Platinum Availability and Economics for PEMFC Commercialization

Report to:
US Department of Energy

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References:
TIAX LLC: D0034
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Table of Contents

Table of Contents

The US DOE engaged TIAX LLC to assess the long-term availability and price stability of platinum given anticipated demand from fuel cell vehicles.

- **Project scope:**
  - The timeframe of the future demand projection is from 2005 to 2050.
  - Platinum applications include Jewelry, Transportation, Industrial, and Stationary Fuel Cells.
  - Demand for fuel cell vehicles (FCVs) is based on projections for five regions (i.e., US, Western Europe, Japan, China, and India).
  - Observed historical platinum prices are from 1880 to the present.
- **Issues outside of project scope:**
  - Potential for political instability in major platinum producing countries.
  - Control of platinum production by a limited number of companies in the major producing countries.
  - Future growth/decline in the world economy.
  - Potential for significant increases in platinum demand from new applications other than fuel cells.
  - Ability of fuel cell technology developers to overcome technical hurdles.
  - Ability of the fueling infrastructure to support commercialization of fuel cell vehicles.

The availability of platinum at a stable price should not be a barrier to fuel cell vehicle (FCV) commercialization.

- Key findings of our study are:

Platinum Demand	*Primary platinum demand is expected to grow at a rate of three to six times the levels seen between 1960 and 2000 if fuel cell vehicles are commercially viable.*
Resources	*There are sufficient platinum resources in the ground to meet long-term projected platinum demand. Economic extraction of primary platinum will depend upon the continuing advancement of mining technology.*
Platinum Supply	*The platinum industry has the potential to meet a scenario where FCVs achieve 50% market penetration by 2050, while an 80% scenario could exceed the expansion capabilities of the industry. Recycled platinum from the transportation sector will be an increasingly critical source of supply.*
Price Stability	*Our simulation of the platinum market indicates that the price of platinum will likely rise in the short-term in response to increased demand from fuel cell vehicles. We expect the price to return to its long-term mean (i.e., $550/troy oz at 2003 prices) once supply catches up with demand. The actual increase in price will depend on a number of factors including the rate of FCV adoption, the rate of growth in supply, and other related market factors.*

Recent historical highs in platinum price (e.g., $840/oz on 12/17/03 - 53% over the long-term mean) highlight the critical impact that a supply/demand imbalance can have on price.

- *Demand Side - Current Situation*
  - Increasing demand from Chinese jewelry market has been driven by China's economic expansion since the mid 1990s.
  - Increasing demand from transportation is due to:
    - More stringent emissions controls on diesel vehicles combined with growing market penetration of diesel vehicles in Europe, and
    - Anticipated higher auto demand due to economic recovery.[1]
  - Mutual funds have increased their investment in platinum.[2]
- *Supply Side - Current Situation*
  - Mine expansion efforts are not meeting published company goals.
    - The strong rand inhibits new capital investment[3]
    - Oversupply of palladium and other PGM byproducts reduces margins[4]

Regardless of new demand from FCVs, such imbalances could keep platinum prices above the long-term mean.

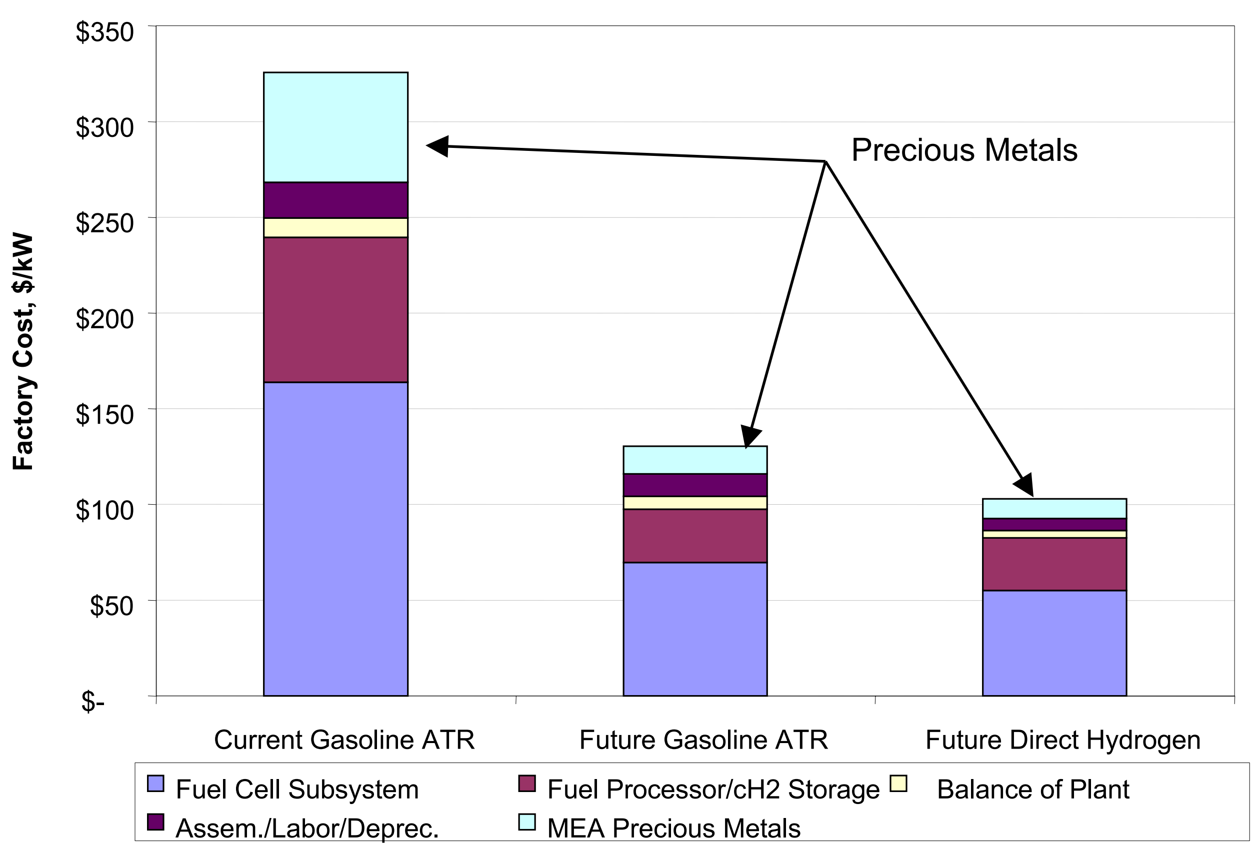
1. Daniel Thole, *Platinum Roars to 23 Year High*, Mineweb.com, 9/2/2003.
2. Alex Hogg, *Dr. Mike Steele: Johnson Matthey, London,* Moneyweb.com11/18/2003.
3. Reuters, *NY gold, platinum gleam as investors dump dollar*, Forbes.com, 12/12/2003.
4. Ken Gooding, *Platinum Outlook Far from Rosy*, Mineweb.com, 10/5/2003.

Platinum is critical to fuel cell performance.

- Platinum is critical to achieving the required levels of fuel cell power density and efficiency.
- Platinum and some ruthenium are essential to the catalysis of anodic and cathodic reactions in the stack.
- Platinum is important for the catalysis of reforming, shift, and preferential oxidation (PROX) reactions in the fuel processor.

Platinum is also a major component of overall fuel cell cost, accounting for 10 to 15 percent of projected fuel cell production costs.

Fuel Cell Cost Breakdown ($/kW)

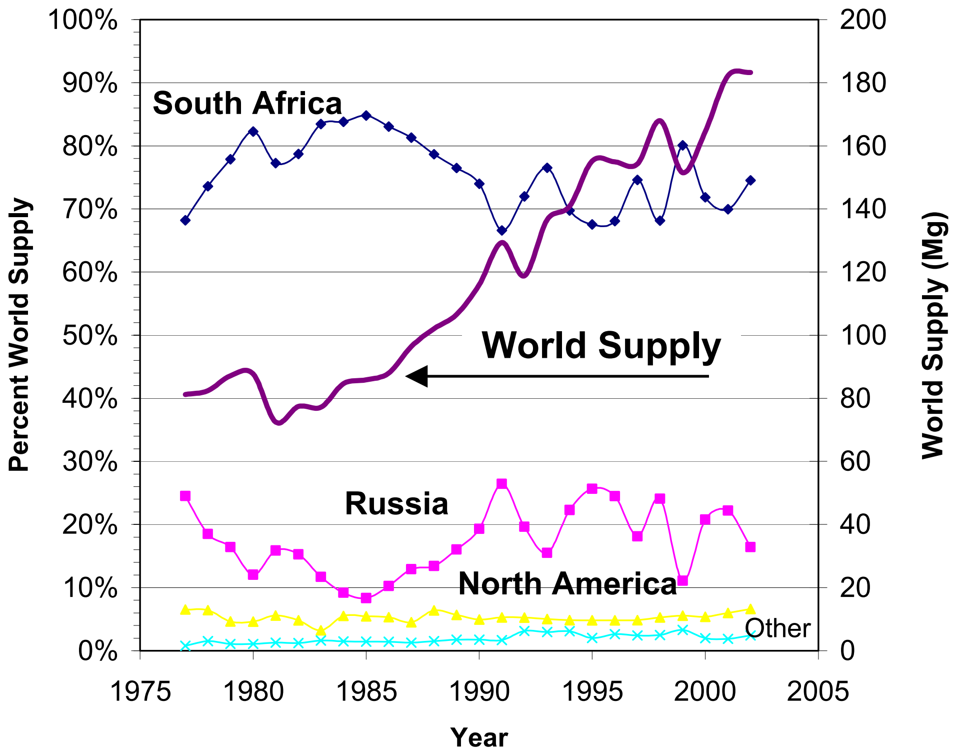


Source: Future Car Congress, 2002, Based on $20/g Pt

ATR: Auto Thermal Reformer
cH2: Compressed Hydrogen
MEA: Membrane Electrode Assembly

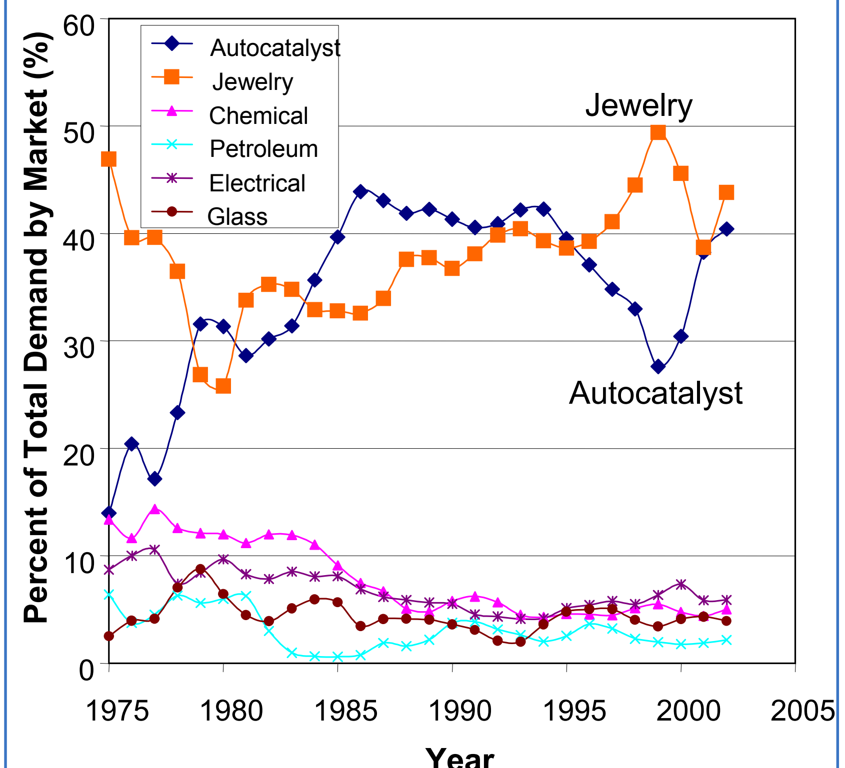
South Africa supplies about 80 percent of the world's platinum; the jewelry and autocatalyst markets account for about 80 percent of the demand.

Platinum Supply (1977-2002)



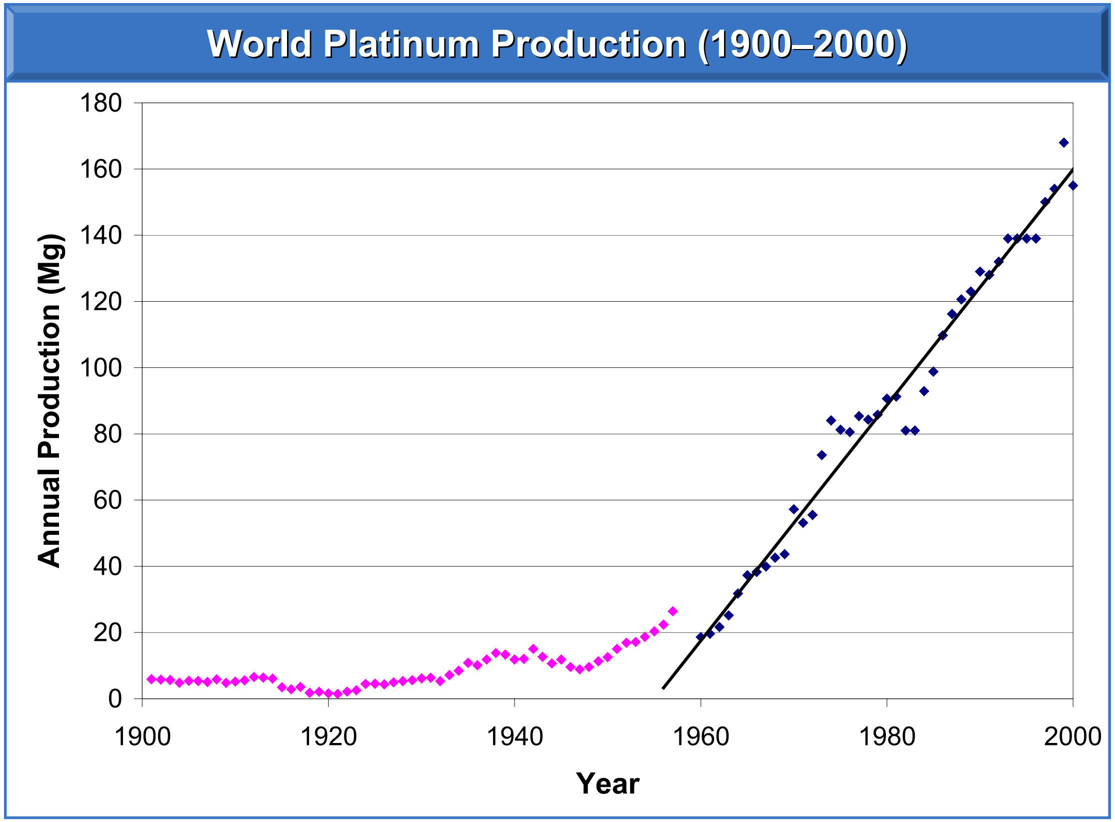
Source: Johnson Matthey, Platinum 2003.

Market Share by Application (%)*



Source: Johnson Matthey, Platinum 2003.

World platinum production has grown at a rate of 3.5 Mg per year since 1960 to keep pace with increases in autocatalyst and jewelry demand.



Data Sources: 1901-1957 Die Metallischen Rohstoffe Heinrich Quiring, pp 98-99.
1963-1983 Mineral Facts and Problems, U.S. Bureau of Mines.
1986-2000 Mineral Yearbook, U.S. Geological Survey.

- In anticipation of the introduction of catalytic converters in the 1970s in the United States and the 1980s in Europe, South African mines expanded production to meet demand.
- In the 1980s and 1990s, South African mines continued to increase production to meet increasing demand for platinum jewelry from Japan and China.

Over the past several years, demand has outpaced supply, but the industry has been aggressively expanding production to meet jewelry and autocatalyst demand.

Our projection of the future demand for platinum is based upon two FCV adoption scenarios.

50% Scenario	80% Scenario
• FCV market entry date around 2020 • 50% FCV market penetration by 2050 • 15 year time lag in FCV adoption by Developing Countries • Vehicles per capita increase at a slower pace than the 80% Scenario	• FCV market entry date around 2020 • 80% FCV market penetration by 2050 • 10 year time lag in FCV adoption by Developing Countries • Vehicles per capita increase at a moderate pace

Important assumptions associated with the two FCV adoption scenarios include:

- Platinum loading in FCVs will decline from 60g/FCV in 2005 to 15g/FCV in 2025.
- Jewelry and Industrial sector demand will grow at a rate of 1.4 percent per year through 2050.
- Stationary fuel cell power generation will enter the market in 2006 and will reach 15 GW/year in 2050, accounting for about one percent of power generated by FCVs.
- Recycling of platinum from fuel cells (considering both recovery and processing) will be 95 percent efficient; recycling of platinum from internal combustion engine vehicles (ICEVs) will be 90 percent efficient.
- Population growth trends in each country will match United Nations projections.

Our projections assume annual vehicle sales of 70 to 95 million units in the selected regions in 2050, two times current production levels.

Developed Countries—2050	
Country	**Million Vehicle Sales**
US	22
W. Europe	18
Japan	7
SubTotal	47

Developing Countries—2050		
Country	**Million Vehicle Sales** (vehicles per capita)	
	50% Scenario*	80% Scenario*
China	9 (0.1)	23 (0.25)
India	16 (0.1)	23 (0.15)
SubTotal	25	46

Totals—2050	
Million Vehicle Sales	
50% Scenario*	80% Scenario*
72	**93**

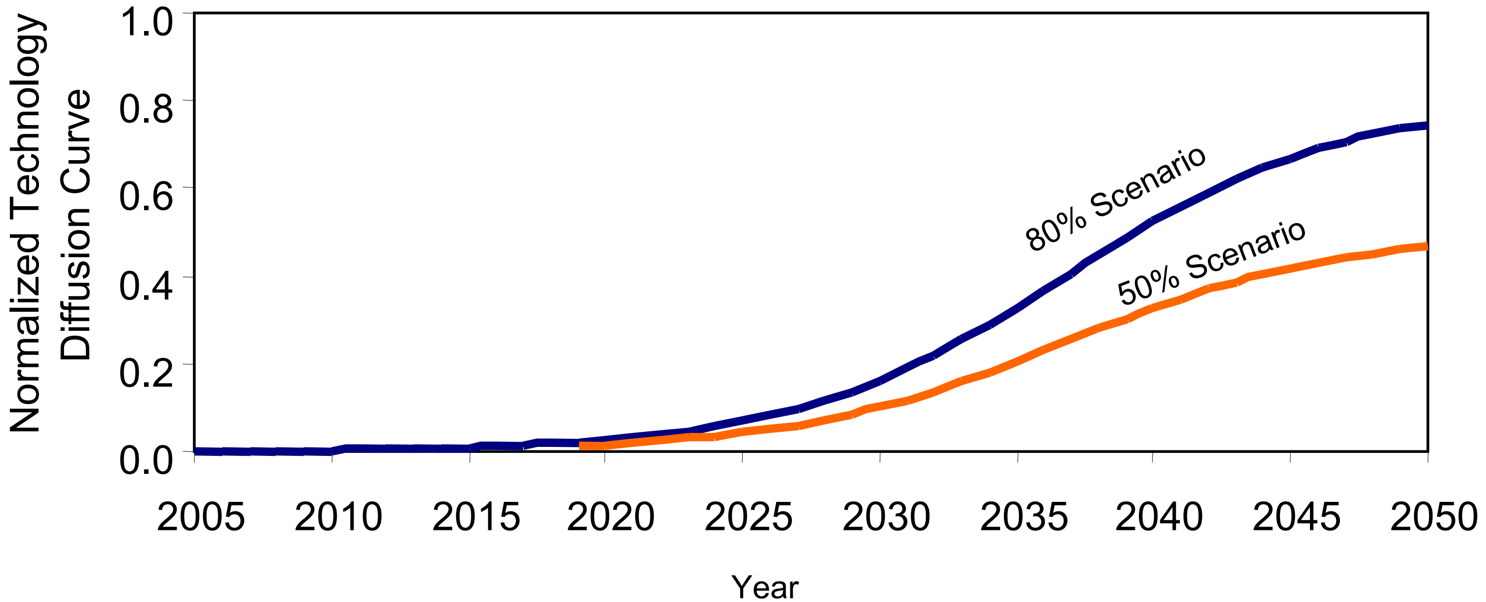
* 50% and 80% Scenarios correspond to the FCV market penetration scenarios considered later in the analysis.

- In 2000, 41 million vehicles were sold worldwide. The selected regions represented approximately 75% of worldwide vehicle sales[1].

1) Ward's Automotive Data (2001)

For both scenarios, we developed market penetration curves to quantify the rate at which FCVs gain market share from ICEVs.

