger mass, due to heat transfer restrictions as compared to the typically much smaller ingot. A detailed study is required on the amount of energy consumed in the dry-hearth reverberatory furnaces at the facility when melting these two shapes and sizes. To conduct this study, the facility will need to work with its natural gas utility and install a gas meter on the furnace to obtain an accurate determination of the gas consumed when melting the various shapes. Once the natural gas consumed for the various shapes is known, the facility can compare those costs to the cost saved from purchasing the sows and make an educated decision as to how to proceed in the future.

Compressed Air System

The 75-hp air compressor at this facility is isolated from the 100-hp compressor and operates without a refrigerated drier. The entire system lacks an air receiver system. The assessment team recommended that the facility reevaluate the operation of this system.

The assessment team suggested that the facility conduct a detailed study to determine its actual compressed air needs. The current system is operating at an unusually high pressure and if that high pressure can be reduced, the facility can save 1% of the energy cost for each 3 psi reduction in air pressure. The facility should also consider installing a refrigerated drier for the system. In general, a compressed air dryer will pay for itself by reducing downtime from water-induced failures in various valves, thus increasing production and improving the facility's bottom line. This is because water buildup in the lines can be damaging to both the machinery and the castings. Standard air procedures suggest that air should be dried to a dew point of 10ºC (18ºF) below the lowest ambient temperature that it will encounter.[59] Finally, the facility should consider installing an air receiver in the system. An air receiver will minimize compressor cycling by providing a constant air pressure to the facility. However, the receivers must be properly sized and placed in order to gain these benefits.

The assessment team recommended that the facility utilize the AirMaster+ software to assist in this analysis. This software tool will help to identify the cost of air leaks, improve end-use efficiency, reduce system pressure, reduce run time, use unloading controls, adjust cascading points, use automatic sequencers, and add primary receiver volume. The proper use of this tool will require that the facility have an employee receive training (at a nominal cost) and expend time to evaluate the system. These costs have proven to be nominal for other facilities when compared to the potential savings they offer.

Lighting

The lighting within this facility needs to be re-evaluated. During the site visit, the assessment team noted unnecessary illumination. For example, there were six overhead lights on in an unoccupied bead storage room, two overhead lights on in an unoccupied cooling water room, and three overhead lights on in an unoccupied boiler room. Keeping these rooms illuminated wastes electricity and raises energy costs for the facility. The assessment team recommended that this facility install occupancy sensors in these rooms. This will allow the light to turn on only when someone is present in those rooms. The assessment team estimated the cost of installing these sensors to be $1,700 and the payback on this investment to be less than two years.

Install Cogged Belts

One of the leading recommendations by the IACs is to install energy-efficient cogged belts on motor systems. This recommendation has the average implementation cost of $1,263 with an annual pay back of $2,169. Cogged belts are more efficient because they slip less than smooth belts. They can save 3-5% of the energy normally used to operate a motor and have a longer life because they run cooler. Based on the savings they can offer, the assessment team recommended that Lost Foam Facility-2 replace the belts on the fan drives in the bead storage room with cogged belts.

Stack Melters

Like many of the other aluminum facilities that participated in this project, Lost Foam Facility-2 should consider replacing its reverberatory furnaces with a stack melter. With the increasing price of natural gas and the low efficiency achieved in using a reverberatory furnace, the economics of this replacement may make sense.

3. Conclusion

Being a new plant, Lost Foam Facility-2 already has incorporated a number of the Metal Casting R&D results into its initial design and practice. Plant management sought the advice of the Lost Foam Consortium when designing the facility and purchasing its equipment. However, the facility could benefit further from analyzing additional energy-saving opportunities involving compressed air, process heat, and motor systems using the ITP suite of BestPractices tools. Furthermore, the facility could fine-tune its process with the assistance from an IAC assessment.

I. Aluminum Casting Facility-1

Plant Profile

Aluminum Casting Facility-1 produces castings for a variety of products including engine products, exercise equipment, and power tools. It produces 40 million pounds of aluminum castings per year and employs a variety of casting processes including die, permanent mold, sand, lost foam, and pressurized lost foam. Due to the size of this facility, the analysis focused on the pressurized lost foam operation. However, senior management did provide the assessment team with an example of a benefit they experienced by incorporating the results from a Metal Casting R&D project into its die casting operation.

The 20,000 square feet pressurized lost foam facility is highly automated. The steps in the operation process are similar to traditional lost foam, although there are a few additional steps. The process begins with fabricating patterns from polystyrene beads. The patterns are then coated with a carefully controlled refractory material by dipping them into a slurry. Once the coating has dried, the patterns are placed into a drum-like flask and packed in molding medium via a programmed vibratory system which fills the space between the pattern and the flask walls. A robotic arm then picks up the flask and places it into one of the pressure vessels. Once inside the pressure vessel, another robotic arm pours the aluminum into the vessel, and the polystyrene pattern begins to vaporize. The molten metal is delivered to the lost foam pressure line using a launder system and is held in a natural gas-fired reverberatory furnace. Once pouring is complete, the lid of the vessel is closed and 150 psi of pressure is applied for 15 minutes as the casting solidifies. A robotic arm removes the solidified casting from the vessel and quenches it in water. The casting then automatically moves to the cleaning and finishing room.[60]

Aluminum Casting Facility-1 has a staff dedicated to identifying opportunities for energy savings, and implementing projects to achieve these energy savings. The annual energy bill for the entire plant is approximately $10 million per year mostly attributable to the need to melt, hold, and distribute molten metal.[61] The plant has an active program in place to identify compressed air leaks and identify any other wasteful practices, and has installed high-efficiency lighting and motors. The furnaces and the launder system were properly insulated and covered.

