Platinum-Group Metals—World Supply and Demand

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Contents

Figures [Complete captions are listed on p. 131.]

Tables

Conversion Factors

Conversion factors of SI (metric) and U.S. customary units of measurement.

Multiply	By	To obtain
degree Fahrenheit (°F)	(temp °F-32)/1.8	degree Celsius (°C)
inch (in)	2.54	centimeter (cm)
mile	1.609	kilometer
ounce, troy	0.0311	kilogram
ton, short (2,000 pounds)	0.9072	ton, metric

ABSTRACT

The United States is dependent on imports of platinum-group metals (PGMs), which includes platinum, palladium, rhodium, ruthenium, osmium, and iridium. PGMs are used in a wide variety of applications, including vehicle catalysts for controlling vehicle pollution, chemical catalysts and coatings, dental alloys, electronic components and computer hard discs, fuel cells for power generation, glassmaking equipment, investment coinage, jewelry, medicines, and petroleum catalysts for gasoline refining. A potential application for PGMs in the future is fuel cells. In 2002, the United States relied on imports for approximately 93 percent of its platinum requirements and 69 percent of its palladium requirements. Most production of PGMs originates from only two countries, Russia and South Africa. The worldwide physical supply of PGMs is influenced by cost of production, environmental consequences, government policies, industry decisions, market price, sociocultural trends, substitution issues, and technological factors.

After studying these factors, this study projects that world platinum production capacity, an approximation of maximum supply, could increase by as much as 69,000 kg from primary capacity and 22,000 kg from recycling, or 38 percent between 2003 and 2010. World production capacity of palladium could increase by as much as 89,000 kg from primary capacity and 107,000 kg from recycling, or 68 percent between 2003 and 2010. World production capacity of other PGMs could increase by as much as 10,500 kg from primary capacity and 7,100 kg from recycling, or 25 percent between 2003 and 2010, as new primary capacity comes on line and with increased recycling of PGM from autocatalysts and electronics. Assuming historical average annual growth levels over the 1985 to 2003 period, minimum platinum use, based on primary platinum purchases and recycling estimates, use could increase by about 65,000 kg between 2003 and 2010, 66 percent from primary purchases and

34 percent from recycling. Palladium use could increase by about 140,000 kg between 2003 and 2010, 14 percent from primary purchases and 76 percent from recycling. Actual supply and demand would likely fall between these levels.

Acknowledgments

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Introduction

Platinum-group metals (PGMs) include platinum, palladium, rhodium, ruthenium, osmium, and iridium. PGMs are used in a wide variety of applications such as vehicle catalysts for controlling vehicle pollution, chemical catalysts and coatings, dental alloys, electronic components and computer hard discs, fuel cells for power generation, glassmaking equipment, investment coinage, jewelry, medicines, and petroleum catalysts for gasoline refining. Although most of our Nation's consumption of platinum and palladium is in the manufacture of catalytic converters, a major potential application for the future may be in fuel cells. A 2003 presidential initiative proposed a 5-year, US$1.7 billion cooperative research program between the public and private sectors to develop fuel cell use in businesses, cars and trucks, and homes by 2010 and develop a commercially practical hydrogen-powered vehicle by 2020.

The United States is dependent on PGM imports. Most mine production of PGMs originates from only two countries, Russia and South Africa. In 2002, the United States relied on imports (over half from South Africa) for approximately 93 percent of its platinum requirements and 69 percent of its palladium requirements (of which 44 percent came from Russia) (Hilliard, 2003).

This study explores the physical worldwide supply of PGMs from estimated in-ground mineral resources and through recycling. It examines drivers and constraints to supply and demand for these important metals, including corporate decisions, cost of production, environmental consequences, government policies, market price, sociocultural trends, substitution issues, and technological factors. An outlook of world production capacity and demand to 2010 is also presented.

Platinum-Group Metal Resources, Production, and Supply

PGM deposits[1] are widespread; however, deposits with economically recoverable platinum-group elements[2] (PGEs) are limited. Canada, Russia, South Africa, and the United States accounted for about 97 percent of the world's platinum production and 95 percent of the world's palladium production in 2002 (Hilliard, 2003). Most of the world's PGMs are derived from magmatic ore deposits found in mafic and ultramafic rocks (Michael Zientek, U.S. Geological Survey, oral commun., 2004). Sutphin and Page (1986, p. 4) outlined three principal categories of this type of geologic occurrence:

- Stratiform deposits in which PGM occur in large Precambrian mafic to ultramafic layered intrusions. Examples include the Merensky Reef of the Bushveld Complex in South Africa, the Great Dyke in Zimbabwe, and the Stillwater Complex in the United States.
- A norite intrusion, such as the Sudbury Irruptive Complex in Canada where meteoritic impact is believed to have been instrumental in allowing emplacement.
- Nickel- and copper-bearing sills, which are found in association with rift-related structures, such as the Noril'sk-Talnakh District in Russia.

Other geologic environments that more recently have generated interest as a source for economically recoverable PGEs[3] include:

- Stratiform chromititic deposits enriched in PGEs in the Upper Group 2 (UG2) reef of the Bushveld Complex.

[1] In this study, PGM deposits include some combination of iridium, osmium, palladium, platinum, rhodium, and ruthenium in concentrations high enough to warrant exploration activity or recovery at current prices.
[2] In this study, the term PGE is restricted to discussion of the mineralogy of PGM-bearing deposits.
[3] The appendix discusses other geologic environments suitable for palladium- or platinum-rich occurrences.

- Disseminated sulfides enriched in PGEs associated with contact zones of mafic/ultramafic intrusions at the Platreef deposit in South Africa or composite plutons at the Lac des Iles deposit in Canada (Michael Zientek, U. S. Geological Survey, oral commun., 2004)

PGMs are currently recovered from 3 sources: primary PGM deposits; as byproducts of nickel and copper recovery; and from secondary (recycled) resources. Large layered mafic-ultramafic intrusions, such as the Bushveld and Stillwater Complexes, typically contain platinum or palladium of sufficient grade and tonnage to be considered primary. PGMs are recovered as byproducts from Canadian and Russian deposits, which produce nickel and copper as primary products. PGMs supplied from recycling efforts have historically not been considered as a separate resource. However, with the introduction of stricter vehicle emission standards, the amount of PGMs available from recycled automobile catalysts has increased significantly, leading to a major aboveground resource capable of providing increasingly greater quantities of PGM-bearing material and offsetting a portion of demand from primary sources (Hilliard, 1998, p. B5).

FIGURE 1

Figure 1 shows the distribution of worldwide primary platinum and palladium supply in 2002 based on company-reported production values and U.S. Geological Survey (USGS) estimates. Data estimates exclude production from stockpile sales and recycled material. Based on these data, South Africa supplied approximately 72 percent of the world's platinum from primary sources in 2002, Russia 19 percent, North American sources 6.6 percent, and less than 3 percent came from other locations. In 2002, Russia supplied approximately 43 percent of the world's palladium, South Africa 37 percent, and North America 16 percent.

PGM resource[4] figures generally include all significant PGEs plus gold. Reserve[5] and resource data listed in this report reflect the composition of the reported deposit or region. Some resource values include platinum, palladium, and gold (commonly referred to as 3E), while other locations include platinum, palladium, rhodium, and gold (commonly referred to as 4E) or platinum, palladium, rhodium, iridium, osmium, and gold (commonly referred to as 6E). Because of the nature of PGM resource reporting, it is often not possible to report the resource of individual PGEs. While resources reported in this study may reflect aggregated PGM composition, individual PGE data have been split out for PGM supply analysis.

FIGURE 2

Figure 2 illustrates the distribution of world PGM resources. Table 1 lists estimates of world PGM reserves and reserve base[6] compiled from information reported in trade journals, published company data, and estimates developed by USGS specialists. Reserve base figures include those resources that are currently economic or marginally economic, but do not include PGM in stockpiles or PGM "in-use" that are potentially available by recycling. Because the intent of this study is to focus on sources thought to be available for use by 2010, resource data reported for this study do not include resource estimates for properties not planned for initial production after 2010. Reserve figures include material from 32 deposits; reserve base figures include material from 80 deposits.

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[4] As defined by U.S. Geological Survey Circular 831, a resource is a material concentration in such form and amount that economic extraction of a mineral commodity from that concentration is currently or potentially feasible (U.S. Bureau of Mines and U.S. Geological Survey, 1980).
[5] As defined by U.S. Geological Survey Circular 831, a reserve is that part of the reserve base which could be economically extracted or produced at the time of determination (U.S. Bureau of Mines and U.S. Geological Survey, 1980).
[6] As defined by U.S. Geological Survey Circular 831, the reserve base is that part of an identified resource that meets specified physical and chemical criteria, including those for grade, quality, thickness, and depth. The reserve base is the in-place demonstrated (measured plus indicated) resource (U.S. Bureau of Mines and U.S. Geological Survey, 1980).

Table 1. Estimates of 2002 platinum-group metal reserves and reserve base.[1]
[kilograms]

Location[2]	Reserve	Reserve base
Canada………………..	400,000	910,000
Russia………………...	NA[3]	6,100,000
South Africa………….	12,000,000	34,000,000
United States…………	780,000	900,000
Zimbabwe…………….	530,000	5,300,000
Other areas……………	NA[3]	380,000
World total…………..	14,000,000[4]	48,000,000[4]

[1] Reserve data are based on 32 sites; reserve base data are based on 80 sites associated with producing or developing operations or planned for development by 2010. Data reflect most recent public data with an average release date of 12/31/02.
[2] Data between countries are not directly comparable, because some sites only report platinum and palladium reserves, while others only report reserves for multiple PGMs. In addition, figures are composites of individual site data obtained from multiple sources. Individual site data may not conform to USGS reporting standards. Site data for South Africa and Russia are reported separately in tables 2 and 3, respectively.
[3] NA = Not available.
[4] Figure totals may not add because of rounding.

About 86 percent of the reported PGM reserve base-level material is located in Russia and South Africa. Zimbabwe is reported to have a significant PGM reserve base. The reserve base estimates for Canada and the United States have increased in recent years. The resurgence in exploration for PGMs in many countries may lead to changes in future PGM reserves or resources.

Reserve and resource estimates may not be comparable because criteria or legal requirements used to determine them may differ among companies or countries. Also, reserve and resource estimates are dynamic and change in response to factors that include additional discoveries, advances in extraction technologies, changes in commodity prices, and other factors that affect the cost of extraction or conducting business, such as currency exchange rates, labor costs, social factors, and taxes or other government policies.

These estimates suggest that currently defined PGM resources are adequate to meet projected PGM demand at least until 2010 and most likely well beyond that date. A high level of PGM exploration took place at the beginning of the 21st century. Should this exploration prove successful and PGM prices remain near 2002 levels, the delineated PGM resources are likely to replace those that will be depleted by 2010.

A discussion of current and possible PGM supply sources follows. Principal producing areas are listed in order of importance based on current production levels. A discussion of other countries with PGM resources or possible resource potential is then given.

South Africa

Primary Resources

The reserve base estimate of more than 34 million kilograms (Mkg) of contained PGMs for South Africa reported in table 1 includes proven and probable reserves and measured and indicated resources for currently producing properties and for properties currently in development or proposed for development before 2010. For comparison, the South African Minerals Bureau reported a South African PGM reserve base as of the year 2000 of more than 62 Mkg, a value significantly larger than the value reported in this study (Chamber of Mines of South Africa, 2001). Cawthorn (1999) calculated that the Bushveld Complex contained an inferred resource down to a 2 kilometer (km) depth of about 61 Mkg, including about 10 Mkg at the proven and probable reserve level. PGM content of the Bushveld Complex, reported at the reserve base level by province, is listed in table 2. Although this estimate is over 10 years old, it is still reported in the most recent publications of the South African Council of Geoscience.

Table 2. Platinum-group metal content of the Bushveld Complex, South Africa.
[Metric tons of platinum-group metal (PGM) content. Source: Van Graan and Fourie, 1992, p. 7]

Province	Reserve base[1], PGM content
North-West…………………………………..	37,200
Mpumalanga…………………………………….	14,000
Northern………………………………………	7,700
Total…………………………………………	58,900

[1] As defined by U.S. Geological Survey Circular 831, the reserve base is that part of an identified resource that meets specified physical and chemical criteria, including those for grade, quality, thickness, and depth. The reserve base is the in-place demonstrated (measured plus indicated) resource (U.S. Bureau of Mines and U.S. Geological Survey, 1980).

Because of the similarity between the Cawthorn and South African Minerals Bureau estimates, it is believed that these higher values include inferred resources according to USGS classification, and likely include areas not currently considered by producing companies for development within the next decade.

South Africa's PGM production was derived principally from the Bushveld Complex, a 370-km diameter layered igneous intrusion. PGMs are recovered from three layers within this complex. The Merensky Reef has been the world's principal source of PGMs since it was first worked in 1929. More recently, other layers have grown in importance so that, by 1999, the Merensky Reef accounted for a little more than 50 percent of the PGM ore processed in South Africa. Exploitation of the UG2 chromitite layer began in the 1970s; production from this layer reached 42 percent of the total in 1999 compared with 15 percent in 1994. UG2 development was delayed at first owing to its different mineralogy and textures. The Platreef, a large mafic-ultramafic intrusion, was mined briefly in the 1920s and 1930s. However, recent strong demand and higher PGM prices stimulated renewed exploration and production of the Platreef during the past decade. Production from the Platreef reached 8 percent of South African PGM production in 1999.

The proportions, textures, and types of the PGMs in the Merensky Reef vary considerably, locally and regionally. The thickness of the reef ranges from 2 centimeters (cm) to 14 meters (m) and is bounded by narrow seams containing chromite. PGE content varies with location. The platinum-to-palladium ratio averages 2.61 to 1 in the Rustenburg area, 2.31 to 1 in the Union area, and 1.81 to 1 in the Amandelbult area but can vary even more depending on intrareef location (Viljoen and Schurmann, 1998, p. 542-550).

The UG2 Reef is 25 to 400 m below the Merensky Reef and ranges from 0.6 to 1.5 m thick and, with the exception of rhodium, has PGM grades typically lower than those found in the Merensky Reef. Platinum contributes from 39 to 54 percent of the total PGM content. The platinum-to-palladium ratio varies between 1.2 to 1 and 2.6 to 1. Because of its differing mineralogy and texture and high chromite content, UG2 ore is more difficult to process and requires different beneficiation methods from ore derived from the Merensky Reef (Edwards, 1989, p. 7).

The Platreef is in the northern limb of the Bushveld Complex. Erratic ore grades in the Platreef contributed to the cessation of mining operations in the 1930s. The platinum-to-palladium ratio averages 1 to 1. Most South African PGM mining is by underground methods because the narrow ore seams of the Merensky and UG2 Reefs continue to great depths. Because the Platreef deposits are generally much thicker than the other South African reefs, often varying from 5 to 90 m, open pit mining methods are used to recover ore when conditions permit (Edwards, 1989, p. 9). Some companies consider open pit mining more cost effective, even though this process generates more waste.

Byproduct Resources

Historically, a small amount of PGM output came from areas outside the Bushveld in South Africa, notably the Evander gold field and the Phalaborwa copper field (Van Graan and Fourie, 1992, p. 10; Viljoen and Schurmann, 1998, p. 565). PGM are recovered when PGM price levels make recovery worthwhile.

Areas Considered for Resource Development

TABLE 3

Table 3 reports published reserve and resource information for selected South African sites either currently producing or under active consideration for development or expansion prior to 2010. Some sites that are being considered for development but have not released resource data have not been included in table 3. Sites that have not yet reached a bankable feasibility stage or that have an insufficient level of drilling to define a reserve also were excluded, as the authors felt such deposits could not achieve full-scale production prior to 2010. Consequently, the data in table 3 do not include all South African PGM resources. The deposits listed account for approximately 55 percent of the 2000 Bushveld Complex PGM reserve base total reported by the Chamber of Mines of South Africa and about 43 percent of the reserve base total reported by the USGS (Hilliard, 2003).

While exploration has focused on areas of mafic/ultramafic intrusions similar to the Bushveld Complex, depleted surface resources and higher PGM prices have stimulated interest in exploring for PGMs in other geologic environments. For example, exploration companies are reevaluating nickel-copper deposits for their PGM potential. New technologies that are able to detect minute levels of PGMs support these evaluations.

Future sources of South African PGMs are likely to be quite different from PGM sources mined in the 20th century. Most of the shallow Merensky Reef in the western limb of the Bushveld Complex has been mined. Much of the future production from the western limb will come from the UG2 intrusive. In 1998, the UG2 accounted for 38 percent of the ore processed; by 2006, it could account for more than 60 percent (Michael Zientek, U.S. Geological Survey, oral commun., 2004). Also, new deposits with PGM composition and mineralogy that are different from previously mined areas on the western limb are being developed on the eastern limb of the Bushveld Complex.

Production and Capacity

Production information on palladium, platinum and other platinum-group metals from 1987 to 2001 are reported in figure 3. In general, South African production has increased during this period. South African production of PGMs in 2001 was reported by Johnson Matthey Plc (2002b, p. 13) to be 127,500 kilograms (kg) [4.1 million troy ounces (Moz)] of platinum, 62,500 kg (2.0 Moz) of palladium, and 14,000 kg [452,000 troy ounces (oz)] of rhodium, and by the USGS, 130,000 kg of platinum, 62,000 kg of palladium, and 13,500 kg of rhodium (Coakley, 2003, p. 25.7). USGS data for South Africa reflect data reported by the South African Minerals Bureau (George Coakley, U.S. Geological Survey, oral commun., 2004).

FIGURE 3

The South African PGM industry has announced significant capacity increases for the period from 2000 to 2010. Improved demand, high PGM prices, and record profits by producers during the period from 1999 to 2001 have spurred expansion of existing mine capacity through development of the stratigraphically lower UG2 ore zones as well as development of deposits on the eastern limb of the Bushveld Complex. Some new production capacity is planned to be online by the year 2006. By 2006, South African platinum production capacity is expected to increase by 18 percent from the 2003 level to about 179,000 kilograms per year (kg/yr), and palladium production capacity is expected to increase by 24 percent from the 2003 level to about 94,000 kg/yr. By the year 2010, South African primary platinum production could increase by about 39,000 kg, palladium could increase by about 24,000 kg, and other PGMs by about 4,300 kg.

While the specifics of their expansion plans have fluctuated with recent changes in PGM prices and exchange rate fluctuations, Anglo American Platinum Corporation Limited (2002) is planning to increase its platinum output to about 90,000 kg/yr [2.9 million troy ounces per year (Moz/yr)] by 2006 from a 2002 level of 70,000 kg/yr (2.25 Moz/yr). Anglo American Platinum commissioned its Bafokeng-Rasimone mine in 2000, adding 7,200 kg/yr [230,000 troy ounces per year (oz/yr)] of PGM production capacity; an additional 7,800 kg/yr (250,000 oz/yr) PGM capacity (Styldrift project) is planned within 5 years. A new project at Modikwa (formerly called Maandagshoek) would add 5,000 kg/yr (161,000 oz/yr) of platinum to South African PGM supply by 2004, and an expansion of the Rustenburg UG2/Waterval operation would add an additional 12,300 kg/yr (395,000 oz/yr) of platinum by 2006. Development plans for the new 5,000-kg/yr (161,000 oz/yr)-platinum and 5,500-kg/yr (177,000 oz/yr)-palladium Twickenham mine were announced in September 2001, with full production scheduled for 2008. Plans for a tailings retreatment operation at Rustenburg were approved in 2002, which would provide an additional 3,700 kg/yr (120,000 oz/yr) of platinum and 1,200 kg/yr (38,000 oz/yr) of palladium when anticipated full production is achieved in 2006.

Lonmin Plc announced that it has increased its production target levels at its South African mines to 27,000 kg of platinum in 2003 and 30,500 kg in 2007 from its 2001 production level of 22,300 kg (Lonmin Plc, 2002b, p. 9). Impala Platinum Holdings Limited has confirmed that it plans to proceed with construction of a 5,400-kg/yr PGM mine at the Marula project (formerly Winnaarshoek) and is reevaluating the Kennedy's Vale project, which is expected to have a production capacity of 10,900 kg/yr by 2006 (Impala Platinum Holdings Limited, 2002).

Aquarius Platinum Limited is increasing production of its Kroondal mine, which began production in 1999, by 50 percent. Full production capacity of 7,500 kg/yr of PGMs was achieved in 2002, although engineering problems prevented sustained production at that level. In addition, the company began construction of its Marikana mine with full production of 5,000 kg/yr of PGMs scheduled for 2003. A feasibility study of the 5,000 kg/yr Everest South PGM project was completed in early 2003 (Aquarius Platinum Limited, 2002b). Development plans call for the Everest South project to reach a production level of 4,200 kg/yr of PGMs by 2005 (Geological Survey of South Africa, 2003).

Other recent PGM development projects included reopening of Impala Platinum Holdings Limited's Crocodile River mine (1,550 kg/yr of platinum) in 2001 and SouthernEra Resources Limited's Messina mine (4,760 kg/yr of PGMs) by 2003 or 2004. The Crocodile River mine, which planned to recover PGMs from the UG2 reef, had a company-reported resource as of June 30, 2001, that contained 2.8 Moz of PGM but was placed on care-and-maintenance status at the end of 2003 for economic reasons (Barplats Investments Limited, 2003). A 30 percent capacity increase to about 13,000 kg/yr of PGMs at Northam Platinum Limited's Northam mine began in 2001 with the commissioning of a new UG2 mining operation (Northam Platinum Limited, 2001). A feasibility study to double capacity at Anglovaal Mining Limited's Nkomati nickel mine to about 3,100 kg/yr (100,000 oz/yr) of PGMs was completed in 2002 (Anglovaal Mining Limited, 2002).

FIGURE 4

Figure 4 illustrates projected platinum capacity changes for South Africa for the period from 2000 to 2010, along with a description of the projects that affect these changes. All these new or expanded projects would also supply palladium and other PGM, and increasing production from the UG2 intrusion would increase the amount of rhodium and ruthenium that could be recovered. Projected production of PGM in South African has been included in figure 5, which shows world supply estimates for platinum, palladium, and other PGM for the period from 2002 to 2010. The strength of the South African rand against the U.S. dollar is likely to affect the timetable of capacity expansion, as it affects the economics of individual South African projects.

FIGURE 5

South African production capacity projections to 2010 were developed based on reported corporate plans and projections. Because of the speculative nature of some proposals for expansion recently announced by various companies, not all the most recent development schedule proposals are reflected in development parameters used in this study. Changing economic conditions, political decisions, social concerns, and technological developments could affect such plans. A description of important issues related to the development and mining of PGMs in South Africa is given in the following section.

Drivers and Constraints of PGM Supply

Factors that affect South African PGM production also affect world supply. Because South Africa contributes such a large percentage of world PGM supply, the country's mining policies and other events are critical to the PGM industry. Appreciation of the South African rand against the U.S. dollar since late 2001 is reportedly affecting the rate of implementation of various South African expansion projects (Mining Journal, 2003). For example, the rand gained 28 percent against the dollar in 2003, causing higher costs at many South African mining operations, which base their internal operating costs on the rand but base sales on the dollar. Differences resulting from short-term exchange rate variations may be as short as 1 year and should not have a major affect on worldwide supply-demand scenarios, but longer exchange rate variations may affect future development plans or economic profitability.

The South African Government maintained its involvement in the mineral industry "in order to provide sound legal and fiscal environment and efficient physical infrastructure" (United Nations Conference on Trade and Development, 2002). Legislation governing the minerals industry includes the Minerals Act of 1991 and the Mineral Resources and Petroleum Development Bill, which was signed into law June 25, 2002, and changed the South African system of mineral rights from dual ownership distributed between the State and private interests to exclusive State ownership with mining activities being licensed to private interests. In October 2002, the South African Government introduced a "proposed broad-based socio-economic empowerment charter for the South African mining industry" (Mining Charter). The Mining Charter addresses the details of the way in which the mining industry is to be transformed to address inequity caused by the race-based apartheid system. The charter set the share of mine ownership at 26 percent for "historically disadvantaged South Africans (HDSA), and was to be achieved over a 10-year period, with an interim 15 percent HDSA ownership level during the next 5 years." In addition, this new regulation aimed at achieving a 40 percent HDSA participation in management and 10 percent participation by women in mining within the next 5 years (Polity.org, 2002).

The South African Government promotes mineral development through a "use it or lose it" policy to achieve equality and encourage development of the country's mineral resources. Companies not sufficiently active run the risk of Government revocation of mining rights and reallocation of such rights to new ownership. Owing to the Government's new policy and in light of recent higher prices for PGMs, South African mining companies announced extensive exploration and expansion programs. Another recent consequence of this policy was the return of selected mineral tenements on the eastern limb of the Bushveld Complex to the Government by Anglo American Platinum, for which more than 200 international prospecting and mining applications subsequently were received (Mineweb, 2002b).

Efforts to increase opportunities for HDSA participation in the industry are ongoing. Partnerships between established mining companies and HDSA groups are required for major new projects to move forward. Consequently, mining companies have an economic incentive for the success of such partnerships. Examples in the PGM industry include partnerships between Anglo American Platinum and Mvelaphanda Resources Limited, Harmony Gold Mining Company Limited and African Rainbow Minerals Limited, Impala Platinum Holdings Limited and Mmakau Mining (Pty) Ltd, and Northam Platinum Limited and Mvelaphanda Resources Limited. In the case of the arrangements of Anglo American Platinum's partnership, 50:50 joint ventures with HDSA groups have been established for project areas identified by the company as being able to support an independently managed stand-alone operation (Mineweb, 2002a). In return, Anglo American Platinum will continue to independently own and develop the remainder of selected project areas. Anglo American Platinum also is preparing to sell 10 to 15 percent of its South African mining assets to HDSA-owned businesses (Skillings Mining Review, 2002).

The Bakubung initiative, an industry stakeholder forum established in 2000, was created to promote the development of cooperation between junior mining companies (companies that derive capital for exploration primarily from issuance of shares) and HDSA groups. Funding has been a major impediment to the creation of a vibrant junior mining sector in South Africa. In June 2002, the International Finance Corporation (IFC) created the US$100 million New Africa Mining Fund to promote junior mining in a way that would address the social challenges and economic development of mineral resources (International Finance Corporation, 2002).

A social issue of concern to the South African mining industry is the high incidence of the human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) epidemic in Africa. Anglo American Platinum reported that testing showed an average of 22 percent prevalence for HIV/AIDS within the company’s workforce (Anglo American Platinum Ltd., 2001). The United Nations reported the estimated prevalence to be 21.5 percent of the country’s population for 2003 (Joint United Nations Programme on HIV/AIDS, 2004). Studies suggest that incidence of the disease will increase at least until 2005, perhaps reaching a 30 percent to 50 percent prevalence level. The debilitating nature of this illness and its high death rate could significantly affect production and worker productivity, particularly in an industry that is currently in an expansion mode.

Although PGM production capacity is slated to increase with the development of new ore bodies, much of this new production would not be economically possible without the development of new mining and processing technologies. For example, mining of the Maroelabult section of the Crocodile River deposit required mining in stopes as narrow as 1.6 m with gradients of up to 18° (Chadwick, 2002). Mining required the development of a low-profile series of load-haul-dump vehicles, drilling rigs, and roof-bolting vehicles. Companies are beginning to adapt the knowledge of deep gold mining to the mining of deeper PGM ores in South Africa. Established ore processing techniques are being modified to accommodate new and finer texture ore zones. Actual production at such new operations will depend in part on whether these new technological modifications prove to be successful. Increases in the prices of PGMs may permit lower grade Platreef ore to be mined, increasing the resource and/or making processing stockpiled material more feasible. Production of UG2 chromites has generated large stockpiles of relatively low-grade chromium "waste," and research has been aimed at its beneficiation (Cawthorn, 1999).

Russia

Primary Resources

Although most of the PGMs recovered in Russia are a byproduct of nickel-copper mining, some primary platinum does occur in placer deposits in the Ural Mountains and Siberia, and is mined by small private production companies called artels. In 1998, about 10,000 kg of PGMs was reported to have been recovered from placers in Russia (Interfax Mining and Metals Report, 1998a-d).

Byproduct Resources

Significant quantities of PGMs are recovered from nickel-copper sulfide deposits in the Noril'sk-Talnakh area of Siberia. Data developed for this study suggest that Russia accounted for about 7.5

percent of the total worldwide reserve base for PGMs and accounted for about 17 percent of platinum production and 52 percent of palladium production in 2002. Almost all resources are in sulfide ores of the Noril'sk complex (Tsvetnye Metally, 1996).

With the long history of nickel-copper production in the Noril'sk-Talnakh region and the relatively low recovery of PGMs from established mines, mine tailings and stockpiles are becoming an increasingly important source of PGMs in Russia, given high PGM prices. MMC Norilsk Nickel recently began recovering PGMs from stockpiles, and additional concentrator capacity was being adapted to process stockpiles with a reported average PGM content of 8 grams per metric ton (g/t). These stockpiles are reported to contain up to 600,000 kg of PGMs (Interfax Mining and Metals Report, 2001b).

Areas Considered for Resource Development

Exploration activities for PGMs in Russia largely go unreported because Russian PGM data are treated as a state secret. Exploration activities by Western companies increased briefly after the fall of the Soviet Union in 1991. In recent years, however, Russian economic difficulties, lack of capital, and territorial disputes have increased the risk for exploration in Russia, and many Western companies have withdrawn. Eurasia Mining Plc, largely funded by Anglo American Platinum, was known to be exploring for PGMs in the Ural Mountains. Kola Mining Company was exploring for PGMs in the Kola Peninsula.

USGS estimates for Russian PGM resources were derived from an analysis of individual mine data, focusing on the relative distribution of various ore types. Based on this analysis by the USGS, approximately 14 Mkg of PGMs, including inferred resources, was estimated (table 4). The estimate focused on the Noril'sk area but included other areas with significant PGM potential, such as the Pana tundra intrusion in the Murmansk region of the Kola Peninsula and the Kursk magnetic anomaly (KMA) in the Ural Mountains. PGM resources at Pana reportedly contained 1.04 Mkg of PGMs with grades reported to reach 17.4 g/t (Interfax Mining and Metals Report, 2001a). In 2001, Russian geologists assessed the possibility of putting the eastern Pana section into commercial production; drilling at the property continued in 2002. The KMA intrusion was reported to contain an additional 0.2 Mkg of PGMs (Kushnerenko, 2002).

TABLE 4

Although most of the PGMs recovered in Russia were from nickel-copper sulfide ore deposits associated with the Noril'sk-Talnakh complex, the potential existed to recover additional PGMs from PGM placer deposits of the Russian far east and the Ural Mountains. Platinum accounted for about 90 percent of past production of PGMs from these sources. After platinum, iridium was generally the most common PGM from Ural Mountains placers, accounting for up to 10 percent of the PGM content of these deposits (Roskill Information Services Ltd., 1999, p. 49).

Production and Capacity

MMC Noril'sk Nickel produces more than 95 percent of the country's PGM (Bond and Levine, 2001). The Russian Government has treated production data for PGMs as a state secret since 1995 (although a new law, signed November 11, 2003, was expected to make Russian PGM production and trade data available by March 2004. Release of these data has since been delayed to June 2005.). It is known, however, that the Oktyabrskiy mine at the Noril'sk complex accounted for almost 60 percent of PGM production in 1999, the Komsomolskiy underground mine accounted for more than 15 percent of PGM production from the Noril'sk region, the Taymirskiy underground mine accounted for more than 10 percent, and the Zapolyarniy underground mine accounted for more than 7 percent of Russian PGM production in 1999 (Piven', Konovalov, and Shtern, 1999). Figure 3b shows Russian production of palladium, platinum, and other PGMs from 1987 to 2001. Table 4 reports estimates for Russian PGM production in 2000 by mine.

Johnson Matthey Plc reported Russian PGM purchases in 2001 of 40,400 kg (1.3 Moz) of platinum, 135,000 kg (4.3 Moz) of palladium, and 3,900 kg (125,000 oz) of rhodium (Johnson Matthey Plc, 2003b). Although these values are significantly larger that those assumed for this study (as listed in table 4), a sizeable portion of these are believed to be attributable to the sale of Russian PGMs from stockpiles maintained by the Government, which are not included in the USGS analysis. Johnson Matthey reported that for the period from 1994 to 1999, about one-half of the total sales of palladium came from these stockpiles. Russia also is reported to have sizeable stockpiles of platinum.