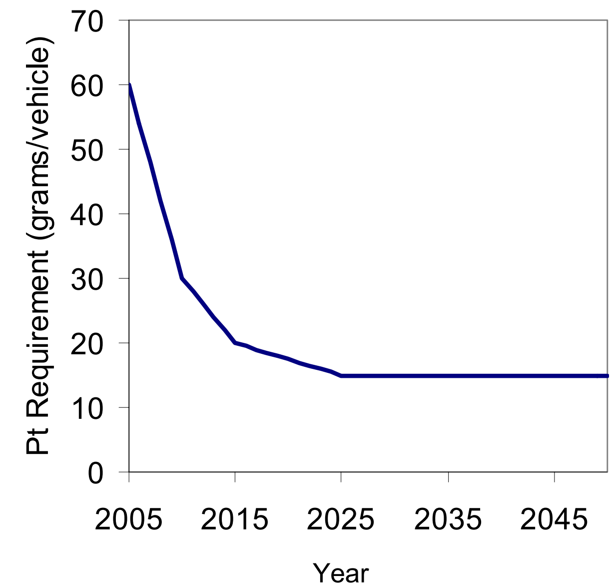
Fuel Cell Vehicle Market Penetration Curves



We have assumed that FCV platinum requirements for a 75 kW powertrain will decline to 15 grams by 2025.

Parameter	Year 2005	Year 2010	Year 2015	Year 2025
g Pt / vehicle	60	30	20	15
g Pt /kW	0.8	0.4	0.3	0.2

Platinum Loading in FCVs



We assume platinum loading must reach at least 20 grams per vehicle to initiate large volume sales.

The 50% and 80% Scenarios identify that total cumulative demand (from 2005 to 2050) will be about one-quarter of the current resource projection.

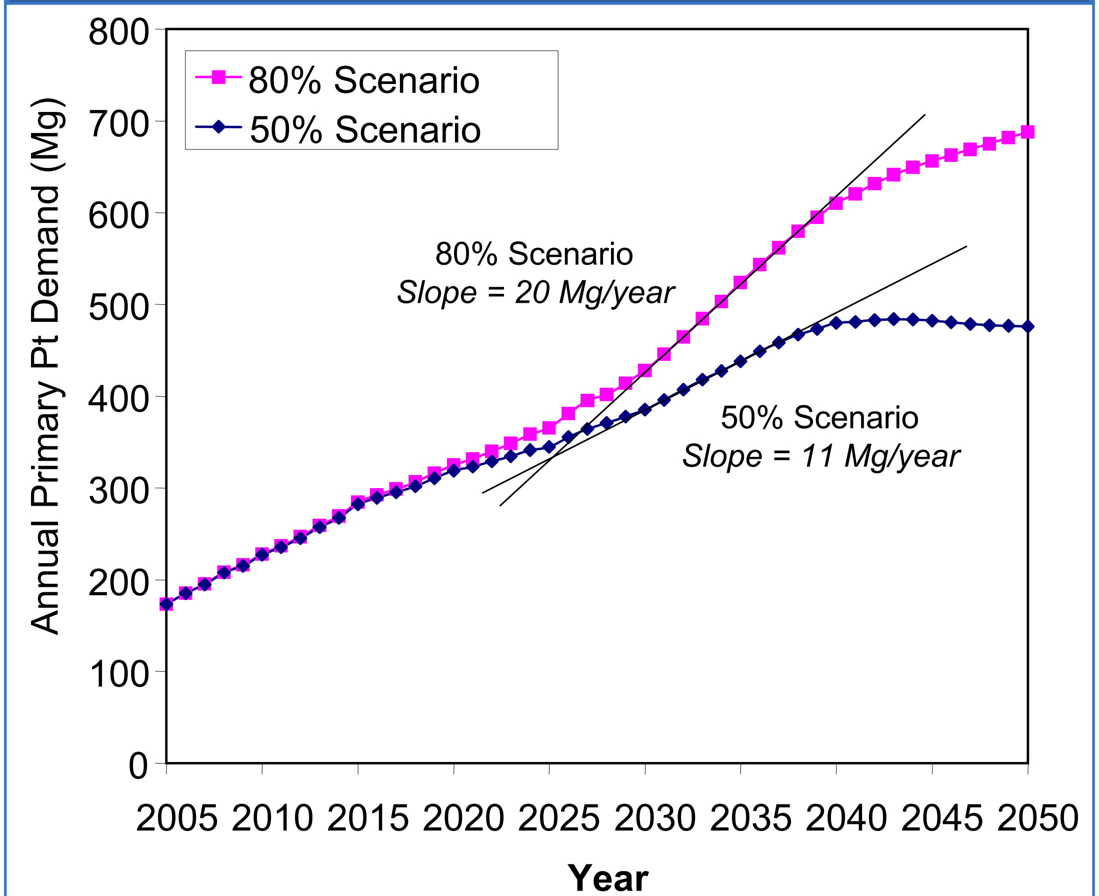
	Transportation		Jewelry	Industrial Catalysts	Stationary Power	Totals	
	50% Scenario	80% Scenario				50% Scenario	80% Scenario
Cumulative Primary Demand from 2005 to 2050 (Mg)	8,500	11,500	5,300	3,200	500	17,500	20,500
Peak Slope in Primary Demand (Mg/year)	11	18	2	1.2	2	11*	20*

* The peak slopes for the identified market segments occur at different time periods. Therefore, the peak slope for Total Demand is not the sum of the peak slopes for each market.

- The 50% and 80% Scenario demand projections account for 22 and 26 percent of projected platinum resource (i.e., 76,000 Mg), respectively.
- For reference, primary platinum supply increased at a rate of 3.5 Mg/year from 1960 to 2000.

The two scenarios identify that following the successful commercialization of fuel cell vehicles, total platinum demand will grow at a rate three to six times the levels seen between 1960 and 2000.

Total Projected Primary Platinum Demand [1]

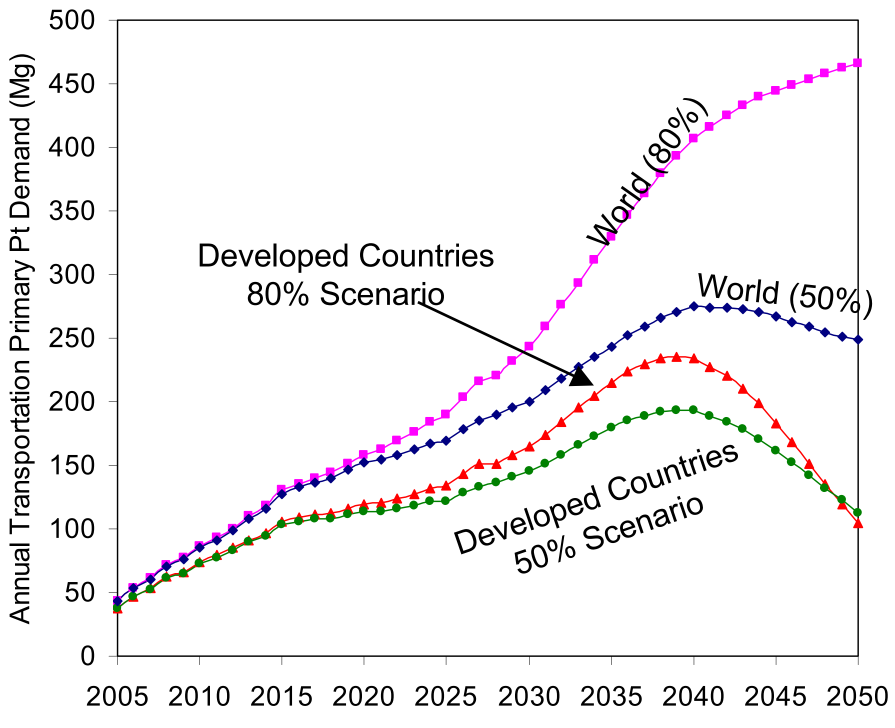


- The highest growth rates occur during a 15 year period between 2025 and 2040.
- Additional supply from recycled FCVs softens demand for primary platinum after 2040.
- The platinum industry is currently planning to expand production at a rate of about 13 Mg/year—a rate sufficient to meet the 50% Scenario demand.[2]
- The 20 Mg/year demand identified in the 80% Scenario could exceed the expansion capabilities of the industry.

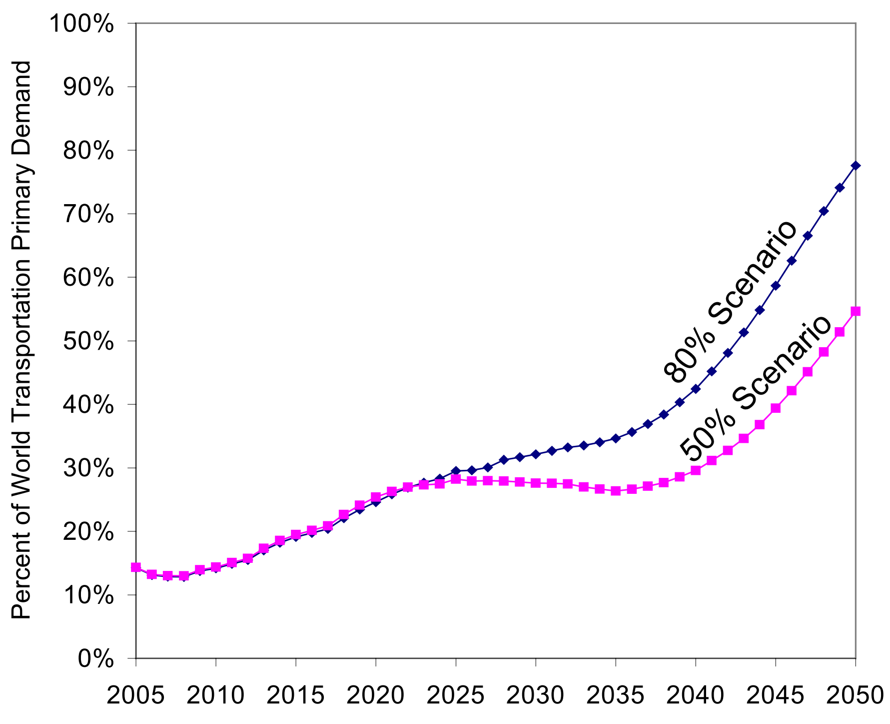
1) Total includes transportation, jewelry, industrial catalysts, and stationary FC power generation
2) 10/22/2003 Memorandum from Johnson Matthey to TIAX. More recent estimates (12/2003) are for 10 Mg/year annual growth.

The complex interplay among recycling, FCV market penetration, and Developing Country market dynamics leads to sharp projected increases in platinum demand in China and India.

Transportation: Primary Platinum Demand



China and India Platinum Demand (Percent of Total Transportation Demand)

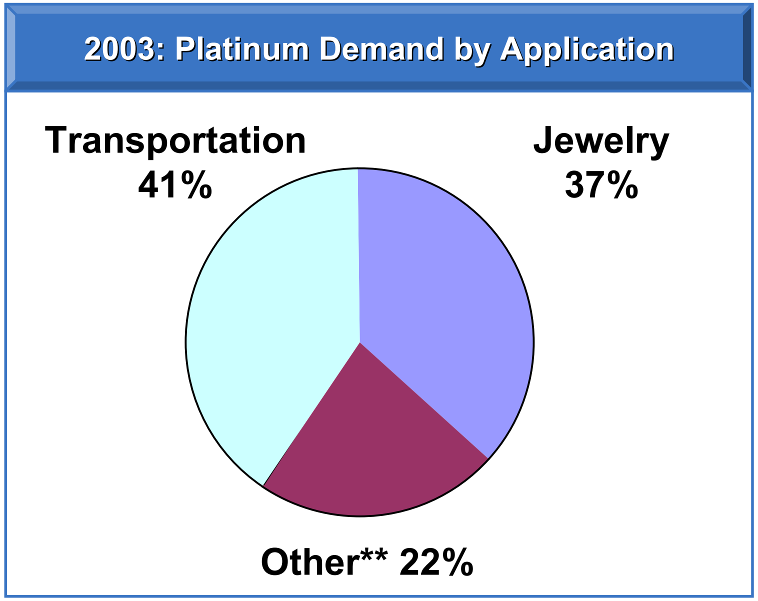


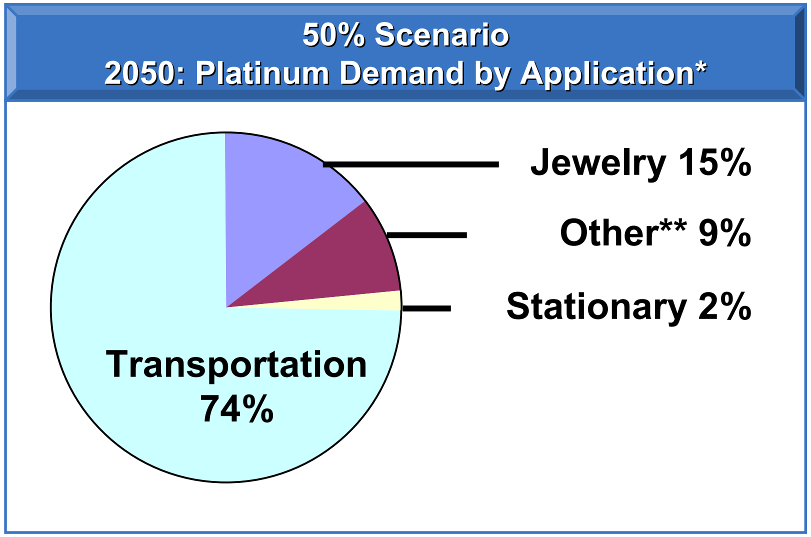
- The decline in primary platinum demand from Developed Countries around 2040 is due to growing supply of secondary platinum (i.e., from FCV recycling).

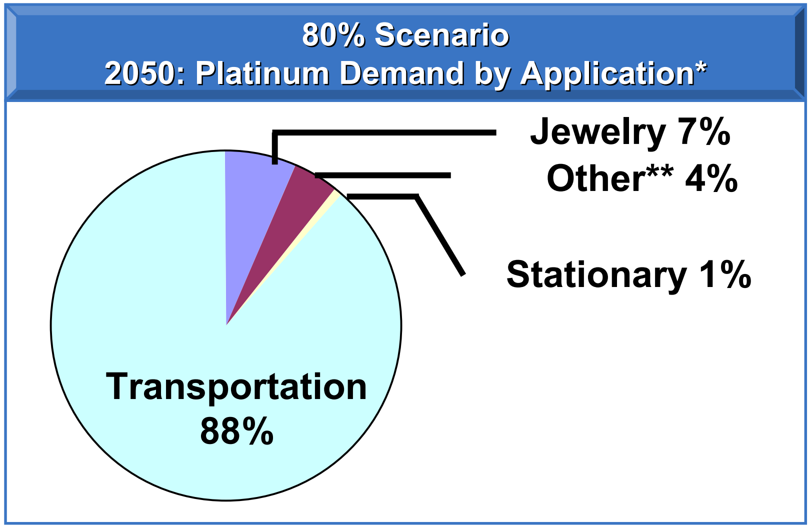
The model results are most sensitive to FCV Platinum Loading, ICEV Recycling Rate, and Jewelry Demand.

Model Parameter	Impact on Model Results
ICEV Recycling Rate	• An increase in the ICEV recycling rate results in a decline of similar magnitude to the growth rate of primary platinum demand. • Increasing the recycling rate has only a moderate impact on cumulative demand for platinum over the period.
FCV Platinum Loading (Pt/vehicle)	• Increasing platinum loading or system power has approximately a linear impact on both the maximum growth rate of primary platinum production and cumulative demand
Jewelry Annual Growth Rate	• Annual growth of platinum jewelry demand is the third most important factor with respect to impact on cumulative demand and production growth rates, but its impact is much less than ICEV recycling or FCV platinum loading. • The size of the jewelry market may provide a buffer to reduce primary platinum production growth rates.

Commercialization of FCVs will make transportation the dominant platinum application with 75 to 90 percent of the total market in 2050.



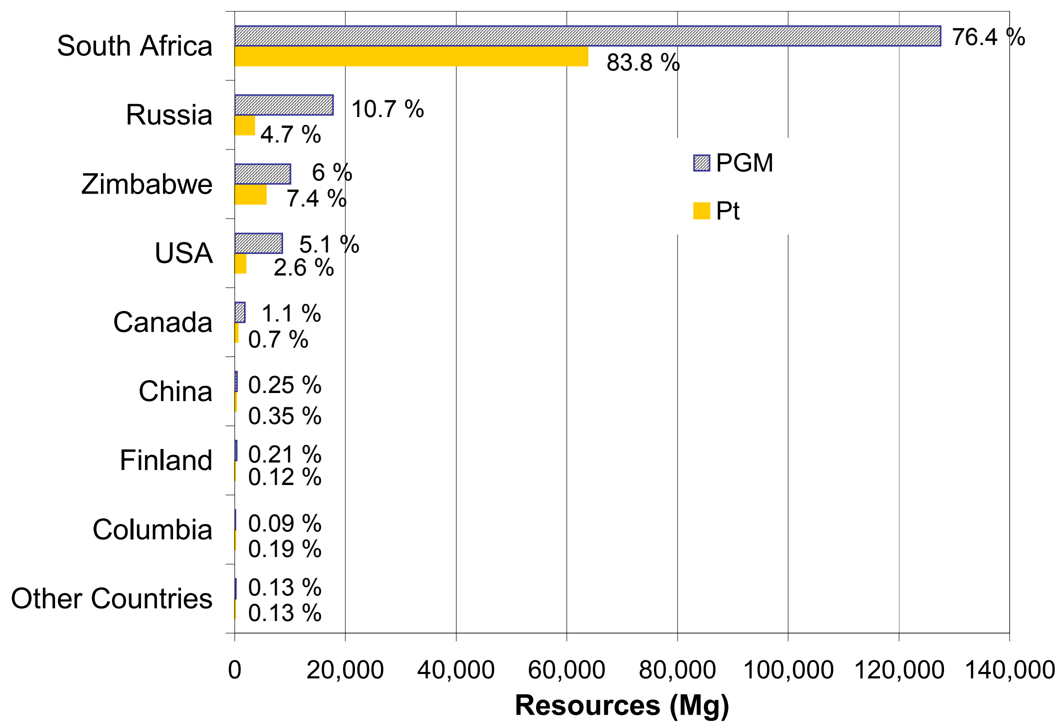




Source: Johnson Matthey, 2003.
* TIAX Projections
** Includes Chemical, Industrial, Investment

There are sufficient platinum resources in the ground to meet long-term projected platinum demand from all applications.

PGM/Platinum Resources by Country



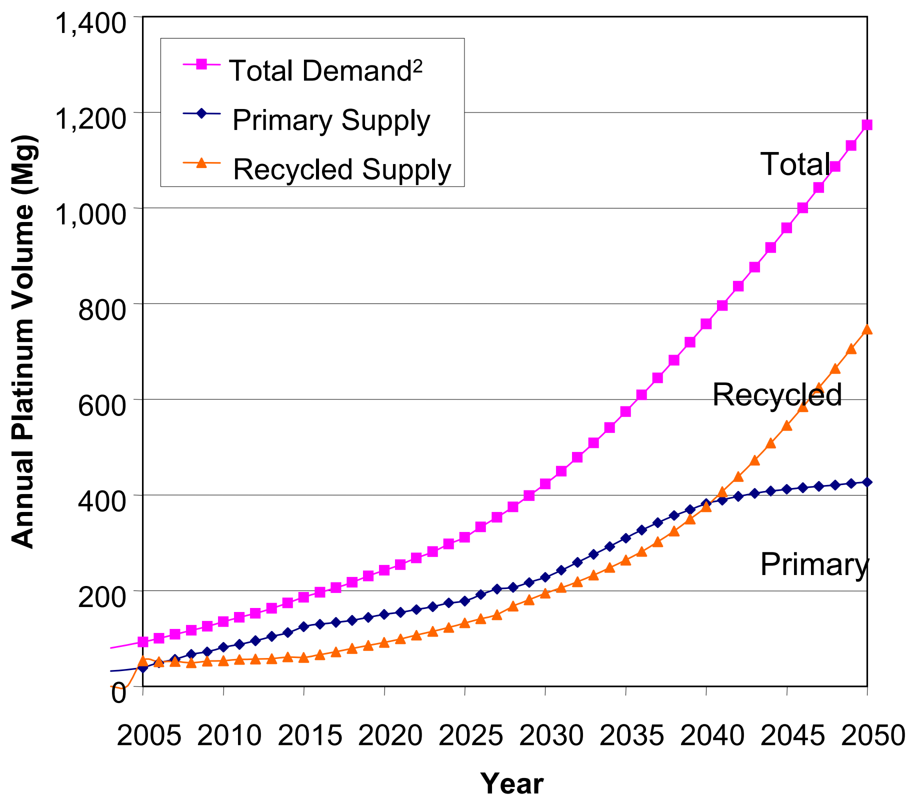
Compiled from a variety of sources, including Cawthorn, Vermaak, Page, Mining Weekly, and Stribyn

- Recent world PGM resource estimates have increased 60% to 160 Gg, largely due to the increased mining depths (2 km) in South African projections
- Total platinum resource projection is 76,000 Mg

Cumulative platinum demand through 2050 is projected to be between 17,500 Mg and 20,500 Mg for all applications.

As demand increases, recycled platinum from transportation markets will be an increasingly critical source of supply.