Onsite Assessment

The format of the site visit followed the same as the others. The facility was aware of the services offered by IAC that are part of the ITP BestPractices subprogram. However, due to its large size, it does not qualify for IAC's services. As the assessment team found at other plants, the management at Aluminum Casting Facility-1 was unaware of the free suite of BestPractices software tools. They also were unaware of the Save Energy Now efforts. Learning about their benefits, Aluminum Casting Facility-1 decided to apply for an Energy Savings Assessment (ESA) of both its die casting and lost foam facilities. They were awarded however at the time of drafting this report the assessment results were not yet available.

1. Implemented R&D and Best Practices

Aluminum Casting Facility-1 has been active in the Metal Casting R&D program to make advances in lost foam, Semi-Solid Metals (SSM) and melting operations. The following provides an overview of the foundry's involvement in these efforts and the benefits it received from them.

Lost Foam with Pressure

As mentioned above, Aluminum Casting Facility-1 applies pressure during the solidification phase of its lost foam operations to eliminate both pressure feeding of the castings and hydrogen porosity, thereby reducing the scrap rate. A decrease in the porosity level by an order of magnitude increases the high-cycle fatigue strength by 50%. For example, when one compares traditional sand casting to permanent mold casting, the former has a porosity level of 1% and high-cycle fatigue strength of approximately 8 ksi, while the typical permanent mold casting has a porosity level of about 0.1% and high-cycle fatigue strength of 12 ksi. With copper-free aluminum-silicon (Al-Si) alloys like A356, lost foam with pressure can lower the porosity level to below 0.01% and obtain a high-cycle fatigue strength of 16 ksi.

This casting process allows Aluminum Casting Facility-1 to produce components that have complex geometry with intricate features that are not easily manufactured using other fabrication methods (e.g., die casting). Prior to the implementation of the pressurized lost foam process, the facility used eight separate die castings to produce one part. Now, with the pressurized lost foam process implemented, Aluminum Casting Facility-1 can produce the part with a single casting which is lighter and less expensive and requires fewer machining operations. When compared to traditional lost foam, the advantages of pressurized lost foam are as follows:

- Lower porosity
- Increased fatigue strength
- Casting life extension
- Casting quality improvement

The low porosity levels achievable by pressurized lost foam and the associated higher cycle fatigue life enabled Aluminum Casting Facility-1 to develop a new product line: aluminum 275-hp, 2.6-liter, 4-stroke super-charged engine blocks.

Aluminum Casting Facility-1 attributes a large part of its success with pressurized lost foam to the work performed by the University of Alabama – Birmingham (UAB) and the Lost Foam Consortium. Due to the work at UAB, the facility can now measure the permeability of its foam patterns. They have also made advancements in the coatings they use, helping the facility to reduce the level of scrap attributed to defects in the foam patterns. Lastly, the UAB work has also provided facility management with a better understanding of the impact that metal cleanliness can have on the final casting, which has resulted in a reduction in the number of casting defects.

The UAB Lost Foam Consortium has played a critical role in advancing the modeling capability of the pressurized lost foam process. Aluminum Casting Facility-1 worked with UAB and Flow-Science to modify the code of the Flow Science 3-D Model so that they could predict the location of shrinkage that had been an on-going and significant problem at the plant. Because of this successful working relationship, Aluminum Casting Facility-1 can now predict the location of shrinkage and has begun validating the model with other castings.

The suppression of hydrogen porosity has led to a shrinkage value that is a full percentage higher than of alloys that solidify at less than one atmosphere of pressure. For example, if the normal shrinkage of an alloy is expected to be 6%, when solidification occurs under 10 atmospheres of pressure, 7% shrinkage is expected. Because of this, the higher shrinkage value and the critical feeding distance for the alloy are major considerations when designing the casting for pressurized lost foam casting. This process may require that the gates stay open longer, which may only necessitate enlarging the gate or may require a major design change to the interior of the casting.

According to Aluminum Casting Facility-1, the feeding failure could result in interior porosity in several ways. First, hydrostatic tensile failure in the interior of the casting can occur because of unclean metal that contains oxides or inclusions. Another defect may be surface-connected porosity due to a puncture of the skin, which can result from low silicon content in the alloy. Another cause may be a distortion of the shell or casting wall due to high hydrostatic tension If 10 atmospheres of isostatic pressure is applied during solidification to lower the hydrostatic tension in the solidifying liquid, none of these failures are likely. This is because pressurized lost foam lowers the hydrostatic tension in the solidifying liquid and thus can avoid exceeding the critical hydrostatic tension value.

Application of modeling tools is necessary to fully capitalize on pressurized lost foam casting. According to personnel at Aluminum Casting Facility-1, it is extremely important that the "filling" event be modeled to define the "cooling curve" at various critical locations throughout the casting and identify and eliminate potential hot spots. In that regard, Aluminum Casting Facility-1 worked with UAB and Flow Science to validate Flow 3D Model.

Aluminum Casting Facility-1 had a 60-pound aluminum casting of a 3.0L V-6 lost foam block that had a high level of porosity between the cylinder bores that caused over 50% of the blocks produced to leak. Several people attempted to model this casting in order to predict the porosity failure, yet none were successful. Aluminum Casting Facility-1 worked with UAB and Flow Science to validate Flow 3D on the 3.0L block to predict the location of shrinkage and convince the casting community and the facility's engineering department that modeling in lost foam had a future. In this investigation, the assessment team determined that the A356 parameters in the program were grossly wrong and needed revision. After that revision, the model accurately predicted the location of the shrinkage and porosity. This was a major accomplishment for Aluminum Casting Facility-1 because had been attempting such prediction for over five years.

Because of this accomplishment, the engineering department at Aluminum Casting Facility-1 has taken over the responsibility for modeling castings for design correctness and for proper gating system using the Flow 3D model. For heads gated into the face of the engine head, modeling indicates that 22 gates freeze off early and solidification is uncontrolled from the bottom up. However, for the engine heads gated into the six spark plug holder, the gates stay open and solidification is horizontally controlled from the face back to the sprue. In the case of the 3.0 L

V-6 blocks, the gating system was changed from a bottom pouring to a top pouring arrangement. This reduced leaks by about nine times from the previous level. Aluminum Casting Facility-1 attributes this success to the efforts of the Lost Foam Consortium, Flow Simulations, and UAB, which were cost shared by ITP.