The nickel-copper deposits of Noril'sk are likely to continue to supply significant quantities of byproduct PGM well into the future. Even with plans to increase production capacity, known resources are sufficient to provide the Noril'sk operation for about 200 years at current production levels (Yakubchuk and Edwards, 2002). In terms of ore type, current work by the USGS suggests that Noril'sk nickel-rich ore could sustain production for about 20 years at projected levels; cuprous ore resources are estimated to last 59 years; and disseminated ore (assuming recovery capability is developed) would last 172 years (Estimates are based on 2003 prices and technology.). In addition, tailings and pyrrhotite concentrate stockpiles accumulated since the 1930s also constitute a large low-grade resource.

Record price increases of palladium in the year 2000 were attributed by Johnson Matthey Plc to have resulted from uncertainties of Russian palladium supply. Significant palladium stockpile sales are believed to have taken place during the period from January to March 2001, at a time when the price for this commodity reached a peak. Palladium prices dropped significantly during 2002, so a sizeable amount of Russian palladium was stockpiled in an effort to reduce the effects of the falling palladium price. One estimate of the Russian palladium stockpile at the end of 2002 was about 25,000 kg (800,000 oz) (Helmer, 2004). Because the quantity of PGM in Russian stockpiles, like production data, have been treated as a state secret, there is considerable uncertainty as to how much or when material will be released from Russia into world markets. Recent legislation allowing for the declassification of Russian PGM data does not include stocks held by the central bank and the state repository. The United Nations believes that Russian palladium formerly held in stockpiles is being used by Western banks as collateral for loans (United Nations Conference on Trade and Development, 2002).

Russian placer PGM deposits have long been a source of significant PGM production. Estimates used in this study assume a production rate of about 10,000 kg/yr of PGMs; there is little information to suggest that this will change dramatically in the near future. Russian production comes from the Russian far east, Siberia, and the Ural Mountains.

Projected production of PGMs in Russia is shown in figure 5b. Russian palladium production capacity for the period from 2000 to 2010 also is shown in figure 6, which provides details of anticipated production start-ups and capacity increases.

FIGURE 5

FIGURE 6

In 2001, MMC Noril'sk Nickel oriented their development strategy toward maximizing nickel and PGM production, rather than just nickel, because much of the remaining resources of the Noril'sk complex are richer in PGM relative to nickel and copper than some ores that were previously mined (Richard Levine, U.S. Geological Survey, oral commun., 2002). Modes of occurrence and composition of PGM in different ore types vary significantly throughout the Noril'sk region. Although the average palladium-to-platinum ratio of Russian sulfide ores is reported to be 3.15 to 1, shifting production between different ore types can significantly impact PGM production (Bond and Levine, 2001). The board of directors of Noril'sk Nickel approved a 15-year plan of production in March 2003. The plan called for maintaining total production at Noril'sk at about 14 million metric tons per year of ore (Mt/yr). The company planned production based on a short-term ore distribution of 54 percent from nickel-rich ore, 35 percent from cuprous ore, and 11 percent from disseminated ore (MMC Noril'sk Nickel, 2003).

Two mines, Glubokiy and Skalistyy, that contain nickel-rich ores with a high PGM content (estimated to be 10.8 g/t PGM) may be developed during the 15-year period. A further increase in PGM production could be derived by increased production of disseminated ores (with an average PGM content of about 9 g/t) at the Medveziy Ruchey and Zapolyarnyy mines (Bond and Levine, 2001). If all these plans come to fruition and PGM markets are favorable for new developments, then Russian PGM production likely could increase by about 49 percent to 178,000 kg from the 2000 level level by 2010 (table 4).

Drivers and Constraints of PGM Supply

The ability of Russia to meet its PGM supply contracts depends not only on its ability to produce these products economically, but also on the political environment within which its PGM industry operates. The industry is affected by the extent of control the Russian Government imposes on the sale of its output. Since 1991, the Government has increasingly controlled PGM export trade and stockpile releases. Clause 19 of the 1991 Russian budget law stipulated that only authorized state agencies would be allowed to export platinum. Until the law was amended at the end of 1999 to allow company sales, Noril'sk Nickel MMC was prevented from selling any of the platinum outside of Russia. No Russian platinum stockpile exports were reported for 2000.

These Government policies and the uncertainty about Noril'sk Nickel being able to control its own production and exports have raised doubts about the company's ability to get the foreign investment capital necessary to implement the capacity increases called for in its development plan. In general, palladium production and sales are less severely regulated than platinum production and sales. Therefore, it may be possible for Norilsk Nickel to use its palladium stockpiles as collateral for loans (Mining Journal, 2002). Noril'sk's development plan to 2010 was used in this study to generate the timetable and quantity of Russian PGM supply. Recent data suggest that development is progressing, but perhaps not at the speed originally envisioned. Future events may further shape the ability to implement such plans. The sometimes uncertain nature of Russian PGM supply becomes important when assessing the accuracy of future world supply projections because Russian platinum and palladium supply is second only to that of South Africa (when stockpiled material is excluded).

Canada

Primary Resources

Most of the PGMs produced in Canada are byproducts of nickel mining. The only primary source of PGMs comes from North American Palladium, Ltd.'s Lac des Iles mine, which began production in 1993 as an open pit mine that produced a concentrate rich in palladium but also contained platinum and small amounts of base metals. Further exploration in the area is being carried out to define resources of similar occurrences. Although the average PGM grade at Lac des Iles is relatively low, generally less than 2 g/t, the PGMs are not confined to a narrow reef as found in South Africa but occur throughout extensive areas of mineralization close to the surface. This makes it possible to mine the deposit using low-cost, open pit mining techniques (Johnson Matthey Plc, 2001, p. 20).

Byproduct Resources

PGMs are recovered in Canada by Inco, Limited and Falconbridge Limited as byproducts from the mining and processing of nickel-copper ores. Most Canadian PGMs are recovered from nickel-copper ores mined in the Sudbury Basin in central Ontario, although small amounts are produced from Inco's nickel operations in Thompson, Manitoba, and Falconbridge's Raglan nickel-copper mine in Quebec. The typical palladium-to-platinum ratio associated with Sudbury ores is 1.16 to 1 with minor amounts of other PGM included in the ore (Inco, Limited, 2001, p. 42).

Inco, Limited continues to be a leading PGM producer in Canada, reporting deliveries attributed to Canadian operations of approximately 7,000 kg palladium, 5,900 kg platinum, and 500 kg of other PGMs in 2002. Inco's mining operations send concentrates to the Copper Cliff complex in Ontario for initial processing; the concentrates are then shipped to Inco's PGM refinery in Acton, United Kingdom. The Lac des Iles mine of North American Palladium Ltd. produced approximately 11,000 kg of palladium in 2002. Falconbridge Limited contributed about a small amount of Canadian PGM production from byproduct production from the Raglan nickel-copper mine in Quebec and byproduct production from the Sudbury basin nickel-copper mines, although production figures are not published. Falconbridge ores are concentrated at the Strathcona mill, transported to the Falconbridge smelter where nickel-copper matte is produced, then shipped to the company's facility in Norway for refining and PGM recovery (Fogg and Cornellisson, 1993, p. 16).

The Raglan nickel-copper mine began operations in 1998. The palladium-to-platinum ratio in the Raglan ore is estimated to be about 3 to 1 (Johnson Matthey Plc, 2001, p. 19). Raglan concentrate is shipped to the company smelter at Sudbury; initial matte is shipped to the company's refinery in Norway where nickel, copper, PGMs, and other metals are recovered. Falconbridge is reported to have the capacity to produce up to 500 kg/yr of platinum and 1,100 kg/yr of palladium (Metals Economics Group, 2000), although actual production levels are much lower.

In addition to PGM recovery from nickel-copper operations, limited amounts of PGMs are recovered from materials imported by the CCR Division of Noranda, Inc. in Montreal, Quebec, and at the nickel refinery of Sherritt Gordon Mines Limited at Fort Saskatchewan, Alberta. Noranda also recovers PGMs from domestic and imported scrap. As with Canadian production by Inco and Falconbridge, this material is refined in Europe (McCutcheon, 1996, p. 45.2-45.3).

Areas Considered for Resource Development

The search for Canadian PGMs has perhaps been the most intense in and around the Sudbury Basin. Since 2000, there has been a marked increase in exploration for PGMs in producing areas of Ontario and areas with no recorded PGM production; this increase in exploration is driven by higher

PGM prices and the commencement of operations at the Lac des Iles mine. Although much exploration is ongoing, based on the current status of exploration and other supply factors, production of PGM from new Canadian sources will be limited to the extension of existing production sources prior to 2010. A brief discussion of Canadian PGM exploration activity is given in the appendix.

Much exploration takes place in areas adjacent to current production. For example, Inco Limited discovered a new PGM-rich zone at its Copper Cliff North nickel mine in Ontario and brought this zone into production in the last quarter of 2000. Exploration continued in 2003, as the deposit was still "open" at depth. Reevaluation of known nickel-copper mining areas for PGMs has also led Inco Limited to identify high-grade PGM mineralization at the McCreedy East copper-nickel mine and a new resource with high precious-metal content at Pump Lake near the Copper Cliff North mine. Development continued on PGM-rich zones discovered in 2002-03 at the Totten nickel-copper mine and the Creighton Deep project, with an expected production after 2002 of 10,900 metric tons per year (t/yr) of nickel, 9,500 t/yr of copper, and 870 kg/yr of PGM (Inco Limited, 2001).

Production and Capacity

Canadian PGM production in 2002, based on reported production and production estimates, amounted to approximately 18,000 kg of palladium, 10,000 kg of platinum, and 500 kg of other PGM. Palladium production increased by about 25 percent from the 2001 level and platinum production increased by about 8 percent from the 2001 level. Canadian PGM production from 1987 to 2002 is shown in figure 3c.

Current PGM capacity from Canada is derived primarily from nickel-copper mines in the Sudbury Basin. Inco Limited recovers PGM from nickel or copper matte at its refinery in the United Kingdom, while Falconbridge Limited recovers PGM from a nickel-copper matte at its refinery in Norway. Although PGM capacities of these refineries are rarely reported, current and future PGM capacities were developed based on the reported nickel production capacity for the mines, announced expansions, expected recoveries, and knowledge of PGM content in the ore. The expansion of Inco's Creighton Deep copper-nickel mine in 2001 and 2002 was included in this study's PGM capacity projections. Development of new ore zones at the Totten copper-nickel mine by 2005 is also planned, but no capacity information has been released.

North American Palladium Ltd.'s Lac des Iles PGM mine completed an expansion in 2001 and reached about 83 percent of its new full production capacity level of about 700 kg/yr of platinum and 7,800 kg/yr of palladium in 2002 (North American Palladium Ltd., 2003). In 2001, the discovery of a new high-grade zone at depth below the open pit resource supported the possibility of future underground production (North American Palladium Ltd, 2001).

Drivers and Constraints of PGM Supply

Partially because of recent higher PGM prices, a well-documented, comprehensive national minerals policy, and legislative and financial incentives for mineral exploration and development, exploration for PGMs has increased in recent years and reevaluation of known mineralized areas for PGMs is ongoing. Results from the Ontario Government's 1999-2001 Operation Treasure Hunt identified areas with high PGM mineral potential (Natural Resources Canada, 2002). Much of this exploration work is at an early stage, but several areas of significant PGM potential have been identified.

While the Canadian Government generally is supportive of mining, social and environmental issues weigh heavily on mineral development policy decisions. Because of renewed interest in exploring for mineral deposits in the three northern Canadian territories, Canadian mineral policy provides for the integration of sustainable development concepts into Federal decisionmaking and promotes aboriginal involvement in minerals- and metals-related activities (Natural Resources Canada, 1996). The Canadian Government provides provincial jurisdiction over mining and limits Federal involvement to core Federal responsibilities in the areas of scientific research, global markets and trade, and regulatory and nonregulatory environmental protection. Government-supported collaboration between the mining industry and indigenous communities is encouraged, so that mineral development is most successful if involvement of First Nations (designation for Canadian indigenous populations) has been secured at an early stage. Delays in the development of the Voisey's Bay nickel/copper deposit, with the potential to recover about 62,000 kg of platinum and 62,000 kg of palladium, illustrates the importance of addressing environmental, social, and technological issues in minerals policy decisions and illustrate how competing interests can affect mineral development (Cawthorn, 1999).

United States

Primary Resources

U.S. PGM production comes from the Stillwater Complex near Nye, Mont. In 2003, following U.S. Federal Trade Commission concurrence, MMC Noril'sk Nickel purchased 51 percent interest in Stillwater Mining Company, which operated the Stillwater and East Boulder mines (with an option to increase its interest to 55 percent). The Stillwater Complex is an igneous layered intrusion that is geologically similar to the Bushveld Complex. The reserves of the Stillwater Complex are found in the Johns-Manville (J-M) Reef, which contains PGM grades averaging about 20 g/t and a typical palladium-to-platinum ratio of slightly more than 3 to 1. As of December 31, 2002, Stillwater Mining Company reported proven and probable reserves of 25.3 Moz of PGMs with an additional delineated resource of 67 Moz of PGMs (Stillwater Mining Company, 2002, p. 8). Resources for the East Boulder mine, which began production in 2002, have been included in this resource estimate.

Areas Considered for Resource Development

The J-M Reef has been drilled to a depth of about 1,800 m, but geologic and geophysical evidence suggests that it continues downward and perhaps flattens to the north. The higher grades and thicker zone of mineralization make the deposit amenable to higher extraction rates and lower underground production costs than the Bushveld mines. Even so, the high-grade ore is not continuous throughout the J-M Reef (Dyas and Marcus, 1998).

Projected production of PGMs in the United States is shown in figure 5d. Possible production by 2010 may come from the Duluth Complex in Minnesota (Polymet Mining Corporation’s NorthMet operation) where a bankable feasibility study was recently completed (Polymet Mining Corporation, 2001).

Production and Capacity

Current PGM production is achieved from two mines (Stillwater and East Boulder) in the Stillwater Complex. During 2002, the Stillwater Complex produced approximately 11,800 kg (379,000 oz) of palladium and 3,500 kg (113,000 oz) of platinum, compared with approximately 12,100 kg (388,000 oz) of palladium and 3,600 kg (116,000 oz) of platinum in 2001. The East Boulder mine commenced production in 2002 and produced 3,000 kg (97,000 oz) of palladium and 900 kg (28,000 oz) of platinum in 2002 (Stillwater Mining Company, 2002, p. 8). The East Boulder mine was scheduled to reach its full production capacity of 14,000 kg/yr (450,000 oz/yr) of palladium and platinum by 2006. PGM production from the United States from 1987 to 2001 are shown in figure 3d.

Drivers and Constraints of PGM Supply

Environmental concerns and high operating costs are likely to be among the greatest constraints to future PGM growth in the United States. While the potential exists for further discovery of PGM resources in Alaska, Arizona, Minnesota, and Montana, mine development of resources from new projects is uncertain within the next 10 years because of the uncertain economic value of current prospects and lengthy environmental evaluation process.

Zimbabwe

Primary Resources

Zimbabwe's Great Dyke has long been recognized as a potentially significant source of primary PGMs. The Great Dyke is an igneous intrusion that extends about 550 km through central Zimbabwe. PGMs occur in a layer known as the Main Sulfide Zone, which is typically about 5 m thick. The width of the ore zone can be as little as 1 m, depending upon geology, grade, metal prices, and the chosen mining method. PGM content is typically lower than that of South African ores with head grades generally below 4 g/t, of which about 55 percent is platinum (Johnson Matthey Plc, 2001, p. 21). Economic, geologic, or political factors have tended to limit growth of the PGM industry in Zimbabwe in the late 20th century.

Areas Considered for Resource Development

By the start of the 21st century, prospects for growth appear to have increased as technological advancements may improve recovery amounts of PGMs from Great Dyke resources. At the end of 2003, two mines, Mimosa and Ngezi, were producing in Zimbabwe, and several more were undergoing development or being considered for development. The Mimosa mine contains a yearend 2002 reserve base (measured plus indicated resource) of 432,000 kg of PGMs and gold (Aquarius Platinum Limited, 2002b). The reserve base at Ngezi as of yearend 2002 was reported to be 1.84 Mkg of PGMs and gold (Zimbabwe Platinum Mines Limited, 2002). The Mhondoro development project has a reserve base of 478,000 kg of PGMs, plus copper, gold, and nickel (Zimbabwe Platinum Mines Limited, 2002). Other possible resources include the Hartley mine with a reserve base of 711,000 kg of PGMs, the Selous area to the northeast with a reserve base of about 227 kg of PGMs and gold, and the Unki project with a reserve base of 242,000 kg of PGMs and gold (Anglo American Platinum, Ltd., 2002; Zimbabwe Platinum Mines Limited, 2002).

Production and Capacity

At the turn of the 21st century, the small Mimosa mine was Zimbabwe’s only primary PGM producer. In 2002, the 6,100 kg/yr (195,000 oz/yr) Ngezi PGM mine began production (Zimbabwe Platinum Mines Limited, 2001). Production of PGMs in Zimbabwe for 2002 was approximately 6,200 kg of PGMs (200,000 oz) from the two sites, although both sites were reportedly undergoing capacity expansions.

An expansion of the producing Mimosa mine to 4,200 kg/yr (135,000 oz/yr) of platinum was completed at the end of 2003. A second expansion was planned for 2005 if conditions warranted the expansion (Aquarius Platinum Limited, 2002a). The Ngezi mine was scheduled to reach initial capacity in 2003 with a possible doubling of capacity by 2006. A third possible site of PGM production in the near future was Anglo American Platinum Ltd.'s Unki project. Anglo American Platinum announced plans to develop the 1,800 kg/yr (58,000-oz/yr) platinum mine in 2003. Also in 2003, Impala Platinum was finalizing plans to acquire Zimbabwe Platinum Mines, which owned the rights to the Mhondoro project and nearby Hartley mine, which closed in 1999. The Hartley mine, which had a full production capacity of about 4,600 kg/yr (150,000 oz/yr) of platinum, 3,400 kg/yr (110,000 oz/yr) of palladium, and 400 kg/yr (11,500 oz/yr) of other PGMs and which produced briefly in the mid-1990s, was reported by the company to be on a care-and-maintenance basis. Because of its high production costs, there are no plans to reopen the Hartley mine while PGM prices are near 2003 levels.

Drivers and Constraints of PGM Supply

Future mineral development in Zimbabwe is linked to the political situation in that country, which has been fragile in recent years. The Zimbabwean Government has proposed a new, more favorable tax regime for PGM mines to provide the stimulus for new investment. If social unrest is eliminated and regional economy stabilized, development in the region may proceed at a faster rate than that projected in this analysis. Investment in the platinum industry has been one of the highlights of the Zimbabwean economy in the early 2000s.

As with South Africa, the debilitating nature of HIV/AIDS and its high death rate could significantly affect production and worker productivity. This disease could also affect the rate of expansion proposed for the mining industry prior to 2010.

Other Resources and Areas Considered for Development

The following discussion outlines other areas where there is or may be PGM production by 2010. The appendix provides a more detailed discussion of other possible resources as defined by recent exploration.

Asia

China

The only production of PGMs in China is believed to be as a byproduct of nickel mining at the Jinchuan nickel-copper mine in Gansu Province. The Jinchuan deposit reportedly contains resources of 276,000 kg (8.9 Moz) of platinum; 108,000 kg (3.5 Moz) of palladium; 12,400 kg (400,000 oz) each of ruthenium, iridium, and osmium; and 6,200 kg (200,000 oz) of rhodium (Roskill Information Services, Ltd., 1999, p. 35). The Jinchuan facility is reported to produce about 2,000 kg/yr (64,000 oz/yr) of PGMs as of 2003 (Engineering and Mining Journal, 2003).

India

Despite reports of PGM discoveries and exploration programs during the last 20 years, no primary production of PGMs is credited to India. Minor byproduct palladium is reported at the Ghatsila copper facility, but output of PGMs in India is not believed to be substantial.

Japan

Japan produces refined PGMs from imports and secondary sources, but does not report production from domestic mining activities.   In 2000, approximately 5,000 kg (161,000 oz) of palladium and 800 kg (26,000 oz) of platinum metal were recovered in Japan, primarily from imported nickel and copper matte. This material was not included in supply analysis in order to avoid double accounting.

Europe

Finland

The USGS reported Finnish production figures of approximately 500 kg/yr (16,000 oz/yr) of platinum and 150 kg/yr (5,000 oz/yr) of palladium derived primarily from domestic nickel-copper production and imported material recovered at the Harjavalta refinery (Kuo, 2004, p. 10.3). Of this, about 100 kg/yr (3,000 oz/yr) of PGM, which was produced from the Hitura nickel-copper mine in western Finland, was included in the PGM production capacity figures reported in this analysis.

Serbia and Montenegro

The USGS reported that up to 10 kg/yr of platinum and 50 kg/yr of palladium have been produced since the 1990s from copper operations in Serbia and Montenegro, although production has been halved since 1998 owing to the social strife in the area (Steblez, 2001, p. 36.4). For the period of this study, it is assumed that PGM production capacity will remain at the lower level of 5 kg/yr of platinum and 25 kg/yr of palladium.

Spain

Rio Narcea Gold Mines, Ltd. has begun construction on the Aguablanca nickel-copper-PGM project in southwestern Spain. The deposit, which occurs in the Santa Olalla plutonic complex, was originally evaluated in the mid-1990s for its nickel and copper. Development was planned to be completed by 2006 with PGM production capacity of about 20,000 oz/yr (Rio Narcea Gold Mines Ltd., 2003).

Latin America

Brazil

Brazilian PGM production is derived primarily from the Fortaleza nickel-copper-PGM-gold mine, which in 1997 began production of 10,000 t/yr of nickel matte that contained PGMs. The nickel matte is exported to the OM Group Inc. Harjavalta nickel refinery in Finland for PGM recovery. Reserves are reported to contain 7,300 kg of PGMs (Roskill Information Services Ltd., 1999, p. 29). Caraiba Metals S/A Camacari copper refinery in Brazil is also reported to produce 150 kg/yr of platinum and 400 kg/yr of palladium. Recovery of PGMs from other copper deposits in Brazil has been proposed, but to date none of these projects have come to fruition.

Colombia

Colombia has produced PGMs since the 16th century. PGM production in Colombia, primarily platinum, is derived from alluvial placer deposits worked by artisanal miners. In some places, the deposits are associated with the production of gold. Colombia produced about 430 kg of PGMs in 1998, 310 kg of PGMs in 2000, and 650 kg of PGMs in 2001 (Torres, 2004). Production is sporadic but was reported to have reached almost 2,000 kg in 1992. For this study, an average of the past 5 years of reported production was used as an estimate of annual PGM production. Colombia ranked sixth among the world's leading platinum producers in 1999 (Doan, 2001, p. 8.3).

Pacific Region and Southeast Asia

Australia

Although small amounts of PGMs have been reported in placers and associated with gold quartz veins in Queensland and several Proterozoic layered ultramafic deposits in Western Australia, virtually all Australian PGM production has been limited to byproduct production from the Kambalda nickel operations in Western Australia. Ores contain about 1 g/t total PGMs with palladium being the dominant metal of the group. Slightly more than 100 kg/yr (3,200 oz/yr) of platinum and 400 kg/yr (13,000 oz/yr) of palladium are recovered from the operations (Smart and Garrad, 1999). Approximately 56 kg (1,800 oz) of platinum and 220 kg (7,000 oz) of palladium are estimated to be contained in nickel matte exported to Canada and Finland for processing.

In 2003, 13 companies were exploring for PGMs in Australia. Properties with some PGM potential that may be developed in the short term include the Panton deposit, a Bushveld-type deposit in the Kimberly region of Western Australia, which contains chromite seams that have an indicated resource of 57,700 kg of platinum and palladium and a dunite rock that has an indicated resource of 35,000 kg of platinum-palladium (Platinum Australia Limited, 2002a, p. 7; 2003, p. 5). Platinum Australia Limited has proposed a 2,100 kg/yr PGM operation at the site. Black Range Minerals Ltd. has proposed to recover approximately 300 kg/yr PGMs from its Syerston nickel laterite project, which has a reported resource that contains 31,100 kg of platinum (Black Range Minerals Ltd., 2000). Initial plans call for production of about 150 kg/yr of platinum by 2005, although it appears there has been some delay owing to lower nickel prices during 2001. Subsequent addition of a magnetic recovery circuit would increase capacity to 460 kg/yr; for this study, it has been assumed that such a circuit would be added by 2008. Helix Resources Limited is investigating the feasibility of recovering PGMs from the Munni Munni deposit, a Bushveld-type intrusive in Western Australia with an indicated resource that contains 58,500 kg of PGMs (Helix Resources Limited, 2002). Lonmin Plc. of South Africa provided funding for the Panton and Munni Munni ongoing feasibility studies but withdrew from the Munni Munni joint venture in 2003. While no firm development plans have been announced, a project start-up date of 2006 has been assumed for Panton and 2008 for Munni Munni for this study.

Philippines

Reevaluation of the Acoje mine in the Philippines for PGMs continued in 2002 with drilling to upgrade reported resources that contain 24,000 kg of PGMs (Rusina Mining Ltd., 2002). The mine operated from 1935 to 1991 and produced more than 3,300 kg of chromium concentrates. It is possible that there could be production from this site prior to 2010, but because no production schedule has yet been determined, this potential site has not been included in the capacity forecast.

Vietnam

To date, minor amounts of PGMs have been identified in the Ban Phuc nickel-copper deposit in Vietnam. The deposit is associated with the Ta Khoa ultramafics but contains lower grades of PGMs than would normally be expected in such an association.

Drivers and Constraints of Supply from Other Areas

Native title (related to aboriginal people groups) issues have affected the PGM industry in Australia significantly, preventing exploration and development activity in certain areas and delaying the approval of exploration titles and permits. Native title claims must be resolved before development can proceed; Development of the Munni Munni, Panton, and Syerston deposits have been delayed to allow for the evaluation of native title claims.

Platinum Australia Limited is reportedly developing a new metallurgical recovery process that would produce a PGM concentrate suitable for direct-sale to PGM refineries, bypassing the need for smelters. The process involves flotation, low-temperature calcination, leaching, and precipitation, all unit processes currently in use in the Australian gold industry. Transportation to a smelter would not be required, so lower total processing and transportation costs are expected. The process is planned for the company's Panton project in Western Australia. Such a process could be used to treat other similar PGM ores and may be applicable to smelter concentrates from ores that have previously proved difficult to treat (Platinum Australia Limited, 2002b). Use of this technology is being evaluated at the Murrin Murrin nickel-cobalt project in Australia and the Phoenix copper-nickel mine in Botswana among others.

Secondary PGM Supply—Recycling

Secondary materials are a significant and readily available domestic source of PGMs, primarily platinum, palladium, and rhodium, and serve to mitigate U.S. dependence on supply from primary sources. The leading secondary sources of PGMs are spent automotive catalytic converters and electronic scrap. Other sources are spent chemical-process and reforming catalysts and equipment used in the manufacture of glass. These materials are broadly categorized as "old scrap."

There are two other broad classifications of scrap from which PGMs are recovered, but which are generally not included in secondary material statistics; these are "home scrap" (includes byproduct material produced during manufacturing, such as casting scrap) and "new scrap" (includes cuttings and trimmings and new material that is off-specification). These materials are usually reinserted promptly into a melt at the point of their generation and are not considered part of the secondary material market.

Among common secondary sources of PGMs, only spent automotive catalytic converters and electronic scrap are significant. Indeed, little statistical information is available on recovery of PGMs from other secondary sources. Used chemical-process catalysts and reforming catalysts are almost always recovered, and small amounts of platinum jewelry are recycled, particularly when platinum prices are high and/or during periods economic slowdowns, but these are not significant sources of PGM recovery.

Automobile catalysts (autocatalysts) are the leading “old scrap” source for recovery of PGMs. When compared to world platinum production, platinum recovery from autocatalysts ranks third after South African and Russian mining operations and is the fourth leading source of palladium after South African, Russian, and North American mining operations. Recovery of rhodium from autocatalysts ranks second after South African mining operations.

FIGURE 7

Figure 7 shows the amount of PGMs recovered from recycled autocatalysts for the period from 1987 to 2002. In 2002, about 17,700 kg (570,000 oz) of platinum, 11,500 kg (370,000 oz) of palladium, and 3,100 kg (99,000 oz) of rhodium were recovered worldwide from autocatalysts (Johnson Matthey Plc, 2003b, p. 48-52). These amounts represent 10, 7, and 16 percent of total reported world supply, respectively. Another study prepared by a large catalytic converter recycler reported that about 22,000 kg (720,000 oz) of platinum, 10,100 kg (325,000 oz) of palladium, and 3,100 kg (100,000 oz) of rhodium were recovered worldwide from autocatalysts in 2002. For 2003, this source estimated that global recovery of PGMs from autocatalysts will total 23,000 kg (735,000 oz) of platinum, 12,000 kg (390,000 oz) of palladium, and 3,400 kg (110,000 oz) of rhodium (Ashok Kumar, Director, A-1 Specialized Services and Supplies, Inc., oral commun., 2003).

The United States is the world’s leading source of recovered PGMs. Approximately 11,500 kg (380,000 oz) of platinum and 8,100 kg (260,000 oz) of palladium were reported to have been recovered from autocatalysts in North America, primarily in the United States, during 2002 (Johnson Matthey Plc, 2003b, p. 48-52). Based on these estimates, the United States accounts for approximately 65 percent of the platinum and 70 percent of the palladium recovered worldwide from autocatalysts and met about 25 percent of total U.S. demand for platinum and 20 percent of U.S. demand for palladium. In addition, an estimated 2,200 kg (70,000 oz) of rhodium was recovered from autocatalysts in the United States in 2002, about 70 percent of such recoveries worldwide (Ashok Kumar, Director, A-1 Specialized Services and Supplies, Inc., oral commun., 2003).

Recovery of PGMs from autocatalysts has been steadily increasing during the past two decades and will continue to increase in the future. However, numerous factors complicate any estimate of the amount of PGMs that are generated from autocatalyst recovery in future years. Changes in regulatory requirements have added to the use of PGMs by increasing the number of cars equipped with autocatalysts and the use of PGMs in each car. Metal ratios change, primarily between platinum and palladium, as their prices change, and a trend of recovering more palladium than platinum will likely continue for a number of years because of the increased substitution of historically less expensive palladium for platinum. In 1987, the average platinum-to-palladium ratio in an autocatalyst was 2.3 to 1; in 1995, it was 2.9 to 1; but by 2002, the average ratio had decreased to 1.5 to 1. This suggests that platinum was favored over palladium in the late 1980s and early 1990s, but by 2002, palladium use had grown faster than platinum use. Voluntary and involuntary recalls of catalytic converters ordered by environmental enforcement agencies have resulted in unexpected supplies of catalytic converters to recyclers. Approximately 300,000 catalytic converters for model years 1991 to 2000 were recalled by the EPA (U.S. Environmental Protection Agency, 2003; Ashok Kumar, A-1 Specialized Services and Supplies, Inc., oral commun., 2003). Other factors that complicate autocatalyst recovery estimation include efficiency of collection, service life of vehicles, technological advances, and overall numbers and types of vehicles placed in service.

Historical trends indicate that the worldwide use of automobiles will grow. Almost all vehicles will be equipped with autocatalysts, which are likely to be recovered for their PGM content. When autocatalysts were first introduced in the 1970s, there was not yet an effective system of recycling infrastructure in place, and most PGMs were not recovered but instead were left in scrapped vehicles and melted with other steel scrap. Through the 1980s, however, more processors came online to process catalytic converters, and a secondary PGM "pipeline" was established. Johnson Matthey, Plc. reported that in 1984, approximately 1,400 kg (45,000 oz) of platinum and 600 kg (20,000 oz) of palladium were recovered through the recycling of catalytic converters. Since the early 1990s, the infrastructure for collecting and processing catalytic converters has improved significantly and losses have been greatly reduced. In 1993, about 7,900 kg (255,000 oz) of platinum, 3,100 kg (100,000 oz) of palladium, and 800 kg (25,000 oz) of rhodium were recovered. Recovery of platinum in 2002 was more than twice that of 1993, and recovery of palladium in 2002 was triple that of 1993 (Johnson Matthey Plc, 2003b, p. 48-52).