Global FCV Platinum Supply and Demand

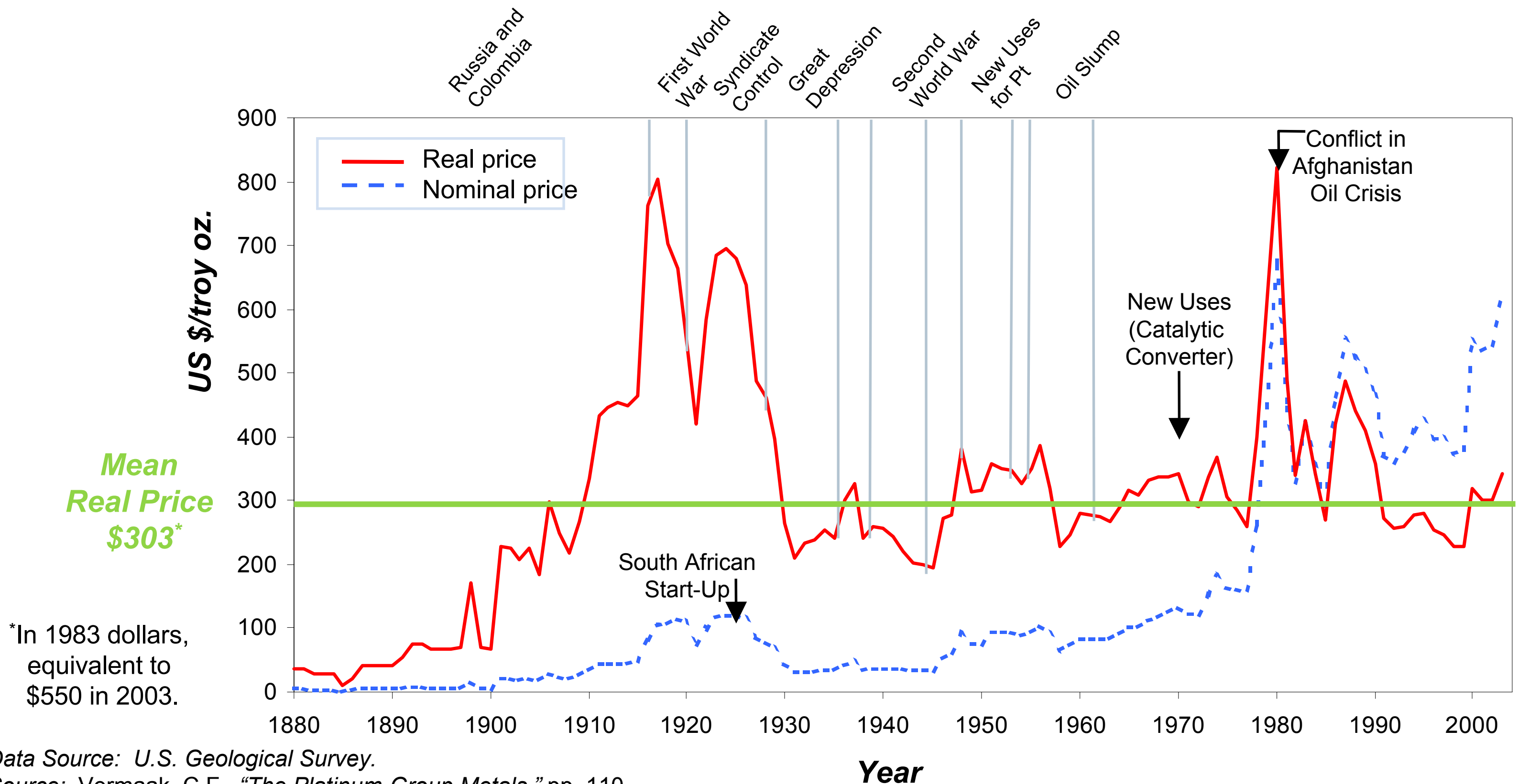


- Today, recycling of industrial/chemical PGM today is greater than 200 Mg/year exceeding primary platinum refining.[1]
- Significant recycling capacity currently exists and will have to grow with the commercialization of FCV.

1) TIAX discussion with the *International Platinum Association*, 2003.
2) Total demand includes Transportation, Jewelry, Industrial Applications, and Stationary FC Power Generation

While there have been short-term platinum price fluctuations, the long-term real price of platinum has remained stable.

Nominal versus Real Platinum Prices, 1880–2002



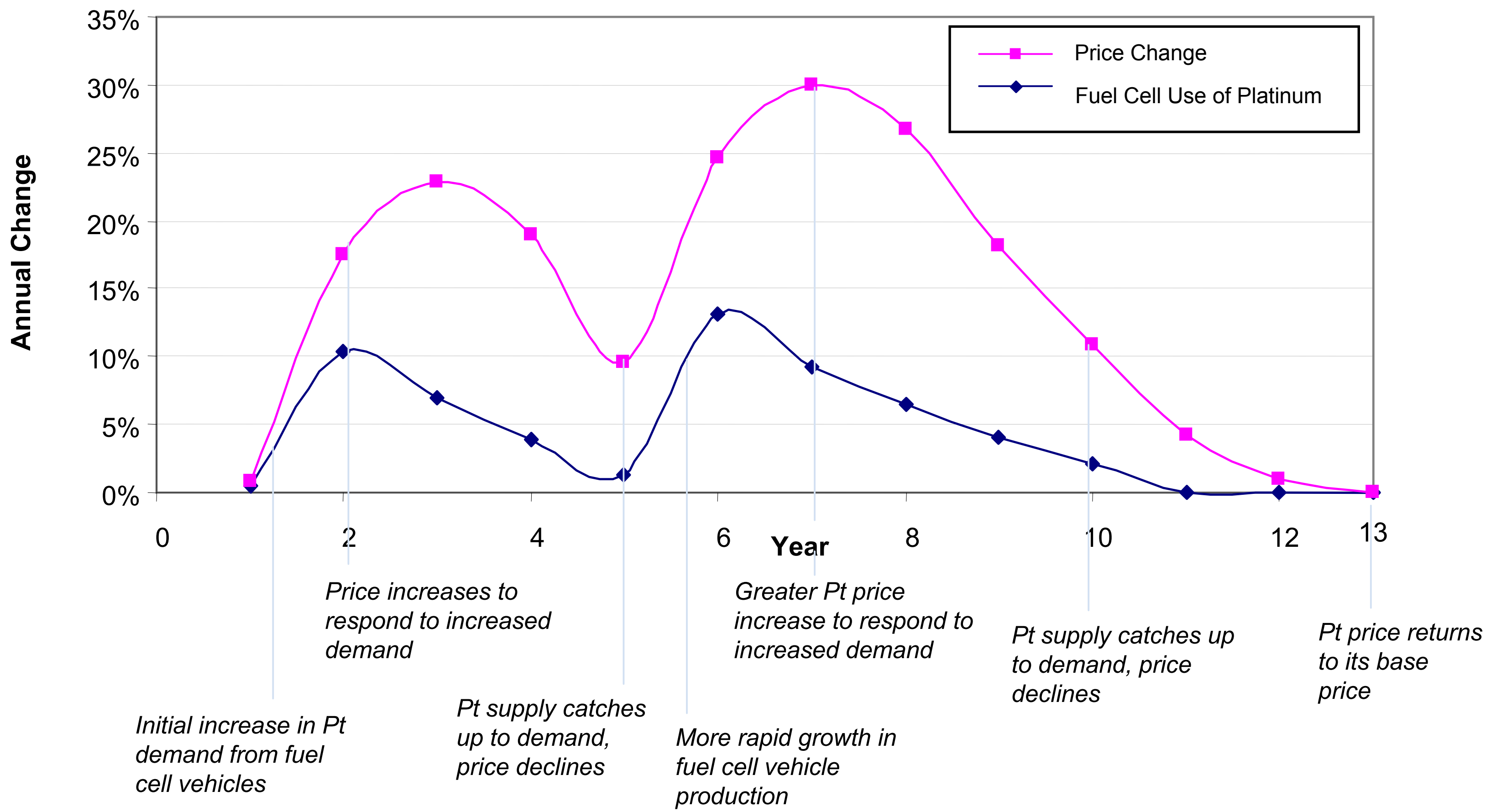
*In 1983 dollars, equivalent to $550 in 2003.

Data Source: U.S. Geological Survey.
Source: Vermaak, C.F., *"The Platinum-Group Metals,"* pp. 110

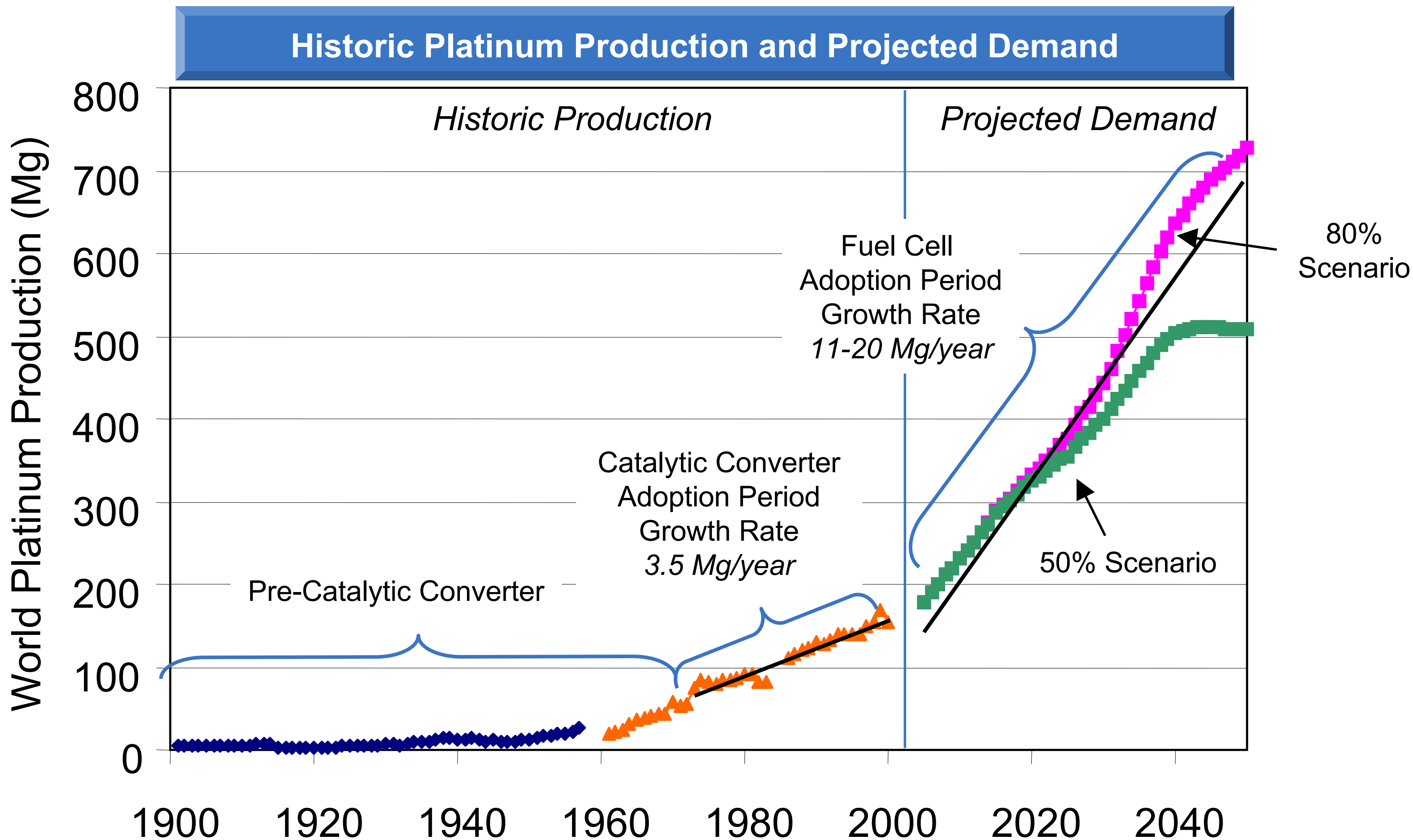
The real price of platinum will remain stable as long as supply and demand are in balance.

Our simulation, based on hypothetical demand over a thirteen-year period, illustrates that increasing demand will increase platinum prices in the short-run before returning to its base price.

Increased Fuel Cell Use of Platinum and Price Changes



To maintain a balance between platinum supply and projected demand from FCVs, platinum producers will need to expand production at a rate beyond historic levels.



While increased demand for platinum from fuel cell technology will likely increase platinum prices in the short-run, the long-run platinum supply is sufficient to meet expected demand levels and thereby stabilize prices.

- Historically, the platinum industry has been able to supply platinum at a rate sufficient to keep supply and demand in balance at a long-term mean price of $550/troy ounce.
- Current South African mine expansion plans suggest that capacity could increase at a rate corresponding to our 50% FCV market penetration scenario.
- An 80% FCV market penetration scenario could exceed the expansion capabilities of the industry.
- Ramp-up of FCV production will likely create a short-term supply shortage or deficit leading to price increases. Typically, it takes three to five years to increase platinum production capacity.
- Regardless of new demand from FCVs, supply/demand imbalances (like those seen in 2003) could keep platinum prices above the long-term mean.

Table of Contents

The US DOE engaged TIAX LLC to assess the long-term availability and price stability of platinum given anticipated demand from fuel cell vehicles.

Key Questions:

- Will the successful adoption of fuel cells in transportation applications be threatened by platinum price increases and limitations in platinum supply in the long-term?
  - Can long-term, primary platinum resources accommodate the new demand from fuel cell markets (transportation, stationary, and portable)?
  - How will supply operations (mining and refining) respond to increases in market demand?
  - What role will recycling play in the supply chain as fuel cell markets develop?
  - Will the relationship between supply, demand, and price of platinum change as fuel cell markets develop?

Given these questions, the US DOE identified the following project objectives.

Project Objectives:

1. Assess current and projected demand for platinum exclusive of fuel cell applications
2. Estimate the relationships between price and supply/demand for platinum
3. Perform sensitivity analysis of critical model parameters related to fuel cell markets and technology advances
4. Simulate the impact of fuel cell market growth scenarios on platinum price
5. Obtain critical feedback from the important participants in the platinum value chain on the model assumptions and projections
6. Develop cost projections for the economics of recycling of platinum from fuel cells and the impact on platinum supply and price

Key elements of the project scope and important issues outside the project scope include the following.

- **Project scope:**
  - The timeframe of the future demand projection is from 2005 to 2050.
  - Platinum applications include Jewelry, Transportation, Industrial, and Stationary Fuel Cells.
  - Demand for fuel cell vehicles (FCVs) is based on projections for five regions (i.e., US, Western Europe, Japan, China, and India).
  - Observed historical platinum prices are from 1880 to the present.
- **Issues outside of project scope:**
  - Potential for political instability in major platinum producing countries.
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  - Future growth/decline in the world economy.
  - Potential for significant increases in platinum demand from new applications other than fuel cells.
  - Ability of fuel cell technology developers to overcome technical hurdles.
  - Ability of the fueling infrastructure to support commercialization of fuel cell vehicles.

The following issues must be considered along with the study results.

- **Focus on Platinum and PEMFCs*:** This study focuses only on potential issues associated with the pricing and availability of platinum in the commercialization of PEMFCs.
- **Prevailing Technical Challenges:** FCV developers are currently focused on resolving technical challenges, reducing cost, and improving manufacturability. In our discussions with OEMs, they did not raise immediate concerns regarding the pricing and availability of platinum.
- **Study Uncertainties:** We developed scenarios to describe potential future demand for platinum:
  – We have stated scenario assumptions (e.g., vehicle markets, fuel cell market penetration, platinum loading, and average powertrain size).
  – Uncertainty inherent to any long-term projection will arise from evolving economic conditions (particularly in Developing Countries), demographics, pricing and availability of hydrocarbon fuels, advances in fuel cell performance and cost, hydrogen infrastructure development, commercialization plans of the OEMs, and advances in ICE technology.

Our approach included five key tasks.

Task 1	Task 2	Task 3	Task 4	Task 5
Data Collection	**Fuel Cell Market Projections**	**Platinum Value Chain**	**Econometric Model**	**Industry Feedback**
• Annual platinum Statistics: - Prices - Supply - Demand by Application - Resources • Economic Statistics (GDP inflation, population etc.)	• Develop projections for stationary, transportation, and portable applications • Develop segmentation for each market • Scenario-based forecasting model	• Description of value chain (mine to market) • Recycling value chain process scenario • Development of high level platinum PEMFC recycling cost model	• Market factor assessment • Model development • Model validation • Simulation of platinum supply, demand, and price for FCV commercialization scenarios	• Solicit feedback from the platinum industry and automotive OEMs • Incorporate feedback into the model, database, platinum market projections, and conclusions

Throughout this report, the following terms and acronyms are used:

Term/ Acronym	Definition
ATR	Auto Thermal Reformer
BOP	Balance of Plant
FC	Fuel Cell
FCV	Fuel Cell Vehicle
GDP	Gross Domestic Product
Gg	Giga gram (1,000,000,000 grams)
GW	Gigawatt
IC	Internal Combustion
ICEV	Internal Combustion Engine Vehicle

Term/ Acronym	Definition
kW	kilowatt
km	kilometer
MEA	Membrane Electrode Assembly
Mg	Mega gram (1,000,000 grams)
OEM	Original Equipment Manufacturer
Pd	Palladium
PEM	Proton Exchange Membrane
PGM	Platinum Group Metal
ppm	Parts per million
Pt	Platinum

Table of Contents

The overall objective of this task is to provide a broad understanding of the current platinum market.

Task Objectives:

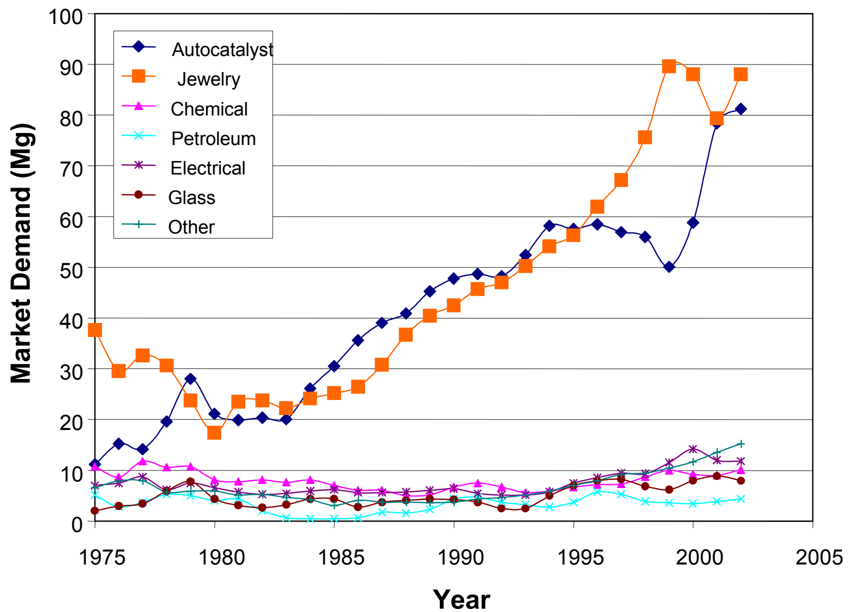
- The specific objectives of this task are to provide a understanding of:
  - Current markets/applications for platinum;
  - Fuel cell technology and the role that platinum and other PGM materials play in the commercialization of FCVs;
  - Sources of primary platinum supply and projected platinum resources; and
  - Sources of secondary platinum supply and the importance of maintaining value in FCV recycling.

This overview identifies the critical role of platinum to the commercialization of FCVs and the importance of both primary and secondary sources of supply.

- *Sources of Demand:* Autocatalysts and jewelry are currently the largest applications for platinum with 80 percent market share and the greatest growth in demand.
- *Importance to FCV:* Platinum is critical to fuel cell performance and is a large component of fuel cell cost, accounting for 10 to 15 percent of total fuel cell production costs.
- *Sources of Supply:* The supply of platinum is dominated by South Africa and controlled by a small network of miners, refiners, and traders/brokers.
- *Availability of Resources:* About 76,000 Mg of platinum resources are estimated to be in the ground to 2 km; advances in mining technology are needed to economically access the deeper ores.
- *Importance of Secondary Supply:* Recycled autocatalyst provides a good model for the anticipated recycling of fuel cells and demonstrates that recycled fuel cells will likely provide a dependable source of platinum supply that is profitable at each stage of the supply chain.

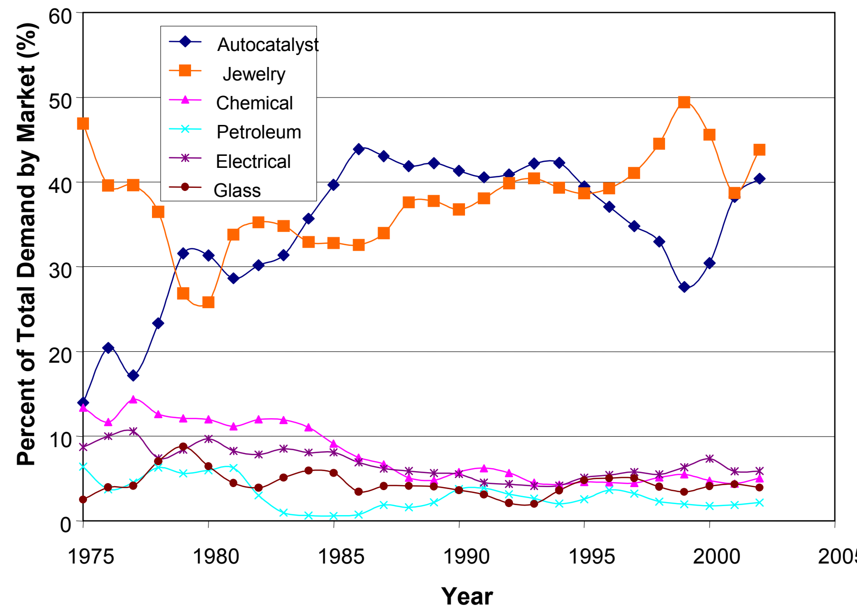
Autocatalyst and jewelry are currently the largest applications for platinum with 80 percent market share and the greatest growth in demand.