Semi-Solid Metalcasting

Aluminum Casting Facility-1 also has a large high-pressure die casting (HPDC) process that has benefited from the research on semi-solid metalcasting (SSM) performed by the Worcester Polytechnic Institute (WPI) with funding from ITP. For this facility, the time required to make a casting, or “cycle time,” is the cost driver in its high-pressure die casting operation. As noted by this facility, the cycle time is a function of part size and weight. For example, for large parts, water channels are incorporated into the die steel to facilitate faster cooling and shorter cycle times. Very large parts, however, require a higher cycle time to allow the heat of fusion to be released, even with water cooling channels in the die. According to Aluminum Casting Facility-1, the SSM casting process developed by WPI is a deviation from the popular HPDC process and can reduce cycle time.

The SSM casting process takes advantage of the thixotropic behavior of semi-solid aluminum alloy. This means that the metal can be handled like a solid when at rest, but flows like a liquid similar to toothpaste or gelatin when force is applied. The billets can be transferred easily to the shot sleeve of a die-casting machine with a robotic arm. The plunger of the die-casting machine can then impose a high rate of shear that will cause the semi-solid alloy to flow like a liquid, filling the mold smoothly without entrapping gas. In the HPDC process, molten metal sprays into the die, which can lead to entrapped gases and high porosity levels in the casting. Because of the semi-solid state of the aluminum in the SSM process and the lower temperatures it employs in the casting, shrinkage is minimized and less energy is consumed in heating the billets as compared to heating the metal to a liquid state.[62]

Developed in the 1970s at MIT and termed rheocasting, the SSM process did not immediately catch on because heating the specialized billets put a size constraint on the billet to avoid sagging. This meant that the cast part could not be much larger than one pound. At this small size, cycle time reductions were difficult to achieve and casting costs were significantly greater than for HPDC. Although SSM offered superior mechanical properties, that benefit was not great enough to compensate for the size constraint.

According to Aluminum Casting Facility-1, this changed when new processes were developed to form billets that were not restricted by size or weight limitations. These new methods formed the 50% solid and 50% liquid SSM billet on cooling rather than the traditional 18-stage induction heating process. The new processes developed billets through magnetic stirring, insertion of cold fingers, grain refinement, mixing of liquids, or other means, all of which produced copious amounts of nucleation just below the liquid state, which is referred to as a “slurry on demand” (SOD) processes.

Aluminum Casting Facility-1 began to work with WPI to gain insight into the SSM process and to explore the possibilities of implementing it in its production. The first element the facility put into production resulted from the modeling efforts carried out by WPI as part of their work with Metal Casting R&D. Furthermore, with the knowledge gained from WPI on SSM, Aluminum Casting Facility-1 purchased an AEMP SOD technology from GMAC and currently manufactures a swivel bracket using the process. Another benefit this facility received from participating in the WPI efforts was that its development engineer for SSM activities was a WPI graduate with training in SSM technologies. In the words of a senior research director at this facility, “Thus, it is easy to say that if we had not been introduced to the SSM process at WPI, and further, if we had not been extensively helped by modeling and fundamental research done at WPI, and if WPI did not train our key SSM development engineer, this facility would not be in SOD SSM die casting process, and our future in the die casting industry would not be as promising. WPI is the Bell Labs of the casting industry!”

Additionally, the research partnership between WPI and Aluminum Casting Facility-1 has enabled the facility to form a 35-pound slurry of 50% solid-50% liquid in 17 seconds. This slurry can be transferred to the shot chamber of a HPDC machine to produce a 50-hp block. This block can be manufactured with a 35% decrease in cycle time using SOD SSM process as compared to the HPDC process, the manufacturing process used for the preceding five years. The SOD SSM die casting process can also make the 35-pound block at lower manufacturing costs when compared to the HPDC process that uses 100% liquid alloy. In the new process, less heat needs to be removed, which translates into shorter cycle time and lower manufacturing costs, according to the facility management.

Due to the experience this facility has had with the SOD SSM die casting process, its management views this development as providing a clear competitive advantage. According to the plant management, U.S. die casters will have to use SOD in their die casting machines to remain competitive in the world market. With the increase in productivity and the energy savings achieved because of reduced energy requirements, SOD SSM die casting has proven to save this facility money. Using this process has increased die life by five times as compared to the traditional HPDC process due to the lower heat value of the billet. Aluminum Casting Facility-1 attributes much of this success to working with WPI in support of their efforts with CMC and ITP.

Melting

Aluminum Casting Facility-1 recently benefited from participating in a research program, *Improvements in Efficiency of Melting for Die Casting*, performed by a team from Case Western Reserve University with funding from the ITP Metal Casting portfolio. This research program examined multiple aspects of aluminum melting and handling to see how the energy efficiency of these operations increased while simultaneously improving the quality of the molten metal. As part of this effort, Aluminum Casting Facility-1 allowed the team from Case Western Reserve University to come into its plant and examine their melting and molten metal handling operations. During their site visit, the research team conducted energy efficiency surveys of the melting, holding, and molten metal handling equipment used in the die casting operation. The team also trained the plant personnel in how to monitor energy use and identify potential improvements.

During their site visit, the team from Case Western took metal samples and measurements from various points in the melting operation to check metal quality. They determined that the die casting dip wells had four times the amount of oxides than that was present at the induction furnace. The large amount of oxides in the metal can lead to porosity formation in the casting, which is a significant cause of scrap. To increase total productivity, these oxides need to be eliminated prior to the metal entering the die cavity.

Initially the facility's management thought that Case Western's findings were a mistake or a misreading. The facility enlisted a second opinion from GKS Engineering. However, the results from GKS were identical to Case Western's research findings. GKS recommended that Aluminum Casting Facility-1 install a degassing head, which they did. Once the degassing head was installed, the oxides were virtually eliminated. Participation in university research has proven critical to this facility's success and has yielded a reduction in scrap rate due to oxides entrapped in their aluminum castings.