From 1980 to 2002, more than 1.1 Mkg (34 Moz) of platinum, nearly the same amount of palladium, and about 200,000 kg (6 Moz) of rhodium have been used in autocatalysts. These amounts can not be completely recovered. Some PGMs from autocatalysts are lost while the vehicle is in use. A World Health Organization study estimated that between 1.2 and 24 nanograms of palladium for each kilometer traveled could be dissipated to the environment from a catalytic converter (World Health Organization, 2002). Assuming the higher estimate of 24 nanograms dissipated to the environment per kilometer, an average distance of 20,000 kilometers per year traveled by an automobile in the United States, and a figure of 136 million automobiles registered in the United States in 2002, approximately 2,000 ounces of palladium are dissipated each year by automobile catalytic converter emissions. Losses that are more significant happen when the autocatalysts are never collected in a PGM recovery system. Some used automobiles are shipped to developing countries where collection and recycling infrastructures do not yet exist; thus their autocatalysts are not collected and recovered. Other PGM losses happen after collection, in recovery processing, even where a relatively efficient recovery system exists. There are losses from improper dismantling, poorly organized collection and transport of catalytic converters, decanning, and metallurgical processing (Hageluken, 2001). PGMs are also lost through metallurgical processing during recycling. These process losses can account for up to 25 percent of the original amount of PGMs available.

Notwithstanding those losses, estimates of future recovery of PGMs from autocatalysts are significantly higher than present recovery because more governments not only require that autocatalysts be used, but also that end-of-life motor vehicles be dismantled and recycled. These initiatives as well as market incentives will result in a more efficient collection system and a well-established worldwide recycling industry. It has been estimated that by 2007, assuming an average vehicle life of 10 years and collection into the recovery system of 50 percent, about 31,000 kg/yr (1 Moz/yr) of palladium could be recovered worldwide from recycled autocatalysts (Mineweb, 2003). Other estimates are significantly higher, as they assume 60 percent of available PGMs were collected in 2003 and about 70 percent will be collected by 2010 (Harler, 2003).

Based on data analyzed for this study by the USGS, it is estimated that more than 41,800 kg (1.3 Moz) of platinum, 98,200 kg (3.2 Moz) of palladium, and 10,800 kg (350,000 oz) of rhodium could possibly be recovered worldwide in 2010 through secondary recovery of PGMs from catalytic converters (figure 8).

FIGURE 8

To accommodate the increased supply of secondary PGMs recovered from catalytic converters, it is likely that an expansion of processing capacity will be necessary. PGM mining companies will probably diversify, as copper companies have, by accepting material from secondary sources. In 2003, for example, Stillwater Mining Company announced that the Montana smelter and refinery would receive autocatalysts from automobile repair shops and dismantling facilities (PRNewswire-FirstCall, 2003). As the recovery of PGMs from recycled motor vehicles increases, PGM use for autocatalysts derived from in-place ores may decline and result in improved resource utilization, which is a goal of resource sustainability. This also may result in a shift in the location of significant production, which is an important factor for security of supply for the United States, which relies on imports to meet over 90 percent of the country's apparent consumption of platinum.

The other significant category of secondary materials from which PGMs are recovered is electronic scrap, such as circuitry boards, computer hard disks, and other electronic components. Statistics on the amounts of PGMs recovered from these secondary materials are not widely available because such data are not published by refiners, but Johnson Matthey has reported that about 7,500 kg (240,000 oz) of palladium were recovered worldwide from electronic scrap in 2002 (Johnson Matthey Plc, 2003b, p. 50). Thus, PGMs recovered from electronic scrap represent the second leading source of all recycled PGMs.

Future recovery rates are likely to be higher with better electronic scrap collection methods and labeling of components, enactment of legislation barring the disposal of electronic equipment in municipal landfills, standardization of design permitting less costly dismantling, and other factors. The use of PGMs in electronic equipment, however, may be lower, which could lead to lower overall recoveries of the metal. Manufacturing companies strive to reduce cost by using less precious metal through substitution and miniaturization in electronics components, a strategy that has met with success during the past several years. For example, the amount of palladium recovered in 2002 dropped to 7,500 kg (240,000 oz) from the 2000 level of 10,600 kg (340,000 oz)(Johnson Matthey Plc, 2001, 2003b), possibly owing to the increased substitution of other metals such as nickel or platinum for palladium when the palladium price rose dramatically in 2001.

Published estimates for recovery of PGMs from electronic scrap in 2003 range from about 9,300 kg (300,000 oz) of palladium, nearly 3,100 kg (100,000 oz) of platinum, and minor amounts of rhodium, up to 20,000 kg (650,000 oz) of palladium and 4,700 kg (152,000 oz) of platinum (CPM Group, 2003, p. 111; Harler, 2003). The 2003 estimate for this report uses the average of those two estimates rounded to two significant digits—15,000 kg (480,000 oz) of palladium and 3,900 kg (126,000 oz) of platinum.

Looking further into the future, one analyst estimated that approximately 31,100 kg (1 Moz) of palladium may be recovered from electronic scrap in 2008 (Harler, 2003). Estimates of PGM recovery in the future are complicated by the need to consider such factors as the consumer demand and useful service life of electronics (currently about 3 to 4 years), materials used, and effectiveness of collection, separation, and recovery of materials. Although less likely for the period considered, the overall use of PGMs may decrease substantially if new technologies are developed that include substitution by other materials and/or if demand for electronics dramatically decreases. Notwithstanding those complications, the authors estimate that in 2010 about 34,200 kg (1.1 Moz) of palladium and nearly

9,300 kg (300,000 oz) of platinum could be recovered through secondary treatment of electronic scrap. These rough estimates are based on published data and the average estimated ratios of platinum to palladium recovered in 2003 (which could change in future years for numerous reasons). An estimate for other PGMs was not made because of insufficient information.

It is possible that PGMs could be recycled from fuel cells, should that technology come widely into use. If fuel cell technology eventually plays a major role in displacing the demand for internal combustion engines, then the PGMs, primarily platinum, in fuel cells would likely be a candidate for recycling.

PGM Supply From 2002 to 2010

Based upon reported industry plans and USGS estimates, platinum production capacity is estimated to grow to approximately 281,000 kg in 2010 from about 192,000 kg in 2002, a 46 percent growth for the 8-year period. The figure does not include material from secondary (recycled) sources. Much of this growth can be attributed to expansion of the industry in South Africa (resulting in a 54,000 kg capacity increase) as well as the sizeable growth in platinum production capacity in Zimbabwe (11,000 kg capacity increase), Russia (10,000 kg capacity increase), and the United States (8,000 kg capacity increase). New projects in Australia and Finland contribute to further growth. Figure 5 shows projections for palladium, palladium, and rhodium in selected regions for the period 2002 to 2010.

Production capacity for palladium is estimated to grow by about 55 percent to about 289,000 kg from about 186,000 kg during the 8-year period. Based on reported industry plans and USGS estimates, South African palladium production capacity is projected to grow by approximately 32,000 kg during the period, and Russian palladium production capacity would grow by 31,000 kg. Palladium capacity in the United States would grow by 18,000 kg over the 8-year period, and the palladium capacity in Zimbabwe would grow by 7,000 kg., assuming company growth plans hold true. Significant growth also is projected for Australia, assuming projects presently at the feasibility stage come into production.

Production capacity for other PGMs is estimated to grow by about 24 percent to about 75,000 kg from about 60,000 kg during the 8-year period. Based on reported industry plans and USGS estimates, most of the projected production capacity change would occur in South Africa (7,400 kg capacity increase) and Russia (4,500 kg capacity increase). Other areas with the potential for change include Australia, Canada, China, the United States, and Zimbabwe, assuming projects come online as envisioned.

PGM End Use

PGM use consists of two components, the amount purchased by consumers and the amount available in inventories. Because data on the amount available in inventories are often not reported, the amount purchased by consumers is used as a proxy for its use. The end use figures developed for this analysis are based on the amounts purchased by consumers as reported by Johnson Matthey Plc. A brief review of the historical data of PGM purchases can provide a framework for projecting end use patterns into the future, if inventory levels are taken into account. Figure 9 shows regional purchases by consumers for platinum, palladium, and rhodium for the period from 1987 to 2002; data are derived from estimates of Johnson Matthey Plc.

FIGURE 9

In 1900, the United States used approximately 2,560 kg of PGMs (based on apparent consumption data), of which domestic production accounted for less than 0.5 percent. By 2000, however, domestic apparent consumption of PGMs had increased to nearly 500,000 kg and domestic production had grown to 13,400 kg (Kelly and Hilliard, 2003). Domestic production in 2000 accounted for about 2.7 percent of U.S. apparent consumption of PGMs. About 55 percent of U.S. platinum demand was met by imports from South Africa, and 44 percent of palladium demand was met by imports from Russia (Hilliard, 2003).

Much of the worldwide PGM production in the early 1900s was used for jewelry, and production and purchases were roughly equal; so inventories of PGMs were small. Much of the growth in worldwide PGM production took place after 1960, first driven by demand for these metals in oil refining, then by use in catalytic converters (Kelly and Hilliard, 2003). It was only in the latter part of the 20th century and early in the 21st century that relatively significant amounts of these materials resided in inventory stockpiles. In 2000, worldwide PGM production were reported at 365,000 kg (Kelly and Hilliard, 2003). Worldwide purchases of PGMs in that year, however, was reported at approximately 481,000 kg (Johnson Matthey Plc., 2003). This suggests that almost one fourth of the PGMs purchased by consumers in 2000 came from inventory stockpiles. Consequently, future end use projections need to consider both the pattern of consumer purchases and the pattern of inventory stockpiles, where possible.

Total platinum use doubled between 1987 and 2002. As shown on figure 9, much of this growth can be attributed to increased use in China and Europe, platinum use in Japan actually declined during this period. Total palladium use almost tripled between 1987 and 1999, but decreased by half between 1999 and 2002. The growth that occurred in North American palladium use between 1987 and 1999 was negated by a corresponding decline in palladium use between 1999 and 2002. Total rhodium use doubled between 1987 and 2002, with most of the growth occurring in China and Europe.

Causes for the apparent increase in PGM use, particularly during the last half of the 20th century, include advances in technology that provide for lower cost extraction of these metals from ores and byproduct recovery; expanded industrial applications for PGMs; increasing use of PGMs in jewelry in China, which is valued as a means of displaying wealth; and the impact of regulatory policies that require pollution abatement equipment (catalytic converters) for vehicles with internal combustion engines.

End Use by Sector

PGM end use is influenced by events and trends related to the various consuming sectors. The major end-use sectors are discussed below, in order of decreasing total purchases by consumers. Figure 10 summarizes purchases for platinum, palladium, and rhodium for each of the principal consuming sectors from 1987 through 2002.

FIGURE 10

Jewelry

In many societies, the jewelry worn demonstrates the status of an individual. Thus, demand for PGMs can change based on societal preferences and tastes regarding jewelry and its availability. The strength and luster of platinum make it a desirable metal for jewelry settings for diamonds and other precious stones because the white color of platinum tends to increase the sparkle and appeal of the gemstones. Jewelers find PGMs easy to work with while retaining the necessary strength and wear characteristics required of jewelry. The color and smooth lines of platinum jewelry are aesthetically pleasing to many. Since pure platinum is extremely soft, it is susceptible to scratching and marring. For jewelry applications, therefore, it is frequently alloyed with other PGMs to improve hardness. A typical alloy for jewelry castings is 90 percent platinum and 10 percent palladium. Adding ruthenium to platinum-palladium alloys increases their hardness while maintaining their oxidation resistance (Gold and silver mines.com, 2002). Since alloyed platinum-palladium is stronger than silver, stone settings can be smaller and thinner, allowing more light to refract off the stone. During the first 40 years of the 20th century, platinum was the preferred metal for wedding and engagement rings and was used to enhance the beauty of diamonds and other gemstones.

Platinum was declared a strategic material by the U.S. Government during World War II, and its use in most nonmilitary applications, including jewelry, was prohibited. Because of its resistance to spark erosion, platinum was incorporated into spark plugs for combat aircraft during World War II (Gold and Silver Mines.com, 2002). During the war years, when platinum was unavailable for jewelry, white gold (various combinations of gold, nickel, silver, or zinc) was developed. The demand for platinum is sensitive to the price and desirability of "white" jewelry. During periods of high platinum prices, often there is an increase in purchases of white gold. Figure 11 shows the amount of platinum purchased for jewelry worldwide during the period from 1987 to 2002 based on data reported by Johnson Matthey Plc. Since 1996, the quantity of platinum purchased for jewelry increased most significantly in China and the United States, but the amount purchased in Japan decreased.

FIGURE 11

The jewelry sector has used the largest amount of platinum worldwide since 1996. The amount of platinum purchased by the jewelry sector has more than doubled since 1991. In 2002, approximately

88,000 kg (2.8 Moz) of platinum and 8,100 kg (260,000 oz) of palladium were purchased for jewelry worldwide, an increase from 81,000 kg (2.6 Moz) and 7,200 kg (230,000 oz), respectively, in 2001 (Johnson Matthey Plc, 2003b, p. 48, 50). In 2002, North American platinum jewelry purchases were only 11 percent of the 86,000 kg of platinum purchased worldwide for jewelry. Platinum jewelry is most popular in Asia where the white metal is considered highly desirable. Approximately 28 percent of the platinum purchased worldwide for jewelry in 2002 originated in Japan (Johnson Matthey Plc, 2003b, p. 49). In 2000, China became the leading market for platinum jewelry in the world when it surpassed Japan for the first time. The Chinese purchased almost five times more platinum jewelry in 2002 than they did in 1997, which was a reflection of an increasingly prosperous population (Northern Miner, 2003). Although a small percentage is exported from China, most was sold to consumers in China, and some small amounts entered inventory stockpiles (Ellen Zadoff, platinum market research manager, Johnson Matthey Plc, oral commun., 2002).

The possibility exists for jewelry usage to increase. As the growth in China's jewelry market affected PGM use in the late 1990s, the jewelry market in India is likely to be the next market for expansion of worldwide PGM jewelry use. If platinum captured only 2 percent of the gold jewelry market in India during the next several years, an additional 15,500 kg (500,000 oz) would be purchased in India. This would increase total platinum jewelry purchases by about 10 percent (Platinum Guild International, 2002).

Drivers and Constraints of Demand

Cultural trends play an important role in PGM demand for jewelry. In many cultures, jewelry is a convenient means to accumulate and display individual wealth and status. The high value-to-size ratio of jewelry makes it a convenient way to possess wealth. Jewelry allows for immediate, direct display of wealth and is recognized universally for its trade value.

Unlike many commodities, because of value and emotional attachment, jewelry is rarely discarded or recycled. During times of rising PGM prices, the value of existing jewelry increases, increasing demand for PGM jewelry by wealthy speculators. When PGM prices are low, PGM jewelry is valued by people that can afford to purchase it in the hopes that it will increase in value when PGM prices rise in the future.

Unless the price of PGM-rich jewelry increases to a point where purchases are discouraged or substitutes offered that reduce consumer appeal for the metals, PGM use in jewelry should continue to grow. Because of the metals' rarity as compared to other metals used in jewelry, its useful properties, and its appearance, it is unlikely that the value of PGMs will decrease to the point where the metals will no longer be symbols of wealth and become less desirable.

Automobile Catalysts

Regulatory policies have been largely responsible for the dramatic increase in the use of platinum-group metals for catalytic converters. In the United States, the EPA estimated that in 1960, prior to mandated motor vehicle pollution control, automobiles emitted 10.6 grams per mile of hydrocarbons, 84 grams per mile of carbon monoxide, and 4.1 grams per mile of nitrogen oxides. In 2001, the EPA automobile emission standards were 0.125 grams per mile of hydrocarbons, 3.4 grams per mile of carbon monoxide, and 0.2 grams per mile of nitrogen oxides. These standards are met through the use of catalytic converters, cleaner fuels, and improved engine design (Bertelsen, 2001).

Regulatory actions set standards for automobile tailpipe emissions. Technology, in the form of catalytic converters, was developed to meet more stringent emissions standards. Catalytic converters require PGMs to maximize performance. In 1975, the United States and Japan became the first countries to require, through legislation, catalytic converters on new domestically produced and imported passenger cars and most light trucks. “Tailpipe” regulations in other countries with large vehicle markets followed, including the Republic of Korea (1987), Mexico (1989), the member states of the European Union (1993), and Brazil (1994) (Johnson Matthey Plc, 2002a).

Catalytic converters are a pollution abatement technology whose main purpose is to reduce the amount of harmful emissions from an internal combustion engine. If an automobile burned fuel with perfect efficiency, then its only exhaust products would be carbon dioxide, nitrogen gas, and water. Because combustion is not perfectly efficient, however, automobiles often emit carbon monoxide, hydrocarbons, and nitrogen oxides into the atmosphere. By passing the automobile exhaust through a catalytic converter (a heated honeycomb-tube structure coated with a porous ceramic embedded with the PGM catalysts palladium, platinum and/or rhodium), about 95 percent of these pollutants can be converted to other substances. Once the exhaust heats the converter to above 300° C, the unwanted molecules bind temporarily to the catalysts and are converted into less toxic gases. Approximately 1 gram (g) of rhodium can reduce nitrogen oxides back into nitrogen and oxygen, and about 5 g of platinum oxidize the hydrocarbons and carbon monoxide by reducing the energy barriers that normally impede such chemical reactions (Bloomfield, 2000). The catalytic converter operates independently from the engine, but it does rely on two factors. First, it relies on the exhaust gases to warm it up. The minimum operating temperature for the process to operate efficiently ranges from 300° C to 400° C. Second, a clean-running engine maximizes the converter’s efficiency. The converter can only operate efficiently if the correct amount of oxygen is in the exhaust system. An oxygen sensor is often incorporated into an engine's computer to regulate oxygen levels in the exhaust system.

Because automobile emissions standards are increasingly being implemented worldwide and appear to be growing more stringent, the use of autocatalysts requiring PGMs will increase. Global wealth also increased throughout the 1990s, so purchases of new vehicles increased, resulting in increased PGM use in the automotive sector. The quantity of PGMs purchased for this sector is shown in figures 10 and 12. Palladium demand grew after 1992, as more and more cars were produced that contained palladium-rich catalytic converters (often at the expense of other PGMs), in reaction to increasing platinum prices. It was only after the price of palladium peaked above US$1,000 per oz in January 2001 that world purchases of primary palladium began to decrease, as the quantity of palladium demanded was provided increasingly by inventory stockpiles.

Because PGMs consumed from manufacturer stockpiles are not included in Figure 12, this figure does not reflect the total use of PGMs in the automotive sector. During periods of low PGM prices, an expectation that shortages may occur or prices may significantly increase motivates manufacturers that are heavy users to stockpile PGMs. When prices are high, automotive manufacturers may use stockpiled material to meet product demand.

FIGURE 12

In 2002, more than 80 percent of new passenger cars produced worldwide contained catalytic converters that used platinum and/or palladium as the major catalysts (Johnson Matthey Plc, 2003a). In 2002, automobile catalysts continued to be the largest demand sector for PGMs in the United States, constituting 65 percent of total U.S. apparent consumption. More than 100,000 kg of PGMs were purchased by the automotive industry in the manufacture of catalytic converters in 2002 (Hilliard, 2003). In 2002, U.S. purchases of palladium decreased substantially owing to the use of stockpiled PGMs. Catalytic converters require 2 to 6 g of PGMs per automobile and 6 to 30 g of PGMs per sport utility vehicle or light truck. The amount of PGMs required per vehicle and the platinum-to-palladium ratio vary with the level of emission control, metal prices, and type of vehicle. Diesel engine catalytic converters use only platinum; gasoline-powered vehicles generally use platinum and palladium. Worldwide, more than 78,000 kg (2.5 Moz) of platinum and 158,000 kg (5 Moz) of palladium were purchased for use in automobile catalytic converters in 2001, and more than 81,000 kg (2.6 Moz) of platinum and about 96,000 kg (3.1 Moz) of palladium were purchased for this application in 2002 (Johnson Matthey Plc, 2003b, p. 48, 50). The apparent decrease in palladium purchases reflects the drop in automobile sales resulting from a downturn in the world economy and the use of PGMs residing in inventories.

The quantity of PGMs purchased in Europe for platinum in the automobile catalyst sector increased by 82 percent from 2000 to 2002 (Johnson Matthey Plc, 2003b, p. 48). The reasons for the dramatic growth include new, more stringent European air quality standards, increased sales of diesel vehicles that use a higher quantity of platinum in catalystic converters, and a switch from palladium-enriched catalysts to platinum-enriched catalysts for gasoline-powered vehicles (Pinkham, 2001).

Although there may be a trend to substitute for some of the platinum and palladium used in automobile catalysts with other materials, consumption of these precious metals is expected to increase during the next several years owing to increasing vehicle production and regulatory control of exhaust emissions. High commodity costs encourage substitution between materials if acceptable performance and service can be achieved at an acceptable cost to consumers. The high cost of some PGMs in 2001 provided further incentives for research to develop commercially viable alternative technologies that would reduce or eliminate the need for PGM in catalytic converters. Both General Motors Corporation (GM) and Honda Motor Company Limited (Honda) are working on substitutes for PGMs.

In March 2001, Honda, in partnership with Catalytic Solutions Inc., announced that it had developed a technologically advanced emission control system that would reduce the use of PGMs from 25 to 80 percent relative to conventional devices (Honda Motor Company Limited, 2001). The converter uses a synthetic form of perovskite (a naturally occurring calcium-titanium-oxide mineral) and functions the same way as conventional catalytic converters by reducing nitrogen oxides and oxidizing hydrocarbons and carbon monoxide. Laboratory tests suggest that the device's durability is similar to that of standard catalytic converters and could be less costly at April 2001 PGM prices.

However, there are several unknowns associated with this new technology. The product's ability to perform in the long term and its compatibility with other manufacturers' technologies or engines is not known. Honda plans to use the technology worldwide in the future, but no timetable has been established (Honda Motor Company Limited, 2001). The economics of recycling the product to recover PGMs and other materials is also unknown.

GM has also announced plans to reduce PGM use in catalytic converters installed in its cars and trucks by 2006 from the current average fleet consumption of 1.5 g of platinum, 3 g of palladium, and 0.3 g of rhodium per vehicle (Platts Metals Week, 2002b).

Development of alternative technologies to meet or exceed the performance of currently employed technologies is representative of the goal of substitution. If the price of a material increases because of such factors as increased demand or limited production resulting in higher cost of materials, substitution is possible. The goal of technology is to develop an alternate form that would provide performance benefits at an acceptable cost to the consumer.

Catalysts may be an interim technology, a temporary solution to the emission problem until a better technology comes along. When considering current world use patterns, development of technological substitutes for PGMs in emission control systems or in other applications could decrease the demand for PGMs. However, economic growth and increasing vehicle sales in China and India, along with more widespread regulatory controls, could actually increase demand. As figure 12 illustrates, the relative proportions among PGMs used in emission control devices can change rapidly with changing price and other market factors, such as the trend to produce more diesel vehicles (Cartoday.com, 2002).

Drivers and Constraints of Demand

Demand for catalytic converters is driven by air pollution standards. In places where atmospheric emissions are regulated, catalytic converters provide an efficient technology that contributes to the automobile's ability to meet these emission standards. As standards become more stringent, more efficient catalytic converters or other technologies will be required. In the United States, for example, air pollution standards proposed for 2015 may require advanced catalytic converters with higher PGM content. Alternatively, research continues to focus on other technologies that may reduce or eliminate the amount of PGMs required in this application.

In the near term, as long as catalytic converters are installed on automobiles that use internal combustion engines, the demand for automobiles will influence PGM demand. As demand increases for new vehicles in developing countries with stringent emission policies, use of PGMs in these regions will also increase. For example, vehicle use in the two most populated countries of the world, China and India, is currently only 10 to 12 vehicles per 1,000 people; the current rate in the United States is about 750 vehicles per 1,000 people. As vehicle use in China and India increases, PGM use would also increase.

Electrical and Electronics Applications

Major uses for PGMs in the electrical and electronics sector include components in capacitors and resistors (palladium), computer storage disks (platinum), electrodes, fuel cells, and thermocouples. Thermocouples are the single leading use for platinum in the electrical/electronics sector. Platinum alloys and platinum-rhodium alloys are used as electrical-resistance heating elements in such applications as cigarette lighters, hot wire ignition systems, and nylon cutters, as sealing devices, and as windings for muffler furnaces. Palladium and palladium alloys are widely used in capacitors, connectors, and electrical contacts. PGMs are also used in carbon monoxide detectors, electrochemical sensors in automobiles, and medical devices (Fogg and Cornellisson, 1993, p. 43).

In the electronics industry, PGMs have substituted for gold in electronic contacts since 1984. The main uses for palladium in the electronics sector are in multilayered ceramic capacitors (MLCC), thick film hybrid integrated circuits, plating connectors, and lead frames. More recently, platinum-coated data storage hard drive disks have become common. Johnson Matthey estimated that more than 90 percent of the hard disks produced in 2001 contained platinum compared with about 50 percent in 1997 (Johnson Matthey Plc, 2003c).

Figure 13 shows world purchases of PGMs for electrical and electronics applications for the period from 1987 to 2002. In general, the quantity of platinum and palladium purchased grew during the period from 1987 to 1995. Platinum purchases increased from 1987 to 2000, while palladium purchases fluctuated significantly during this same period, peaking in 1995. Since 2000, use of both commodities in electrical and electronics applications has dropped, most significantly for palladium, primarily as a result of economic recession and high commodity prices.

FIGURE 13

In 2002, worldwide purchases of PGMs in electrical and electronics applications were approximately 22,100 kg (710,000 oz) of palladium, 11,800 kg (380,000 oz) of platinum, 4,500 kg (145,000 oz) of ruthenium, 680 kg (22,000 oz) of iridium, and 200 kg (6,000 oz) of rhodium (Johnson Matthey Plc, 2003b, p. 41, 48, 50, 52). Only palladium purchases fell over the timeframe shown, but it is likely that palladium from inventory stockpiles made up the difference between lower purchases reported for the period 2000 to 2002 and the total sector use. Platinum and rhodium are used primarily in electrical applications; iridium, palladium, and ruthenium are used primarily in electronics.

PGMs, primarily palladium, platinum, and ruthenium, have become important materials for performance of critical components in computers and other electronic devices. The rise in platinum consumption in electronics applications from 1998 to 2000 was primarily owing to an increase in the platinum content in computer hard disks. Although there was a reduction in the number of units sold during the period from 2000 to 2002, the increase in platinum content per disk and the spread of hard disks to video game consoles were offsetting factors. Platinum use in hard disks improves the strength of the magnetic field, which results in greater storage capacity, and is expected to increase with increasing consumer demand for greater storage capacity in computers, onboard vehicle navigation systems, and video recording equipment. Platinum use has also increased for use in thermocouples.

During 2002, two of the leading hard disk manufacturers introduced products that contain a thin layer of the PGM ruthenium, which increased the data storage density. It is likely that other manufacturers will follow their lead, which could lead to increased use of ruthenium in this sector, at least in the short term (Johnson Matthey Plc, 2003b, p. 40).

Palladium has lost market share to base metals, primarily nickel and silver, as a result of successful research into the development of lower cost materials that offer similar or superior performance in the manufacture of MLCC used in many consumer products, including mobile phones. The market share of palladium measured by the number of MLCC produced has decreased to 37 percent of the total in 2002 from 62 percent of the total in 1999; however, more than 500 billion MLCC were produced in 2002. Successful research into materials that can substitute for palladium in MLCC may result in significantly less use in this sector in the future unless new applications are found or the price of palladium relative to other metals decreases substantially.

Drivers and Constraints of Demand

In general, the relative prices of precious metal constituents (gold, iridium, palladium, platinum, rhodium, ruthenium, and silver) of electrical and electronics components are a contributing factor to the extent that they are used. The alloying composition and the degree of substitution depend on what constituents can be acquired most easily and at the lowest price. Changes in technology also can help determine what materials are used. Because electronics components are mass-produced, a slight variation in the relative prices of substitutable metals can affect significantly the total cost. An ongoing area of technological research is the design of equipment that allows for more substitution flexibility.

Another factor that affects the demand for PGM in the electronics sector is the use of computers and video equipment. With the development of new electronic equipment, one factor in component design is the reduction of the use of precious metals to lower production cost. The decrease in per unit consumption, however, may be outweighed by the greater number of total units being produced, which would result in a net increase in PGM use in this sector. Particularly in the United States, cell phones are replacing regular telephones, the number of households with multiple computers is increasing, and digital cameras and video games are enjoying increased popularity. Each of these products contain PGMs.

Fuel Cells

Platinum use related to fuel cells may change dramatically during the next several years. Research and application of fuel cell technology that uses hydrogen as a fuel to produce energy has increased dramatically. Research is focused on power generation uses in commercial electricity generation plants and for electric motors in automobiles. In the 1980s, platinum coatings on the anode and cathode were discovered to greatly accelerate chemical reaction time, which enabled fuel cells to produce energy at a rate sufficient to power an automobile. Fuel cells have proven to be effective, long lasting, quiet, and reliable since they have no moving parts. Fuel cells are considered “clean energy”; their only gaseous waste product is water vapor, when hydrogen is the primary fuel. The National

Aeronautics and Space Administration developed the first major use for fuel cells when it used them in the U.S. space program. Building on the success of this technology, research was initiated to develop fuel cells for vehicle use. The first generation of these fuel cells was expensive to produce and not commercially viable owing in large part to the high platinum content and lower cost of competing energy sources (Uravan Minerals Inc, 2002).

Current generation fuel cell technology includes the proton exchange membrane (PEM) fuel cell to power cars with hydrogen. PEM fuel cells produce electricity by combining oxygen from the air and hydrogen from a fuel source that, depending on the type of fuel used, can produce carbon dioxide, water vapor, and other gases as byproducts. Platinum is used in the electrocatalyst layer of the fuel cell. Current prototypes use over 2 g of platinum per kilowatt of electricity. The U.S. Department of Energy (DOE) goal is to develop PEM fuel cells that need only 0.2 g of platinum per kilowatt by 2010 (Garland, 2003).

The International Platinum Association (IPA) estimated that a commercially viable fuel-cell-powered vehicle would use slightly more platinum than the current average catalytic-converter-equipped passenger car, or 6 to 7 g of PGMs per vehicle. The IPA also estimated that about 50,000 fuel-cell-powered automobiles could be produced in the United States by 2012. This would result in a possible platinum demand increase of 300 to 350 kg for this new application by 2012 (Platts Metals Week, 2002a). If these estimates hold true, then PGM use could increase dramatically during the second decade of the 21st century.

Although fuel cell technology has become much more attractive owing to increasing fuel costs and improved and less expensive fuel cell technology, less than 600 kg (20,000 oz) of platinum was used in this application in 2002 (Johnson Matthey Plc, 2003b, p. 32). Yet notable advances in fuel cell technology were made during 2002. Several full-size-vehicle test programs were initiated by GM, Honda, Toyota Motor Corporation, and other automobile manufacturers. Also in 2002, there was increasing interest and funding support by governments in Europe, Japan, the United States, and other countries for fuel cell research (Johnson Matthey Plc, 2003b, p. 31). GM expects fuel cells to be available for general automotive consumption by the end of this decade (General Motors Corporation, 2002).

Another area where fuel-cell technology is expected to boost PGM demand is stationary fuel cells. They can provide a reliable supply of energy for businesses that require an uninterrupted flow of energy, such as hospitals. In 2004, Dow Chemical Company (Dow) and GM jointly placed into service the first of several GM-designed fuel cells at a Dow facility. The fuel cell uses waste hydrogen from the facility to generate electricity. Plans call for up to 400 fuel cells that will use the plant's waste hydrogen. The power generated from these cells would be sufficient to supply 25,000 average-size homes in the United States (General Motors Corporation, 2005).

Miniature fuel cells in a flat-pack configuration are being developed as alternatives to rechargeable batteries in cellular telephones, laptop computers, and other small, portable electronic devices. The preferred anode catalyst is a combination of platinum and ruthenium; the preferred cathode catalyst contains platinum (Electronic Design, 2002).

Drivers and Constraints of Demand

Demand for PGMs in automotive fuel cells is tied to the demand for fuel-cell-driven vehicles. To be successful, fuel cell technology must be affordable and reliable, hydrogen must be produced with minimal negative impacts on the environment, and safe and efficient transport and storage of the gas must be achievable. As fuel-cell-powered automobile use increases, so too will PGM use. For now, however, PGM consumption for this experimental use is relatively low. Current research is being directed at reducing platinum requirements for fuel cells to make the systems more affordable. The DOE reported in 1999 that fuel-cell designs required approximately 100 g of platinum, down from 200 g just a few years before. At an average 2002 price of $17.97 per gram, the platinum in a fuel cell would add about $1,800 to the cost of a typical 2002 vehicle. DOE's long-term goal is to attain a commercially and technically viable design that requires substantially less, perhaps only 10 g of platinum. If technical success is achieved, and is proven to be commercially viable, then the need for fuel cells would increase overall demand for PGMs in this application.