Demand for Platinum by Application (Mg)*



Source: Johnson Matthey, Platinum 2001.

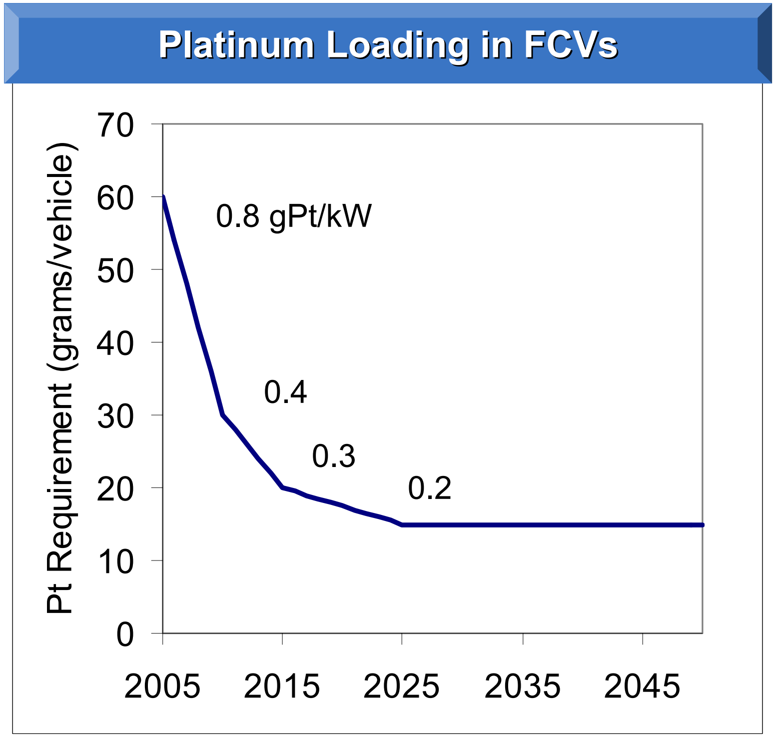
Market Share by Application (%)



Source: Johnson Matthey, Platinum 2001.

Demand from other applications including chemicals, petroleum, electronics, and glass has been relatively stable.

Demand for FCVs will drive up the demand for platinum because of the high content of platinum in FCVs as compared to ICEVs.



Gasoline ICEVs currently use approximately 2 to 5 grams of platinum per vehicle.

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- Platinum is critical to achieving the required levels of fuel cell power density and efficiency.
- Platinum and some ruthenium are essential to the catalysis of anodic and cathodic reactions in the stack.
- Platinum is important for the catalysis of reforming, shift, and preferential oxidation (PROX) reactions in the fuel processor.

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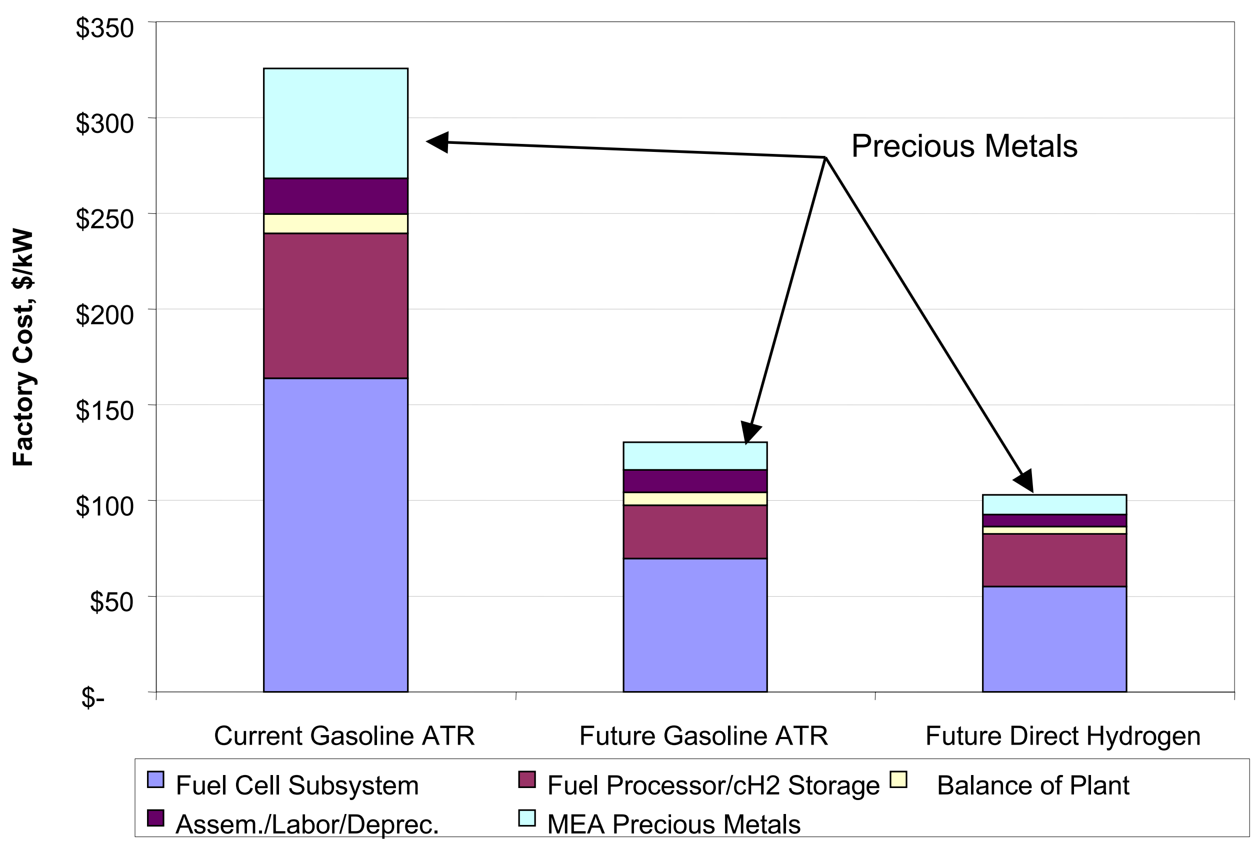


Source: Future Car Congress, 2002, Based on $20/g Pt

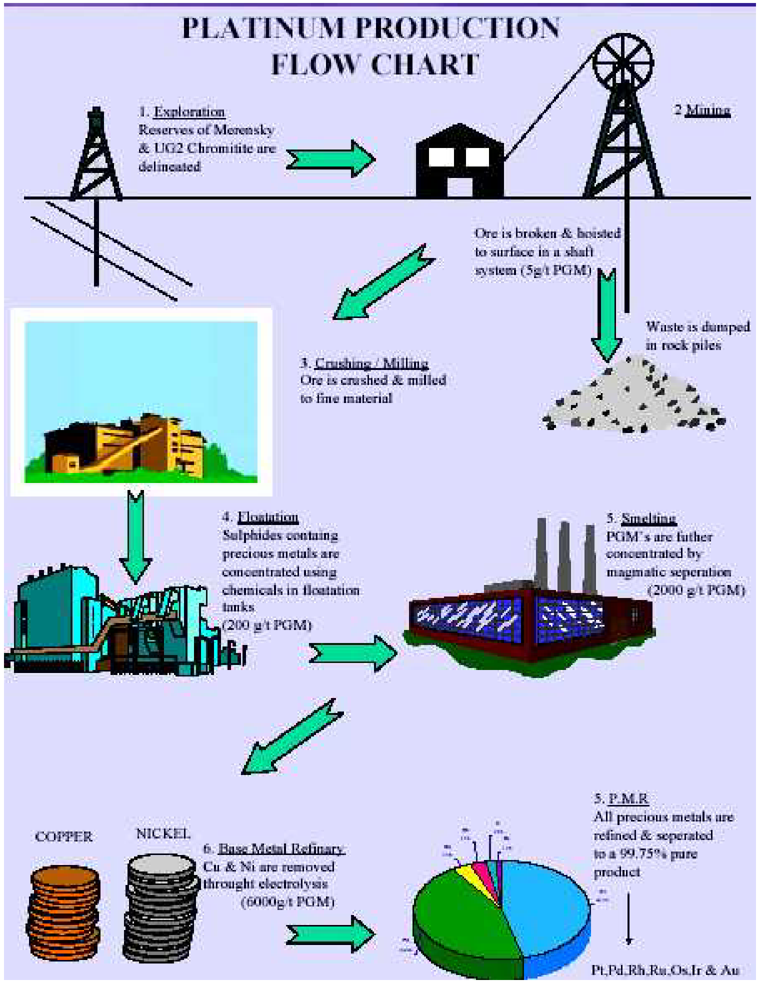
ATR: Auto Thermal Reformer
cH2: Compressed Hydrogen
MEA: Membrane Electrode Assembly

Platinum is one of the six PGMs recovered along with base and precious metals.

PGMs	
• Platinum	• Iridium
• Palladium	• Osmium
• Rhodium	• Ruthenium

Base Metals	Precious Metals
• Nickel	• Gold
• Chromium	• Silver
• Copper	

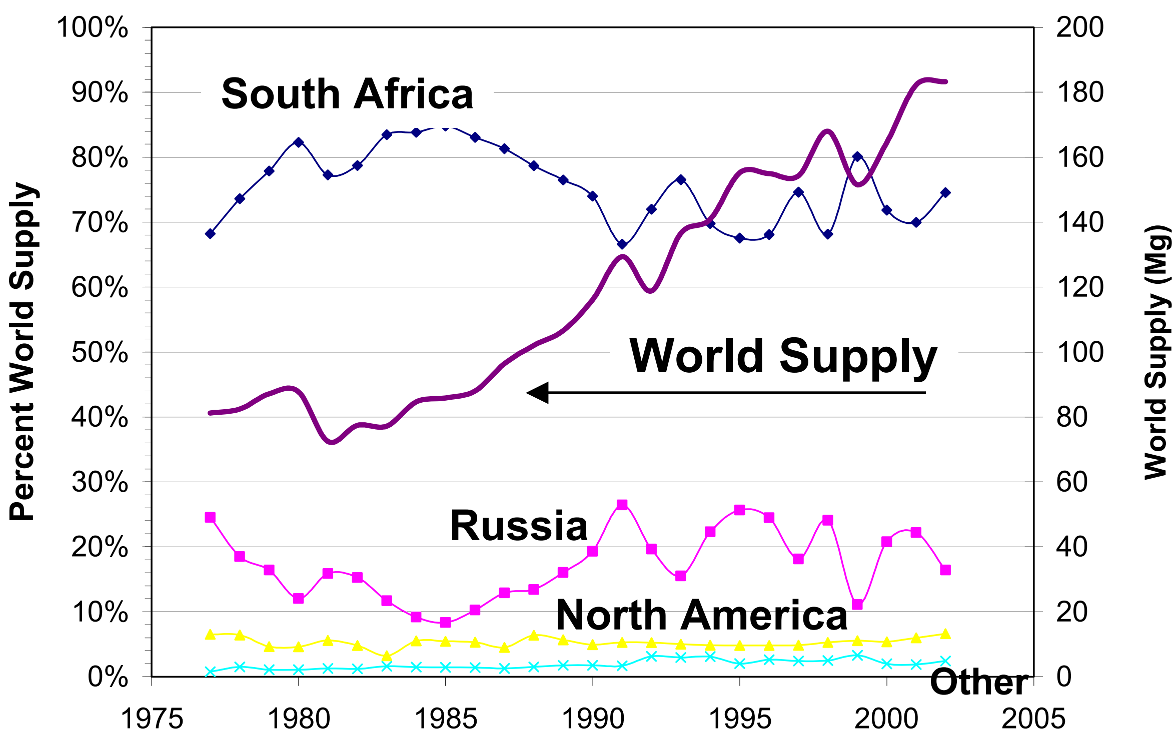
Note: The appendix provides a more extensive description of platinum mining and ore bodies.



Source: Lonmin Platinum, Geology of the Bushveld Complex, 2003.

South Africa currently produces about 80 percent of the world's platinum.

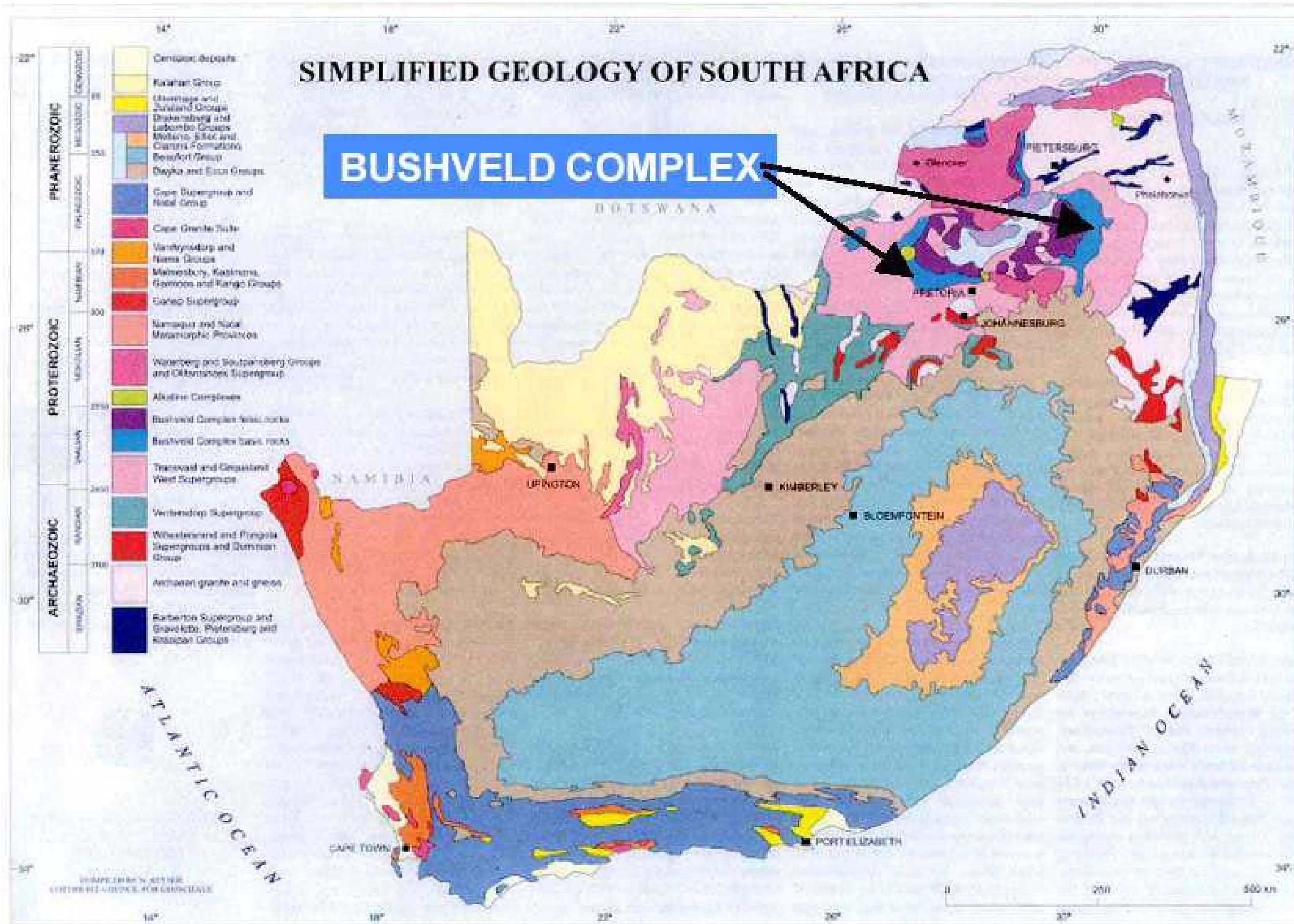
Platinum Supply (1977-2002)



Source: Johnson Matthey, Platinum 2001.

In the 1990s, Russia's manipulation of their PGM sales disrupted the market.

The Bushveld Complex in South Africa contains the world's largest deposit of platinum.



Source: Lonmin Platinum, Geology of the Bushveld Complex, 2003.

Platinum accounts for 40 to 60 percent, by weight, of the PGM and gold content of South African ores.

Percent of PGM and Gold*				
Material	**Merensky Reef E&W Limbs**	**UG2 Western Limb**	**UG2 Eastern Limb**	**Platreef**
Platinum	55–59	46–52	39	44
Palladium	25	23–27	39	44
Rhodium	3–4	7.5–8.5	7	2.7
Rutherium	6–8	8.5–16	9	3.3
Iridium	0.8–1.3	2–3	4	0.9
Osmium	0.5–1	1	1.5	0.8
Gold	4–5	0.6–1.5	0.9	4.9

Source: Lonmin Platinum, Geology of the Bushveld Complex, 2003.

* $\% = (W_{metal_i} / (\Sigma W_{PGMs} + W_{Au})) \times 100$
W = Weight

The concentration of platinum in the ore typically ranges from 1 to 10 ppm.

Platinum resource data is reported on a geological basis and was used in our study for the assessment of potential long-term platinum availability.

- Significant platinum deposits are located in dense formations and can be detected by aerial magnetic surveys.
- South African ores are located in well defined layers—the depth of these layers can be accurately estimated.
- South African resource data is now reported to a depth of 2 km (reported resource data for gold is based on a greater depth).

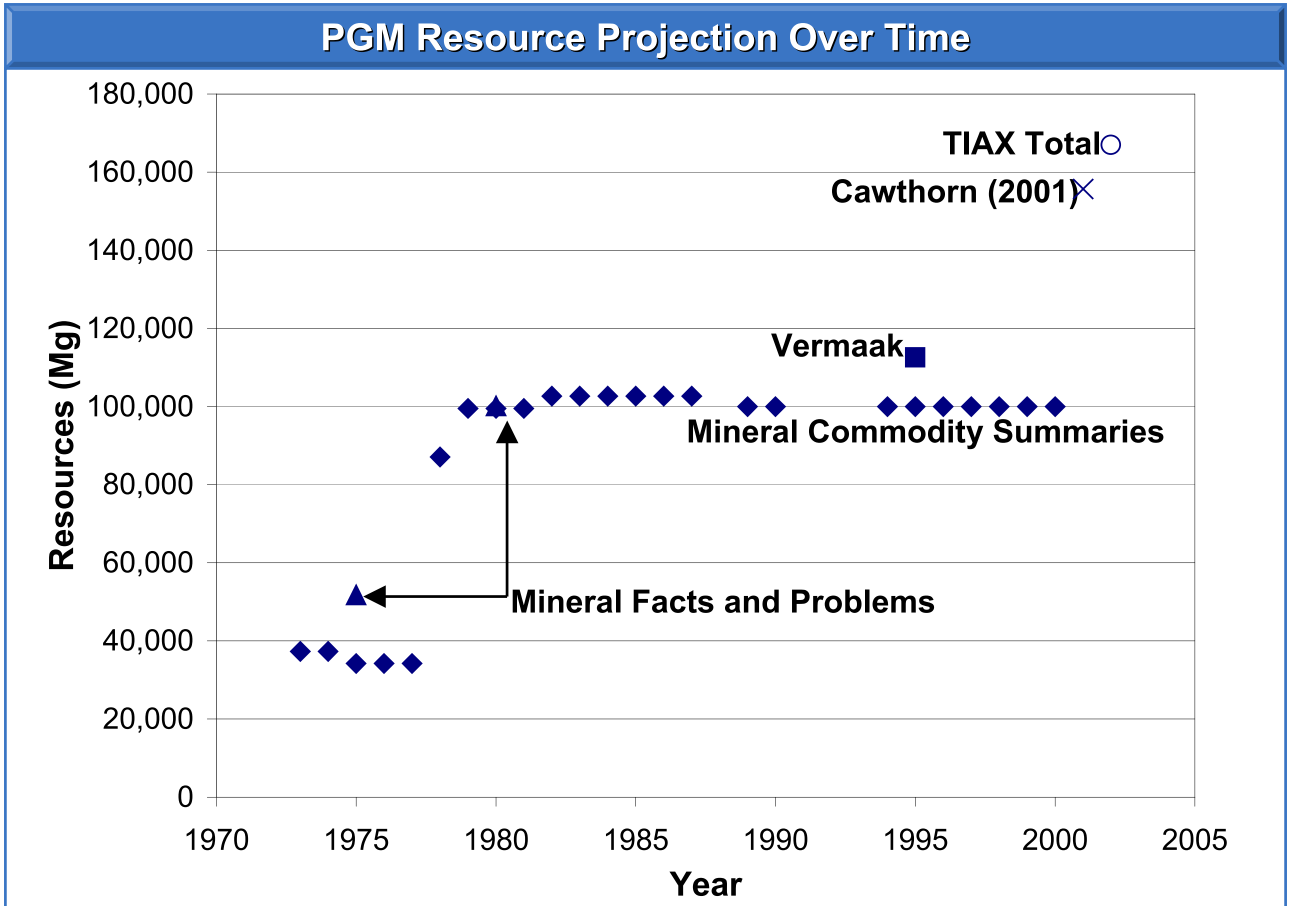
Reserve data, which focus on near-term available ores (i.e., 3-5 years), were not used to characterize future platinum availability.