Participated in Save Energy Now (SEN) Effort

As part of this effort, Aluminum Casting Facility-1 was provided background information on the free tools and services offered by the ITP BestPractices program, including the Save Energy Now solicitation that encourages large energy-using plants to apply for an Energy Saving Assessment (ESA). Because of this, Aluminum Casting Facility-1 decided to apply and was selected to be a recipient of ESA. A team of ESA experts visited their plant for several days and audited their energy use. The ESA experts were all BestPractices-qualified specialists who are skilled at using the BestPractices assessment and analysis software tools (PHAST, AirMaster+, MotorMaster, etc.). The purpose of their assessment at Aluminum Casting Facility-1 was to identify immediate opportunities to save energy and money, primarily by focusing on the process heating systems (melting, holding, molten metal handling) and steam use (for fabricating the EPS patterns). These processes were responsible for over half of the plant's energy use. The facility realized that savings achieved in these systems could dramatically reduce their annual $10 million energy bill. Aluminum Casting Facility-1 realized that fine-tuning these systems may cost little but offers the potential to yield large savings. Facility management also believed that quick successes with optimizing these systems could lead to significant long-term savings for their facility. The results of this assessment were not available at the time of writing this report. To learn more about ESA results, please visit the Save Energy Now results site at: http://www.eere.energy.gov/industry/saveenergynow/partners/results.cfm.

2. Conclusion

The assessment team found the operating practices at Aluminum Casting Facility-1 to be among the best in all the plants evaluated. The facility and its management have participated and benefited from the research from the CMC and ITP Metal Casting portfolio. These efforts have proven valuable to the facility's success in lost foam and die casting. The efforts at UAB for measuring pattern permeability and pattern coatings have significantly benefited facility's pressurized lost foam production plant. Through their cost share efforts working with UAB and Flow Science, this facility was able to work out the bugs with the Flow 3D model and make it more useful for correcting design flaws before they cause manufacturing and quality problems.

Working with WPI proved critical to this plant in maintaining its competitiveness in the die casting market by increasing productivity while simultaneously reducing energy consumption. The facility's participation in the Case Western's efforts identified the cause for increased oxidization in the molten metal, which was a major source for increased porosity in some of their die castings. Identifying this issue and taking proper corrective measures has decreased the level of scrap this facility produces.

Not only has the participation and incorporation of the Metal Casting R&D results improved Aluminum Casting Facility-1's productivity and reduced its energy consumption, it has also been a source of needed knowledge. In fact, this facility has relied on the UAB Lost Foam Consortium and WPI to act much like its own R&D resource. The facility has donated equipment and provided financial support to cost share Metal Casting R&D. Aluminum Casting Facility-1 has benefited from this by being a recipient of unbiased research. The facility also views its participation as an incentive that will attract young engineers.

Finally, Aluminum Casting Facility-1 is a best-practice facility because it proactively seeks ways to improve its energy efficiency. The plant has an energy management team that is responsible for identifying potential areas for improvement and designing projects to implement those improvements. This team also seeks the advice of outside experts that may be able to identify potential areas for improvement that the team may have overlooked. This was the case when the facility applied to have an ESA performed through the Save Energy Now initiative. In combination, these efforts have led to the success and growth experienced by Aluminum Casting Facility-1.

J. Aluminum Casting Facility-2

Plant Profile

Aluminum Casting Facility-2 is a 200,000 square foot family-owned foundry with a work force of 270 employees; it uses a wide range of aluminum alloys to produce a variety of castings, such as aircraft cylinder heads, boating parts, military equipment, and specialty car parts. The foundry utilizes a variety of casting methods wherein 50% of their production uses green sand, 30% permanent mold, and 20% die casting. Although the two major alloys used for production are A535 and A206, the foundry pours 30 different alloys. Due to the diverse nature of the alloys poured at the facility, it does not use a large central melter but instead employs 42 natural-gas-fired crucible furnaces to do its melting. The facility has a full range of heat treating furnaces, quench tanks, and aging ovens. The castings produced at this facility range from ½ pound to 2,000 pounds. The annual aluminum casting shipments from this facility amounts to 4.5 million pounds.

Aluminum Casting Facility-2 takes pride in its emphasis on quality. Foundry management is always striving to improve quality and productivity within their manufacturing system. To enhance its competitive position, the foundry focuses its efforts on prevention rather than detection. Implementing and participating in the CMC and Metal Casting R&D efforts has been an important part of this effort. The foundry also employs a variety of tools and techniques to ensure and inspect quality. They model and perform simulations on almost all of their castings using advanced CAD system simulation software. They also check the quality of their castings by using tools that verify dimensional accuracy and by performing tensile testing, spectrographic analysis, real-time and conventional X-ray analysis, and eddy current testing.

Onsite Assessment

The assessment team's visit to Aluminum Casting Facility-2 started in the morning with a meeting with the Vice-President of Engineering at the facility. Eppich Technologies and BCS personnel received an overview of the research results the foundry had implemented to date. A unique situation about this visit was that one of the Energy-Saving Melting and Revert Reduction Technology (E-SMARRT) project primary investigators (a project funded by ITP) was performing some trials on site. The assessment team provided facility management with an overview of the tools and services of the ITP BestPractices subprogram. Management had no awareness of the suite of BestPractices tools prior to the assessment team's visit, although they had heard at a society meeting of the IACs a week prior to the site visit. The facility is the right size to qualify for an IAC assessment, and the assessment team provided them with contact information for the IAC closest to the foundry.

1. Implemented R&D and Best Practices

Partnering in DOE Research

During the site visit at Aluminum Casting Facility-2, the assessment team observed first-hand the research institution/industrial partnership at work. The foundry was working with researchers from CANMET* on an E-SMARRT project funded by ITP, *Light Metals Permanent Mold Castings*. The main objectives of this research are to establish the processing parameters for selected prototype automotive, marine and other components during gravity and low-pressure permanent mold casting of Al-Mg alloy 206 and 535. The study set out to determine the microstructure and mechanical properties of these alloys in their as-cast and heat-treated phase to benchmark the casting processes and alloy properties.