The "Hydrogen Economy" and Platinum-Group Metals

A potential driver for future demand of platinum-group metals (PGMs), especially platinum, is their use in fuel-cell technology, primarily for hydrogen-fueled vehicles. Fuel-cell vehicles in 1999 required approximately 100 grams (g) of platinum per vehicle. Considering the goal of the U.S. Department of Energy (DOE) for platinum use in fuel cell vehicles of 0.2 g of platinum per kilowatt (or 9 g of platinum per vehicle), total platinum use by fuel cell systems could increase 8 to 12 percent by 2013, an additional 24,900 to 37,300 kilograms of platinum, from the 2003 demand level (Allied Business Intelligence, Incorporated, 2003). To be successful, the technology must be affordable and reliable, hydrogen must be produced with minimal negative impacts on the environment, and safe and sufficient transport and storage of the gas must be achievable and in place. The pursuit of researchers to improve the efficiency of fuel cells or develop cells that require less PGMs have met with some success. Although not commercially proven, research has developed cells that use coatings of platinum for manufacturing catalysts that can be used to manufacture or purify hydrogen that have similar performance characteristics but use approximately 15 g per vehicle of platinum. While many scientists agree that hydrogen-fuel-cell use will increase with advances in technology and a commensurate decrease in cost (between 10 and 20 percent of the cost of a fuel cell system is attributed to platinum), there is disagreement as to the extent of use of the technologies and the impact on future PGM demand, especially in the automotive sector.

A presidential initiative supports a cooperative effort by Government and industry to overcoming key technical and cost barriers for fuel cells, permitting their use in businesses and fleet buses, cars, trucks, and homes by 2010 and making it practical for large numbers of Americans to choose a commercially practical hydrogen-powered vehicle by 2020. Fleet vehicles offer the advantage of centralized fueling and use in urban environments reducing pollution on a localized basis. In 2003, the President proposed a total of $1.7 billion directed towards these efforts. The goals of the initiative include overcoming cost and technical barriers, reducing dependence on foreign oil, and improve air quality (White House, 2003). The President's proposed fiscal year 2005 budget requested an additional $69 million compared with that of 2004, bringing the program's total funding for 2005 to $228 million (Reuters, 2004).

There is debate among some scientists, however, whether hydrogen-powered cars, which are a major application of fuel-cell technology, are the best choice for decreasing the contribution of greenhouse gases from the transportation sector. Although some of the hydrogen fuel may be produced by electricity generated from solar panels and wind energy, over the next several decades most of the hydrogen will be produced from electricity supplied by or hydrogen recovered from coal gasification, natural gas, and nuclear energy. Urban areas might benefit from cleaner air, but these gains may be offset on a wider regional basis with the production of greenhouse gasses, such as carbon dioxide, from generating electricity using fossil fuels. Researchers at the DOE Los Alamos National Laboratory in New Mexico and by other agencies and organizations are investigating methods to produce electricity from fossil fuels with less environmental consequences that could potentially overcome concerns relating to greenhouse gas production that results from recovery of hydrogen. These technologies are not currently commercial, nor are they anticipated to be at a commercial scale within the next decade. Alternative sources of energy that may be used to produce hydrogen include geothermal and solar. Geothermal sources of energy are geographically limited.

Reductions in air pollution and oil imports might be achieved in other ways than by pursuing the development of hydrogen-fueled vehicles. For example, researchers at Carnegie Mellon University concluded that, for the next several decades, the most cost effective method to address the issues related to motor vehicles would be to improve the fuel efficiency of gasoline-powered vehicles (Carnegie Mellon University, 2003). Realizing that the use of fuel-cell-driven cars have disadvantages related to the production, storage, and transportation of hydrogen fuel and development of necessary infrastructure, the Japanese Ministry of Economy, Trade, and Industry planned to expedite the use and development of passenger cars powered by advanced diesel engines and hybrids.

Because obstacles must yet be overcome before commercially-viable fuel cell vehicles require a substantial quantity of PGMs beyond current levels for catalytic converters, the magnitude and timing of such a use is not currently clear. The main obstacles to building fuel-cell-powered automobiles are how to produce, store, and transport hydrogen safely for use in cars and how to make fuel-cell-powered cars affordable for the average consumer. Compressed gas tanks are most likely to be the first generation of portable hydrogen storage, but there are inherent safety issues that must first be resolved (Platts Metals Week, 2002b).

Other End Use Sectors

PGMs are used in small quantities in many other applications. In order of quantity purchased, other applications that require PGMs include dental and medical, chemical, investment, glass making, and petroleum refining.

Palladium and small amounts of platinum are used as alloying elements in dental restorations. Palladium purchases for this application peaked in 1997 at 42,000 kg (1.35 Moz), primarily in Japan, North America, and Europe. Since 1997, palladium purchases have decreased significantly as a result of the relatively high palladium price and substitution by base metals, ceramics, and gold in this application. Purchases of palladium for this sector were about 23,000 kg (750,000 oz) in 2002 (Johnson Matthey Plc, 2003b, p. 50). Small quantities of platinum are also purchased for use in anticancer drugs and medical implants.

PGMs are used as catalysts in the production of nitric acid, silicones, and in electrode coatings. In general, purchases of PGMs in these applications grew during the past decade, such that by 2002, PGM purchases for this sector was reported to be about 10,000 kg (325,000 oz) of platinum, 7,900 kg (255,000 oz) of palladium, and 1,300 kg (42,000 oz) of rhodium (Johnson Matthey Plc, 2003b, p. 48-52).

Purchases of platinum coins and bars for investment purposes are extremely small by weight and value when compared with gold. From 1992 to 1998, purchases of platinum for investment purposes averaged only about 8,100 kg/yr (263,000 oz/yr). From 1999 to 2003, the trend shows decreasing investment in the metal, averaging about 1,900 kg/yr (61,000 oz/yr), and reflect reduced sales of platinum coins and sales back to the market (Johnson Matthey Plc., 2004, p. 31). The average price of platinum in 2000, 2001, and 2002 was $549 per troy ounce, $533 per ounce, and $559 per ounce, respectively (Hilliard, 2003).

Use of platinum and rhodium in glassmaking equipment has increased during the past decade, fueled by the growth of liquid crystal displays in digital watches and laptop computers. Purchases for this sector in 2001 were about 9,000 kg (290,000 oz) of platinum and 1,200 kg (42,000 oz) of rhodium. The reduction in use of platinum and rhodium in this application in 2002 and 2003 occurred because of high inventories and reduced use of platinum and rhodium in these applications (Johnson Matthey Plc, 2003b, p. 48, 52).

PGM Use From 2003 to 2010

World PGM use data are not reported annually by the USGS, therefore historical purchase data reported by Johnson Matthey Plc. were used as a basis for developing use projection scenarios. Johnson Matthey defines the annual purchase estimate as the amount of primary material that is acquired by consumers in a particular year (Johnson Matthey Plc, 2003b, p. 52). Government and private stockpiles are not included in these estimates. The Johnson Matthey estimates are net estimates, or total purchases by consumers minus sales of recycled PGMs back to the consuming market. PGMs recovered from the autocatalyst sector are shown as a separate data series in figure 14. Estimates for recycled PGM use from other than the autocatalyst sector were developed and are analyzed separately in this study

FIGURE 14

Based on historical purchase data for primary platinum, palladium, and rhodium, several projections were developed to show possible total use of these commodities from 2003 to 2010. Figure 14 illustrates the base data from which primary use projections were developed. The selected data period of 1985 to 2003 reflects years for which purchase data were available for platinum, palladium, and rhodium. The simple average annual level of change for the period 1985 to 2003 for each of these three PGMs was calculated using end points of 1985 and 2003. These end points were selected to best represent the projected growth level of primary PGM purchases because they appeared to best reflect observed trends of the historical data. Therefore, variation in purchases caused by changes in stockpile inventories (most noticeably shown for the period of 1993 to 2002 for palladium in figure 14b) was reduced.

Historical average annual growth levels for platinum, palladium, and rhodium were estimated. For the period 1985 to 2003, platinum purchase levels increased an average of 6,150 kilograms per year, palladium purchase levels increased an average of 4,733 kilograms per year, and rhodium purchase levels increased an average of 661 kilograms per year.

FIGURE 15

Figure 15 illustrates several possible primary platinum and palladium production and use trends projected for the period from 2003 to 2010. Projection B reflects USGS estimates of aggregated platinum or palladium production from currently producing mines or deposits scheduled for production by 2010, based on individual sites operating at full production capacity as reported by the industry. This projection approximates the maximum level of platinum or palladium supply that would be available during the study period. Projection D reflects USGS estimates of aggregated platinum or palladium purchase requirements for 2003 to 2010 based on the average annual growth levels developed from the 1985 to 2003 purchase data reported by Johnson Matthey Plc. Because this projection excludes platinum or palladium used from inventory stockpiles, which may be significant, this scenario is considered an approximation for the minimum use level, and assumes that growth for the 2003 to 2010 period reflects the historical growth trend for 1985 to 2003. These projections have been superimposed over three other arbitrary growth projections in order to show reference points reflective of the level of annual increase in use that would be required to justify PGM production at capacity levels shown. The three arbitrary growth projections for platinum assume annual growth of 5,000 kilograms, 10,000 kilograms, and 15,000 kilograms per year from the 2003 base level of purchases reported by Johnson Matthey Plc. The three arbitrary growth projections for palladium assume no growth, and annual growth of 10,000 kilograms and 20,000 kilograms per year from the 2003 base level of purchases reported by Johnson Matthey Plc.

Based on historical annual growth rates for platinum and current use trends, it would seem reasonable that platinum near-term (until 2010) use is likely to grow between 5,000 kg/yr (160,000 oz/yr) and 15,000 kg/yr (480,000 kg/yr). Palladium use is more subject to changes in stockpile inventories, so its growth limits are wider, ranging from negligible growth to a possible growth rate of 20,000 kg/yr (640,000 oz/yr). Commodity prices and the amount of material recovered from inventory stockpiles during this period will influence the pattern of near-term growth.

For comparison, platinum purchases grew by 1,600 kg (50,000 oz) between 2003 and 2004, and palladium purchases grew by 22,700 kg (730,000 oz) between 2003 and 2004 (Johnson Matthey Plc, 2005. This occurred during a time when the platinum price was high and stockpiles were low while the palladium price was low and stockpiles were high. When movements in stocks are taken into consideration, platinum use increased 7,200 kg (230,000 oz) between 2003 and 2004, and palladium use increased 21,800 kg (700,000 oz) between 2003 and 2004 (Johnson Matthey Plc, 2005).

Based upon these projections, primary platinum purchases, following a 5,000 kg/yr growth scenario, would grow to 235,000 kg/yr (7.5 Moz/yr) of platinum in 2010 from a base 2003 level of 200,000 kg/yr (6.4 Moz/yr) of platinum. Primary platinum purchases would grow to 305,000 kg/yr (9.8 Moz/yr) by 2010 following a 15,000 kg/yr growth scenario. Primary platinum purchases, based on the average annual growth level developed from the 1985 to 2003 Johnson Matthey Plc. purchase data, would increase to 243,000 kg/yr (7.8 Moz/yr) of platinum by 2010.

Projections reported for this study are in general agreement with projections reported by Allied Business Intelligence, Incorporated (ABI, 2003) that reports world primary platinum demand estimates, exclusive of fuel cells, to be 248,800 kg in 2008 to 2009 and 311,000 kg in 2013. A study by analyst Ross Norman (2001) suggests a similar platinum demand value of 262,800 kg in 2010. When fuel cells are included, world platinum demand by 2013 is projected by the ABI to increase by an additional 8 to 12 percent. If fuel-cell technology is found to be efficient and cost effective and comes into widespread use, then subsequent platinum use could potentially increase even more dramatically.

Primary palladium purchases, based upon the no growth projection scenario, would remain at the 2003 base level of about 168,000 kg/yr (5.4 Moz/yr) of palladium in 2010. Primary palladium purchases would grow to about 308,000 kg/yr (9.9 Moz/yr) in 2010 following a 20,000 kg/yr growth scenario. Primary palladium purchases, based on the average annual growth level developed from the 1985 to 2003 Johnson Matthey Plc. purchase data, would increase to about 201,000 kg/yr (6.5 Moz/yr) of palladium by 2010. Palladium data reported since 2002 suggest that the 2002-2004 growth rate of about 20,000 kg/yr is likely to peak before 2005, and a more modest growth in palladium purchases is likely between 2005 and 2010.

For the 14-year period from 1989 to 2003, purchases of PGMs other than platinum and palladium grew steadily, with the average growth over the period of about 1,600 kg/yr (51,000 oz/yr). For the same period, rhodium purchases increased at a slower rate of about 660 kg/yr (21,000 oz/yr). In 1989, rhodium accounted from about 65 percent of all purchases of other PGMs, by 2003, however, rhodium accounted for just over half of all other PGM purchases. The use of iridium and ruthenium in the chemical, electrochemical, and electronic sectors has grown rapidly in recent years, surpassing the growth rate of rhodium in the automotive sector. Rhodium use in other sectors has either held constant or grown slightly. Rhodium recovered from autocatalysts has doubled between 1998 and 2003.

Primary purchases of other PGMs, based on the average annual growth level developed from the 1989 to 2003 Johnson Matthey Plc. purchase data, would increase to about 49,000 kg/yr (1.6 Moz/yr) 2010. Primary purchases of other PGMs, assuming a no growth scenario, would remain at the 2003 base level of about 38,000 kg/yr (1.6 Moz/yr) of other PGMs. Primary purchases of other PGMs would grow to about 80,000 kg/yr (2.6 Moz/yr) in 2010 following a 6,000 kg/yr growth scenario.

Inventories

Although this study does not include inventories of stockpiled material in its quantitative analysis, some discussion of this subject is warranted because stockpiled material historically has occasionally contributed significantly to total world PGM supply, and speculation on future direction of PGM stockpiles can influence PGM pricing and demand.

Unlike gold, there are only a few large stockpiles of PGMs that can be sold into the market to fill the gap during periods of significant supply shortfalls, disruptions, or other events contributing to high PGM market prices. Historically, one of the largest stockpiles was held by the U.S. Department of Defense's Defense Logistics Agency (DLA). In 1995, the DLA inventory consisted of 39,300 kg of palladium, 13,700 kg of platinum, and 920 kg of iridium (Hilliard, 1996). By September 30, 2002, however, the DLA stockpile had been drawn down to an inventory that contained 7,027 kg of palladium, 784 kg of iridium, and 649 kg of platinum (Hilliard, 2003).

Russian Government stockpiles also have historically contained significant inventories of PGMs. The Government maintains two PGM stockpiles, a reserve maintained by the Russian Ministry of Finance and a Central Bank stockpile supplied by transfers from the Ministry of Finance reserve to sell on the world market for cash to offset Government obligations and to reduce budget deficits (Bond and Levine, 2001). Their holdings are treated as a state secret, so no specific information concerning the size of the stockpiles has ever been released, and available estimated data vary widely. Most analysts believe that these Russian inventories are significantly reduced from the early 1990s. Johnson Matthey estimated that approximately one-half of the 900,000 kg (29 Moz) of palladium exported by Russia between 1994 and 1999 came from stockpiles (Johnson Matthey Plc, 2001, p. 17), the rest originated from mine production.

Modest inventories of PGMs also are held for short periods of time by banks and commodity exchanges, consuming companies, and PGM producers. Automobile manufacturers are reported to hold PGMs in stockpiles to supply internal production needs. For example, Ford Motor Company reportedly sold palladium from its stockpile in 2002, after losing more than $1 billion from high-metal-price purchases of palladium from 2000 to 2001 (American Metal Market, 2002).

The uncertain nature of PGM stockpiles by banks, manufacturers, and producers can affect consumption patterns and demand for PGMs, particularly in periods of excess demand as was the case during the period from 1997 to 2000. During such a period, stockpiled material often is sold to augment production. When demand drops, as was the case for palladium after 2000, stockpiles tend to increase owing to lagging sales and lower PGM prices.

Historical Average Prices

Figure 16 illustrates the average annual price of platinum and palladium in actual and constant dollars for the periods from 1900 through 2002 and from 1911 through 2002, respectively. Palladium price data for the period 1900 – 1910 were not available. The figure illustrates the changes in the price of the metals in response to numerous global economic, political, and technological events. Increases in PGM prices resulted from higher industrial demand and/or concerns about possible scarcity of supply. Notable events include World War I, World War II, the post-World War II industrial boom, and the emplacement of legislation in many countries that requires the use of catalytic converters on certain internal-combustion-driven vehicles in the mid-1970s to the early 1980s. The anticipation of increased PGM demand in the early 1970s; speculation by international investors for precious metals in the late 1970s when inflation was high, the U.S. dollar was depressed, and the prime rate reached 21 percent; and strikes at South African mines in 1986 caused prices to increase for the years 1974, 1980, 1983, and 1987 (Hilliard, 1999). The response of the price of palladium to world events followed the same trends as that of platinum except for the periods 1930 to 1970, and 1987, when use for palladium remained essentially unchanged, as well as 1995 to 1998, when uncertainty about Russian stockpile sales drove the palladium price to a record level.

FIGURE 16

Although the real price of platinum and palladium remained relatively stable until the Arab Oil Embargo of 1972. Declines in PGM prices resulted from increases in supply from new sources, primarily in South Africa in the 1920s, and technological advances in recovering the metals; economic recessions; and large releases of the metals by Russia and other countries of the Commonwealth of Independent States. In the early 1990s, platinum metal prices dropped when automakers switched to using larger amounts of palladium for catalytic converters because of price differences and technological breakthroughs but reverted to platinum when palladium prices rose sharply in 2000 (Norman, 2001).

In 2000, palladium prices surpassed platinum for the first time since the early 1900s, in response to reduced sales from Russia. Other factors that contribute to price volatility of PGM in recent years include announcements of stricter standards for diesel-powered vehicles in the United States, growth followed by slowdown of the global economy, and stockpiling and selling of the metals by automakers. World political tensions brought about by events since late 2001 also have contributed to speculation and resulted in generally higher precious metal prices. Stockpile uncertainty and manipulation also fueled higher PGM prices. In early 2003, platinum reached the highest price in nominal terms since 1986, partially in reaction to the U.S. Government proposal to provide $1.7 billion in Federal funding to develop hydrogen-powered vehicles that would use platinum in fuel cells. Hilliard (1999) provides a detailed history of PGM metal prices and events that influenced them.

In times of high PGM prices driven by real or perceived reductions in supply, forecasted higher demand in the future, or the increased strategic position of PGMs, aggressive exploration programs are launched for PGMs. This was the case during the latter part of 2000 and early 2001 when the price of platinum exceeded $600 per ounce and the price of palladium exceeded $1,000 per ounce. Nevertheless, many South African mining companies, which denominate operations in the South African rand and sales in U.S. dollars, are considering closure or delay in development of some operations because of the weakening of the dollar. Thus, the future near-term strength of the U.S. dollar will affect the rate of future PGM development in South Africa.

Projected Supply and Use From 2003 to 2010

Analyses were performed using information acquired from various sources, including Johnson Matthey, USGS specialists, industry contacts, trade journals, and government organizations to collect up-to-date PGM data and to develop production capacity and use projections to 2010. These analyses assume that production capacity values are a reasonable approximation of the supply from each source for the year under evaluation. Data on currently operating facilities and announced expansions or closures were included as well as information on developing facilities. Capacity estimates were based on the presumption that announced events would happen, although it is likely that a range of economic, political, social, and technological events, including environmental actions or delays, market conditions, new and recent discoveries, and regulatory actions, will affect projections. A portion of PGM supply is dependent on the production of other mineral commodities, such as copper, gold, or nickel. Decisions on expansions and closures of sources where these commodities are primary may depend on inventory levels, market conditions, or other events affecting these commodities. As conditions change, it is likely that higher cost producers could be squeezed out of the marketplace;

however, no capacity adjustments were made in this study to reflect such possibilities. A portion of PGM supply comes from recycled material, primarily from the autocatalyst and electronics sectors. PGM capacity estimates were developed for the 2003-2010 study period; estimates for secondary PGM capacity from the electronics sector are also reported.

Production capacity projections for palladium, platinum, and other platinum-group metals have been developed for the period from 2003 to 2010. Projections for primary platinum and palladium supply are included in figure 15, and projections for secondary platinum and palladium supply are shown in figure 17. Potential sources of primary PGMs have been classified into four groups based on when the site would supply PGMs to the market. The first group included all producing operations as of 2002. The second group included those under development in 2002 with announced plans to enter production on or before 2006. The third group included those sites where there have been extensive exploration, where bankable feasibility studies have been completed or are proceeding, and where production may begin by 2010. Each of these three groups were included in the supply analysis, although it is possible that some of the properties in the third group may not reach production status or not produce at projected capacity because of funding limitations, inadequate reserve definition, market changes, and/or other factors. The fourth group of potential sources included other sites with known PGM values based on historical or ongoing exploration activity; this group has been excluded from this analysis because development is unlikely prior to 2010.

FIGURE 17

Secondary (recycled) sources of PGMs are included in the supply estimates. Estimates for the recovery of PGM from autocatalysts and electronic scrap were developed for the 2003 - 2010 period.

Projections for recycled PGM supply from 2003 to 2010 are shown in figure 17. Projections for platinum and palladium recovered from autocatalysts were developed using a separate set of assumptions from primary supply sources of PGM. Projections of PGMs recycled from autocatalysts have been estimated by the USGS based on oral communications with Ashok Kumar, Director, A-1 Specialized Services and Supplies. Capacity projections for this source of platinum for the period from 2003 to 2010 were developed based on a study of historical production of catalyst-equipped vehicles, assumptions on catalyst recovery rates, PGM content in autocatalysts, and average worldwide vehicle life expectancies. Projections of PGMs recycled from electronics have been estimated based on estimates of Harler (2003), assuming the average ratio of platinum to palladium recovered in 2003. In 2002, platinum from primary sources contributed about 88 percent of total production capacity. By 2010, platinum from primary capacity would account for about 85 percent of total capacity. Primary platinum will remain the predominant source of platinum throughout the decade.

Based upon these projections, recycled platinum supply from the automotive sector would grow to about 42,000 kg (1.3 Moz) in 2010 from a 2003 level of about 25,000 kg (800,000 oz) of platinum. Recycled platinum from the electronics sector would increase to over 9,000 kg/yr (300,000 oz/yr) in 2010 from a 2003 level of 3,900 kg (125,000 oz). Recovered autocatalysts accounted for 11 percent of total platinum capacity in 2003 and could account for about 12.5 percent of capacity in 2010. Platinum from recovered electronics could account for an additional 3 percent in 2010.

Estimates for palladium show a different pattern. In 2002, palladium from primary sources contributed about 92 percent of the total production capacity. By 2010, however, the capacity from primary sources would represent 69 percent of total production capacity because recovery of palladium from recycled sources is expected to increase at a faster rate than production of primary palladium. Recycling of palladium also is becoming strategically important for suppliers. Recycled palladium supply from the automotive sector is projected to grow to about 98,000 kg (3.2 Moz) in 2010 from a 2003 level of 10,500 kg (340,000 oz) as more vehicles carrying catalytic converters are recycled. Recycled palladium supply from the electronics sector is projected to increase to about 34,000 kg (1.1 Moz) in 2010 from a 2003 level of about 15,000 kg (480,000 oz/.

Although not shown on figure 17, estimates for rhodium recovered from recycled autocatalysts for the period 2003 to 2010 were determined. As with platinum and palladium, an increase in supply is projected based on the growing number of vehicles containing catalytic converters, higher recovery rates, and increased rhodium content of catalysts. Recycled rhodium supply from the automotive sector is projected to grow to about 11,000 kg (350,000 oz) in 2010 from a 2003 level of 4,000 kg (130,000 oz). Estimates for other PGMs are not available.

Figure 18 summarizes estimates for total supply and use of platinum, palladium, and other PGMs from both primary and secondary sources as developed by the USGS for the period 2003 to 2010. Supply estimates are based on announced company expansion or development plans, assumed dates of initial production developed for this analysis, and estimates of the amount of PGMs available for recycling at specified dates. Use estimates reflect both the primary PGM purchase estimates (see figure 15a for platinum and figure 15b for palladium) and the PGM recycling estimates (see figure 17a for platinum and figure 17b for palladium). Because the use estimates exclude quantities recovered from inventory stockpiles, they represent the minimum use scenario. Production capacity and use projections for PGMs during the period from 2003 to 2010. As with figure 17, PGM production capacity includes primary and byproduct source material and recycled material. Production estimates for platinum, palladium, and other PGM in 2002 also are shown in figure 17 for reference.

FIGURE 18

Total platinum supply from primary and secondary sources totaled about 241,000 kg in 2003. By 2010, the projected total platinum supply from primary producers and secondary sources considered in this analysis was 333,000 kg. This represents an increase of about 92,000 kg, or 38 percent higher than the 2003 estimate. The largest projected increase between 2003 and 2010 would be in South Africa, with an estimated primary production capacity increase of about 39,000 kg of platinum. During this period, the amount of platinum recovered from recycled autocatalysts would increase by about 17,000 kg. Projections for the period show primary platinum production capacity would increase 9,600 kg in Russia, 8,800 kg in Zimbabwe, and 7,300 kg in the United States. Platinum primary production capacity in other areas is projected to increase by 4,900 kg by 2010. Secondary platinum recovery from electronics would increase by 5,400 kg. Although much exploration is taking place in Canada, the projected increase in Canadian platinum capacity is expected to be less than 500 kg because the likelihood of significant production coming online by 2010 is relatively small.

Johnson Matthey data suggests that there was an undersupply of primary platinum of about 15,200 kg (570,000 oz) in 2002 which resulted in a drawdown of stockpiled material (Johnson Matthey Plc, 2004). Also, Johnson Matthey reported that market stocks of metal in Zurich, Switzerland, were depleted by as much as 17,400 kg in 2002 (Johnson Matthey Plc, 2003b, p. 42). Subsequent Johnson

Matthey Plc. data show a decreasing primary platinum undersupply in 2003 and 2004, and suggest that the prospect for a oversupply of platinum in the near-term is likely.

Figure 18a suggests that when secondary platinum supply sources are included, a slight oversupply of total platinum of about 12,000 kg occurred in 2003. New mine development and increased refining capacity are expected to further boost short-term platinum supply, and the high price of platinum (more than $27,000 per kilogram in 2003) relative to palladium (just less than $7,600 per kilogram in 2003) may switch demand to palladium from platinum, primarily in gasoline-powered automotive sector. Under current company production plans, platinum mine production capacity would increase until 2006. Using the 1985 to 2003 growth rate scenario, primary platinum supply as determined by production capacity would exceed projected use as determined by purchases by about 35,000 kg and secondary supply would exceed secondary use by about 9,000 kg. After 2006, when new mine construction levels off, total primary plus secondary oversupply would remain at about the 40,000 kg level. Because full production capacity of all producing sites was assumed for this analysis, projection A on figures 18a, 18b, and 18c are considered maximum levels of supply. Actual capacity utilization rates typically range from 70 to 95 percent of the full production rate, an average estimated capacity utilization rate of about 90 percent has been assumed. Using this value, estimated 2010 platinum supply would be about 5,000 kg more than the projected use in 2010.

The projected supply-to-demand picture for palladium for the 2003-2010 period is somewhat different. In 2003, palladium production capacity from primary sources totaled about 200,000 kg. Significant expansion of palladium production capacity in Canada, South Africa, and the United States is in progress or has been announced. In addition, a shift in the focus of production from nickel and copper to PGM recovery in Russia has the potential to increase palladium production. Based on announced expansion or development plans or assumed dates of initial production developed for this analysis, the projected total palladium production capacity by 2010 from the PGM producing sites considered in this analysis would be approximately 289,000 kg, a projected increase of about 89,000 kg, or about 44 percent above the 2003 production capacity estimate. The largest projected increase would be in South Africa with the development of the UG2 reef that contains higher palladium and rhodium content. Announced expansions at Raglan in Canada and the Stillwater Complex in the United States also would lead to increased palladium production in the 2003-to-2010 period.

As shown on figure 17b, palladium recovered from autocatalysts in 2003 was estimated to be about 5 percent of total palladium supply, or 10,500 kg. Based on available data and previously stated assumptions, it was estimated that about 98,000 kg of palladium could be recovered from spent autocatalysts by 2010, and 34,000 kg of palladium could be recovered from recycled electronics. Palladium recovered from autocatalysts could account for about 23 percent of total palladium supply in 2010, and recycled electronics could account for an additional 8 percent.

Johnson Matthey data suggested that palladium supply exceeded palladium purchases in 2002 by about 900 kg. By 2003, palladium production exceeded purchases by more than 32,000 kg. The apparent oversupply was exacerbated by weak palladium demand in most sectors during 2002. Some customers reportedly consumed material from inventories; the DLA sold about 10,900 kg of palladium in 2002 (Johnson Matthey Plc, 2003b, p. 44). A maximum palladium oversupply of about 70,000 kg by 2006 and 88,000 kg by 2010 is possible if all the new or expanding projects included in this analysis come into production and operate at full capacity and the purchases of palladium continue to increase at the average rate represented by the 1985 to 2003 period (figure 18b). A continued low palladium market price during this period could also significantly affect incentives for future primary palladium production or for secondary recovery of palladium so that palladium capacity may not reach the level projected in this analysis. Surplus capacity often results in suspension of activities at the higher cost facilities. Consequently, as the industry attempts to adjust its production to reflect changing palladium market conditions and price, it would not be unreasonable to assume that while projection A of figure 18 would still reflect the maximum amount of material available, projection B would more closely match the available palladium supply.

A significant component of this projected surplus is a consequence of increased supply of PGMs resulting from autocatalyst and electronic component recycling. It is estimated that palladium production from these sectors could increase by 107,000 kg between 2003 and 2010. In terms of primary production, a capacity increase of about 24,000 kg palladium is projected for South Africa; Russian palladium capacity could increase by 29,000 kg from 2003 to 2010. Developments in the automotive sector could favor increased use of palladium during this period; a palladium oversupply would generate a downward pressure on the palladium price.

Figure 18c shows supply and use projections for other PGMs. Although projection A shows the full production capacity of operations recovering PGMs, it is unclear how many of the operations included in this projection actually recover PGMs other than platinum or palladium. This curve, therefore may overstate actual supply in any given year. Also, projection B reflects reported purchases. Many companies do not report purchases of individual PGMs separately, nor report purchases from inventories, so this projection may understate actual use of PGMs other than platinum or palladium. The curves therefore reflect maximum and minimum conditions, actual supply or use likely falls between the projections shown in figure 18c.

Conclusions

PGM resources are adequate to meet projected PGM use requirements at least until 2010 and most likely well beyond that date. In addition, the high level of ongoing PGM exploration and the number of deposits that are planned for development suggest that PGM resources that are being delineated are likely to be more than sufficient to replace those that will be depleted during the next decade. This assumes that both PGM use patterns and prices do not change significantly from present levels.

PGM capacity from South Africa will increase significantly during the decade under favorable economic conditions with the development of deeper UG2 ore zones and eastern Bushveld deposits. This study projects a possible production capacity increase from 2003 levels of approximately 39,000 kg of platinum, 24,000 kg of palladium, and 4,300 kg of other PGM from South Africa by 2010. The growth is dependent on economic, political, social, and technological factors. For example, the strength of the South African rand against the U.S. dollar is likely to play a role in the rate of capacity expansion in the short term. Because South Africa contributes such a large percentage to global PGM supply, the country's mining policies and other in-country events are critical to the PGM industry. Developments in South African mineral legislation, mineral rights provisions, and the prevalence of HIV/AIDS in the mining industry all affect development activities and industrial output.

Russia is likely to continue to supply significant quantities of PGMs well into the future. For the study period, nickel-rich ore will remain the predominant source of Russian PGMs, but increases in production from concentrate stockpiles, cuprous ores, disseminated ores, and tailings are projected by 2010. This study projects a potential growth from 2003 levels of approximately 9,600 kg of production capacity for platinum, 29,000 kg of palladium capacity, and 3,700 kg of capacity for other PGMs from Russia by 2010.

Uncertainty about Russian Government policies and Noril'sk Nickel being able to control its own production and exports have raised doubts about the company's ability to generate the foreign investment capital necessary to implement the capacity increases called for in its development plan. Because Russian PGM supply is second only to that of South Africa, the erratic and volatile nature of this supply becomes important when assessing the accuracy of future supply projections. The uncertainty regarding Russian PGM stockpiles further complicates supply projections.

PGM production capacity in the United States is expected to grow modestly during the next decade through planned expansion at the Stillwater Complex and possible development of byproduct production from a proposed nickel operation in Minnesota. The acquisition of Stillwater Mining Company by Noril'sk Nickel will complicate the U.S. PGM supply situation. Environmental concerns are likely to be among the greatest constraints to future PGM production growth in the United States. As efforts to address environmental and sustainability issues increase, the strategic value of resources derived from recycling will increase, and as a result, these resources may be called upon to satisfy a larger part of the strategic needs of the United States.