Several different sources have developed estimates for the amount of available platinum resources.

Overview of Platinum Resource Estimates

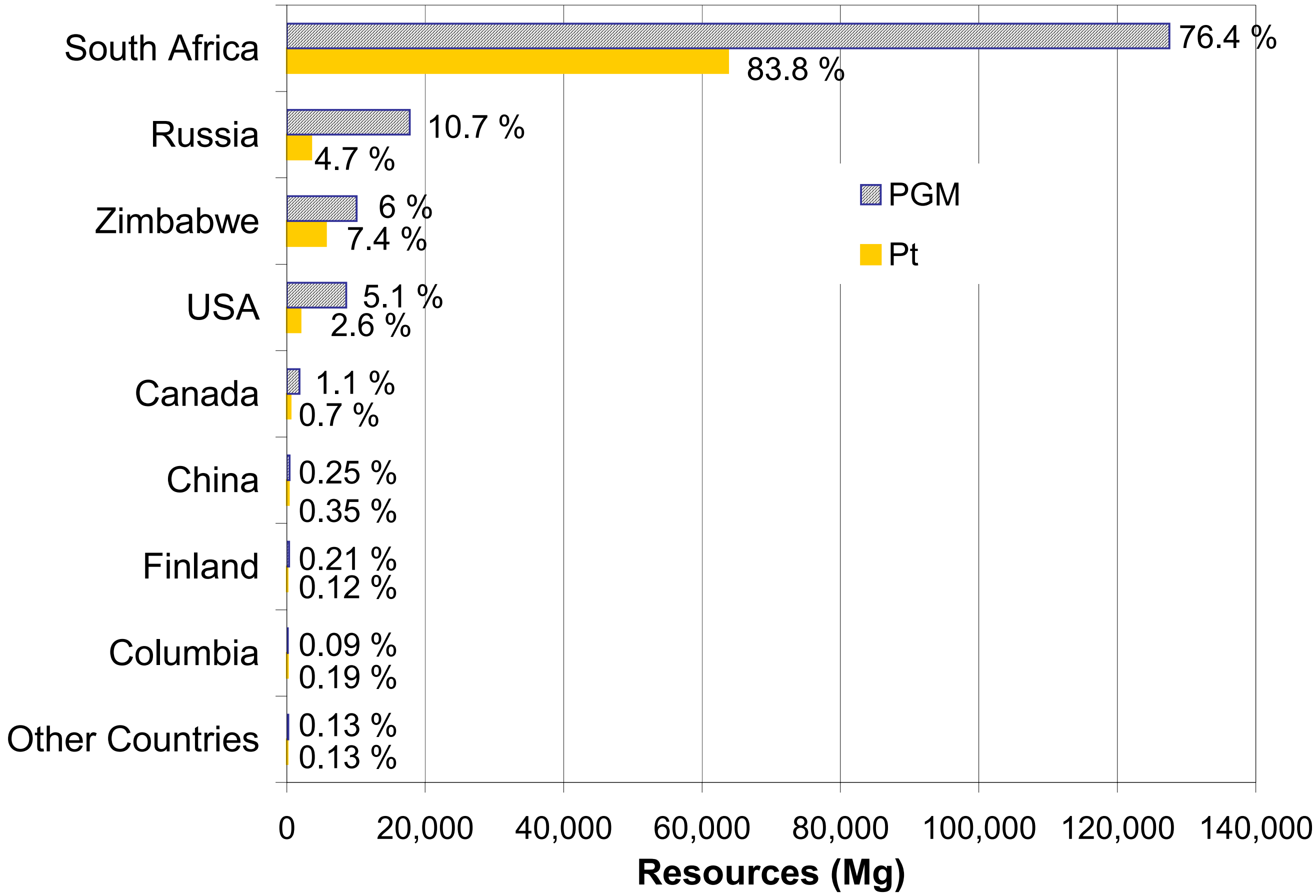
Source	Description
Vermaak	• *The Platinum-Group Metals, A Global Perspective*, by C.F. Vermaak, 1995.
Cawthorn	• Professor Grant Cawthorn, The Platinum Industry's Professor of Igneous Petrology, Department of Geosciences, University of the Witwatersrand • Prepared the most recent South African resource estimate and considered increased mining depths (2 km) in South African projections
Mineral Commodity Summaries	• Prepared by the U.S. Geological Survey
Mineral Facts and Problems	• Prepared by the U.S. Bureau of Mines

World PGM resource estimates have steadily increased over time as advances in technology have to increased mining depths.



The TIAX estimate is based on the Vermaak's Russia estimate and Cawthorn's South Africa estimate.

TIAX projects that world PGM resources are about 160,000 Mg and world platinum resources are about 76,000 Mg.

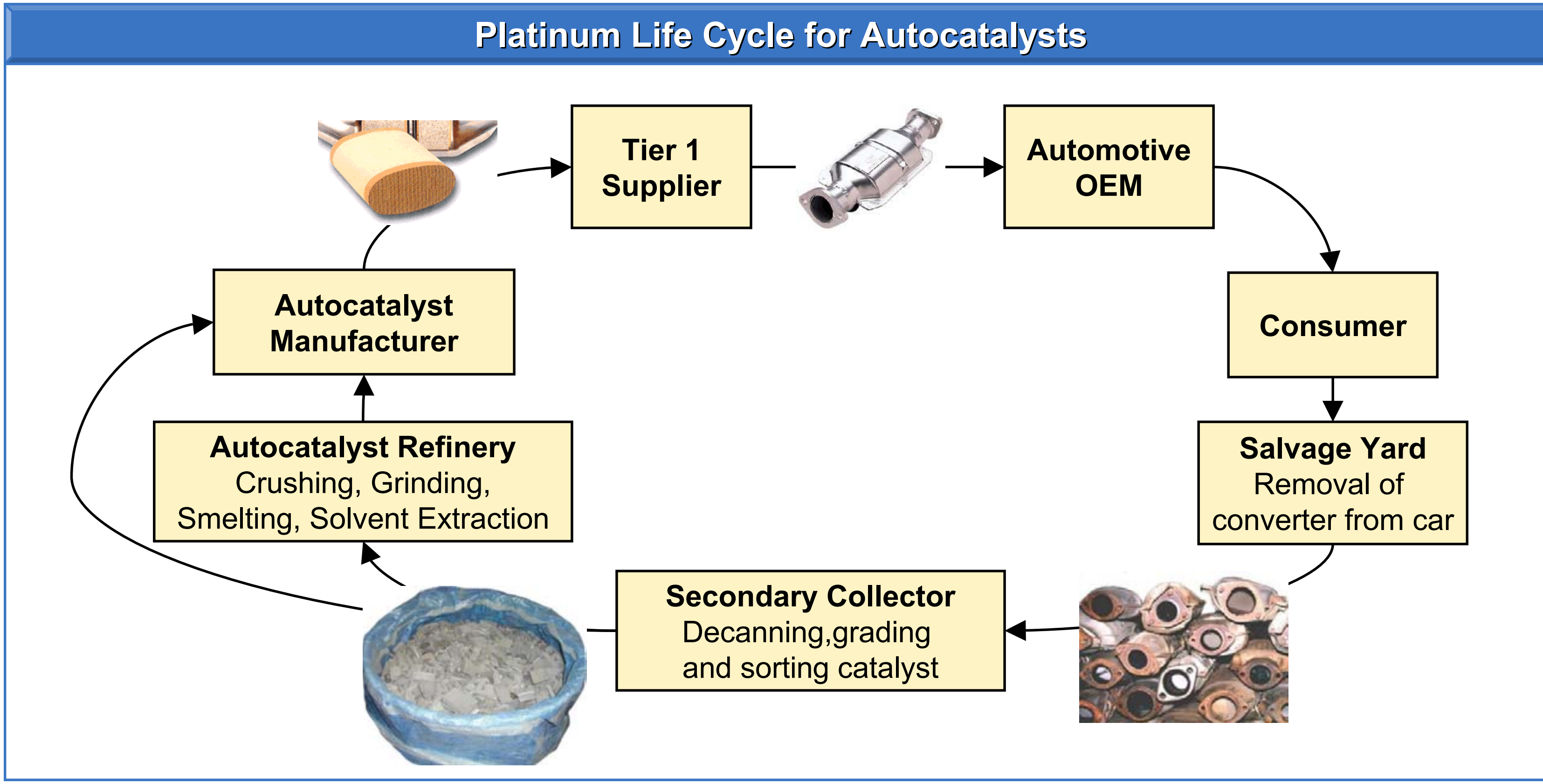


Source: Compiled from a variety of sources, including Cawthorn, Vermaak, Page, Mining Weekly, and Stribyn
Note: A comparison of these resource estimates to other recent estimates is provided in the appendix.

About 85 percent of primary platinum goes directly to OEMs or through companies like Johnson Matthey and Engelhard.

- *Examples of platinum industry companies:*
  - Mining Facilities
    - Bushveld Complex, South Africa (e.g., Anglo Platinum, Impala Platinum, Lonmin Platinum)
    - Norlisk Nickel, Russia
    - Stillwater Mine, USA
  - Product Manufacturers and Refiners
    - Johnson Matthey, USA and Europe
    - Engelhard, USA and Europe
    - Umicore, Belgium (now includes dmc^2 of Germany)
  - Toll Refiners/Concentrators
    - Inmetco, USA
    - Multimetco, USA
    - Tanaka Kikinzoku, Japan

A major source of secondary platinum comes from the recycling of autocatalyst.

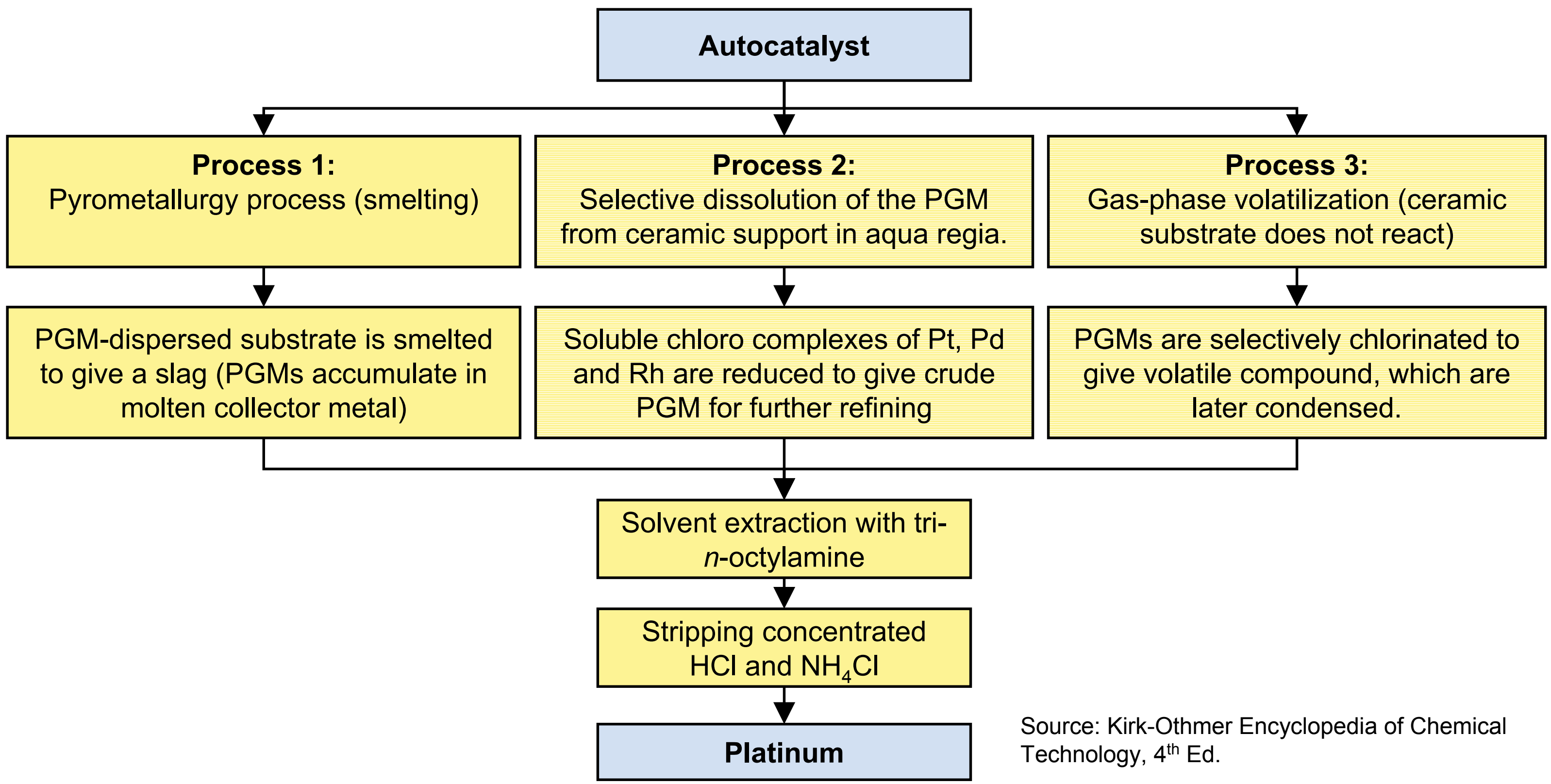


Autocatalyst recyclers currently recover approximately 700,000 troy ounces (22 Mg) of platinum per year.

Sources: A1 Specialized, phone discussion

Several different methods are available to recover platinum from spent autocatalyst.

Methods of Platinum Recovery from Autocatalyst

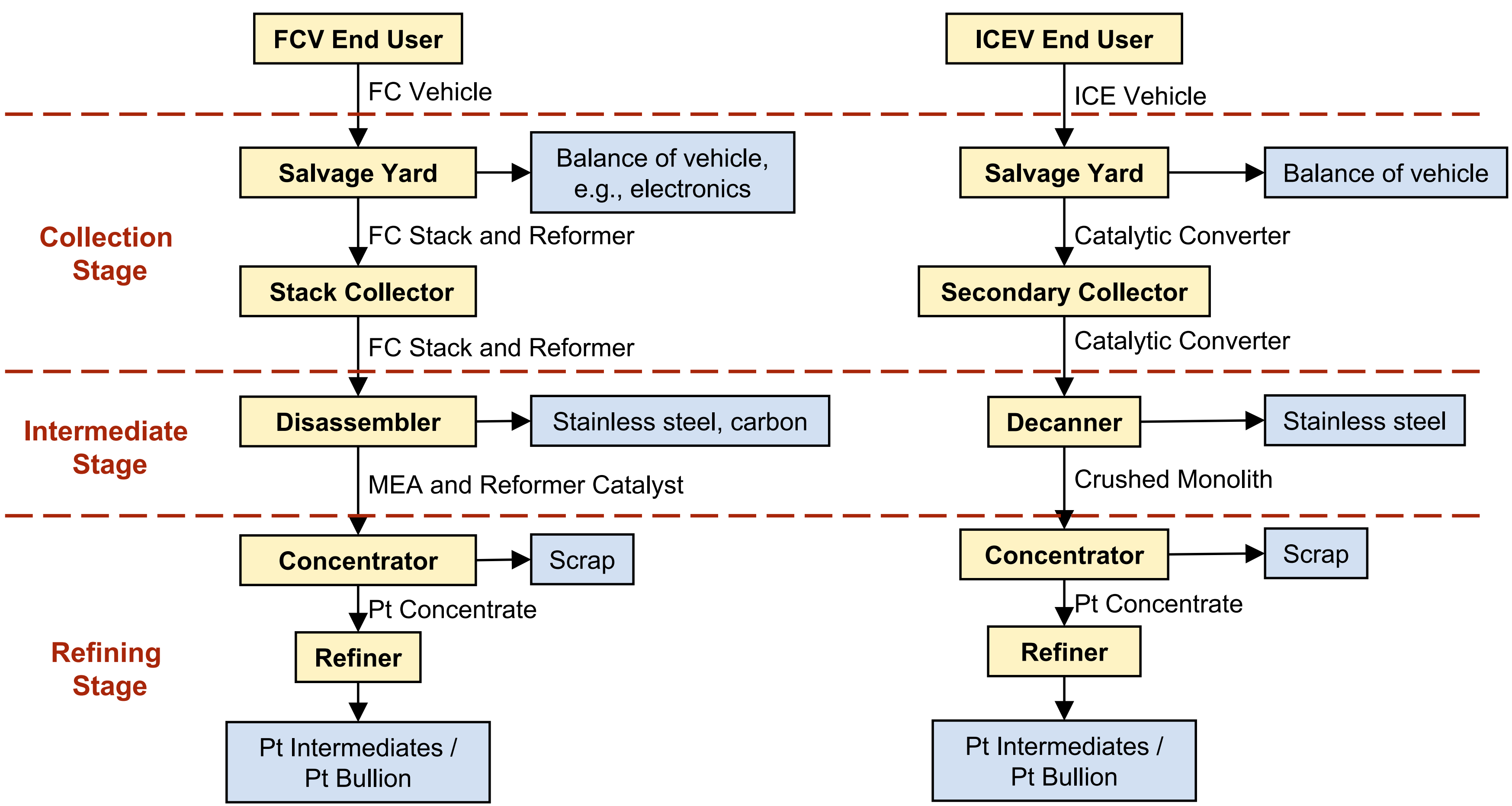


Source: Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed.

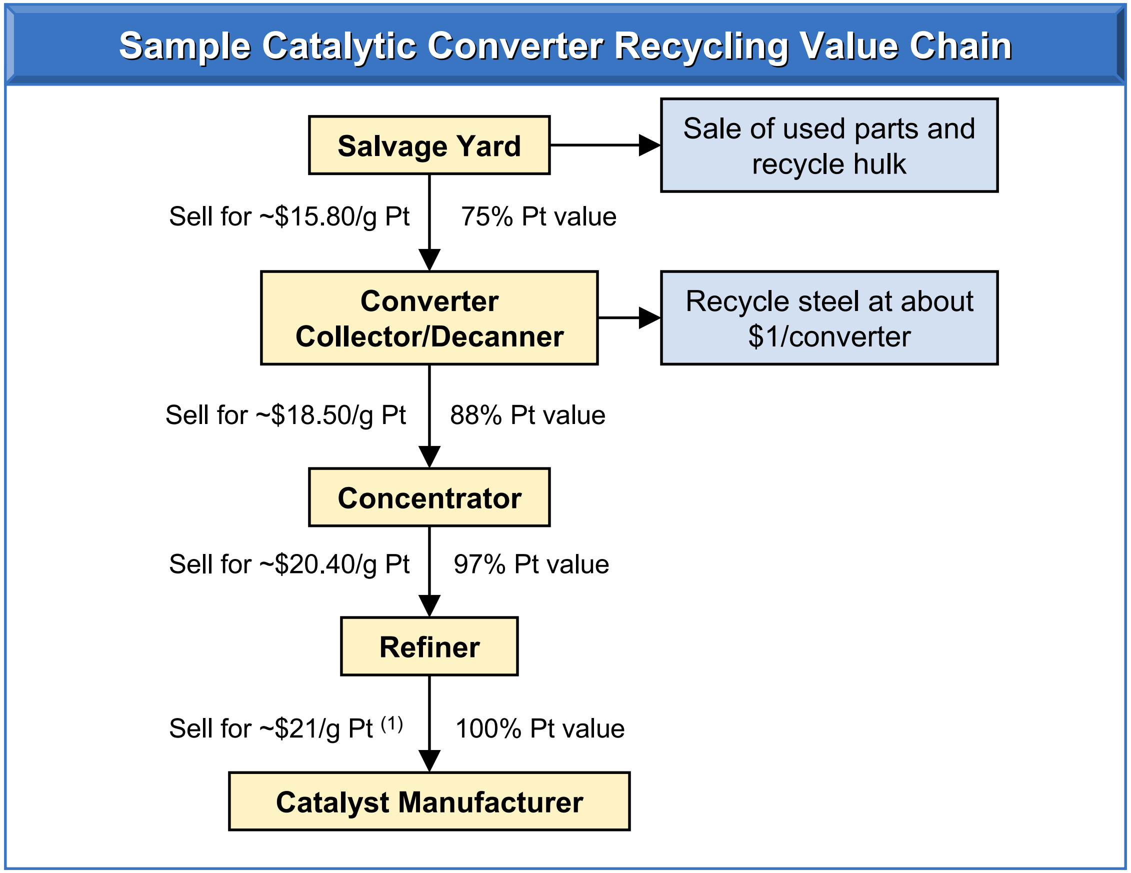
Pyrometallurgy is the most common and economical recovery method.