Currently, A206 and A535 are difficult to cast because they have the propensity to "hot tear" – a crack that forms near the surface of casting prior to the completion of the solidification because of hindered contraction.[63] Despite the propensity to hot tear, A206 has characteristics (i.e., a tensile strength of 60 ksi, elongation of 10%, and a yield of 40 ksi) that make it an ideal alloy for light-weight military applications. A535 has superior corrosion resistance when compared to A335, naturally ages, which makes it ideal for marine products because of the corrosive environments in which they must operate, and does not require heat treating.

During the assessment team's visit, Aluminum Casting Facility-2 and CANMET were working together to develop casting and metallurgical techniques to avoid "hot tearing" concerns with the two alloys using the permanent mold process. The two groups worked together and conducted casting trials with a substantial amount of Titanium (Ti) added. Once the castings cooled, they were visually inspected and no "hot tears" or other visual defects could be found. Even X-ray examination yielded no defects. This was an exciting finding for both Aluminum Casting Facility-2 and the researchers at CANMET, because it contradicted previous rule that said high Ti would cause hot tearing.

At the beginning of its research, CANMET was producing simple castings in a lab-controlled environment. Many industry members were skeptical of CANMET's results because they their results were not obtained from large, complex geometries in an industrial setting. There was a need for industry to get involved, which Aluminum Casting Facility-2 did by allowing CANMET to perform casting trials at its plant.

This project is an example of excellent industry-research institution partnership. CANMET would not have been able to progress without the cooperation of Aluminum Casting Facility-2 or a similar facility. With these exciting results, Aluminum Casting Facility-2 now has proof that the subject alloys are viable. This has the potential to open a new product line for the facility.

Metal Casting R&D Portfolio Research Results as a Resource

Aluminum Casting Facility-2 has benefited from the utilization of the past ITP funded research and has realied it to be a valuable asset for developing marketing material, improving their overall operations, and finding solutions to their waste generation. Facility staff also found *AFSearch* to be valuable in finding solutions by allowing effcient searches of abstracts of past projects, many of which were funded by ITP. For example, one study, *Mechanical Properties – Structure Correlation for Commercial Specification of Cast Particulate Matrix Composites*, conducted by University of Wisconsin-Milwaukee was regarded as particularly helpful in

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* **CANMET** is a Canadian government organization focusing on research to develop and deploy new materials and material processing technologies to produce value-added manufactured goods.

promoting a product line for the facility. Aluminum Casting Facility-2 casts a large amount of metal matrix parts and was able to use the results of this research in its marketing efforts. The objective of the research project was to evaluate mechanical testing and structural characterization procedures for commercially available particulate metal matrix composites (PMMCs), in particular for aluminum alloy-silicon carbide particle composites. This study provided quantitative comparative data generated cooperatively by material suppliers, casting producers, and casting users, including the U.S. Automotive Materials Partnership (USAMP), to establish industry procedures for mechanical testing and structural characterization. This project generated a "Metals Handbook" on mechanical properties and examined variations in properties with different material suppliers, foundries, and testing agencies. Aluminum Casting Facility-2 uses this research to promote the benefits of the composites they cast. The facility views this as a growing market with growth being dependent upon its ability, and that of other foundries, to demonstrate the advantages of matrix composite products—an objective this research seeks to facilitate.

The facility has also benefited from using the research results to troubleshoot or improve its operations. Facility staff search through abstracts on *AFSearch* to find solutions to their production problems or improve the quality of their castings. According to facility managers, some of the research results have been critical to their operations and to the industry overall. For example, the *Clean Metal Casting (Aluminum)* project conducted by Worcester Polytechnic Institute (WPI) was important in that it led to incorporation of a reduced pressure filter in the manufacturing process. This project developed a technology for clean metal processing that is capable of consistently providing a high metal cleanliness level. It was designed to reduce the incidence of defects that cause scrap and poor yields, thereby reducing re-melting costs.

Aluminum Casting Facility-2 found that Metal Casting R&D research has also provided environmental solutions and saved the foundry money. The facility currently implements the results of research on a *Non-Incineration Treatment to Reduce Benzene and VOC Emissions from Green Sand Molding Systems* that Pennsylvania State University (PSU) conducted. During this project, researchers from PSU evaluated the use of advanced oxidation (AO), and AO with underwater plasma, as green sand "additive." AO can be incoporated into to a foundry's green sand system wherever water is. In production, before water or black water slurries are added to the sand, the sand is treated by the AO combined with ultrasound. PSU showed that AO treatment cleans the clay, allowing it to be more easily activated. AO was shown to activate the seacoal causing the mold to absorb VOCs. Hazardous pollutants and VOCs are oxidized within the green sand mold, and the amount of clay and seacoal required in the mold are reduced. Smoke and odor emitted during cooling and shakeout were reduced significantly.

The Vice President of Sales and Engineering at Aluminum Casting Facility-2 believes that the research funded by ITP is critical to their operations. They have been able to find remedies to problems in their operations that save them time, money, and energy. Industry involvement in these projects ensures that the results will have pragmatic value.

2. Areas for Improvement

Crucible Furnaces

Aluminum Casting Facility-2 has unique melting requirements because it produces a variety of castings utilizing over 30 different aluminum alloys. The facility uses 42 crucible furnaces to melt this diverse group of alloys. These furnaces are located throughout the facility and utilize either blowers or compressed air as their air source. These furnaces constitute a substantial source of wasted energy at this facility due to their operational inefficiencies.