High PGM prices at the end of the 20th century led to intensive PGM exploration in Canada, but only limited development was expected prior to 2010. Most of the modest growth projected for the

Canadian PGM industry before 2010 will come from expansion of byproduct PGM recovery from nickel-copper operations. Delays in the development of the Voisey's Bay nickel-copper deposit illustrate how competing social and political interests can affect mineral development.

Future mineral development in Zimbabwe is linked to the political situation in that country, which has led to a fragile economy and great social unrest. PGM capacity growth expected prior to 2010 is associated with the development of the Ngezi and Unki operations.

Minority ownership rights is a social issue that could potentially affect future short-term PGM activity. This includes issues related to First Nations (Canada), HDSA (South Africa), and Native Title (Australia). First Nations and Native Title center around the rights of indigenous peoples to have control of mineral resources under their authority; HDSA relates to the government mandated level of ownership in mines and minerals-related industries by HDSA groups. HIV/AIDS ia also a major issue in South Africa. Because much PGM exploration is centered in locations affected by these issues, future discussion and legislation related to this topic will influence the rate of PGM activity and development in these areas.

Technological developments influence the PGM industry's capability to detect new sources of PGM, determine which discoveries will be most economic, and process potential sources of material. New or improved methods can allow access to new areas, provide more detailed exploration data with greater accuracy, and improve operational productivity and recovery rates. Technology innovations will create new applications for PGMs, improve recycling and remanufacturing capability, and make possible economic PGM recovery from a wider range of primary and byproduct resources.

Innovations in technology also may allow for increasing substitution and other innovations that will reduce the amount of PGMs used in particular applications.

Although numerous factors complicate an estimate of the amount of PGMs generated from the recycling of autocatalysts in future years, it is likely that there will be significant growth in the sector by 2010. This study projects a possible increase of approximately 16,800 kg of platinum, 87,700 kg of palladium, and 6,800 kg of rhodium from recovered autocatalysts by 2010 compared with estimated 2003 levels. Much of this growth is attributed to the greater quantity of vehicles that contain catalytic converters that will be scrapped during this period, improved material separation techniques, and legislative mandates.

PGM recovery from recycled electronics also is likely to grow through 2010. For 2010, it is estimated that approximately 34,200 kg of palladium and nearly 9,300 kg of platinum will be recovered through secondary treatment of electronic scrap. As the recovery of PGMs from recycled sources increases, PGMs that originate from ores may decline and result in more of a “closed loop” for the industry, which is a goal of resource sustainability.

During the 7-year period from 2003 through 2010, primary platinum production capacity, which approximates supply in this study, is projected to increase by 33 percent to about 281,000 kg, palladium production capacity is projected to increase by 44 percent to about 289,000 kg, and production capacity of other PGMs is projected to increase by 10 percent to about 75,000 kg.

In 2003, platinum from primary sources contributed about 88 percent of total production capacity. By 2010, platinum from primary sources is projected to make up 85 percent of total capacity.

A stronger trend is indicated for palladium. In 2003, palladium from primary sources contributed about 89 percent of total production capacity. By 2010, however, palladium from primary sources is projected to decrease to 69 percent of total capacity with recovery of palladium from recycled sources increasing at a faster rate than mine production.

During the past 17 years, the average level of primary platinum purchased increased by 6,150 kg/yr. Similarly, the average level of primary palladium purchased increased by 4,733 kg/yr, and the average level of primary rhodium purchased increased by 661 kg/yr.

Jewelry represents the leading demand sector for platinum. Future growth in PGM jewelry demand is dependent on its continuing popularity and expanding its market penetration in China and India. The potential exists for the demand for jewelry to become significantly larger but at a relatively slow rate.

Catalytic converters represent the leading demand sector for palladium and the second leading sector for platinum. Although there may be a trend to substitute for some of the platinum and palladium used in autocatalysts with other materials, demand is expected to increase during the next decade with increasing vehicle production and more strict regulatory control of exhaust emissions. Because of the high cost of PGMs, research continues to focus on technologies that reduce or eliminate the amount of PGMs required in this application. Barring substitution, PGM demand in the electronics sector should grow, with increasing consumer demand for greater storage capacity in computers, onboard vehicle navigation systems, and video recording equipment. Greater quantities of palladium are required for multilayered ceramic capacitors and integrated circuits, and platinum consumption in computer hard discs is on the increase. The relative price of the precious metal constituents of electrical and electronic components contributes to the extent to which they are used. The alloying composition and degree of substitution often depends on which constituents can be acquired most easily and at the lowest price. PGM consumption is likely to increase because the total number of electronic units produced will overshadow the decreasing PGM use per unit.

There is much effort to develop economic and efficient fuel-cell technology. Current research is directed at reducing platinum requirements for fuel cells to make the systems more affordable. Legislation, consumer acceptance, the price of fossil fuels, and the speed of development and rate of success, among other factors, will determine future PGM use in this application. Because of the many obstacles yet to be overcome, however, it is unlikely that fuel cells will significantly contribute to PGM use prior to 2010. It is likely that significant commercial-scale PGM recovery from recycled fuel cells would not take place before 2015.

Using the historical platinum purchases growth level of 6,150 kg for the period from 1985 through 2003, and estimates of the amount of platinum recycled in autocatalysts and electronic components, approximately 294,000 kg of platinum are projected to be used in 2010. Similarly, an annual level of approximately 334,000 kg of primary and secondary palladium is projected to be used in 2010, based on the historical palladium purchases growth level of 4,733 kg/yr for 1985 through 2003, and estimates of the amount of palladium recycled in autocatalysts and electronic components. An annual level of approximately 60,000 kg of other PGMs is projected to be used by 2010.

A slight oversupply of total platinum of about 12,000 kg is indicated for 2003, when full production capacity of producing operations is assumed. Projections based on historical growth levels suggest that platinum production capacity could exceed projected use by about 40,000 kg in 2010. However, when a 90 percent capacity utilization rate is applied, projected 2010 platinum supply would be about 5,000 kg more than the projected use in 2010.

Available data suggest that there existed an apparent oversupply of palladium of as much as 32,000 kg in 2003. Much of the excess supply went to restock palladium inventories that had been depleted as a consequence of recent high palladium prices. this oversupply is projected to continue in the short term, when developing mines and announced expansion projects in North American and South Africa come online, Russian production shifts toward increased PGM recovery, and the amount of palladium recycled increases. Based on data from this study, a maximum palladium oversupply of 70,000 kg is possible by 2006, and a maximum 88,000 kg oversupply is possible by 2010. Assuming a capacity utilization rate of 90 percent, the oversupply in 2010 would be 46,000, only slight higher that that of 2003. These maximum conditions will only occur if all the new or expanding projects included in this analysis begin production and operate at full projected production capacity, the demand for palladium grows at the historical growth rate, and the quantity of palladium projected from secondary sources is actually recovered.

The uncertainty of PGM stockpiles and inventories can affect PGM supply and demand estimates. Supply projections based upon production capacity and use projections based only upon purchases thus reflect maximum and minimum supply and use levels. Better inventory data will likely increase the confidence level of PGM projections.

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APPENDIX

This discussion provides a generalized overview of geologic environments for platinum-group metals (PGM) and outlines principal regions that contain identified sources of PGM where exploration is ongoing or has taken place in the recent past. The discussion is not intended to include all locations where historically there has been PGM exploration. This discussion does not include recovery of PGM from secondary (recycled) sources.

Overview

The majority of PGM deposits are associated within magmatic intrusions. Classification schemes for magmatic ore deposits integrate principal mineral association (sulfide versus oxide), rock associations and magma type, setting and geometry within an intrusion, and tectonic setting. Genetic classification schemes also have been proposed. Page and others (1982), Naldrett (1981, p. 637; 1989, p. 6), and Eckstrand (1996, p. 593) base their classification on the tectonic setting and petrologic characteristics of the mafic and ultramafic rocks. Cabri and Naldrett (1984, p. 17) proposed a classification of platinum-group element (PGE)-bearing deposits that recognized two classes of occurrences—a sulfide association and an oxide-silicate association. These two associations were then subdivided into deposit types based on differences in geochemistry, mineralogy, and tectonic setting. Hulbert and others (1988) proposed four subclasses of magmatic deposits (discordant, marginal, stratabound, and other) based on the spatial association of the mineralization to the enclosing ultramafic and mafic host rocks. MacDonald (1988) proposed a classification scheme that emphasized the genesis of these deposits as listed in table 1.

Table 1. Classification of platinum-group metal deposits

Class	Setting	Deposit type	Concentration	Significance	Examples
Magmatic……	LI—layered ultramafic-mafic intrusion	Layers of disseminated sulfides enriched in platinum-group elements (PGE) (reef-type deposits)	Primary PGE deposit……….	Global resource…...	Merensky Reef (South Africa); J-M Reef (Montana); main sulfide layer, Great Dyke (Zimbabwe).
……Do….......	……Do.........................	Stratiform chromitites enriched in PGE……...	……Do……….	……Do…….	Upper Group 2 (UG2) (South Africa); Panton sill (Australia).
……Do………	……Do………………..	Discordant dunite pipes…	……Do……….	Small, high-grade deposits.	Dreikopf, Onverwacht, and Mooihoek deposits (South Africa).
……Do………	……Do……………...	Disseminated to massive sulfide deposits at contacts with host rocks………….	Polymetallic deposit (copper, nickel, PGE)	Global resource……	Platreef (South Africa); Suhanko-Kontiijarvi (Finland); Duluth (Minnesota, United States); Marathon, East Bull Lake, River Valley intrusions (Ontario, Canada).
……Do……...	LIP—relatively small sills and dikes that are conduits that feed large intrusions or flood basalt provinces……	Disseminated to massive sulfide deposits…….....	……Do……….	……Do…….	Noril’sk-Talnakh (Russia); Jinchuan (China); Voisey’s Bay (Newfoundland, Canada).
……Do………	Archean greenstone belt	Komatiite-hosted disseminated to massive sulfide deposits……….	……Do……….	Significant resource……	Western Australia; Thompson Belt (Manitoba, Canada).
……Do……...	Astrobleme—large mafic intrusion……..	Sulfide deposits at margins of large ultramafic-mafic intrusions……...	……Do……….	……Do…….	Sudbury Irruptive Complex (Ontario, Canada).
……Do………	Subduction-related orogenesis………….	Disseminated sulfides in contact zone between phases of a composite pluton…………	Primary PGE deposit……….	……Do…….	Lac des Iles (Quebec, Canada).
……Do………	Ophiolite (divergent plate margin)……….	Disseminated sulfides in ultramafic cumulates	Polymetallic deposit (copper, nickel, PGE)	Minor production	Acoje (Philippines).
……Do………	Subduction-related orogen—zoned “Alaskan-type” ultramafic intrusions	Platinum-iron alloys in chromitite schlieren or dunite……….	Primary PGE deposit……….	No significant production	Ural Mountains; Kondur (Russia); Fifield (Australia).
Surficial……..	……Do………………	Placer PGM deposits derived from zoned intrusion……	……Do…….....	Significant production	Ural Mountains (Russia); Colombia; Russian Far East; Goodnews Bay (Alaska, United States).
……Do………	……Do………………..	Laterite developed on zoned intrusion………	Polymetallic (nickel and PGE)	Proposed	Syerston (Australia).

PGE have been described from a variety of other deposit types, as listed in table 2.

Table 2. Hydrothermal platinum-group metal deposits

Deposit type	Platinum-group element status	Examples
Coal……………………………………..	Previously reported…………………….	Many.
Copper skarns…………………………....	……Do………………………………….	Singenggoe (Finland); Carr Fork (Utah, United States).
Ferromanganese crusts………………….	……Do………………………………….	NA
Hydrothermal gold deposits…………….	……Do………………………………….	Dome mine (Ontario, Canada; Sukhoi Log (Russia).
Hydrothermal polymetallic veins……….	Previously recovered or reported……….	New Rambler (Wyoming, United States).
Metalliferous black shales (molybdenum and nickel)……………………………	Previously reported	Lower Cambrian black shales (China); Nick property (Yukon, Canada)

Porphyry copper and gold deposits……..	Previously recovered…………………...	Many.
Sediment-hosted copper deposits (reduced facies)………………………	Previously recovered or reported……….	Kuperschiefer (Poland); unnamed deposit in central Africa.
Unconformity uranium and gold deposits	Previously reported…………………….	Cluff Lake and Beaverlodge area (Saskatchewan, Canada); Athabasca basin (Alberta, Canada); Coronation Hill and Jabiluka deposits (Australia).
Volcanic-hosted antimony, arsenic, and copper deposits………………………	Previously recovered…………………..	Bor and Recsk (Hungary).

Potential resources - Africa

Botswana

PGM resources are being investigated at nickel-platinum prospects in Botswana. The country has been explored since the 1970s for its nickel and copper, and nickel is currently being recovered from the Selkirk and Tati mines. Extensive work has been conducted since 2002 at the Phoenix nickel-copper mine to expand production from the recovery of polymetallics, including PGMs, using new process technology. Based on 2002 research, the mine may be able to recover about 660 kilograms per year (kg/yr) of palladium and platinum from the nickel concentrate. The new technology could allow for the recovery of up to 930 kg/yr of PGMs (Sergeant, 2003). No production decisions have been released yet, and production from this source was not included in this analysis.

Congo (Kinshasa)

Palladium and platinum values are being reported in trench samples currently being recovered on the Kabolela deposit in the Katangan copper belt of Congo (Kinshasa). Should political and social tensions in the area ease, it is possible that reevaluation of this rich copper-producing area for PGMs could promote possible PGM recovery from the region (Melkoir Resources Inc., 2001)

Guinea

Rio Tinto plc., recently investigated the copper, gold, nickel, and PGM resource possibilities of four prospects on the Mont Kakoulima deposit in Guinea. The deposit occurs in an ultramafic intrusive complex detected by geophysical surveys (SEMAFO, Inc., 2000).

Mauritania

Drilling in 2001 by Rex Diamond Mining Corporation (2001) in north-central Mauritania has turned up evidence of gold, nickel, and PGM mineralization. The company planned to continue exploration in the country.

Namibia

Limited exploration has taken place at the Karasberg nickel-PGM deposit in southern Namibia. The deposit, which is hosted in an ultramafic unit, is being sampled and drilled following geophysical surveys conducted by BHP Billiton Limited (2001).

Tanzania

High-grade PGM values have been found in Tanzanian chromite deposits and the Kapalagulu layered mafic-ultramafic intrusive east of Lake Tanganyika. Initial fieldwork in this area was conducted by Barrick Gold Corporation in 2001 (Goldstream Mining NL, 2001).

Potential resources - Asia

China

Little is publicly available about PGM resources of China, but the large size of the country and what is known about its geology suggest that it would be reasonable to assume that there should be significant undiscovered resources of PGMs. Zhou and others (2002, p. 619-635) evaluate Chinese magmatic sulfide deposits for their PGM potential.

India

Despite reports of PGM discoveries and exploration programs during the past 20 years, no primary production of PGMs is credited to India. Minor byproduct palladium is reported at the Ghatsila copper facility, but output of PGMs in India is not believed to be substantial. The Geological Survey of India reports ongoing work in the Baula-Nuasahi chromite belt in Orissa Province (Mining Journal, 1999b).

Mongolia

Early PGM exploration was conducted in Mongolia during 1999 with a preliminary estimate of 700 kg of PGMs reported (Mining Journal, 1999a). There are also reports of platinum being recovered from gold mined in Mongolia.

Other Areas

PGMs have been identified in gold placers in Burma and Indonesia. The most recent production in the Philippines was between 1971 and 1975 at the Acoje mine where platinum and palladium were recovered from nickel concentrate. The Acoje resource was estimated to be 4.8 million metric tons (Mt) with a platinum to palladium grade of 10 grams per metic ton (g/t) (Rusina Mining Limited, 2003). Rusina Mining Limited is currently drilling the property and evaluating the feasibility of reopening the mine.

Potential resources - Europe

Finland

Extensive exploration for PGMs was ongoing in Finland during 2003. The country is known to contain eight layered mafic intrusions, all of which either contain PGMs or show encouraging indications (Geological Survey of Finland, 2003). Finnish PGM occurrences are similar to deposits found on the Kola Peninsula of Russia, with a dominance of palladium over platinum. The Penikat and Portimo intrusions in northern Finland have generated the most interest. Drilling by the joint venture of Gold Fields Ltd. and Outokumpu Oui have led to a resource estimate of 284,000 kg of PGMs for the Konttijarvi and Ahmavaara deposits and an estimate of 163,000 kg of PGMs for the SK Reef with an average palladium-to-platinum ratio of approximately 4 to 1 (Gold Fields Limited, 2002). This project shows promise to become a significant PGM producer; however, no production decisions have been reached yet, so the property has not been included in this study's production capacity figures. Other PGM-rich occurrences being explored in 2002 included the Koillismaa and Keivitsa intrusions.

Greenland

Platinova A/S explored the Skaergaard gold-PGM deposit in Greenland in the mid-1990s and reported a resource that contained 22,800 kg of PGMs (Platinova A/S, 2002). Exploration for PGMs in Greenland is continuing. PGM resources may exist in Greenland because of the geologic similarity to other areas, such as the Duluth Gabbro in the United States.

Kazakhstan

Osmium is produced on a pilot scale in Kazakhstan as a byproduct of copper smelting. The Yuzhno-Kimpersaiskaya chromite, Kimpersaiskaya nickel-cobalt, and Bakyrchik gold deposits are all thought to contain PGMs, but none are recovered (Roskill Information Services, Ltd., 1999, p. 41).

Sweden

Initial drilling conducted in 2001 suggested palladium potential at the Bottenbacken project in central Sweden. This occurrence is found in a series of mafic, metavolcanic bodies identified by geophysics (Poplar Resources Ltd., 2001).

Russia and Central Eurasia

PGM-bearing deposits of magmatic origin in Russia were discovered in the 1950s and 1960s. Although no definitive resource figures are available, prospective deposits include the Kingash copper-nickel sulfide deposit in Siberia, the Chiney chromium-iron-PGMs-titanium deposit in northern

Transbaikalia, and the Burakovskove chromite-PGM deposit in Karelia, which is currently reportedly under development (Yakubchuk and Edwards, 2002).

There is mounting evidence that recoverable levels of PGMs occur in unconventional geologic environments in Russia, such as the black shale hosted gold deposits of Sukhoi Log in Siberia. Elevated PGM levels of 1 to 2 g/t of PGMs are correlated with high sulfide concentrations. Insoluable organic matter contains as much as 10 g/t of gold and PGMs (Wilde and others, 2003). Similar deposits are being mined for gold in the Tien Shan region of Kyrgyzstan and Uzbekistan. The Kumtor and Muruntau gold deposits of Kyrgyzstan and Uzbekistan also contain elevated levels of PGMs. There is no record of any PGM production from this deposit type, however.

Potential resources - Latin America

Argentina

PGM exploration in Argentina has been focused principally on the Tecka layered ultramafic complex, a largely unexplored ultramafic-mafic intrusion similar to the Bushveld and Stillwater Complexes. Early-stage exploration in 2001 by Southwestern Gold Corporation has yielded PGM values in reconnaissance sampling (Southwestern Gold Corporation, 2001).

Bolivia

Exploration for PGMs in Bolivia has been conducted periodically on the Rincon del Tigre layered ultramafic intrusion (Pendergast, 2000). Solitario Resources Corporation (2001) conducted a phase 1 drilling program on the deposit in 2001 as part of its search for PGMs.

Mexico

Interest in Mexican PGM exploration has been focused on the Puerto Nuevo chromite-bearing ultramafic intrusive in Baja California and the Tropico copper-PGMs-gold project near Mazatlan (Morgain Minerals Inc., 2000; Santoy Resources Ltd., 2000). At each site, there is early-stage exploration. No resources are reported.

North America

Canada

The two leading PGM-producing companies in the world are involved in funding exploration of the River Valley intrusion in Ontario in an advanced greenfield exploration project within the Sudbury basin. The River Valley intrusion is a layered gabbro-anorthosite complex with elevated copper, nickel, and PGM mineralization near its contact with the country rock. Anglo American Platinum Corp. Ltd. of South Africa and Pacific North West Capital Corp. of Canada are participating in an ongoing phase-5 program of 20,000 meters of diamond drilling. An indicated resource at the Dana Lake and Lismer's Ridge areas has been estimated to contain 18,000 kilograms (kg) of palladium and 6,000 kg of platinum, and significant additional resources may exist along strike and down dip (Pacific Northwest Capital Corp., 2002). Exploration success at this site has stimulated other exploration ventures on the River Valley intrusion. In a second River Valley intrusive joint venture, Impala Platinum Corp. of South Africa and Mustang Minerals Corp. of Canada are conducting geophysical surveys and drilling at an adjacent site.

PGM exploration activity is heaviest in Ontario and Quebec. With the release of an Ontario Geological Survey report in early 1999 that indicated that large areas of Ontario and western Quebec were highly prospective for PGMs, 40 junior companies reported exploration activity on PGMs in three tectonic terranes in Ontario, which include the Sudbury and Nipigon basins and the Quetico belt (Metals Economics Group, 2000). Based on data collected by the U.S. Geological Survey, 33 companies reported activity in Ontario during 2002 at 56 sites that had PGM potential. Junior mining companies dominate exploration for PGM deposits. As with the River Valley deposits, junior exploration companies solicit joint-venture agreements with larger, well-financed companies when initial exploration indicates potential for significant resources and additional exploration becomes expensive. Higher PGM prices combined with a general contraction in the resource sector and weak equity markets have encouraged junior companies to focus their limited funds on the most promising commodities for the short term. Based on data available from public sources, 8 companies were reported conducting PGM exploration during 2002 at 18 sites in Quebec. Significant PGM intersections were reported at several locations.

PGM exploration continued in other areas of Canada. PGMs have been targeted in Alberta, Manitoba, Nunavut, and Yukon Territory. Examples of recent discoveries that contain PGMs in the new province of Nunavut, which was created in 1999, include Starfield Resources Inc.'s Ferguson Lake deposit and Muskox Minerals Corp.'s Muskox deposit. As of December 31, 2002, an inferred resource of 75,000 kg [2.4 million troy ounces (Moz)] of palladium and 12,000 kg [(400,000 troy ounces (oz)] of platinum had been defined at Ferguson Lake (Starfield Resources Inc, 2003).

In 2004, Mustang Minerals Corporation acquired the Maskwa deposit in Manitoba, which was reported to have the potential to recover byproduct platinum and palladium from a 1,000-metric-ton-per-day nickel/copper operation. The previous owner, Canmine Resources Corp., estimated that approximately 2,800 kg of palladium and 800 kg of platinum could be recovered during a projected 10-year mine life (Mustang Minerals Corp., 2004). Short-term development of this deposit is dependent upon permit approval and financing, and no production timetable has been announced. While several PGM exploration projects in Canada have reached the advanced stage, bankable feasibility studies on these projects have not yet been completed, so no production is expected prior to 2006. Although development of the Voisey's Bay nickel-copper project is proceeding, it is unlikely that there will be significant byproduct PGM production during the study period.

United States

Future PGM production from the Duluth Complex in Minnesota (Polymet Mining Corporation's NorthMet operation) was being evaluated. A bankable feasibility study was completed for the NorthMet operation in 2001 (Polymet Mining Corporation, 2001). Similar evaluations are being made on PGM-rich placer deposits in central Alaska and PGM-rich placer sands in Arizona (Corral Creek Corporation, 2000; Global Platinum & Gold, Incorporated, 2001).

Pacific Region and Southeast Asia

Australia

Exploration for PGMs in Australia is ongoing. Deposits from which PGMs are potentially recoverable include the following:

- The Weld Range deposit, a Bushveld-type ultramafic intrusive in Western Australia with an estimated resource of 16,500 kg (530,000 oz) of PGMs (Smart and Garrad, 1999).

- The Fifield region of New South Wales contains an Alaska-type ultramafic intrusive that contains several deposits, which are presently poorly defined, with grades in the order of 0.5 to 1.4 g/t platinum. Historically, this area produced 640 kg (21,000 oz) of platinum from alluvial deposits (Smart and Garrad, 1999).

- The Coronation Hill low-temperature hydrothermal gold-PGMs-uranium deposit southeast of Darwin, Northern Territory, contains an estimated 29,900 kg (961,000 oz) of platinum and 102,000 kg (3 Moz) of palladium (Smart and Garrad, 1999).

- The Thompson River copper deposit in Victoria contains a copper-nickel sulfide deposit in a dike that contains a small tonnage estimated to be 11,600 kg (373,000 oz) of PGMs at a relatively high grade (Smart and Garrad, 1999).

New Zealand

In New Zealand, exploration for PGM has focused on the Longwood layered intrusion on the South Island. The Longwood target has been the subject of sporadic exploration in the past 30 years, the latest taking place in 1999 (Mining Journal, 2000).

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Figure 1. Distribution of world production for platinum and palladium in 2002. Data are derived from company reported production values and U.S. Geological Survey estimates, excluding stockpile sales and recycled material.

Figure 2. Platinum-group metal resource distribution based on company data as of 2002 reported at the reserve base level. As defined by U.S. Geological Survey Circular 831, the reserve base is that part of an identified resource that meets specified physical and chemical criteria, including those for grade, quality, thickness, and depth. The reserve base is the in-place demonstrated (measured plus indicated) resource (U.S. Bureau of Mines and U.S. Geological Survey, 1980). Reserve base figures include those resources that are currently economic or marginally economic, but do not include platinum-group metals in stockpiles or platinum-group metals that are potentially available by recycling. Data are derived from company reported production values and U.S. Geological Survey estimates.

Figure 3. Primary platinum-group metal (PGM) production data from 1987 to 2001. *A*, South Africa; *B*, Soviet Union (1987 to 1991) and Russia (1992 to 2001); *C*, Canada; and *D*, United States. Data are derived from U.S. Geological Survey, Minerals Yearbook series, various years.

Figure 4. Projected South African platinum production capacity from 2000 to 2010. Estimates are derived from reported company development plans for individual sites.

Figure 5. Estimated primary production capacity for platinum-group metals from 2002 to 2010.   *A*, South Africa; *B*, Russia; *C*, Canada; and *D*, United States. Data are derived from reported company development plans for individual sites.

Figure 6. Projected Russian palladium production capacity from 2000 to 2010. Estimates are derived from reported company development plans for individual sites.

Figure 7. Platinum-group metals recovered by recycling of autocatalysts from 1987 to 2002. Modified from Johnson Matthey Plc.

Figure 8. Estimated or projected recovery of recycled platinum, palladium, and rhodium from catalytic converters in 1984, 1990, 2000, and 2010. Data for 1984, 1990, and 2000 reported from Johnson Matthey Plc.

Figure 9. Regional purchases of the three principal platinum-group metals from 1987 to 2002. *A*, Japan; *B*, North America; *C*, Europe; *D*, Other areas. Modified from Johnson Matthey Plc.

Figure 10. Purchases of three platinum-group metals by end use from 1987 to 2002. *A*, Platinum; *B*, Palladium; *C*, Rhodium. Modified from Johnson Matthey Plc.

Figure 11. Platinum purchases for jewelry by region from 1987 to 2002. Modified from Johnson Matthey Plc.

Figure 12. Primary and recycled material purchases of three platinum-group metals for use in autocatalysts from 1987 to 2002. Inventories from stockpiles are not included. Modified from Johnson Matthey Plc.

Figure 13. World platinum-group metal purchases for electrical and electronics applications from 1987 to 2002. Modified from Johnson Matthey Plc.

Figure 14. Primary platinum-group metal (PGM) purchases and PGMs recovered from catalysts from 1985 to 2002. Recovered electronic scrap is not included. *A*, Platinum; *B*, Palladium; *C*, Rhodium. Modified from Johnson Matthey Plc.

Figure 15. Production capacity and purchase projections for primary platinum and palladium from 2003 to 2010. A starting point in 2003 was derived from data from Johnson Matthey Plc. and U.S. Geological Survey. *A*, Primary platinum; *B*, Primary palladium. Historical growth data derived from Johnson Matthey Plc.

Figure 16. Price history for platinum and palladium from 1900 to 2002. Real prices deflated using Consumer Price Index, 1998 base year. Modified from Hilliard, 1999, 2003.

Figure 17. World recycled platinum and palladium projections from autocatalysts and electronics for the years 2003 to 2010. *A*, Recycled platinum; *B*, Recycled palladium. Estimates based on Harler (2003), U.S. Geological Survey data, and oral communication with Ashok Kumar, Director, A-1 Specialized Services and Supplies.

Figure 18. Supply and use limits for platinum, palladium, and other platinum-group metals from 2003 to 2010. *A*, Platinum; *B*, Palladium; *C*, Other platinum-group metals.

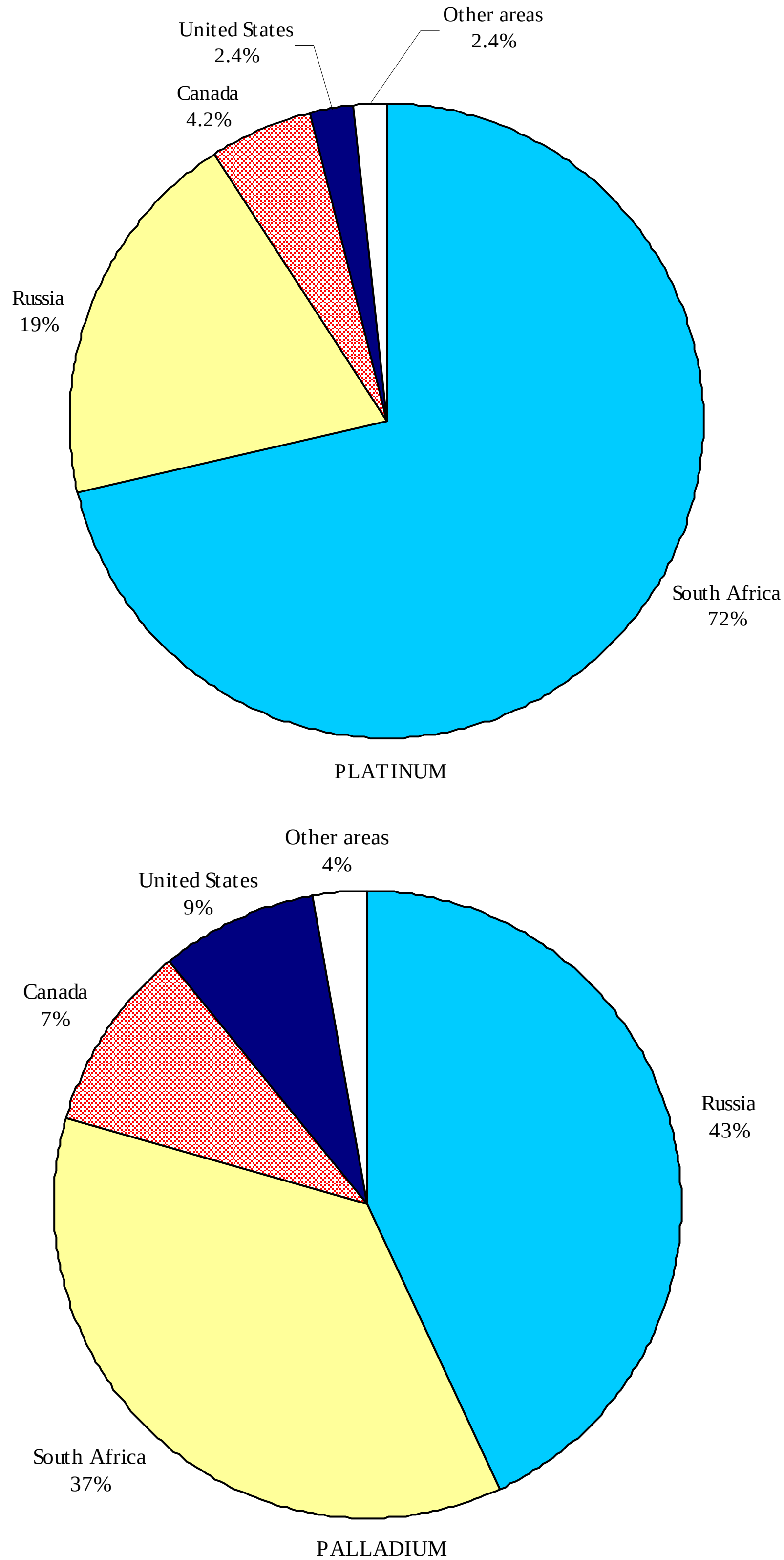

United States
2.4%
Other areas
2.4%
Canada
4.2%
Russia
19%
South Africa
72%
PLATINUM
Other areas
4%
United States
9%
Canada
7%
Russia
43%
South Africa
37%
PALLADIUM

Figure 1.