The process for recycling fuel cells will be similar to the current autocatalyst recycling process.

Side by Side Comparison of the Fuel Cell and Autocatalyst Process Flows



As demonstrated by the existing catalytic converter recycling process, the fuel cell recycling business must be profitable at each process stage.



(1) Based on current platinum market price

Sources: CPM Group, Barnard Jacobs Mellet Securities

Table of Contents

The overall objective of this task is to develop projections for platinum demand in the period from 2005 to 2050.

Task Objectives:

- The specific objectives of this task are to provide a understanding of:
  - – Likely growth in vehicle demand in selected Developed and Developing Countries;
  - – Key issues associated with the adoption of new transportation technology;
  - – Future scenarios that describe the adoption rate of FCVs in selected Developed and Developing Countries;
  - – The impact of FCV demand for platinum on both primary and secondary supply; and
  - – The model variables that have the most significant impact on demand projections.

If FCVs are commercialized to the point that they achieve 50% or 80% market penetration, significant pressure will be placed on both the primary and secondary sources of platinum supply.

- ***Projected Vehicle Sales:*** Annual vehicle sales in 2050 are projected to be 70 to 95 million units in the selected regions, approximately two times current production levels
- ***Production Growth Rate:*** Both the 50% and 80% Scenarios identify a period of rapid growth in primary platinum demand (11 to 20 Mg increases per year) between 2025 and 2040. During this period, average annual growth in primary platinum production will be 3 to 6 times greater than the growth rate from 1960-2000.
- ***Recycling:*** Recycling of transportation catalyst will play a critical role in the supply of platinum, with requirements comparable to primary platinum.
- ***Resources:*** Cumulative platinum demand in the 50% and 80% Scenarios represents 22 to 26 percent of currently estimated primary platinum resources.
- ***Market Concentration:*** The transportation sector will be the major user of platinum, about 75 to 90 percent of primary demand, in 2050.

Fuel cell use in transportation will be the major driver of new platinum demand; however, traditional applications will still remain important components of overall platinum demand.

Transportation

- More demanding emission regulations will increase PGM demand.
- Increasing penetration of diesel vehicles will increase platinum demand.
- Increasing GDP in Developing Countries will increase vehicles per capita.
- Developing Country emission standards will approach or equal those of the Developed Countries.
- Adoption of fuel cell powertrains will increase platinum demands per vehicle.

Stationary Power

If PEMFCs are commercially viable in passenger vehicles (e.g., $50/kW), the cost will be well below what is required to penetrate distributed generation markets.

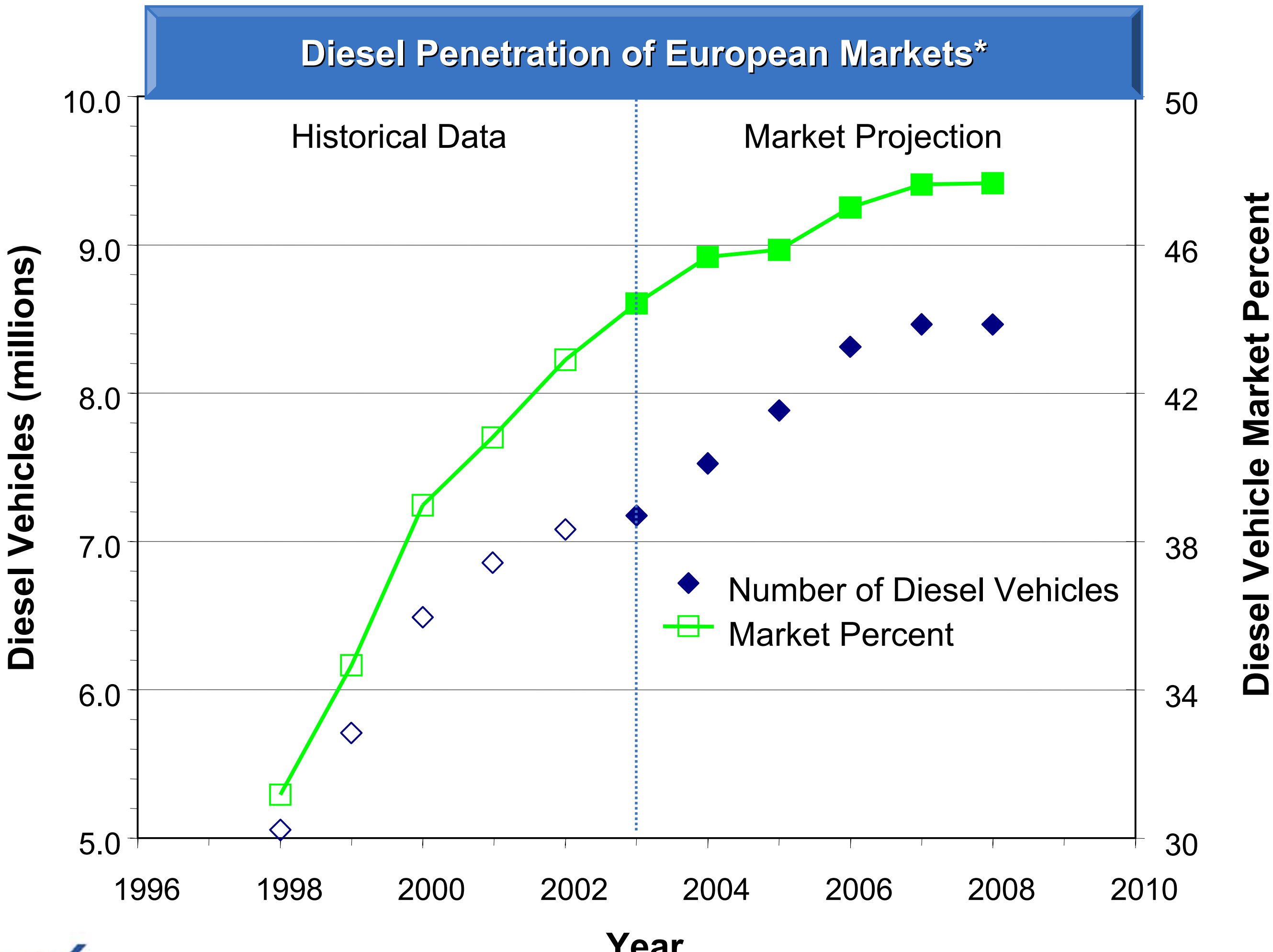
Other Traditional Applications

Jewelry and industrial demand will remain important components of overall platinum demand.

Before developing market penetration scenarios, we considered the following historic trends in automotive technology introductions.

- A paradigm shift in powertrain technology development analogous to the introduction of FCVs does not exist; however, non-regulatory driven changes have typically taken place over a 10-15 year period.
- Regulatory driven technology changes (e.g., catalytic converters) have been adopted in less than 10 years.
- Two scenarios may apply to technology adoption in Developing Countries:
  – Traditionally, technology introduction in Developing Countries lags Developed Countries by 10 -15 years.
  – Alternatively, Developing Countries could choose to leapfrog current technology. With significant growth in vehicle fleets, Developing Countries may choose to invest in new technology rather than an older production systems with limited “useful” life.
- Characteristics of typical automotive technology introductions include:
  – Initial slow growth while the marketplace validates the quality of the technology (e.g., reliability, performance, consumer feedback) and the cost performance (e.g., learning curve improvement, cost reduction efforts).
  – Rapid growth period displacing older technology when economies of scale shift to the new technology.

The introduction of <u>improved</u> diesel powertrain technology in Europe illustrates rapid market share penetration in the transportation industry; it is expected to reach 45-50% penetration by the end of the decade.



* Source: P. Gott of *Global Insight*

For reference, the hybrid Toyota Prius has sold 120,000 units in the 5 years since its introduction in 1997 and has had 3 powertrain evolutions.

Current Generation Prius (Compact)	
Toyota Hybrid System	
Engine	**1.5-Liter VVT-i**
Horsepower	70 @ 4,500 RPM
Torque	82 lb.ft. @ 4,200 RPM
Electric Motor	**Permanent Magnet**
Voltage/Horsepower (HP)	273.6V/44 HP
Torque	258 lb.-ft. @ 0-400 RPM

2004 Prius (Midsize)	
Hybrid Synergy Drive Concept	
Engine	**1.5-Liter VVT-i**
Horsepower	78 @ 5,000 RPM
Torque	85 lb.-ft. @ 4,200
Electric Motor	**Permanent Magnet**
Voltage/Horsepower (HP)	500V/67 HP
Torque	295 lb.-ft @ 0-1,200RPM

Source: Toyota Motor Corp

Toyota projects worldwide annual sales of 36,000 units of the 2004 Prius.

Our approach for developing long-term projections for the transportation sector was built upon population projections, vehicle per capita scenarios, and projected FCV and ICEV platinum requirements.

Population Projection

- UN Forecast for
  - United States
  - Western Europe
  - Japan
  - China
  - India

Vehicle Per Capita Projections

- Vehicle per capita trends
  - US values set the maximum level
  - EIA* Annual Energy Outlook 2003 provides estimates out to 2020

* *EIA: DOE Energy Information Administration*

Total Vehicle Forecast

- Replacement factor
- New demand

Fuel Cell Vehicle Projection

- Use diffusion model to simulate market penetration
- Define Scenarios
  - Commercialization start date
  - Time to rapid growth
  - Ultimate market penetration
  - Delay between Developed and Developing Countries
- IC vehicle market is the difference between total market and FCVs

Fuel Cell and IC Powertrain Pt Requirements

- Fuel Cell - g Pt/kW
- IC vehicle - g Pt/vehicle
- Vehicle Life

Platinum Demand vs Time

We selected Developed and Developing regions that account for about 50 percent of the world population and about 75 percent of vehicle sales.

		2000 Population		2000 Vehicle Fleet	
		Number (million)	% Total	Number (million)	% Total
Selected Developed Regions	United States	290	5	213	30
	Western Europe*	330	5	210	30
	Japan	130	2	73	10
Selected Developing Regions	China	1300	21	14	2
	India	1000	17	9	1
	Rest of World	3000	50	182	26
	Total	6100	100	701	100

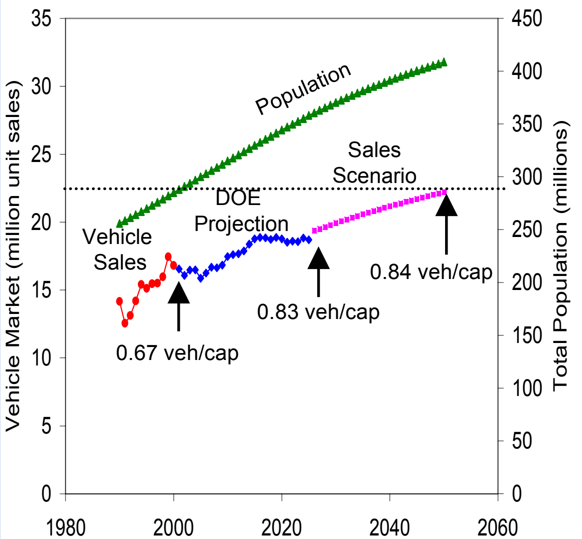
* *Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom*

The Developed regions, with 12 percent of the world population, account for 70 percent of the vehicle fleet and are the most likely FCV early adopters.

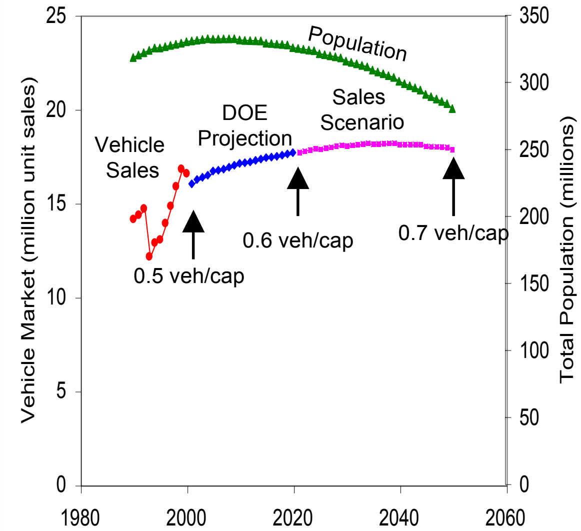
Sources: United Nations Population Database, Ward's Automotive Vehicle Data (2001)

In the Developed regions, overall vehicle sales increase modestly driven by the US vehicle demand.

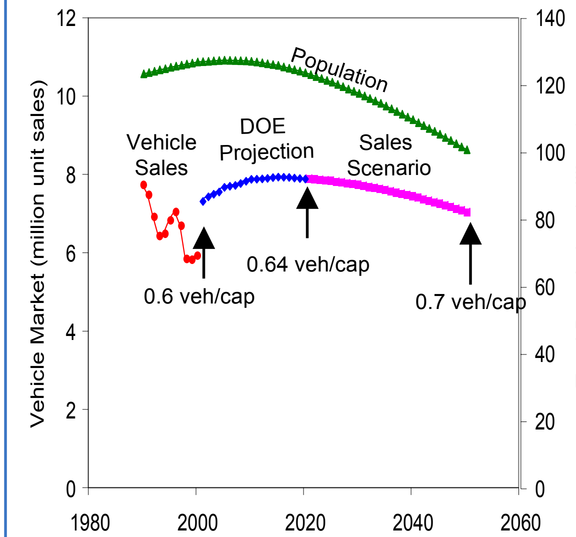
US



Western Europe



Japan

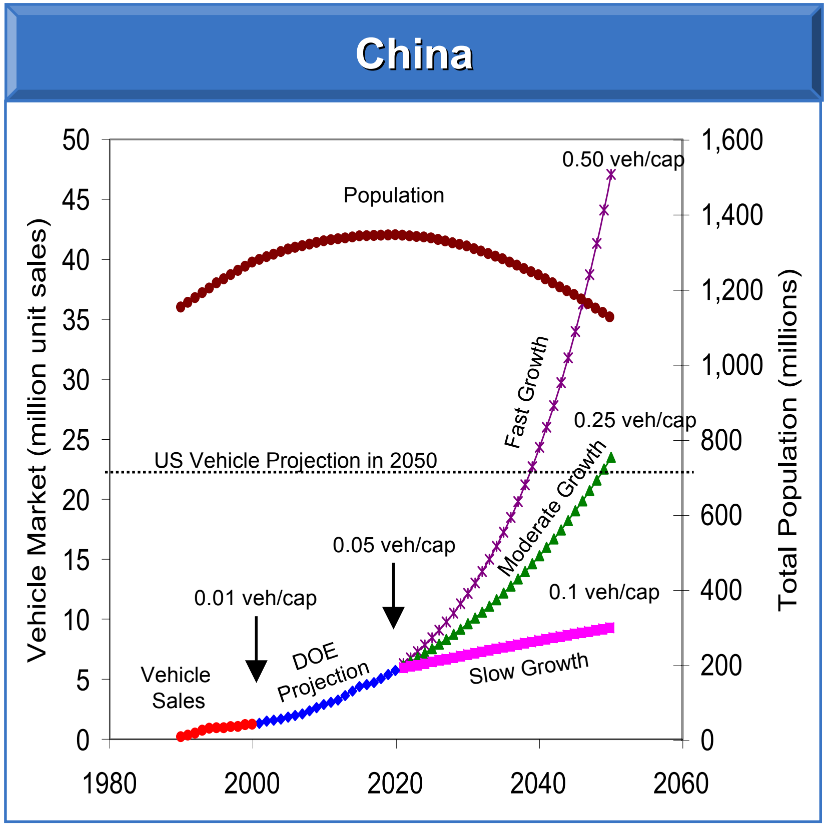


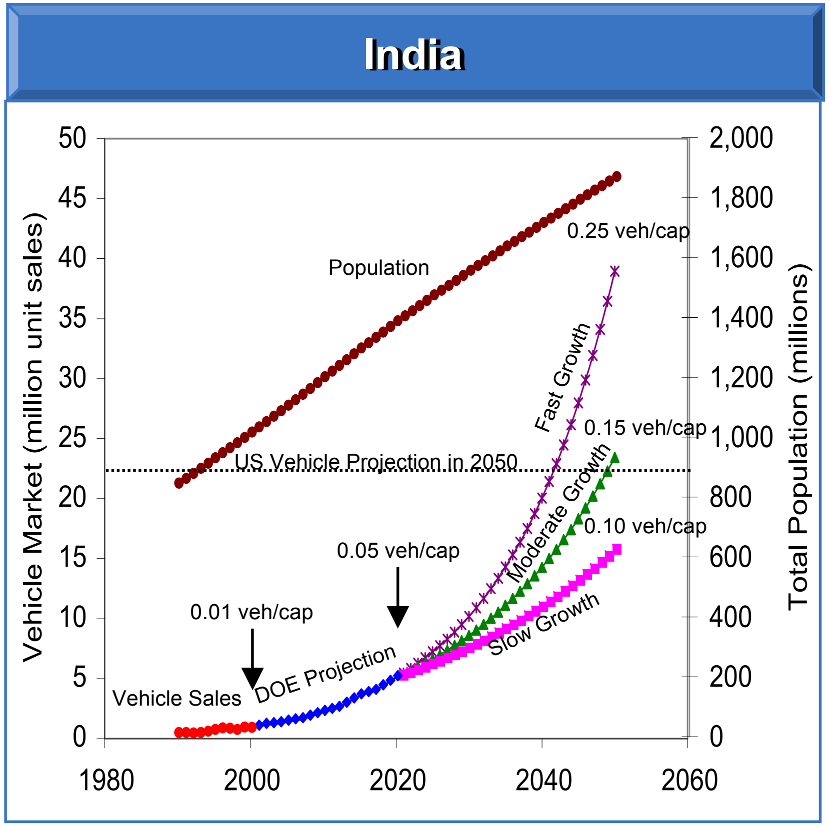
The assumed increases in vehicle per capita for Europe and Japan partially offset declining populations.

Sources: United Nations Population Database, Ward's Automotive Data (2001), DOE Energy Information Administration Annual Energy Outlook 2003

Vehicle Turnover Period = 15.5 years (US), 11.5 years (Europe) and 10 years (Japan)

In China and India, large population growth and increasing vehicles per capita will likely lead to significant growth in new car sales.



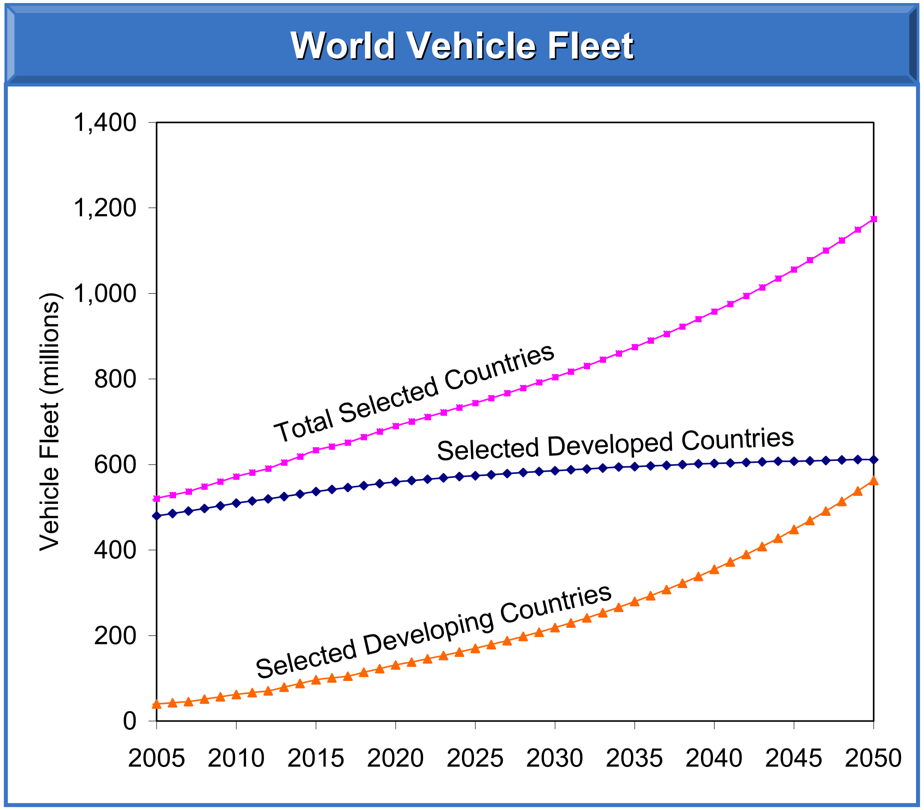


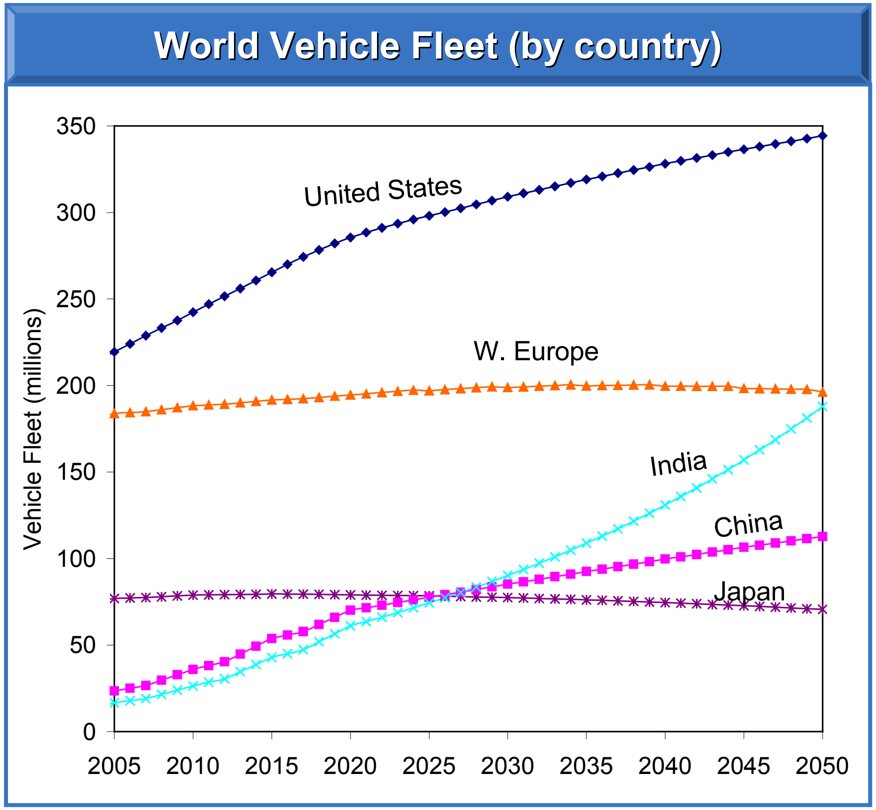
These projections were used to address long-term uncertainties.