Crucible furnaces are popular among jobbing shops such as this facility because they are easy to tap and charge with a variety of alloys. There is no direct impingement of the flame on the metal, and the heat loss to the outside normally is limited by the refractory and insulation material. However, these furnaces have a low efficiency ranging from 7-19%, with over 60% of the heat loss occurring due to radiation.[64] These furnaces also contribute to high melt losses ranging from 6-7%, which is much higher than the industry average of 3-5%. The low efficiencies of these crucible furnaces mean that Aluminum Casting Facility-2 is paying an excessive amount for fuel (i.e., natural gas) used to fire them.

Another issue that was apparent in the site visit was the fact that every crucible furnace was uncovered, which exacerbated the energy losses. Properly covering the furnaces would minimize the heat losses and reduce its natural gas consumption. Exhibit A.3 illustrates the heat loss from an uncovered molten metal surface.

Exhibit A.3: Heat Loss from an Uncovered Molten Metal Surface

Metal Temperature (ºF)	Heat Loss (Btu/Ft^2/hr)
1,000	5,560
1,100	7,000
1,300	12,200
1,400	14,000
Furnace Shell Temperature (ºF)	
150	155
200	285
250	450
300	630

Source: Industrial Heating, Nov 2006, pg 36. and private communication with Schafer Furnace.

To improve the facility's energy consumption, the assessment team suggested alternatives that may improve the efficiency of the melting operations. First, the facility can examine the use of radiant panels in its crucible furnaces. The panels are currently being benchmarked by researchers at Case Western Reserve University as part of ITP and CMC's E-SMARRT project. These panels combine a dense, high-alumina radiant panel with low thermal mass insulation back-up material and raised nodules. Their design creates a high surface area that promotes radiant energy transfer to the outer surface of the crucible. Installing this liner in conjunction with low thermal conductivity refractory insulation will allow the furnace to stay cooler, thus reducing the heat lost through its sides. These panels are easy to install and do not require mixing or drying, which is typical of cast liners. It is estimated that these liners can improve the efficiency of a crucible furnace by 30% and also improve its melt rate.[65] Such large improvement in efficiency would significantly lower the facility's natural gas bill. Case Western Reserve University recently conducted a trail at this facility, using both panels and a different burner – with the furnace still uncovered, as was the current practice. The furnace efficiency was benchmarked at 8% versus 16% with the panels and a more efficient burner.

Another alternative for the facility is to evaluate the benefits of replacing traditional crucible furnaces with induction furnaces. Induction melting has a thermal efficiency of 59-76%, which is significantly more efficient than a crucible furnace at 7-19%. Induction melting also has a significantly lower melt loss when melting aluminum (i.e., 0.75-1.25%).[66] This is much lower than the 6-7% loss currently experienced at the facility. The analysis that the facility conducts should examine its current and projected alternative fuel costs (i.e., natural gas versus electricity), and should factor in the following:

- Number & size (exposed diameter) of the melting crucibles
- Crucibles that use blowers vs. compressed air
- Actual pounds of castings sold per year vs. purchased ingots
- Number and size of air compressors
- Data on natural gas use for melting (if it is available) in summer vs. winter

This analysis will enable the facility to make a business decision as to whether it would be in its financial advantage to undertake such a large project.

Heat Treating Furnaces

Aluminum Casting Facility-2 heat treats approximately 90% of its castings using conventional natural gas-fired furnaces. The assessment team recommended that Aluminum Casting Facility-2 perform a combustion gas analysis on these furnaces. The facility should also examine using heat exchangers to capture waste heat from the furnaces. In the past, heat exchangers have been a capital-intensive investment and their economics were not attractive. However, rising natural gas prices could change that conclusion.

Sand Heater

The no-bake line at Aluminum Casting Facility-2 does not utilize a sand heater. The assessment team recommended that the facility reconsider installing one of these heaters because of the potential differences in summer versus winter cure times caused by low sand temperatures. Chemical reaction rates double with each 10ºC increase in temperature. Cold sand temperatures in the winter will either slow down production while waiting for sand to cure or, if cure times are not adjusted, cause castings to be poured into under-cured molds which often causes gas-related defects.

Die Steels

Currently Aluminum Casting Facility-2 utilizes H-13 die steels for its permanent mold and die material. The assessment team recommended that the facility consider some of the die steel research performed by Case Western Reserve University that has identified a number of commercially available steels that can outperform conventional H-13 steel.

3. Conclusion

Aluminum Casting Facility-2 has actively participated in DOE-sponsored research. Participating with CANMET in their E-SMARRT activity has proven beneficial to the facility by bringing a new alloy to the facility's production line. Also, the facility's work with Case Western is improving its crucible melting facility and lowering its natural gas bill. The facility does have areas it could improve upon, and has the drive to take on these projects. In particular the facility could improve their energy efficiency by improving their efficiency of all their crucible furnaces.

K. Copper Foundry-1

Plant Profile

Copper Foundry-1 has approximately 100 employees and specializes in both copper and ferrous (iron and steel) castings. For this analysis, the facility was classified as a copper foundry because over 50% of its castings are brass, 30% ferrous, and the remaining 20% are of various copper alloys. The facility employs a number of casting processes, including permanent mold, die casting, and sand casting. It performs its own melting on site, utilizing both induction furnaces and smaller crucible furnaces.

Copper Foundry-1 primarily ships to pump and valve manufactures and to electrical hardware component manufacturers. Its most commonly produced casting is an impeller made of Si-Bronze and Al-Bronze, of which it ships approximately 140,000 per year. The facility performs many short runs for its customers. Due to this practice, pattern storage has become an issue that may necessitate additional warehousing space. The large storage requirement is forcing Copper Foundry-1 to consider charging its customers a warehousing fee.

Copper Foundry-1 quality and process control operations utilize the latest devices and techniques. Process control procedures include continuous inspection of castings and analysis of casting alloys during production to ensure compliance with product specifications. The quality control system is designed to ensure customer satisfaction by employing controls throughout the business, from receipt of customer order to the delivery of the products.