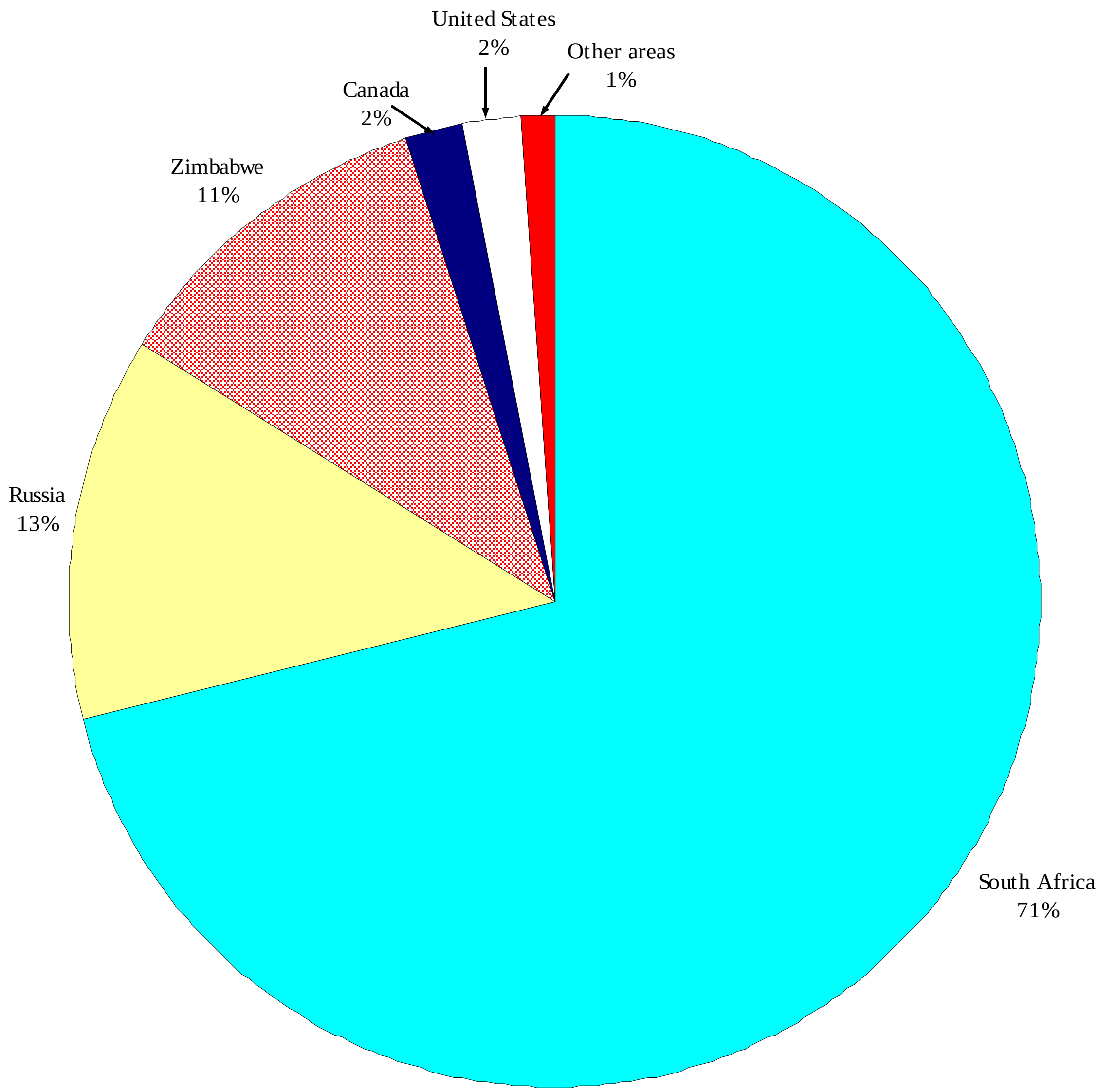
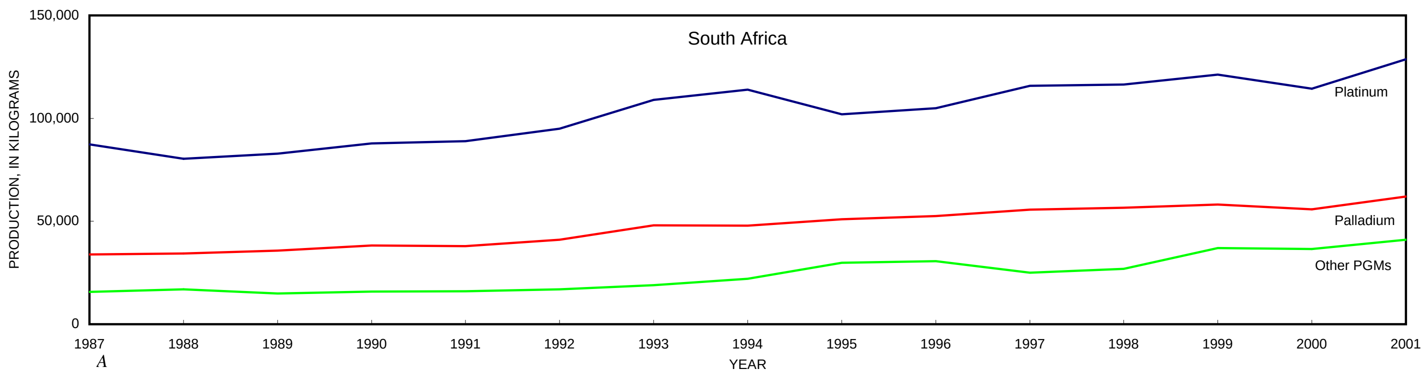
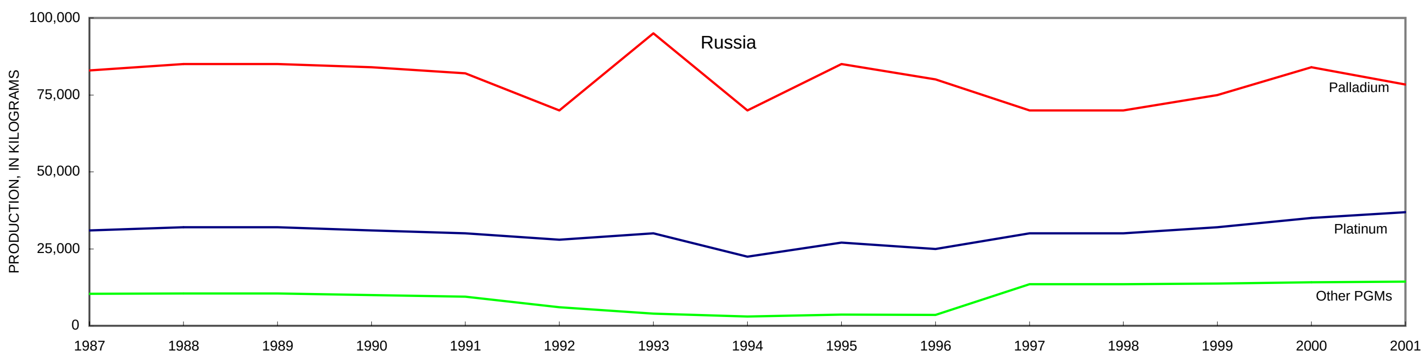

United States
2%
Other areas
1%
Canada
2%
Zimbabwe
11%
Russia
13%
South Africa
71%

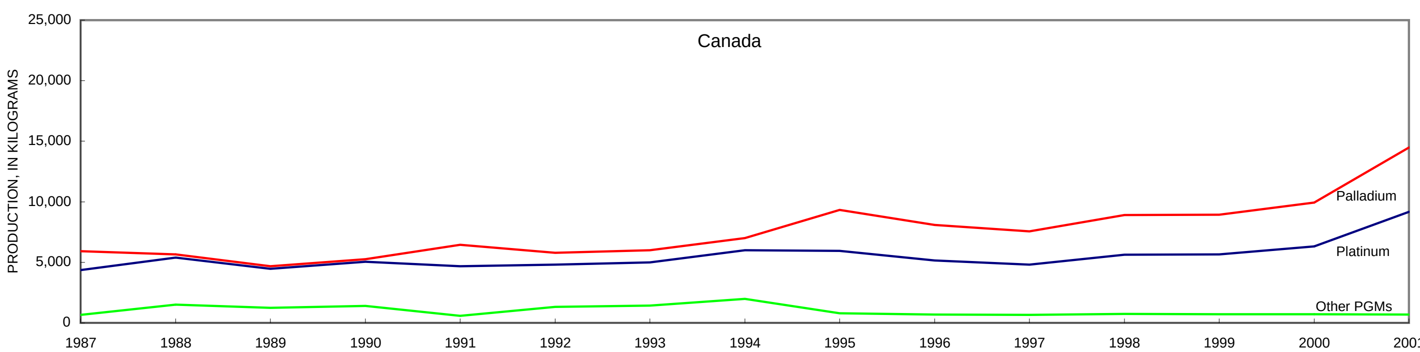
Figure 2.



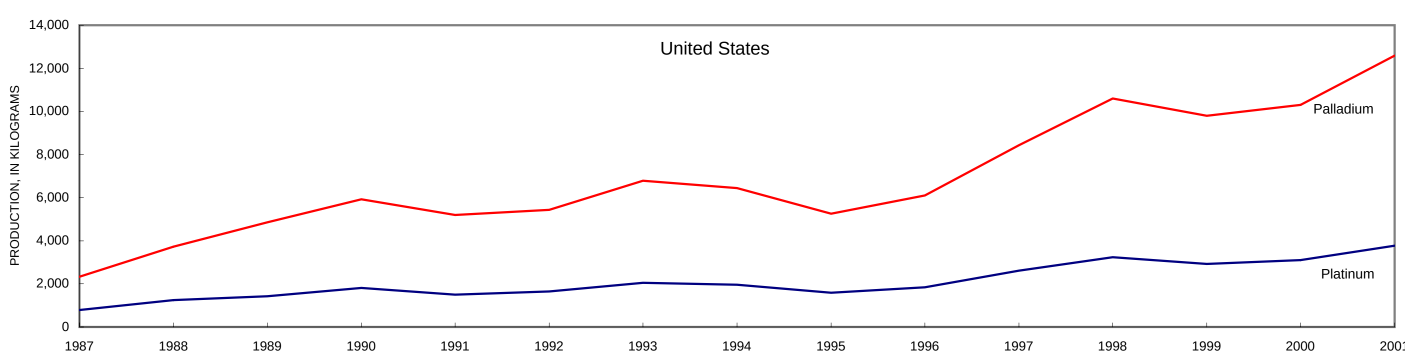
A



B

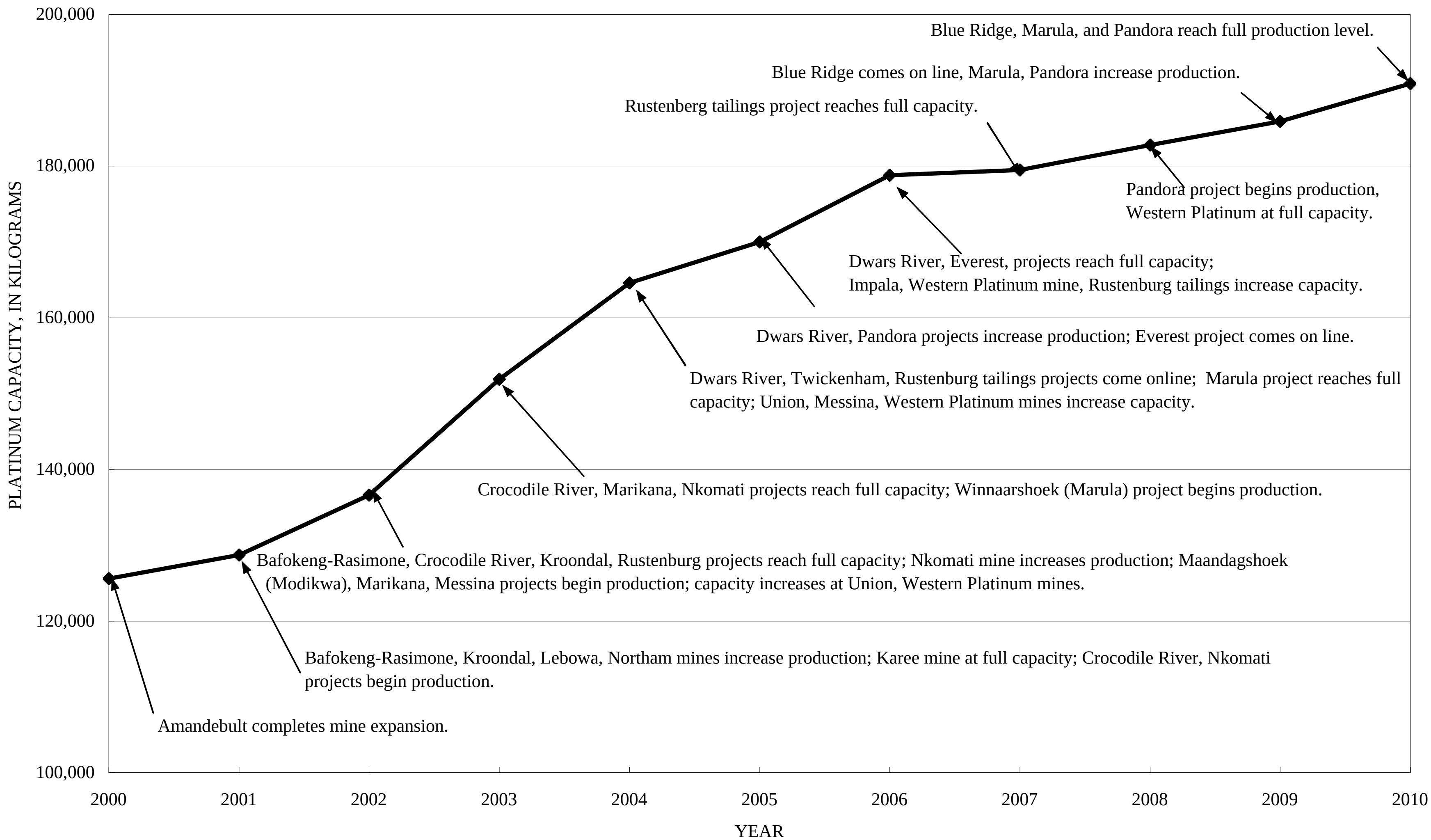


C



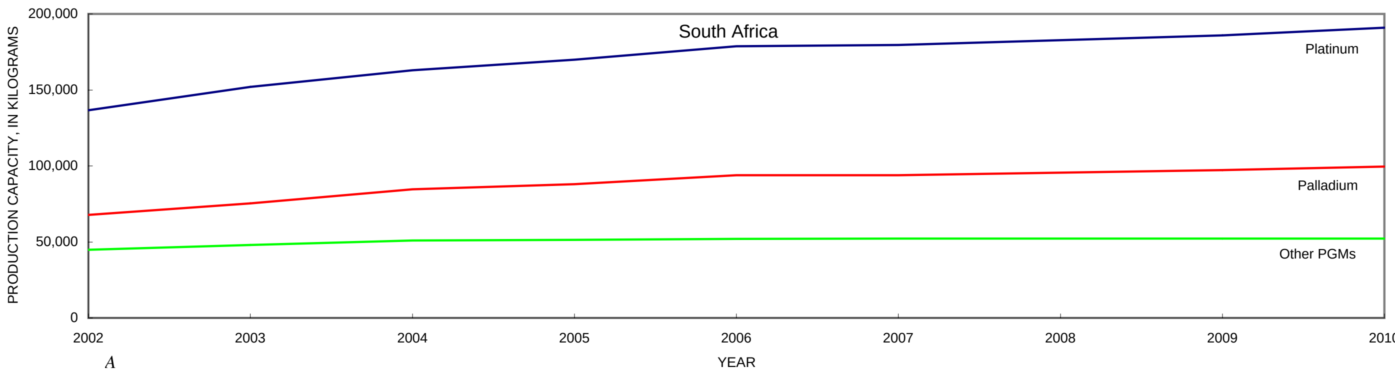
D

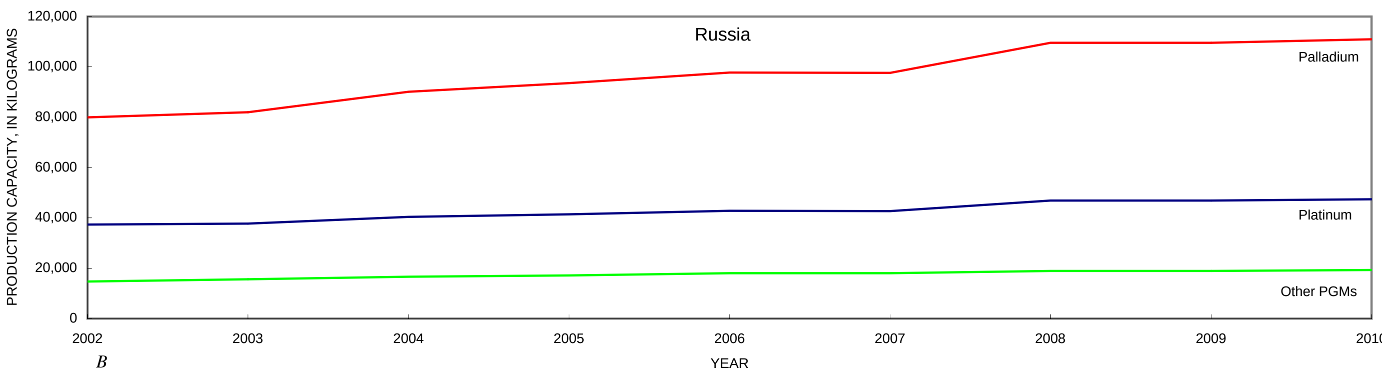
Figure 3.

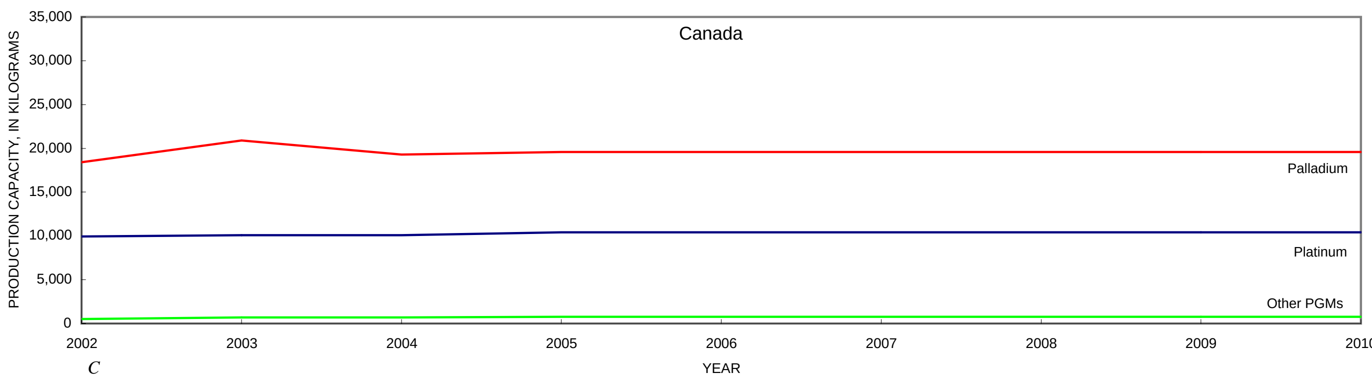


200,000
180,000
160,000
140,000
120,000
100,000
PLATINUM CAPACITY, IN KILOGRAMS
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
YEAR
Blue Ridge, Marula, and Pandora reach full production level.
Blue Ridge comes on line, Marula, Pandora increase production.
Rustenberg tailings project reaches full capacity.
Pandora project begins production, Western Platinum at full capacity.
Dwars River, Everest, projects reach full capacity; Impala, Western Platinum mine, Rustenburg tailings increase capacity.
Dwars River, Pandora projects increase production; Everest project comes on line.
Dwars River, Twickenham, Rustenburg tailings projects come online; Marula project reaches full capacity; Union, Messina, Western Platinum mines increase capacity.
Crocodile River, Marikana, Nkomati projects reach full capacity; Winnaarshoek (Marula) project begins production.
Bafokeng-Rasimone, Crocodile River, Kroondal, Rustenburg projects reach full capacity; Nkomati mine increases production; Maandagshoek (Modikwa), Marikana, Messina projects begin production; capacity increases at Union, Western Platinum mines.
Bafokeng-Rasimone, Kroondal, Lebowa, Northam mines increase production; Karee mine at full capacity; Crocodile River, Nkomati projects begin production.
Amandebult completes mine expansion.

Figure 4.


South Africa
PRODUCTION CAPACITY, IN KILOGRAMS
200,000
150,000
100,000
50,000
0
Platinum
Palladium
Other PGMs
2002
2003
2004
2005
2006
2007
2008
2009
2010
A
YEAR


Russia
PRODUCTION CAPACITY, IN KILOGRAMS
120,000
100,000
80,000
60,000
40,000
20,000
0
Palladium
Platinum
Other PGMs
2002
2003
2004
2005
2006
2007
2008
2009
2010
B
YEAR


Canada
PRODUCTION CAPACITY, IN KILOGRAMS
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Palladium
Platinum
Other PGMs
2002
2003
2004
2005
2006
2007
2008
2009
2010
C
YEAR

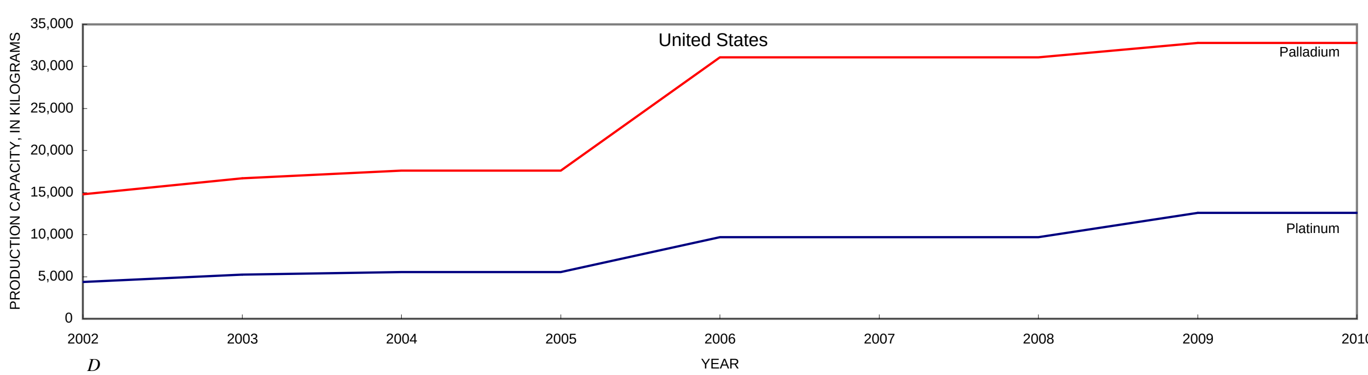

United States
PRODUCTION CAPACITY, IN KILOGRAMS
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Palladium
Platinum
2002
2003
2004
2005
2006
2007
2008
2009
2010
D
YEAR

Figure 5.

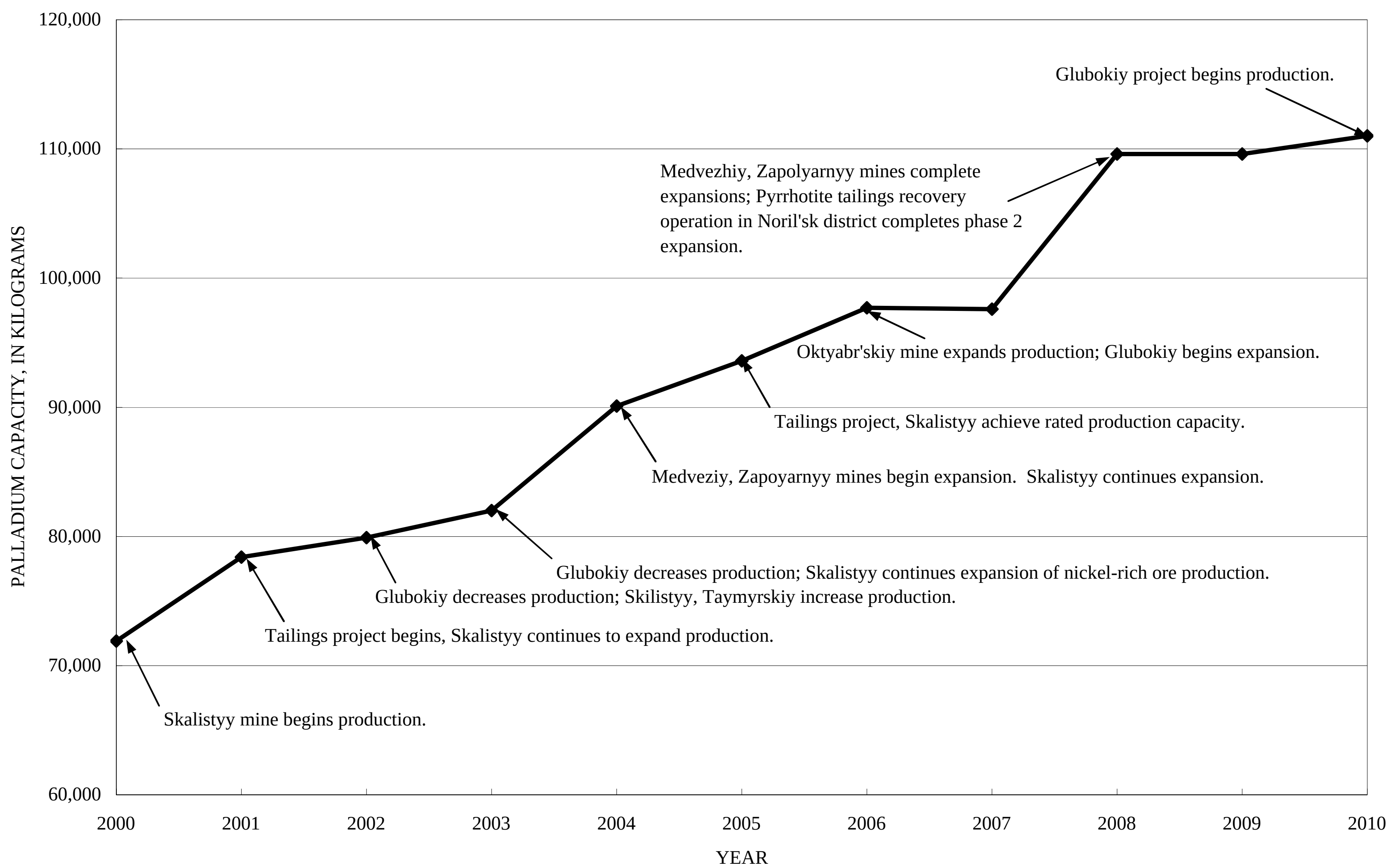

PALLADIUM CAPACITY, IN KILOGRAMS
120,000
110,000
100,000
90,000
80,000
70,000
60,000
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
YEAR
Glubokiy project begins production.
Medvezhiy, Zapolyarnyy mines complete expansions; Pyrrhotite tailings recovery operation in Noril'sk district completes phase 2 expansion.
Oktyabr'skiy mine expands production; Glubokiy begins expansion.
Tailings project, Skalistyy achieve rated production capacity.
Medveziy, Zapoyarnyy mines begin expansion. Skalistyy continues expansion.
Glubokiy decreases production; Skalistyy continues expansion of nickel-rich ore production.
Glubokiy decreases production; Skilistyy, Taymyrskiy increase production.
Tailings project begins, Skalistyy continues to expand production.
Skalistyy mine begins production.

Figure 6.

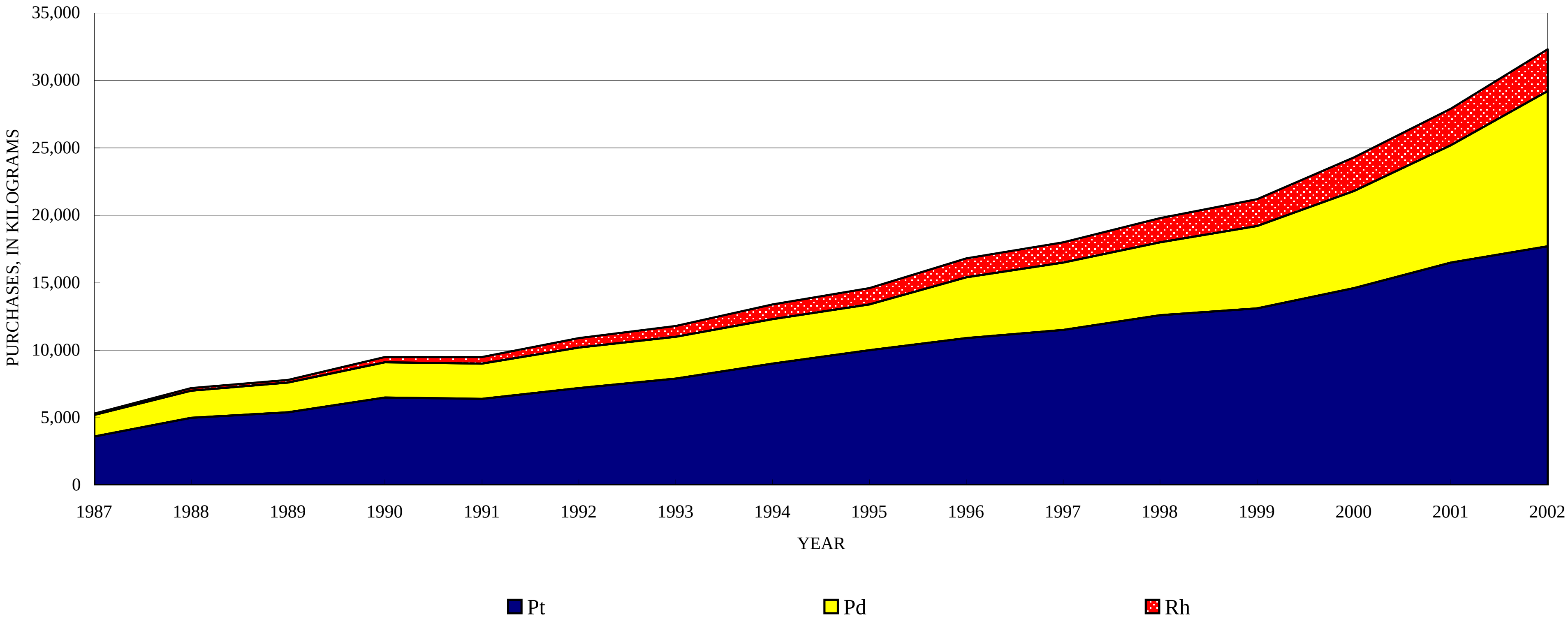

35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
PURCHASES, IN KILOGRAMS
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
YEAR
Pt
Pd
Rh

Figure 7.