Sources: United Nations Population Database, Ward's Automotive Data (2001), DOE Energy Information Administration Annual Energy Outlook 2003

Vehicle Turnover Period = 12 years (China and India)

Growth in the world vehicle fleet will be driven by the US, India and China.





Sources: United Nations Population Database, DOE Energy Information Administration Annual Energy Outlook 2003.
Rest of world may add 20% to vehicle sales based on 2000 statistics (Ward's).
Assumed 0.25 veh/cap and 0.15 veh/cap (Moderate Scenario) for China and India respectively in 2050.

Annual vehicle sales in 2050 are estimated to be 70 to 95 million units in the selected regions, two times current production levels.

Developed Countries—2050	
Country	**Million Vehicle Sales** (vehicles per capita)
US	22 (0.84)
W. Europe	18 (0.70)
Japan	7 (0.70)
SubTotal	47

Developing Countries—2050		
Country	**Million Vehicle Sales** (vehicles per capita)	
	50% Scenario	80% Scenario
China	9 (0.1)	23 (0.25)
India	16 (0.1)	23 (0.15)
SubTotal	25	46

Totals—2050	
Million Vehicle Sales	
50% Scenario	80% Scenario
72	**93**

In 2000, 41 million vehicles were sold worldwide and the selected regions represented approximately 75% of worldwide vehicle sales.

Source: Ward's Automotive Data (2001)

Using this information, we developed two FCV adoption scenarios on which to base our projections of future demand for platinum.

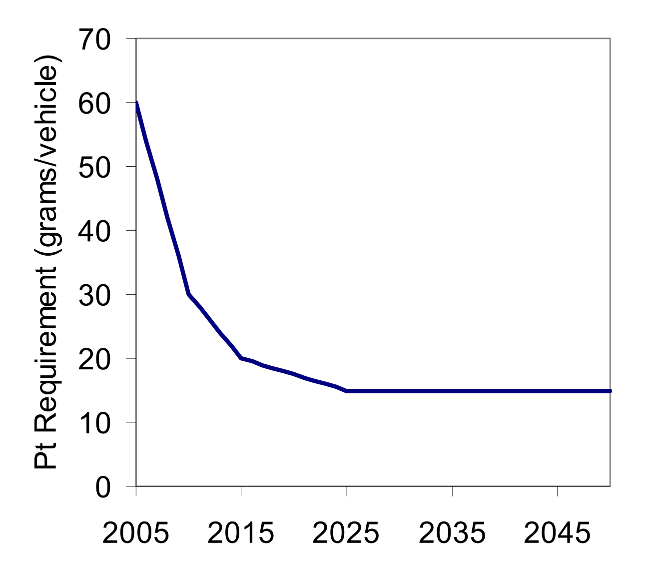
50% Scenario	80% Scenario
• FCV market entry date around 2020 • 50% FCV market penetration by 2050 • 15 year time lag in FCV adoption by Developing Countries • Vehicles per capita increase at a slower pace than the 80% Scenario	• FCV market entry date around 2020 • 80% FCV market penetration by 2050 • 10 year time lag in FCV adoption by Developing Countries • Vehicles per capita increase at a moderate pace

- Key assumptions that apply to each scenario include:
  - Platinum loading in FCVs will decline from 60g/FCV in 2005 to 15g/FCV in 2050.
  - Jewelry and industrial sector demand will grow at a rate of 1.4 percent per year through 2050.
  - Stationary FC power generation will enter the market in 2006 and will reach 15 GW/year by 2050.
  - FCV life will be 10 years and recycling of platinum from fuel cells (considering both recovery and processing) will be 95 percent efficient.
  - ICEV life will be 15 years and recycling of platinum from IC engines will be 90 percent efficient.
  - Platinum loading in ICEVs will grow steadily from 2g in 2005 to 8g in 2050 as a result of the global adoption of catalytic converters and increasing diesel vehicle sales.

We have assumed that FCV platinum requirements for a 75 kW powertrain will decline to 15 grams by 2025.

Parameter	Year 2005	Year 2010	Year 2015	Year 2025
g Pt / vehicle	60	30	20	15
g Pt /kW	0.8	0.4	0.3	0.2

Platinum Loading in FCVs



- We assume platinum loading must reach 20 grams per vehicle to initiate large volume sales.
- The US DOE's loading target is 0.2 g Pt/kW by 2010.

Our scenarios include platinum demand from jewelry, industrial applications and stationary fuel cell power generation.

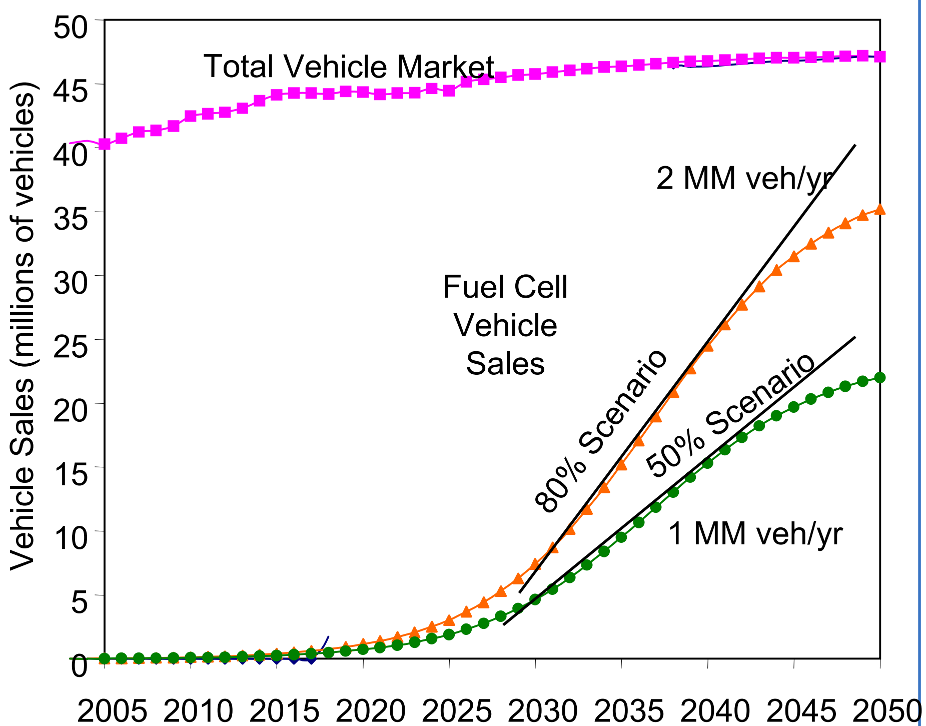
	Jewelry	Industrial
Rate of Annual Growth*	1.4%	1.4%

	Stationary Fuel Cell Power Generation
Market Entry Date	2006
New Installations in 2050	15 GW/year
FC Life	5 years
Plant Life	> 45 years
FC Pt Loading (g/kW)**	0.8 g in 2005; 0.4 g in 2010; 0.3 g in 2015; 0.2 g in 2025
FC Pt Recycling Eff.	95%

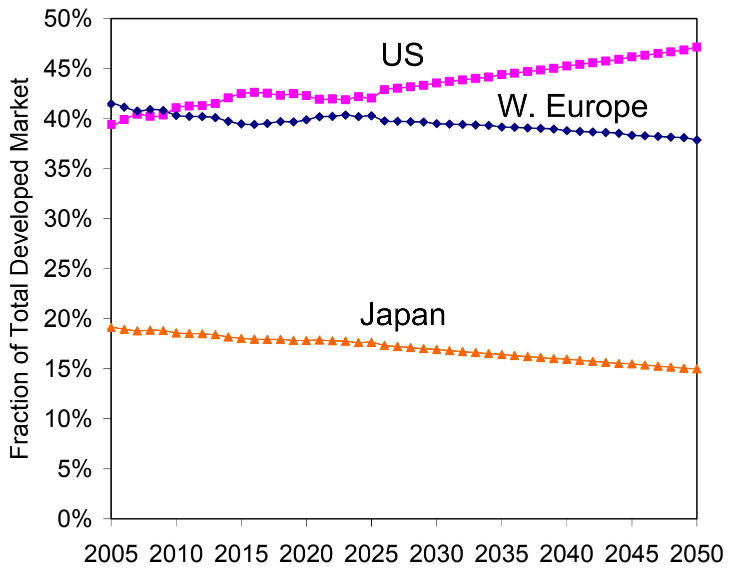
* *2000 Annual global population growth rate.*
** Based on projected platinum loading of FCVs

In Developed Countries, FCV sales in 2050 are estimated to be 20 to 35 million vehicles in the 50% and 80% Scenarios.

FCV Sales—Developed Countries



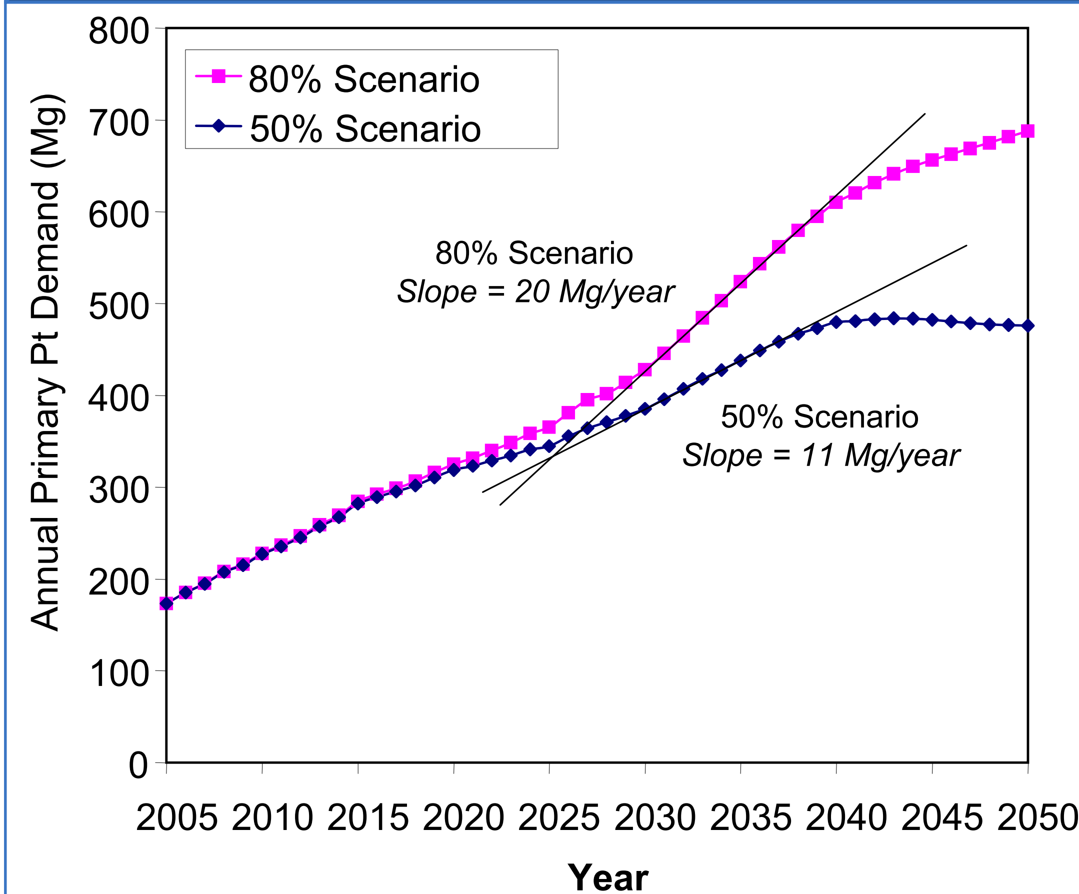
Market Fractions by Country



The assumed penetration rates translate into increases in FCV production capacity of 1 and 2 million vehicles per year for these scenarios.

The 50% and 80% Scenarios predict a ramp up in primary platinum production with a leveling off when recycling becomes significant.

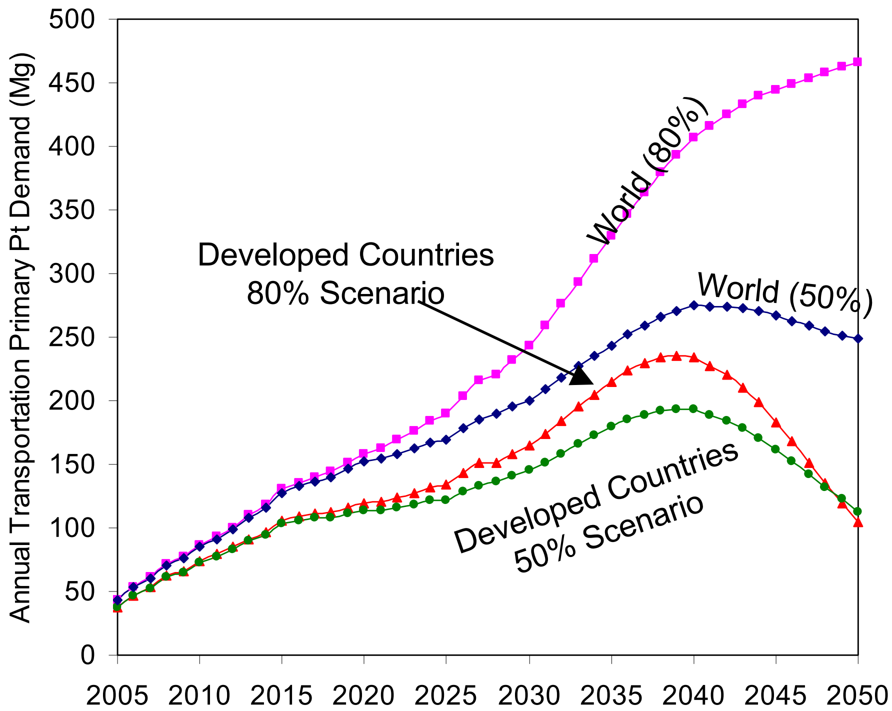
Total Projected Platinum Demand[1]



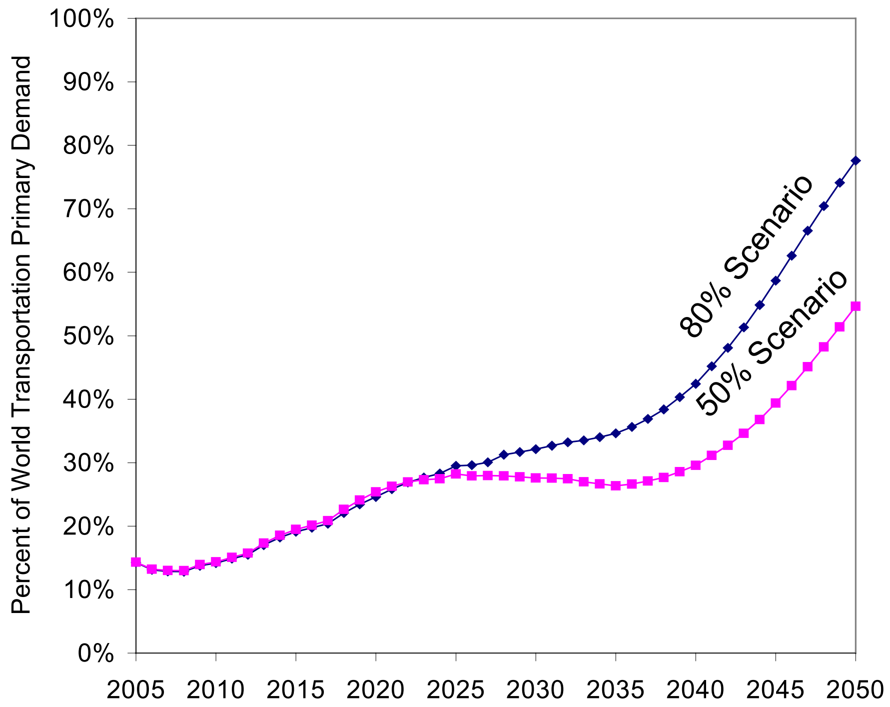
1) Total includes transportation, jewelry, industrial catalysts, and stationary FC power generation

The complex interplay between recycling, FCV market penetration, and Developing Country's market dynamics lead to sharp increases in primary platinum demand in the Developing Countries.

Transportation: Primary Platinum Demand



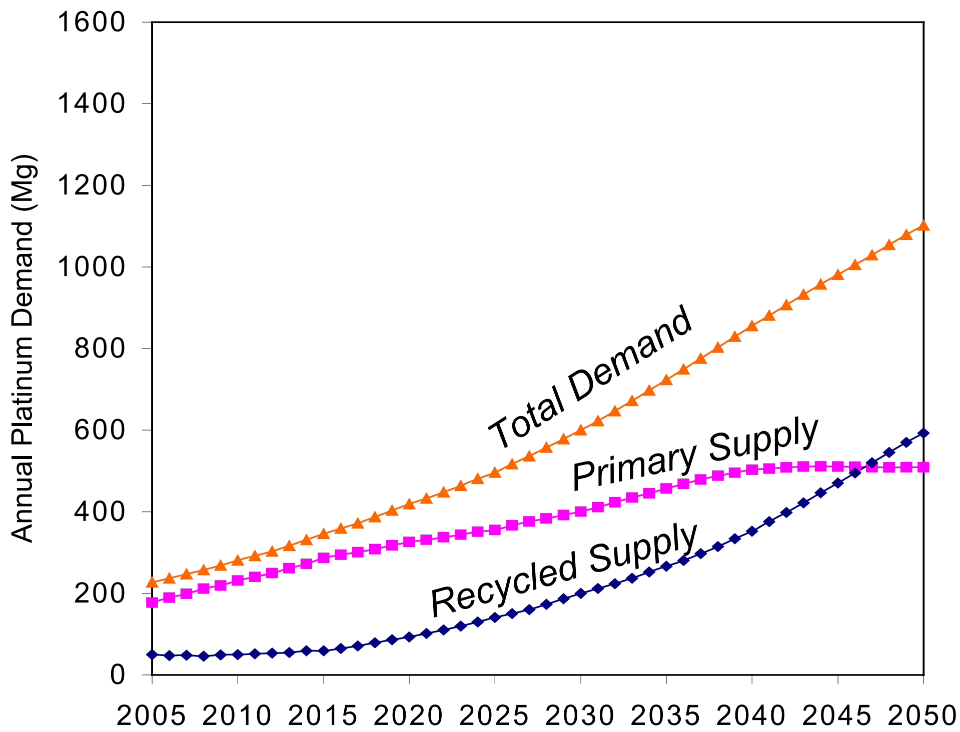
China and India Primary Platinum Demand (Percent of World Transportation Demand)



- The decline in primary platinum demand for Developed Countries around 2040 is due to growing supply of secondary platinum (i.e., from FCV recycling).

In the 50% Scenario, annual platinum recycling requirements will potentially reach 600 Mg by 2050.