Onsite Assessment

During the site visit, the company's president accompanied the assessment team. In the morning, plant personnel provided the assessment team with an overview of plant operations and of their implementation of Metal Casting R&D research results. The team then gave plant personnel an overview of the free tools and services offered by the ITP BestPractices subprogram. The facility was aware of the IAC services and had participated in an assessment in May of 2002. However, facility managers were unaware of the suite of available BestPractices tools. The assessment team toured the facility in the afternoon.

1. Implementation

IAC Assessment

Copper Foundry-1 participated in an IAC assessment in 2002. The facility's president explained how beneficial the assessment was and how it lead to some changes in their plant. The facility incorporated some but not all of the recommendations made by the IAC team. This is because some of the recommendations were low cost and simple to implement, while others were cost prohibitive.

One IAC recommendation made to Copper Foundry-1 was to replace its lighting with more efficient mercury lighting. The facility integrated this into 100% of its sand casting operation, 50% of its permanent mold casting operation, and 20% of the machine shop. The reason for this incremental implementation was that it was only cost effective for the foundry to replace its lighting once the ballast system failed. It did not make economic sense to replace the working ballasts. The foundry also consolidated its vacuums in the permanent mold operation (from 3 to 2) as recommended during the assessment and thereby achieved energy savings. Finally, the foundry installed a surge tank and a separate compressor in its machine shop as recommended.

The facility did not adopt the IAC recommendation to use carburized sand because the engineers experienced problems integrating that into their operations. The foundry also did not understand how that practice could add value to their castings, and thus abandoned the recommendation.

Although they did nit implement all of the IAC recommendations, management did consider each to identify those that would be cost effective. Subsequent adoption of such cost-effective recommendations has enabled the foundry to reap cost savings. The facility's president noted further that the assessment process itself motivated them to search for and implement other energy-efficient and cost-saving projects. For example, they implemented a lean manufacturing approach which involves a continual effort to reduce and eliminate waste. The facility has also engaged a private consultant to improve the sand casting operation and to assist in integrating a vacuum in that operation. Adding a vacuum has the potential to reduce internal scrap, improve casting yield, and reduce the machining time for the facility's sand castings.

DOE Research

Copper Foundry-1 participates extensively in Metal Casting R&D projects. It is a member of the AFS Permanent Mold and Copper Committee, which provides technical oversight to a number of Metal Casting R&D projects. Participation in the technical committee has allowed Copper Foundry-1 to stay abreast of new developments occurring in the area of permanent mold and copper castings. By keeping informed on such evolving developments, Copper Foundry-1 has been able to implement the latest modeling techniques, grain refinement, and die material improvements.

At present, Copper Foundry-1 does perform solidification modeling of its castings using the AFS SolidCast and Finite Solutions which were developed with funding from ITP. The facility does not model its routine castings because it has extensive experience with those. However, it models all new jobs received to identify any potential defect issues before a casting goes to production. Modeling allows the foundry to determine the proper rigging system before pouring a casting, thereby avoiding costly trial-and-error tests.

Copper Foundry-1 has also gained substantial knowledge on grain refinement from R&D efforts of the CMC and ITP partnership. The foundry uses copper-zirconium as a grain refiner based on a recommendation by CANMET, a R&D partner organization with ITP. A grain refiner is material that is added to the molten metal or alloy to produce a finer grain size when a casting solidifies.[67] Having a finer grain size strengthens the casting and ensures that the casting meets the customers' requirements. The addition of grain refiner improves the mechanical properties of the casting while also reducing the propensity for hot tears during solidification.

The facility also stays abreast of the latest developments in die steels for both its die casting and permanent mold casting operations. At the time of the site visit, the facility was investigating the test results of Case Western's research in die materials, an ITP Metal Casting project. The facility was analyzing whether it should incorporate the use of superior steels into its operations and whether the added cost would be justified. The facility was in the process of developing the business case to help in decision-making.

Copper Foundry-1 has benefited from the efforts funded by the ITP Metal Casting portfolio. Participating on the AFS technical committees has enabled the foundry to stay abreast of innovative developments in the industry. Incorporation of these R&D results has assisted Copper Foundry-1 in improving the quality of its castings and has reduced its process energy costs.

2. Conclusion

Copper Foundry-1 is using modeling for new, unfamiliar work. The foundry's active participation in the AFS technical committees has kept the facility personnel abreast of all relevant research; this enables them to evaluate the suitability of the latest research into their operation on a case-by-case basis. The facility has been proactive in improving their energy efficiency and has even participated in an IAC assessment.

Glossary

Aluminum casting alloys – Super-purity or commercial-purity aluminum to which metallic additions were made. The additions, which are called alloying elements, are made to provide benefits such as an increase in mechanical properties. The most important alloying elements for aluminum include magnesium, copper, silicon, manganese and zinc.[68]

Argon Oxygen Decarburization (AOD) - A refining treatment used to control the carbon content of steel.[69]

Best Practice - A technique or methodology that, through experience and research, has been proven to lead to a desired result. In this report, there are two types of best practices: 1) ITP metal casting research outcomes once proven on the plant floor, and 2) best practices recommended by the ITP BestPractices subprogram (and IAC recommendations).

Billet - A cylinder of alloy made from ingots by hot forming (rolling or forging). A billet can be of any metal and alloy.

Captive Foundry - A foundry operation that is wholly incorporated into a larger manufacturing operation. A captive foundry only produces castings for the operation of which it is a part of.[70]

Clamping capacity - The force a die casting machine is capable of applying against the platen to hold the die closed during metal injection.[71]

Coke - A porous, gray, infusible product resulting from the dry distillation of bituminous coal that drives off the volatile matter. Coke is mainly used as a fuel in blast furnaces and some cupolas. Petroleum coke results from distillation of petroleum and pitch coke from distillation of coal tar pitch.[72]

Cope - The upper or topmost horizontal section of a flask, mold or pattern.[73]

Crucible Furnace - A furnace in which metal is melted in crucibles.[74] The furnace is typically fueled with coke, oil, gas, or electricity.