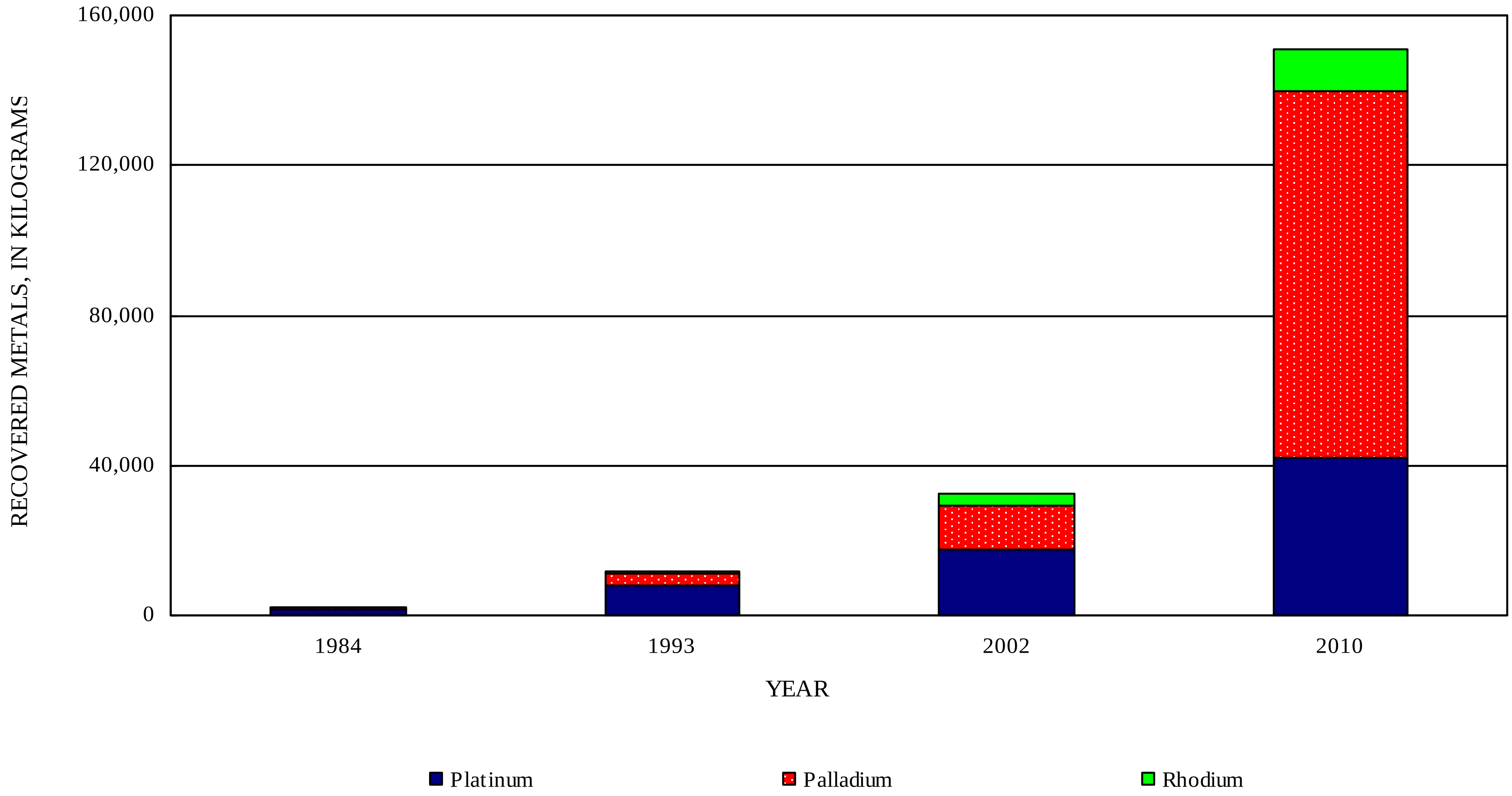

160,000
120,000
80,000
40,000
0
RECOVERED METALS, IN KILOGRAMS
1984
1993
2002
2010
YEAR
Platinum
Palladium
Rhodium

Figure 8.

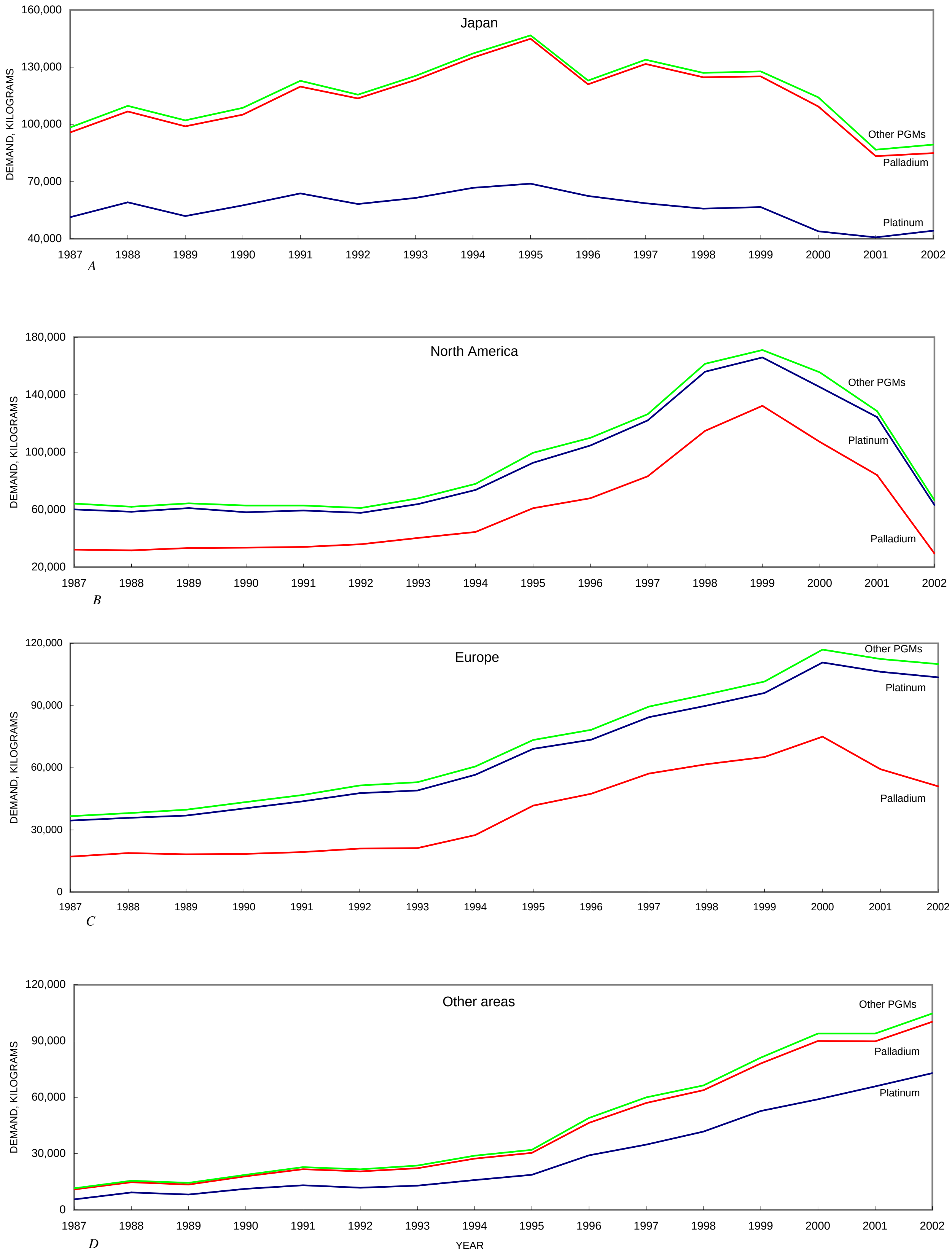
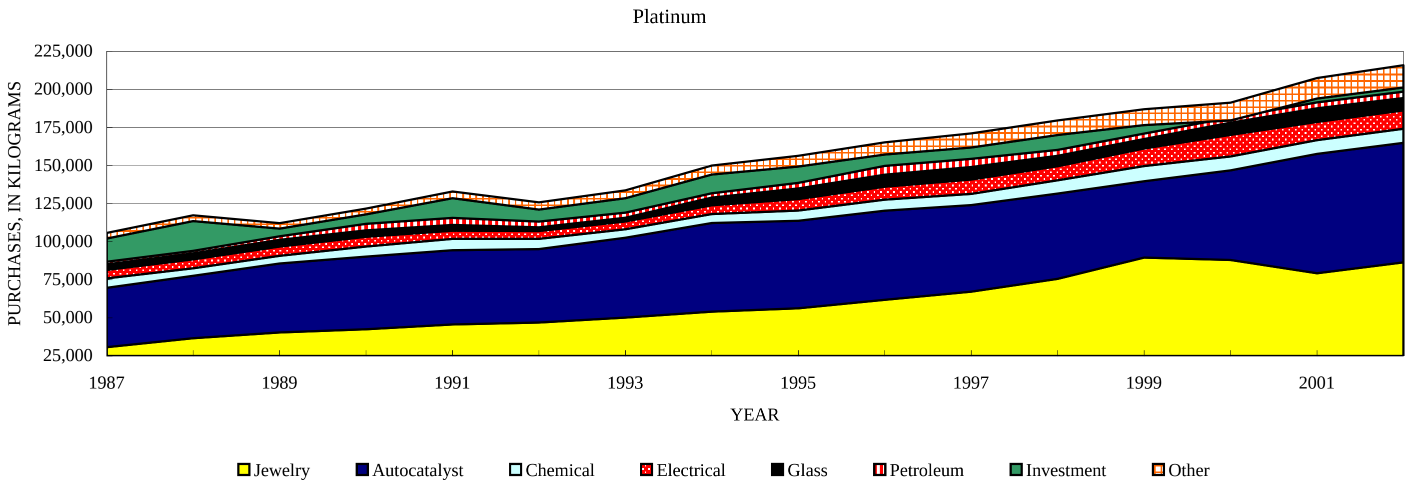
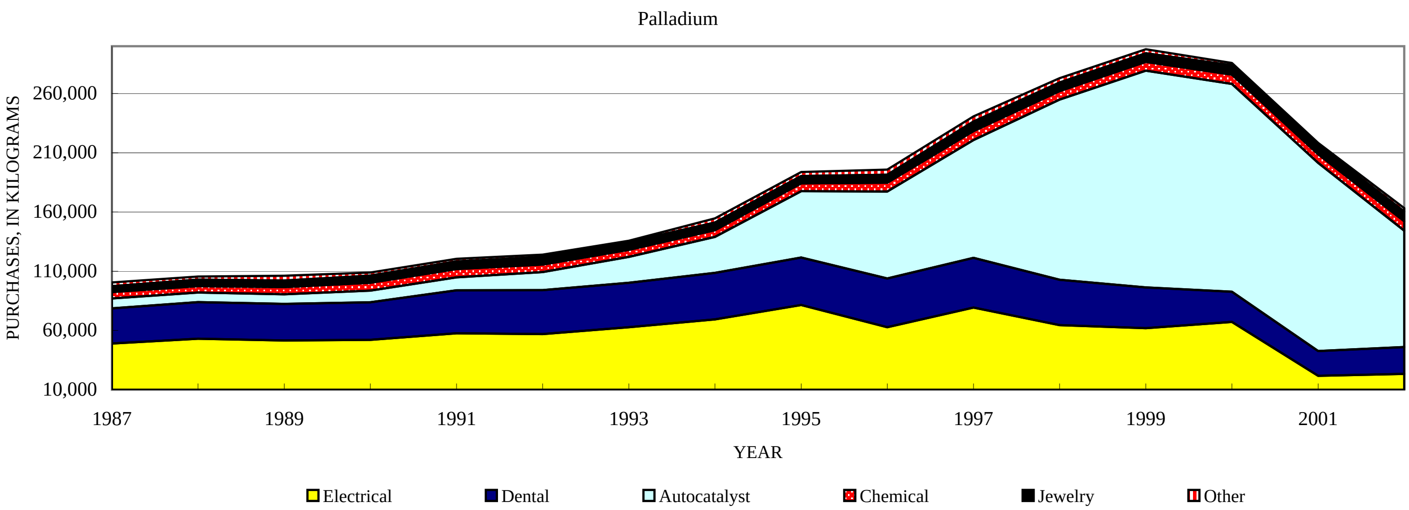

Japan
DEMAND, KILOGRAMS
160,000
130,000
100,000
70,000
40,000
Other PGMs
Palladium
Platinum
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
A
North America
DEMAND, KILOGRAMS
180,000
140,000
100,000
60,000
20,000
Other PGMs
Platinum
Palladium
B
Europe
DEMAND, KILOGRAMS
120,000
90,000
60,000
30,000
0
Other PGMs
Platinum
Palladium
C
Other areas
DEMAND, KILOGRAMS
120,000
90,000
60,000
30,000
0
Other PGMs
Palladium
Platinum
D
YEAR

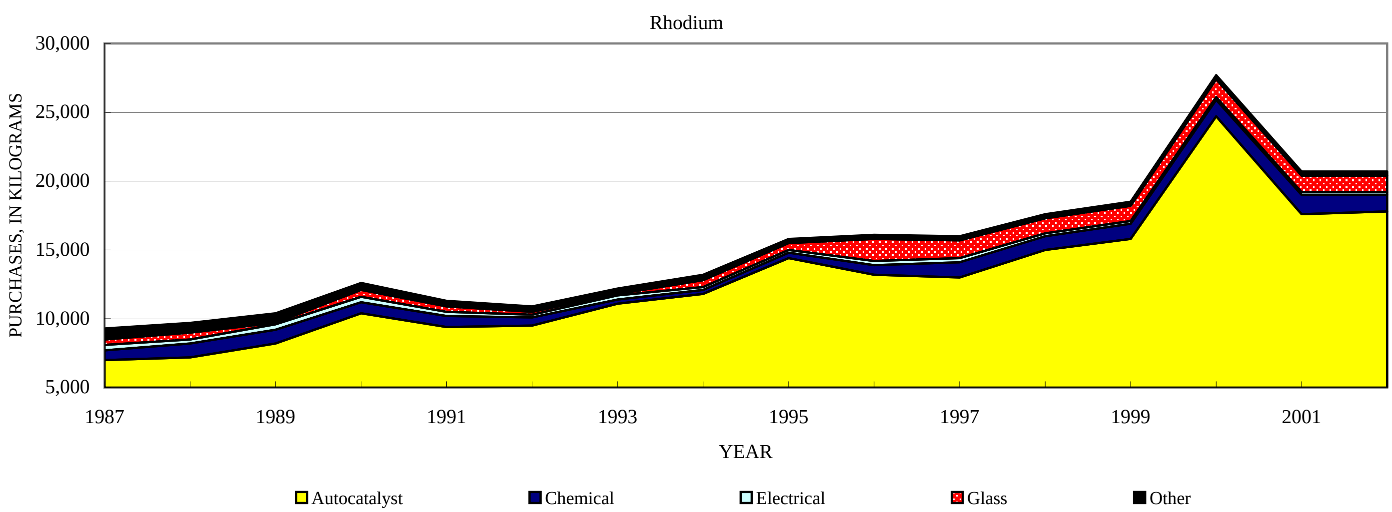
Figure 9.



A

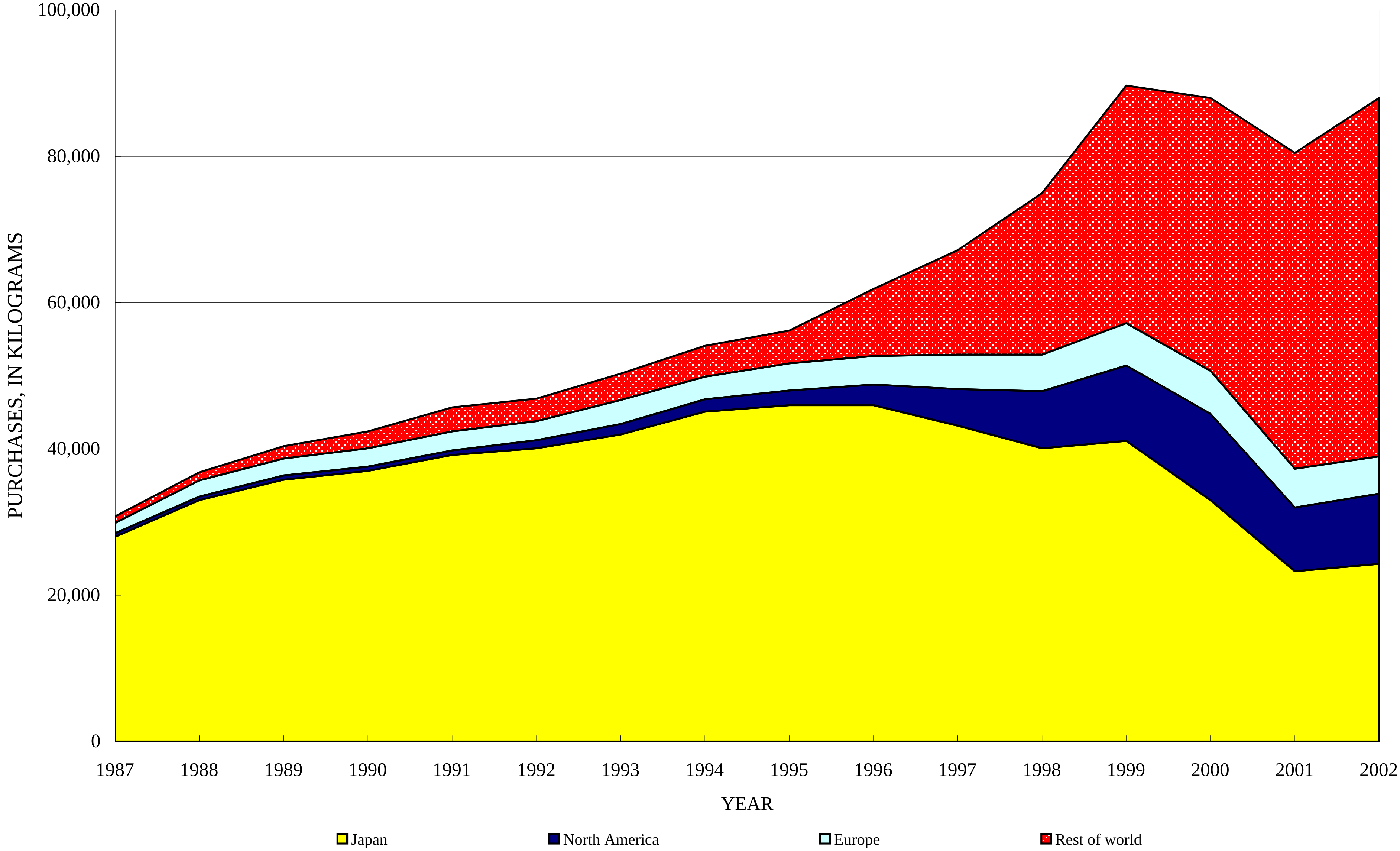


B



C

Figure 10.



100,000
80,000
60,000
40,000
20,000
0
PURCHASES, IN KILOGRAMS
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
YEAR
Japan
North America
Europe
Rest of world

Figure 11.

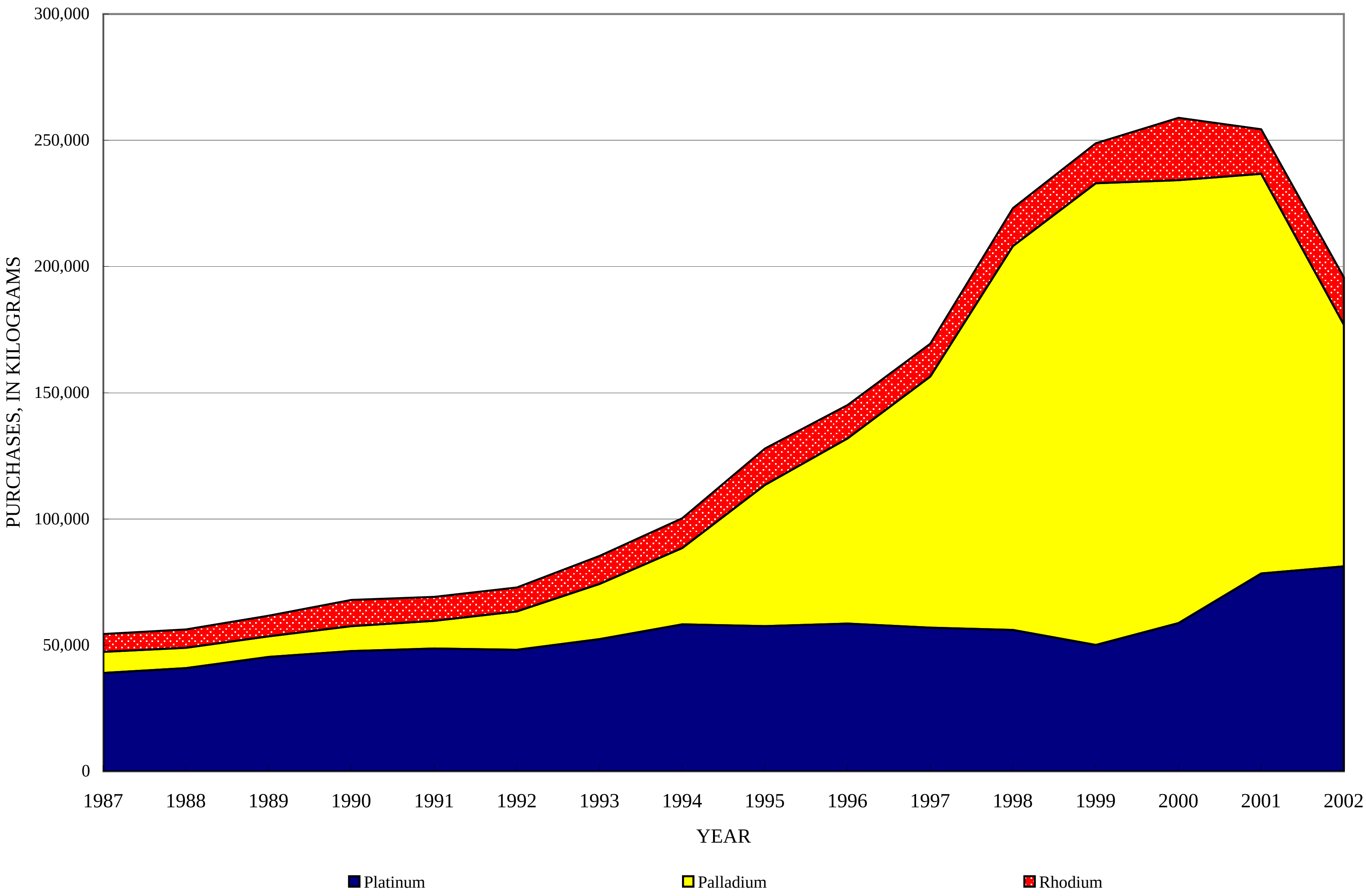

300,000
250,000
200,000
150,000
100,000
50,000
0
PURCHASES, IN KILOGRAMS
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
YEAR
Platinum
Palladium
Rhodium

Figure 12.

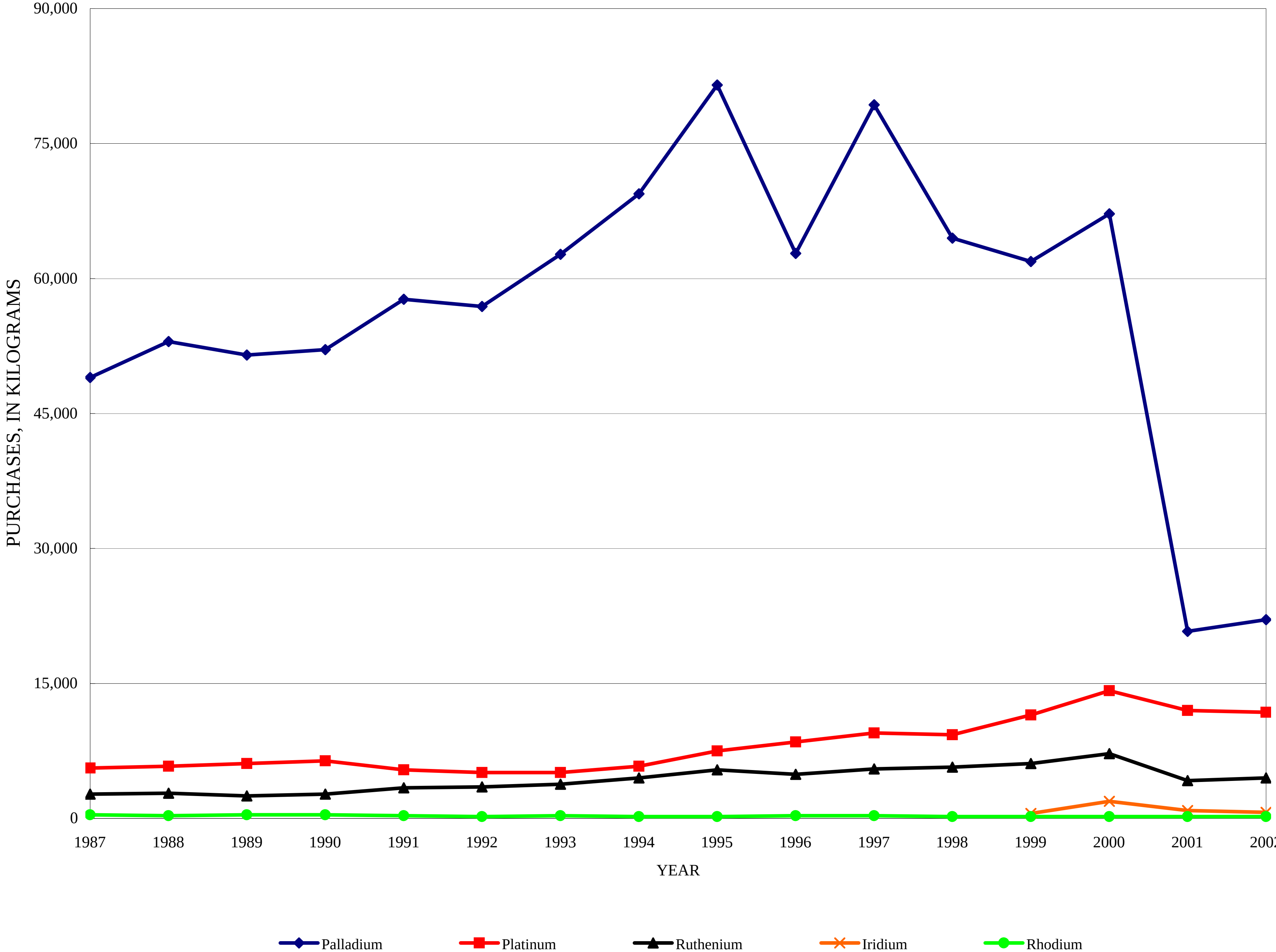
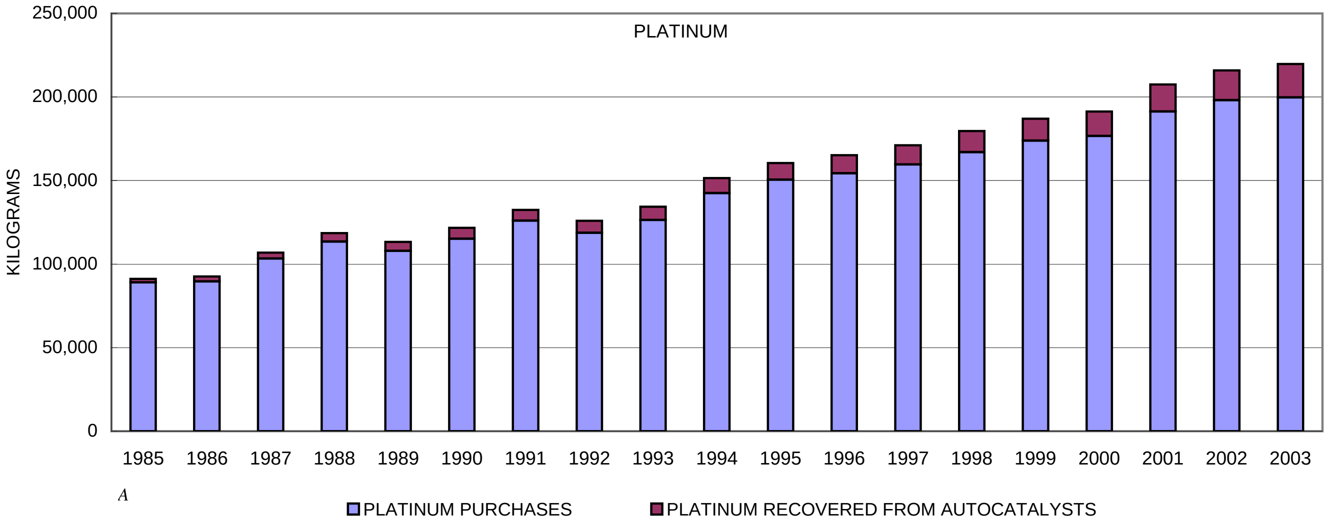
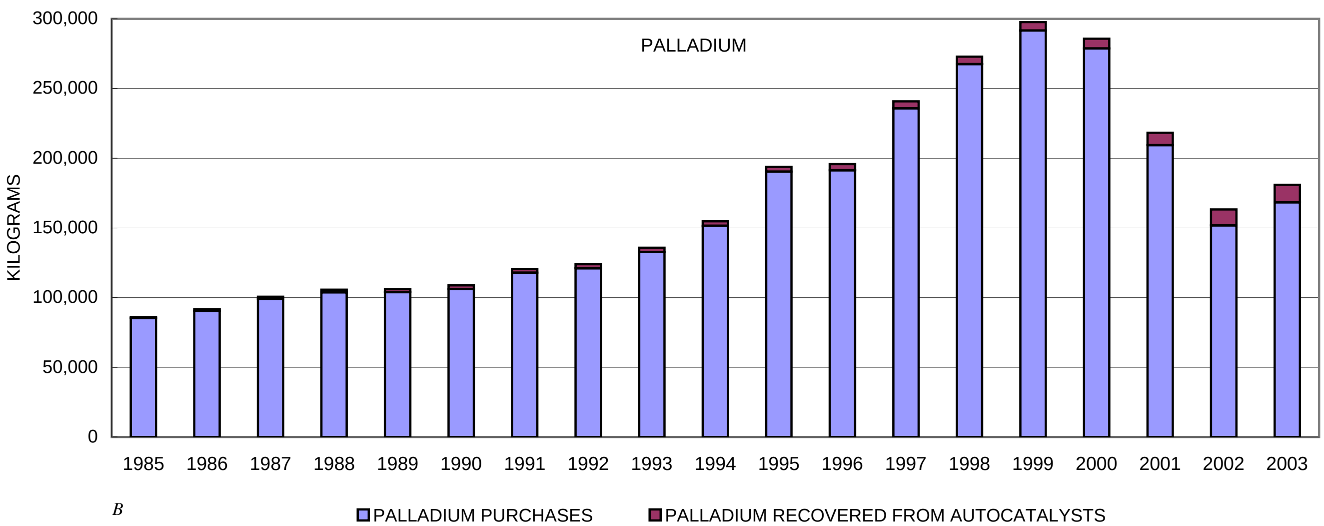

90,000
75,000
60,000
45,000
30,000
15,000
0
PURCHASES, IN KILOGRAMS
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
YEAR
Palladium
Platinum
Ruthenium
Iridium
Rhodium

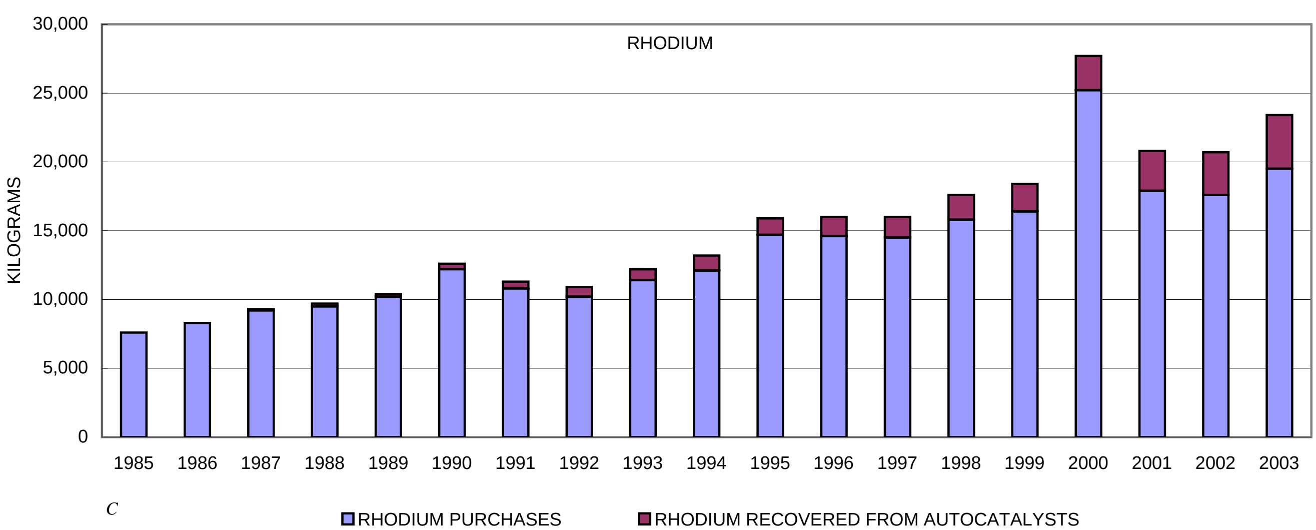
Figure 13.



A

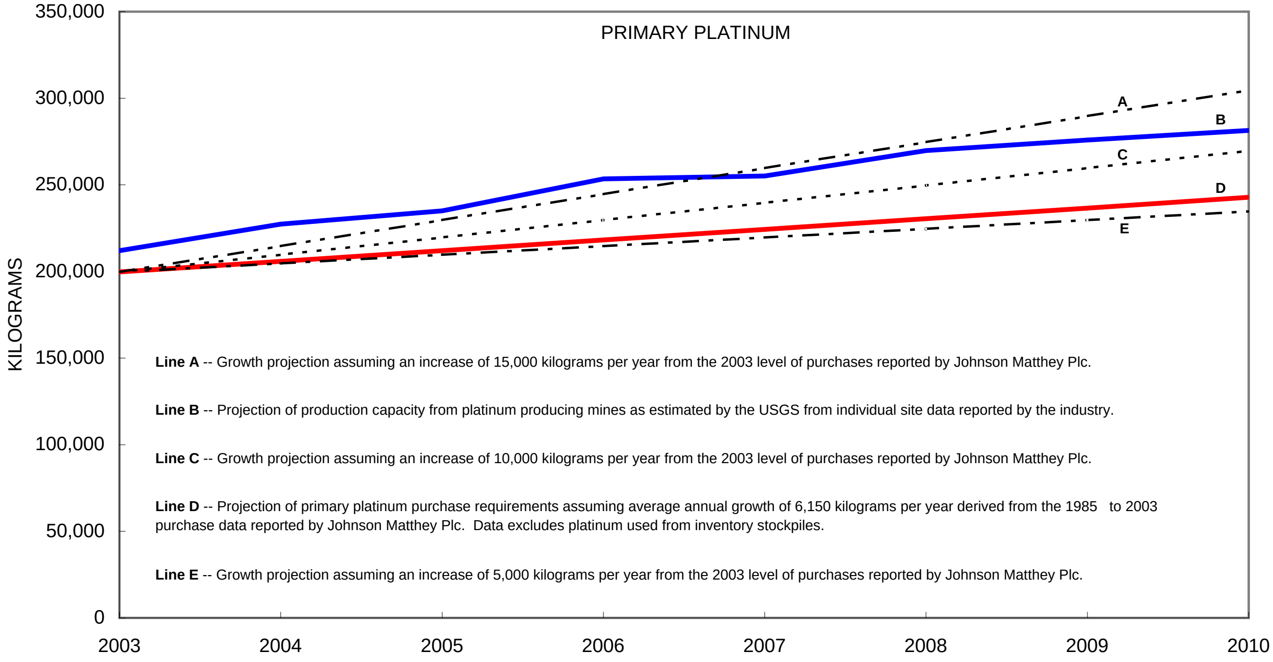


B



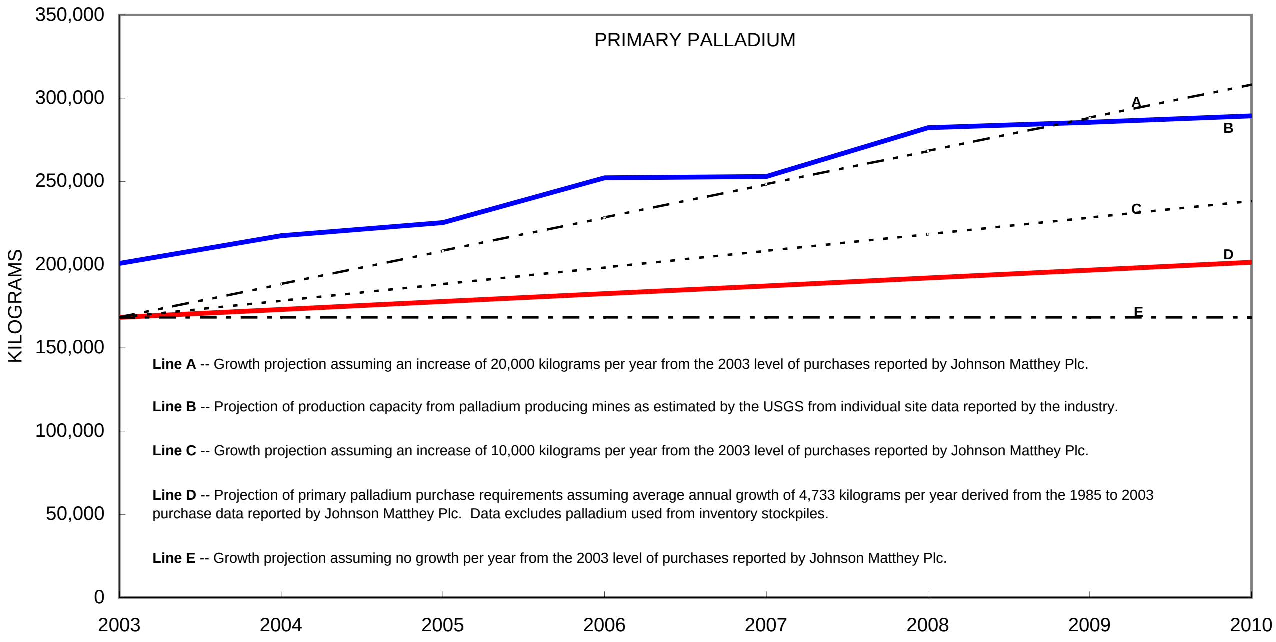
C

Figure 14.



PRIMARY PLATINUM
KILOGRAMS
YEAR
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
2003
2004
2005
2006
2007
2008
2009
2010
A
B
C
D
E
Line A -- Growth projection assuming an increase of 15,000 kilograms per year from the 2003 level of purchases reported by Johnson Matthey Plc.
Line B -- Projection of production capacity from platinum producing mines as estimated by the USGS from individual site data reported by the industry.
Line C -- Growth projection assuming an increase of 10,000 kilograms per year from the 2003 level of purchases reported by Johnson Matthey Plc.
Line D -- Projection of primary platinum purchase requirements assuming average annual growth of 6,150 kilograms per year derived from the 1985 to 2003 purchase data reported by Johnson Matthey Plc. Data excludes platinum used from inventory stockpiles.
Line E -- Growth projection assuming an increase of 5,000 kilograms per year from the 2003 level of purchases reported by Johnson Matthey Plc.

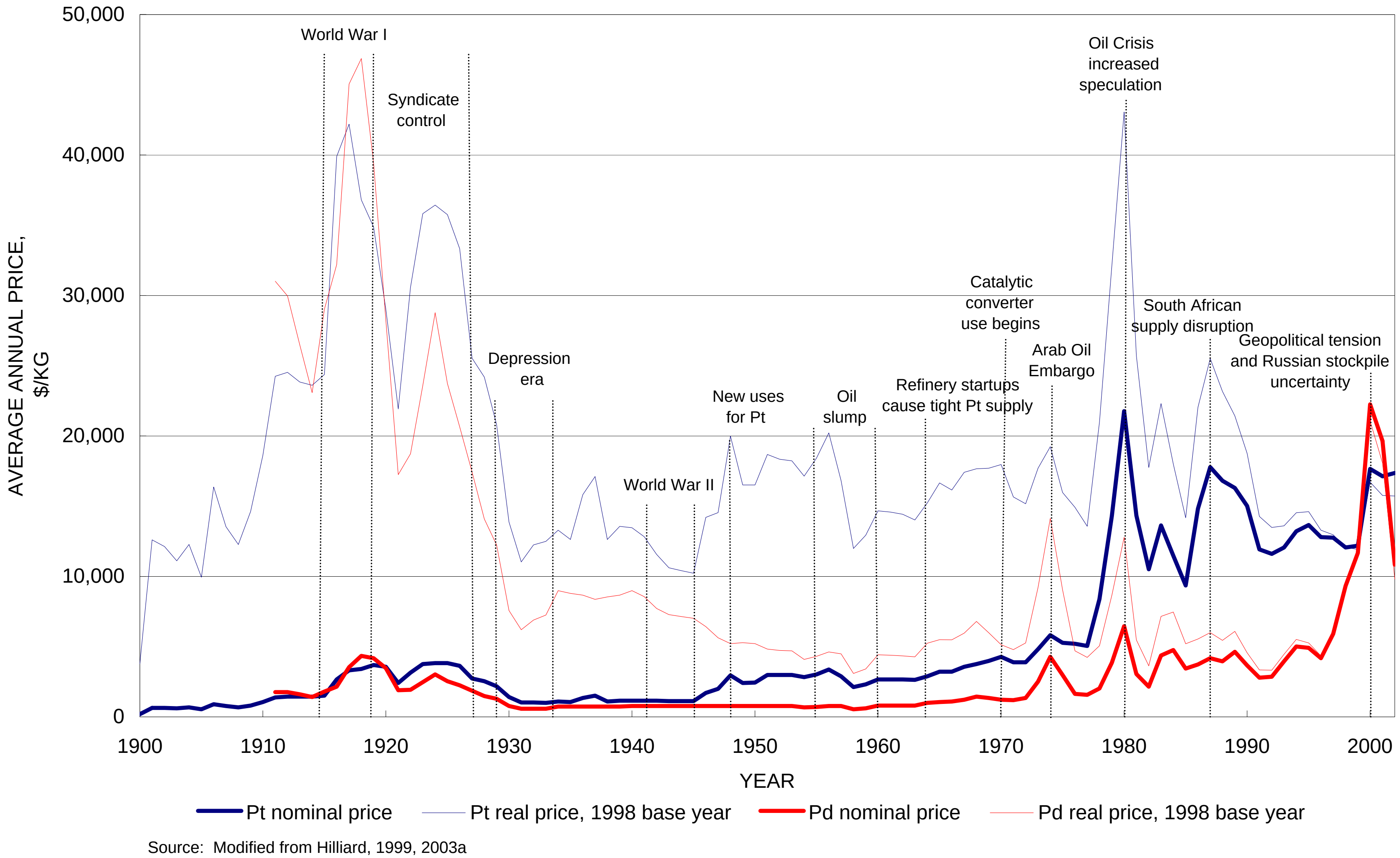
A



PRIMARY PALLADIUM
KILOGRAMS
YEAR
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
2003
2004
2005
2006
2007
2008
2009
2010
A
B
C
D
E
Line A -- Growth projection assuming an increase of 20,000 kilograms per year from the 2003 level of purchases reported by Johnson Matthey Plc.
Line B -- Projection of production capacity from palladium producing mines as estimated by the USGS from individual site data reported by the industry.
Line C -- Growth projection assuming an increase of 10,000 kilograms per year from the 2003 level of purchases reported by Johnson Matthey Plc.
Line D -- Projection of primary palladium purchase requirements assuming average annual growth of 4,733 kilograms per year derived from the 1985 to 2003 purchase data reported by Johnson Matthey Plc. Data excludes palladium used from inventory stockpiles.
Line E -- Growth projection assuming no growth per year from the 2003 level of purchases reported by Johnson Matthey Plc.

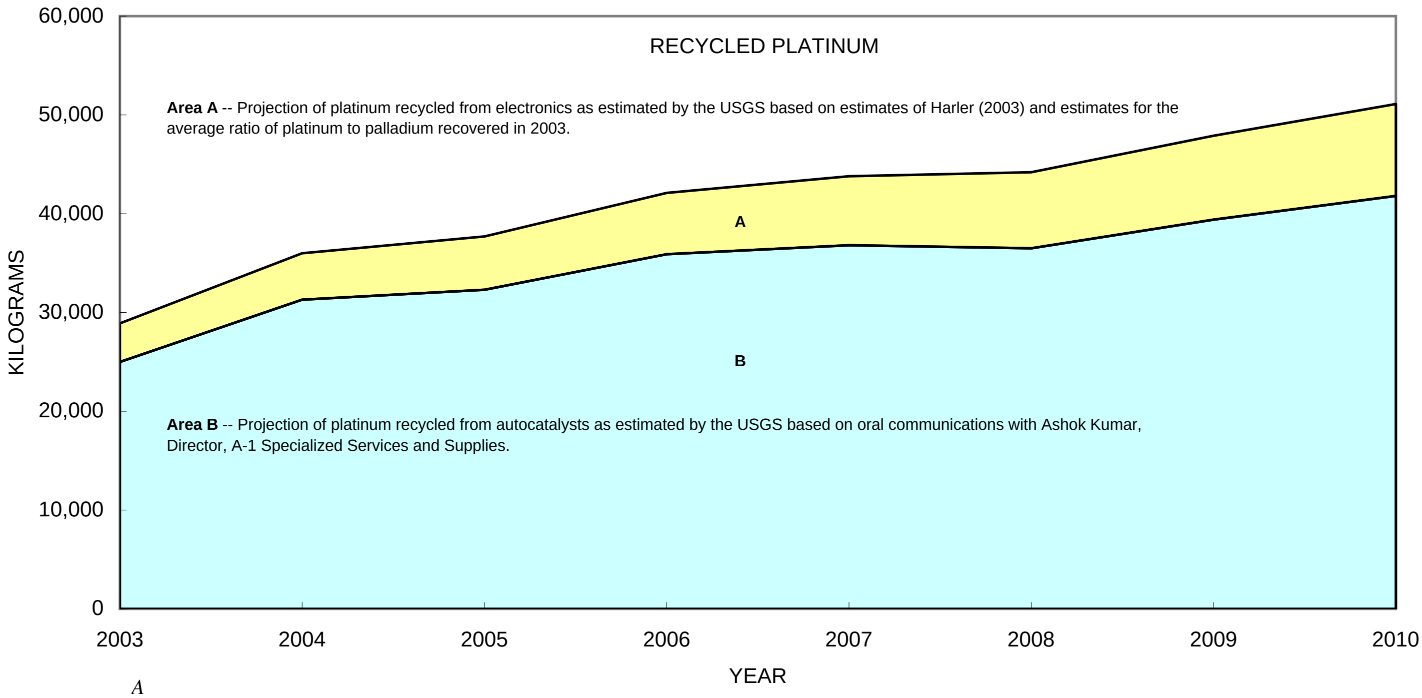
B

Figure 15.

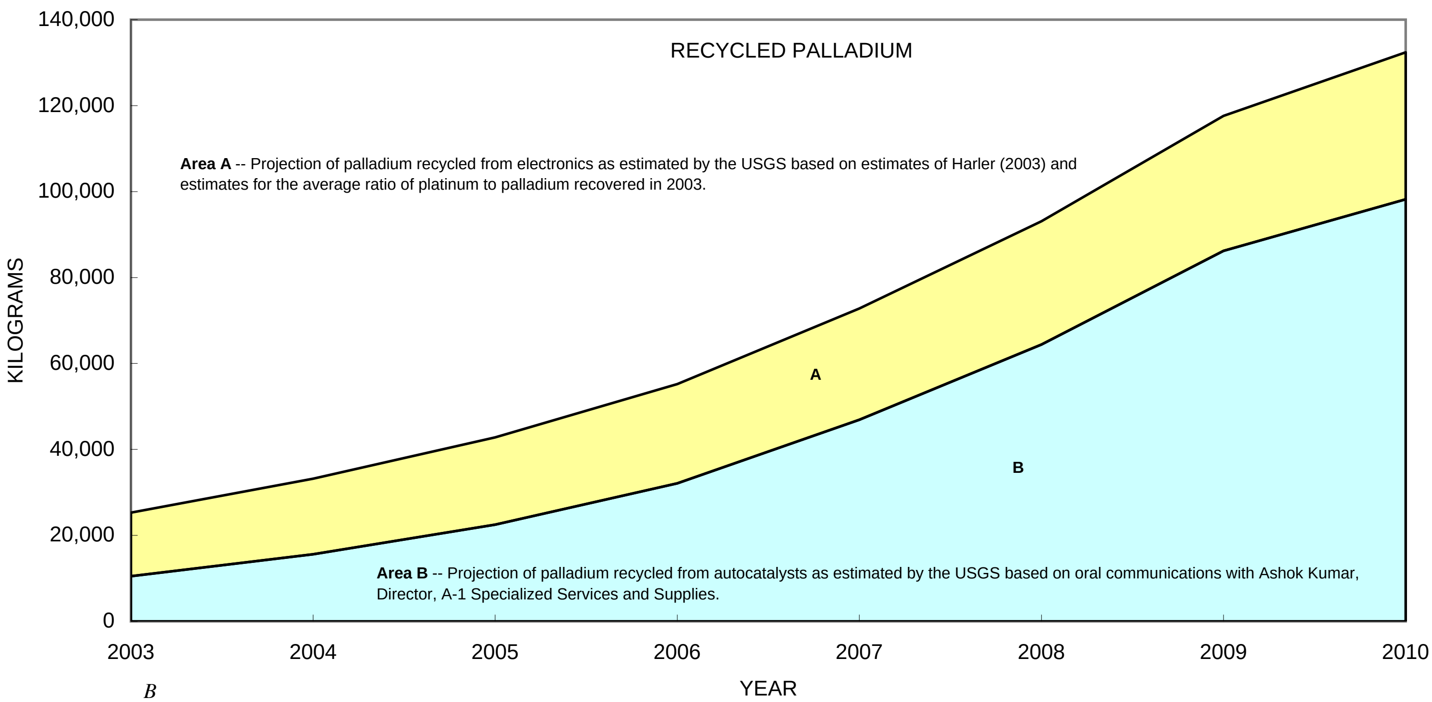


50,000
40,000
30,000
20,000
10,000
0
AVERAGE ANNUAL PRICE, $/KG
World War I
Syndicate control
Depression era
World War II
New uses for Pt
Oil slump
Refinery startups cause tight Pt supply
Catalytic converter use begins
Arab Oil Embargo
Oil Crisis increased speculation
South African supply disruption
Geopolitical tension and Russian stockpile uncertainty
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEAR
Pt nominal price
Pt real price, 1998 base year
Pd nominal price
Pd real price, 1998 base year
Source: Modified from Hilliard, 1999, 2003a

Figure 16.


RECYCLED PLATINUM
Area A -- Projection of platinum recycled from electronics as estimated by the USGS based on estimates of Harler (2003) and estimates for the average ratio of platinum to palladium recovered in 2003.
A
B
Area B -- Projection of platinum recycled from autocatalysts as estimated by the USGS based on oral communications with Ashok Kumar, Director, A-1 Specialized Services and Supplies.
KILOGRAMS
60,000
50,000
40,000
30,000
20,000
10,000
0
2003
2004
2005
2006
2007
2008
2009
2010
YEAR

A


RECYCLED PALLADIUM
Area A -- Projection of palladium recycled from electronics as estimated by the USGS based on estimates of Harler (2003) and estimates for the average ratio of platinum to palladium recovered in 2003.
A
B
Area B -- Projection of palladium recycled from autocatalysts as estimated by the USGS based on oral communications with Ashok Kumar, Director, A-1 Specialized Services and Supplies.
KILOGRAMS
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
2003
2004
2005
2006
2007
2008
2009
2010
YEAR

B

Figure 17.

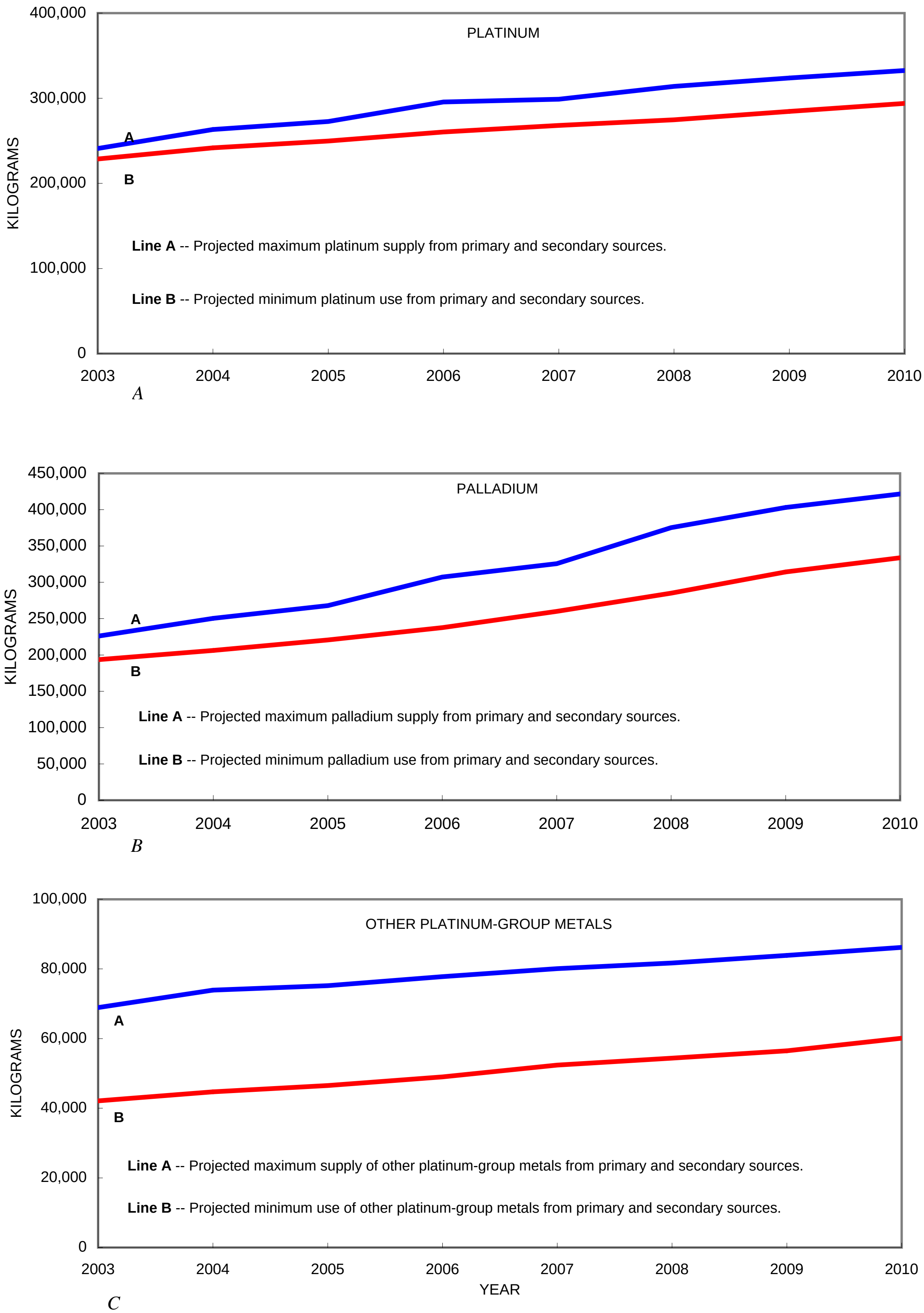

PLATINUM
KILOGRAMS
400,000
300,000
200,000
100,000
0
2003
2004
2005
2006
2007
2008
2009
2010
A
B
Line A -- Projected maximum platinum supply from primary and secondary sources.
Line B -- Projected minimum platinum use from primary and secondary sources.
A
PALLADIUM
KILOGRAMS
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
2003
2004
2005
2006
2007
2008
2009
2010
A
B
Line A -- Projected maximum palladium supply from primary and secondary sources.
Line B -- Projected minimum palladium use from primary and secondary sources.
B
OTHER PLATINUM-GROUP METALS
KILOGRAMS
100,000
80,000
60,000
40,000
20,000
0
2003
2004
2005
2006
2007
2008
2009
2010
YEAR
A
B
Line A -- Projected maximum supply of other platinum-group metals from primary and secondary sources.
Line B -- Projected minimum use of other platinum-group metals from primary and secondary sources.
C

Figure 18.

Table 3. South African platinum-group metal resources for selected sites. [Includes only South African platinum-group metal resources for sites either producing or under active consideration for expansion or development before 2010. Data are based on reported company data and projected production schedules. Quantities are expressed in million troy ounces unless otherwise specified]

Status	Property	Location	Proven and probable reserve	Measured and indicated resource	Inferred resource	Reserve base	Date of data	Source of information	Company web page
Producing in 2002……………	Amandelbult……………………..	Bushveld western limb……………	[1] 68.95	[1] 32.26	NA	[1] 101.21	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	http://www.angloplatinum.com.
….Do………..………………..	Atok/Lebowa……………………	Bushveld eastern limb……………..	[1] 76.28	NA	NA	[1] 76.28	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	….Do………………………..
….Do………..………………..	Bafokeng-Rasimone…………..	Bushveld western limb……………	[1] 7.05	[1] 9.96	NA	[1] 17.01	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	….Do………………………..
….Do………..………………..	Eastern Platinum[2]……………	….do…………………………….	[3] 76.80	[3] 34.15	NA	[3] 110.94	9/30/2002	Lonmin plc. presentation.	http://www.lonmin.com.
….Do………..………………..	Impala (Bafikeng/Wildebeest)..	….do…………………………….	[3] 32.65	[3] 74.06	[3] 41.12	[3] 106.71	6/30/2003	Impala Platinum Holdings Limited 2003 annual report.	http://www.implats.co.za/2003ar.
….Do………..………………..	Kroondal……………………….	….do…………………………….	[1] 2.53	[1] 3.76	NA	[1] 3.76	12/31/2002	Aquarius Platinum Limited 2002 annual report.	http://www.aquariusplatinum.com.
….Do………..………………..	Maandagshoek (Modikwa)……	Bushveld eastern limb……………	[1] 0.97	[1] 82.05	NA	[1] 83.02	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	http://www.angloplatinum.com.
….Do………..………………..	Marikana……………………..	Bushveld western limb…………..	[4] 2.3	[4] 3.1	[4] 0.1	[4] 3.1	12/31/2002	Aquarius Platinum Limited 2002 annual report.	http://www.aquariusplatinum.com.
….Do………..………………..	Maroelabult/Crocodile River[5]..	….do…………………………….	[3] 1.32	[3] 15.62	[3] 5.33	[3] 15.62	6/30/2003	Impala Platinum Holdings Limited 2003 annual report.	http://www.implats.co.za.
….Do………..………………..	Nkomati[6]……………………..	Nickel mine, Mpumalanga province	[7] 0.21	[7] 3.86	NA	[7] 3.86	6/30/2002	Anglovaal Mining Limited 2003 annual report.	http://www.avmin.co.za.
….Do………..………………..	Northam……………………….	Bushveld western limb…………..	[1] 10.78	[1] 23.51	NA	[1] 23.51	12/31/2002	Northam Platinum Limited 2002 annual report.	http://www.northam.co.za.
….Do………..………………..	Phalaborwa…………………….	Copper mine, Northern province	NA	[8] 5.8	NA	[8] 5.8	1999	Roskill Information Services Ltd. (1999)	http://www.roskill.com.
….Do………..………………..	Potgietersrust…………………	Bushveld western limb…………..	[1] 28.49	[1] 64.48	NA	[1] 92.97	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	http://www.angloplatinum.com.
….Do………..………………..	Rustenburg…………………….	….do…………………………….	[1] 45.71	[1] 18.4	NA	[1] 64.11	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	….Do………………………..
….Do………..………………..	Union…………………………..	….do…………………………….	[1] 23.00	[1] 18.71	NA	[1] 41.71	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	….Do………………………..
Full production by 2006………	Dwars River (Two Rivers)…….	Bushveld eastern limb…………..	NA	[7] 3.48	NA	[7] 3.48	6/30/2001	Anglovaal Mining Limited press release.	http://www.avmin.co.za.
….Do………..………………..	Messina………………………..	….do…………………………….	[3] 4.54	[3] 11.68	[3] 4.87	[3] 11.68	12/31/2002	SouthernEra Resources Limited 2002 annual report	http://www.southernera.com.
….Do………..………………..	Winnaarshoek (Marula)……….	….do…………………………….	[3] 5.79	[3] 15.64	[3] 2.22	[3] 21.43	6/30/2003	Impala Platinum Holdings Limited 2003 annual report.	http://www.implats.co.za.
Proposed for 2006 production	Blue Ridge (BB-TBM)………..	….do…………………………….	[9] 2.1	[3] 3.7	[9] 0.9	[3] 5.8	12/12/2002	Cluff Mining plc. press release.	http://www.cluff-mining.com.
….Do………..………………..	Everest North/South………….	….do…………………………….	[4] 3.34	[4] 4.5	[4] 2.7	[4] 4.5	9/30/2002	Aquarius Platinum Limited press release.	http://www.aquariusplatinum.com.
….Do………..………………..	Elandsfontein…………………..	Bushveld western limb…………..	NA	[1] 14.89	NA	[1] 14.89	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	http://www.angloplatinum.com.
….Do………..………………..	Kalgold………………………..	Gold mine, North West province	NA	NA	[4] 3.42	NA	6/30/2001	Harmony Gold Mining Company Limited presentation.	http://www.harmony.co.za.
….Do………..………………..	Twickenham……………………	Bushveld eastern limb…………..	NA	[1] 69.63	NA	[1] 69.63	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	http://www.angloplatinum.com.
Proposed for 2010 production	Buffelshoek……………………..	….do…………………………….	NA	NA	[8] 10.64	NA	1997	Impala Platinum data.	http://www.implats.co.za.
….Do………..………………..	Der Brochen……………………	….do…………………………….	NA	[1] 126.35	NA	[1] 126.35	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	http://www.angloplatinum.com.
….Do………..………………..	Dwaalkop (Messina phase 3)..	….do…………………………….	NA	[9] 3.175	[9] 4.688	[9] 7.86	12/31/2002	SouthernEra Resources Limited 2002 annual report	http://www.southernera.com.
….Do………..………………..	Fonte Verde…………………….	Nickel deposit, Northern province	NA	NA	[1] 0.67	NA	2001	Cluff Mining plc. data.	http://www.cluff-mining.com.
….Do………..………………..	Kennedy's Vale…………………	Bushveld eastern limb…………..	NA	[3] 38.18	[3] 21.15	[3] 38.18	6/30/2003	Impala Platinum Holdings Limited 2003 annual report.	http://www.implats.co.za.
….Do………..………………..	Leeuwkop 402JQ………………	….do…………………………….	NA	[1] 20.56	NA	[1] 20.56	2003	Southern Africa Resources plc. press release.	http://www.sar-plc.com.
….Do………..………………..	Pandora[10]………………………	Bushveld western limb…………..	NA	[3] 20.99	NA	[3] 20.99	12/31/2002	Anglo American Platinum Ltd. 2002 annual report.	http://www.angloplatinum.com.
	Total………………………..		392.81	722.50	97.81	1095.26			
	….Do...……………….kilograms		12,000,000	22,000,000	3,000,000	34,000,000			

NA - Not available

[1] Includes gold, palladium, platinum, and rhodium values.

[2] Includes the resources of the Karee and Western Platinum properties in the Bushveld western limb.

[3] Includes, gold, iridium, osmium, palladium, platinum, and rhodium values.

[4] Includes gold, palladium, and platinum values.

[5] Crocodile River was temporarily closed at the end of 2003. Production expected to begin again before 2010.

[6] Includes the resources of the Kransberg nickel mine in Mpumalanga province, which is scheduled to begin byproduct platinum production by 2006.

[7] Includes palladium and platinum values.

[8] Unspecified PGM values.

[9] Includes gold, iridium, palladium, platinum, and rhodium values.

[10] Delay of production schedule announced in 2002.

Table 4. Estimated Russian platinum-group metal resources and production for 2000 and 2010 [Resources are in kilograms; production figures are in kilograms per year. Stockpiles held by banks, companies, or the Russian government, have not been included. Source: Levine, Richard, and Wilburn, David, 2003, Russian PGM—Resources for 100+ years: U.S. Geological Survey Open-File Report 03-059 (Also available at http://pubs.usgs.gov/of/2003/of03-259/index.html.)]

Source	Resource	Ore type	2000 production	2010 production
Oktyabr'skiy……..	740,000	Nickel-rich…..	45,800	36,700
….Do…………….	940,000	Cuprous……...	2,600	14,700
….Do…...………..	2,020,000	Disseminated...	200	2,700
Taymyrskiy………	1,800,000	Nickel-rich…..	29,300	32,400
Komsomol'skiy….	30,000	Nickel-rich…..	5,500	1,000
….Do…………….	480,000	Cuprous……...	9,800	3,000
….Do…………….	3,680,000	Disseminated...	900	9,000
Mayak……………	10,000	Nickel-rich…...	4,300	--
….Do…………….	640,000	Disseminated...	--	3,600
Skalistyy…………	370,000	Nickel-rich…..	1,900	21,600
Glubokiy…………	370,000	Nickel-rich…..	--	2,100
Zapolyarnyy……..	590,000	Disseminated...	6,100	22,300
Medvezhiy Ruchey	160,000	Disseminated...	3,500	8,900
Pyrrhotite tailings..	600,000	Various………	400	9,600
Placer mining……	300,000	NA…………..	10,000	10,000
Kursk Magnetic Anomaly……….	200,000	NA…………..	--	--
Pana deposit……..	1,000,000	NA…………..	--	--
Total…………..	14,000,000	Various………	120,000	178,000

NA Not available; -- Zero.

Note -- Column totals may not total because of rounding.