Cupola - A cylindrical, straight-shaft furnace (usually lined with refractory materials) used for melting in direct contact with coke by forcing air under pressure through openings near its base.[75]

Diecasting - (noun) Casting resulting from diecasting process. (verb) A process in which molten metal is injected at high velocity and pressure into a mold (die) cavity.[76]

Drag - The bottom half of a horizontally parted mold.

Dross - Metal oxides, etc. on or in a metal or alloy.[77]

Electric Arc Furnace (EAF) - A steel-producing furnace in which scrap generally makes up 100% of the charge. Heat is supplied from electricity that arcs from the electrodes to the metal bath. These furnaces may operate on AC or DC.[78]

Energy Intensity - Energy use per unit of product output (i.e. Btu per dollar value of shipments).

Feeding - The process of supplying molten metal to the die cavity to compensate for volume shrinkage while the cast part is solidifying.[79]

Flask - A metal or wood frame used for making or holding a sand mold. The upper part is the cope and the bottom half is the drag.[80]

Feeding - Supplying molten metal to compensate for volume shrinkage while a casting is solidifying.[81]

Fluidized bed - A bed of small solid particles (as in a coal burning furnace) suspended and kept in motion by an upward flow of a fluid (as a gas) -- called also *fluid bed*.[82]

Fluxing - The process of treating a bath of molten metal with a flux. This may involve covering the bath with the flux material, thereby reducing dross formation through oxidation. It may involve a more complex procedure of mixing the flux into the dross layer separating the contaminants from the good trapped metal. Oxides up to 80-85% aluminum and 85-90% zinc can be released through the use of flux, in combination with separation units used to separate liquid metal from the dross.[83]

Green Sand - Moist sand that is bonded by a mixture of silica, bentonite clay, carbonaceous material, and water.[84]

Gate - A thin passage of molten metal that connects the runner to the cavity of the mold.[85]

Heat checking - The formation of fine cracks in a die surface due to alternate heating and cooling of the mold. These cracks are reflected in the surface of the casting. [86]

Hot tear - A crack or irregularly-shaped fracture formed prior to completion of metal solidification because of hindered contraction. A hot tear is frequently open to the surface of the casting and is commonly associated with design limitations.[87]

Ingot - Commercial pig mold or block in which usually copper, copper base, aluminum, aluminum alloys, magnesium, magnesium alloys and other metals usually are made available to the metal caster.

Ladle - The name for a variety of receptacles used to move and pour molten metal during the casting process. [88]

Launder system - A trough system that carries molten metal from melting furnace to a system of several holding furnaces.[89]

Lost Foam Process - A casting process that uses foam to form the pattern. The foam is eventually melted out of the mold when the molten metal is poured in.[90]

Metrology - The science of weights and measures or of measurement.[91]

Modulus [System or Process] - (1) In tension, it is the ratio of stress to the corresponding strain within the limit of elasticity (yield point) of a material. For carbon and low alloy steels of any composition and treatment, the value is approximately 30,000,000 psi. (2) A constant or coefficient that expresses usually numerically the degree to which a body or substance possesses a particular property (as elasticity)[92]

Mulling - The thorough mixing of sand with a binder and a lubricant or fluid, such as water.

Permanent Mold - A steel mold into which molten metals are poured by gravity to produce castings.[93]

Porosity - Voids or pores, commonly resulting from solidification shrinkage, air trapped in a casting or hydrogen exuded during electroplating.[94]

Refractory - A material, usually made of ceramics, which is resistant to high temperature, molten metal, and slag attack.[95]

Reverberatory Furnace - Melting unit with a roof arranged to deflect the flame and heat toward the hearth on which the metal to be melted rests. [96]

Revert - To come or go back (as to a former condition, period, or subject)

Riser - Reservoir of molten metal from which casting feeds as it shrinks during solidification. [97]

Runner - A portion of the gate assembly that connects the gate or sprue with the casting.[98]

Seacoal - Finely ground bituminous coal.[99]

Six Sigma Analyses - A statistical methodology to manage process variations that cause defects and to systematically work towards managing variation to eliminate those defects.[100]

Slag - A fused nonmetallic material that protects molten metal from the air and extracts certain impurities from the melt.[101]

Slag Inclusions - Casting surface imperfections similar to sand inclusions but containing impurities from the charge materials, silica and clay eroded from the refractory lining, and ash from the fuel during the melting process. May also originate from metal-refractory reactions occurring in the ladle while pouring the casting.

Sprue - Metal that fills the conical passage (sprue hole) that connects the nozzle or hot chamber to the runners of a hot chamber machine. [102]

Stack Melter - A type of melting furnace where the metal is charged, preheated, and melted in the exhaust. Also referred to as a tower or shaft melter.[103]

Tundish - A reservoir in the top part of a mold into which molten metal is poured.[104]

Tuyere - An opening through which the air blast enters the cupola (or a blast furnace, or any other vessel).

V-process - A molding process, developed in Japan, in which the mold is formed by stretching a sheet of Mylar plastic over a heated metal pattern so that it conforms to the shape of the pattern. A box of loose sand is placed over the pattern, and a vacuum is applied to the sand, which then conforms to the shape of the Mylar film. Thus supported, the sand-backed film is removed from the pattern and is used as one part of mold. When the metal is poured, the vacuum is released, and the loose sand falls away from the casting. [105]

Vacuum Casting - A process of casting that uses a vacuum to draw molten metal into a mold.[106]

Yield - In production of castings, a value expressed as a percentage indicating the relationship of the weight of a casting and its gating system. For example, if the casting and gating system weigh 125 lb. and the casting weighs 100 lb., the yield is 80%.[107]

Zinc casting alloys - Alloys that are well suited for connectors and other electronic components due to good electrical conductivity, which ranges from 25 to 27% IACS (International Annealed Copper Standard). Zinc alloys have electrical conductivity properties similar to those of aluminum casting alloys and are superior to brass, magnesium and cast iron.[108]

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