50% Scenario - Annual Supply and Demand



Assumptions

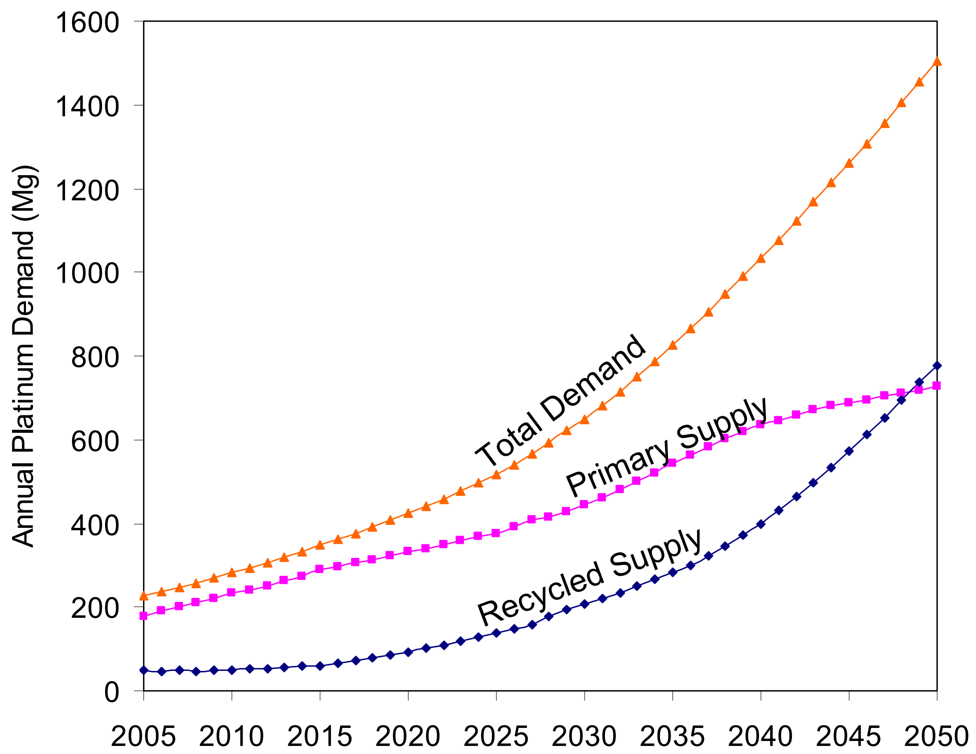
- Total demand includes Transportation, Jewelry, Industrial Catalyst and Stationary Power Generation
- The platinum recycling rate is 95% for transportation applications and 90% for stationary applications.

Currently, recycling of catalytic converters generates 22 Mg platinum annually*.

* *Phone interview with A1 Specialized Services*

In the 80% Scenario, annual platinum recycling requirements will potentially reach 800 Mg by 2050.

80% Scenario - Projected Supply and Demand



Assumptions

- Total demand includes Transportation, Jewelry, Industrial Catalyst and Stationary Power Generation
- The platinum recycling rate is 95% for transportation applications and 90% for stationary applications.

Currently, recycling of catalytic converters generates 22 Mg platinum annually*.

** Phone interview with A1 Specialized Services*

The 50% and 80% Scenarios identify that total cumulative demand (2005 to 2050) will be about one-quarter of current resource projections.

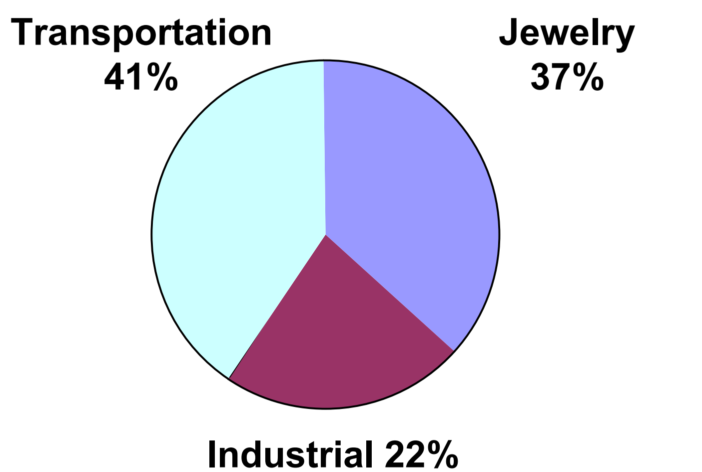
	Transportation		Jewelry	Industrial Catalysts	Stationary Power	Totals	
	50% Scenario	80% Scenario				50% Scenario	80% Scenario
Cumulative Primary Demand from 2005 to 2050 (Mg)	8,500	11,500	5,300	3,200	500	17,500	20,500
Peak Slope in Primary Demand (Mg/year)	11	18	2	1.2	2	11*	20*

* The peak slopes for the identified market segments occur at different time periods. Therefore, the peak slope for Total Demand is not the sum of the peak slopes for each market.

- The 50% and 80% Scenario demand projections account for 22 and 26 percent of projected platinum resource (i.e., 76,000 Mg), respectively.
- For reference, primary platinum supply increased at a rate of 3.5 Mg/year from 1960 to 2000. Production had been projected to increase by about 13 Mg/year between 2000 and 2007. This estimate has been recently revised to 10 Mg/year due to scaled-back capital investments mainly caused by the high value of the South African rand.

Commercialization of FCVs will make transportation the dominant application for platinum with 75 to 90 percent of the total market in 2050.

2003: Platinum Demand by Application

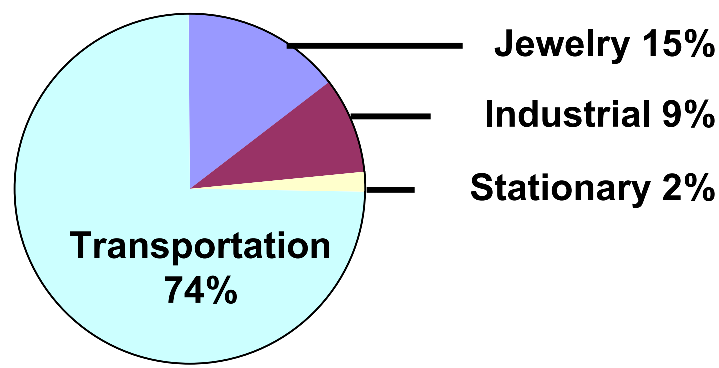


Source: Johnson Matthey, 2003.

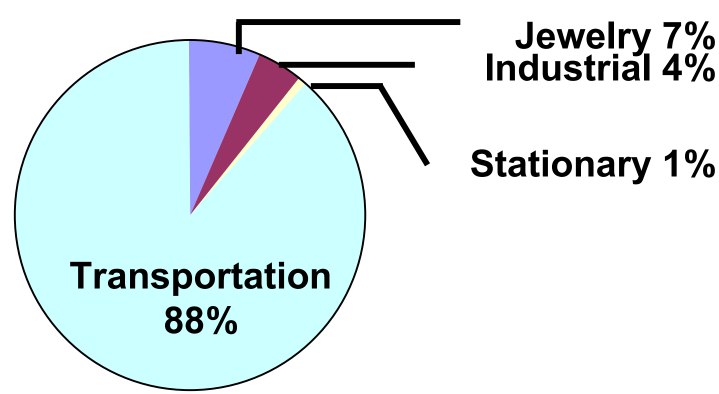
* TIAX Projections

** Includes Chemical, Industrial, Investment

50% Scenario
2050: Platinum Demand by Application*



80% Scenario
2050: Platinum Demand by Application*



To test the sensitivity of the model, we increased individual factors by 5 percent and measured the resulting change in both cumulative demand (2005 to 2050) and maximum growth in demand for primary platinum.

- By varying each factor by the same amount (5 percent), we were able to identify the relative sensitivity of each factor.
- The sensitivity analysis focused on those factors most likely to have a significant impact on cumulative demand and maximum demand over a 5 year period.
- In each case, the 5 year maximum demand period occurs between 2030 and 2040.

Factors Considered
• FCV Platinum Loading • Jewelry Demand • India: Population Growth Rate • India: Vehicles per Capita • China: Population Growth Rate • China: Vehicles per Capita • FCV Recycle Rate • ICEV Recycle Rate

The sensitivity analysis identified that the model is relatively insensitive to changes in individual factors; of all factors considered, changes to FCV platinum loading levels and ICEV recycling rates have the greatest impact on model results.

- Cumulative demand is relatively insensitive to change in both the 50% and 80% Scenarios:
  – Changes in platinum loading in FCVs, ICEV recycle rates, and growth in jewelry demand have the greatest impact on cumulative demand, but even then, a 5 percent increase in these factors results in only a 1 to 2 percent change in cumulative demand.
- Maximum growth in demand over a five year period tends to be more sensitive to change than cumulative demand in both the 50% and 80% Scenarios.
  – Changes to platinum loading in FCVs and ICEV recycle rates have the greatest impact on maximum growth in demand. A 5 percent increase in these factors causes a 2.5 to 4.5 percent change in the maximum growth in demand over a five year period.

The 50% Scenario was most sensitive to changes in ICEV Recycling Rates and Platinum Loading .

50% Scenario Sensitivities Tests:

A 5% increase in:	Yields an increase in Cumulative Demand of:	And an increase in Maximum Slope Over a 5 Year Period of:	Comment (Change in the factor)
ICEV Recycle Rate	(2.0%)	(3.5%)	From 90% to 94.5%
Pt Loading	1.1%	4.3%	Increased each Pt loading estimate by 5%
Jewelry Demand	0.9%	1.7%	From 1.35% to 1.42%
FCV Recycle Rate	(0.5%)	(1.7%)	From 95% to 99.75%
India: Population Growth	0.4%	0.7%	Increased population by 5%
China: Population Growth	0.3%	0.1%	Increased population by 5%
India: Vehicles per Capita	0.3%	1.1%	From 0.0279 to 0.0293
China: Vehicles per Capita	0.2%	0.7%	From 0.022 to 0.023
India: Time Lag	(0.1%)	Not assessed	From 15 to 16 years
China: Time Lag	(0.1%)	Not assessed	From 15 to 16 years

The 80% Scenario was most sensitive to changes in Platinum Loading and ICEV Recycling Rates.

80% Scenario Sensitivities Tests:

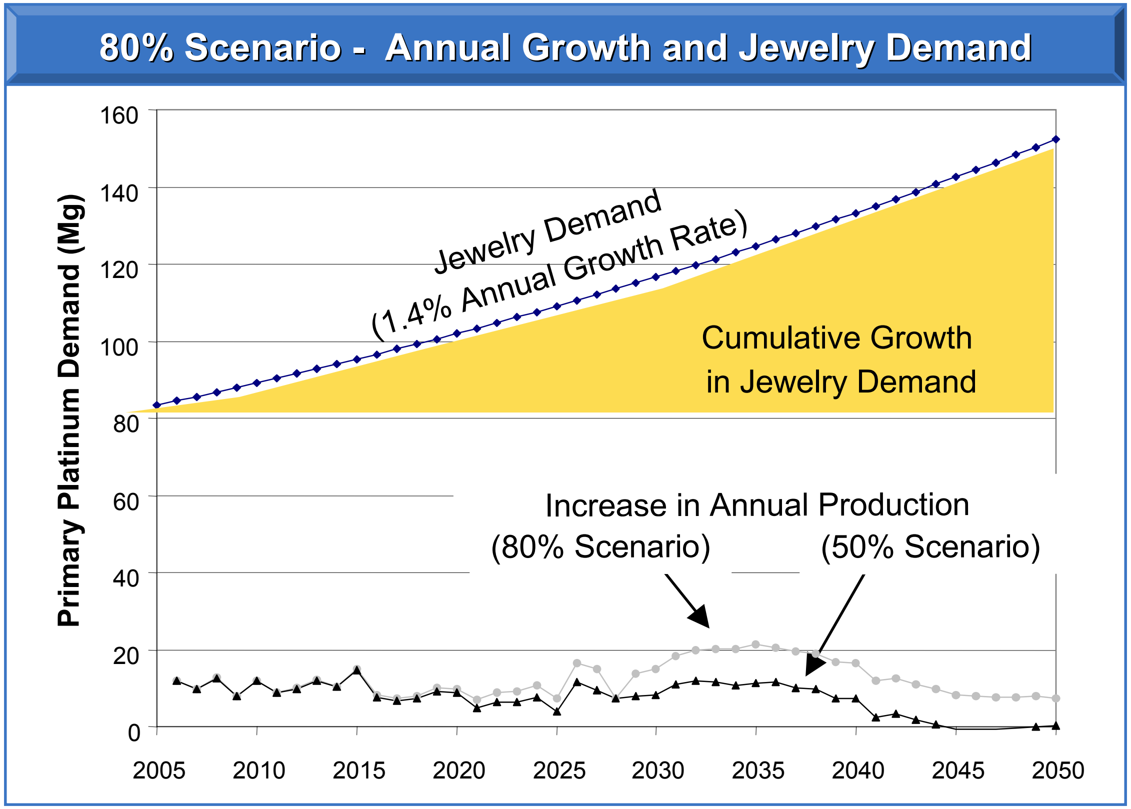
A 5% increase in:	Yields an increase in Cumulative Demand of:	And an increase in Maximum Slope Over a 5 Year Period of:	Comment (Change in the factor)
Pt Loading	1.8%	4.5%	Increased each Pt loading estimate by 5%
ICEV Recycle Rate	(1.7%)	(2.5%)	From 90% to 94.5%
Jewelry Demand	0.8%	0.9%	From 1.35% to 1.42%
FCV Recycle Rate	(0.8%)	(1.6%)	From 95% to 99.75%
China: Vehicles per Capita	0.8%	1.9%	From 0.0537 to 0.0564
China: Population Growth	0.6%	1.0%	Increased population by 5%
India: Vehicles per Capita	0.6%	1.4%	From 0.0418 to 0.0439
India: Population Growth	0.6%	0.9%	Increased population by 5%
China: Time Lag	(0.2%)	Not assessed	From 10 to 11 years
India: Time Lag	(0.2%)	Not assessed	From 10 to 11 years

In another test of the model, we found that shifting from a 75kW to a 50kW FCV powertrain had only a small impact on platinum demand in the 50% Scenario, but a relatively large impact on the 80% Scenario.

Impact of shifting from a 75kW to a 50kW FCV Powertrain*		
Scenario	**Cumulative Demand (2005 to 2050)**	**Maximum 5 Year Growth Rate**
50% Scenario	(~6%)	(~6%)
80% Scenario	(~11%)	(~27%)

* To represent a 50kW FCV, we reduced the estimated platinum loading for a 75kW FCV by 30 percent.

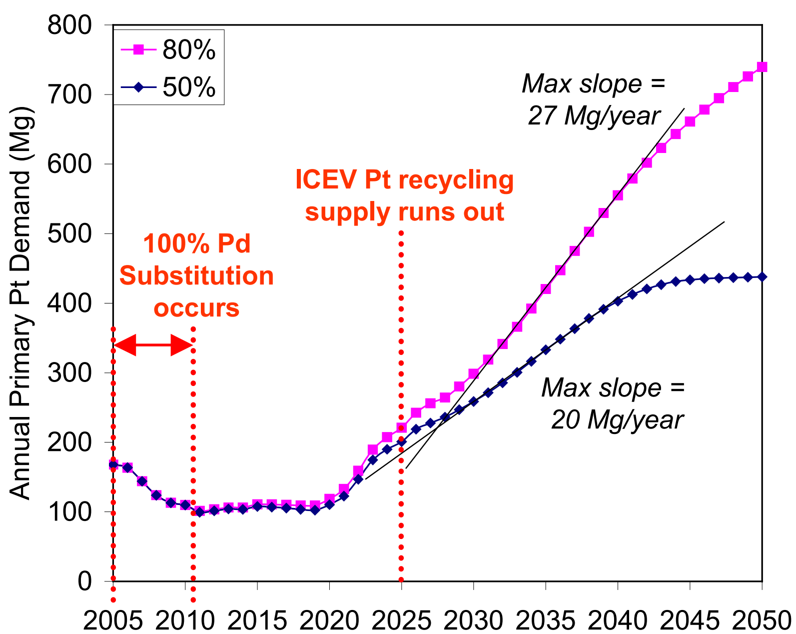
Platinum produced for jewelry applications could serve as a buffer to soften the annual rate of mining expansion.



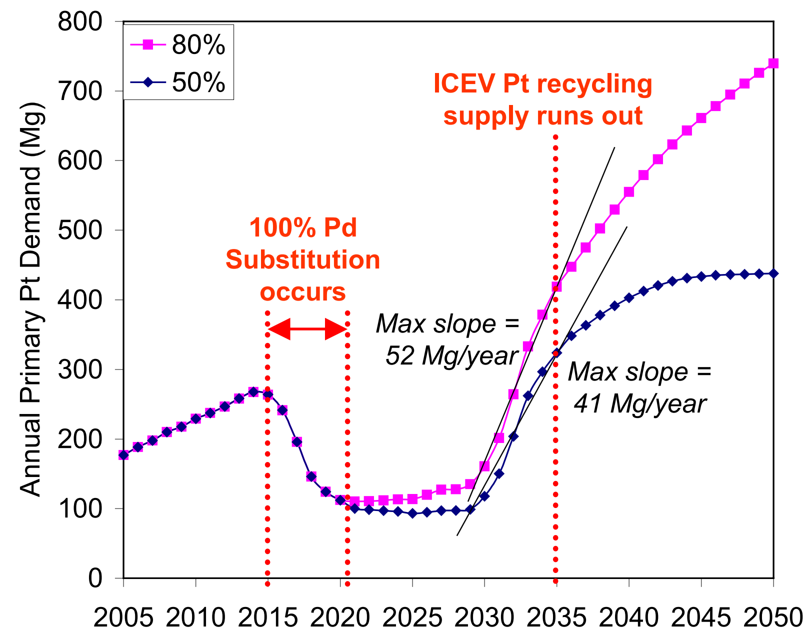
The amount of platinum consumed annually by the jewelry industry is far greater (5-10 times) than the expansion rates predicted by the model.

An initial analysis of the substitution of palladium for platinum in ICEV autocatalyst indicates that it may not be a favorable strategy.

Palladium Substitution - Scenario 1



Palladium Substitution - Scenario 2



Palladium substitution increased the rate of platinum production due to the loss of the "platinum reservoir" accumulated in catalytic converters prior to the ramp up in FCV production. Both scenarios reduced cumulative demand when compared to the baseline projection.

Table of Contents

The overall objective of this task is to use econometric methods to model platinum supply and demand and simulate the impact of increased platinum demand from FCVs on price.

Task Objectives:

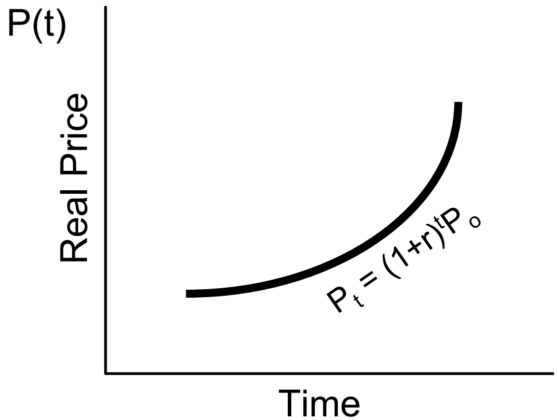
- The specific objectives of this task are to:
  - Study the historical behavior of platinum prices;
  - Estimate the platinum demand function; and
  - Estimate the platinum supply function.

Our analysis of platinum supply, demand and price concluded the following:

- Jewelry Demand: Historically, platinum jewelry demand has not been very sensitive to increases in price.
- Total Platinum Demand: In the short-run, platinum price increases will have a relatively small impact on total quantity demanded; however, in the long-run price increases will have a relatively large impact on demand.
- Platinum Price: The real platinum price has been stationary (i.e., the real price has always returned to the long-term mean) over the last century - particularly since the introduction of platinum supply from South Africa.
  - In the short-run, an increase in demand for platinum from fuel cell vehicles will likely increase the platinum price.
  - In the long-run, if supply meets demand, we expect the price of platinum to return to its long-term mean.

In the 1930's, Hotelling developed a hypothesis that predicted increasing commodity prices for nonrenewable natural resources.

Hotelling's Hypothesis*
Given constant marginal extraction cost, the real price of a nonrenewable natural resource is a positive function of the real interest rate (e.g., increase each year by the real interest rate).



* H. Hotelling," The economics of exhaustible resources", *The Journal of Political Economics*, 39, 137-175 (1930).

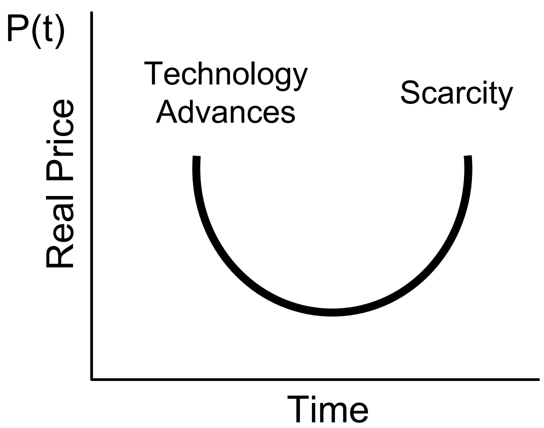
If this hypothesis were true for platinum, its price would steadily increase over time.

In the 1980's, Slade attempted to reconcile the theoretical predictions from Hotelling's model with empirical findings of falling prices for some commodities.

Slade's Hypothesis*

The refined metal price reflects two offsetting trends

- As mining and refining technology advances, the costs of extraction and processing decline.
- As cumulative extraction increases, only deeper and less concentrated ore deposits are available.



* M. Slade, "Trends in Natural-Resource Commodity Prices: An Analysis of the Time Domain," Journal of Environmental Economics and Management, 9, 122-137 (1982).

Eventually, the forces of scarcity will outweigh the forces of technological advance; as a result, observed metal price series should be U-shaped.

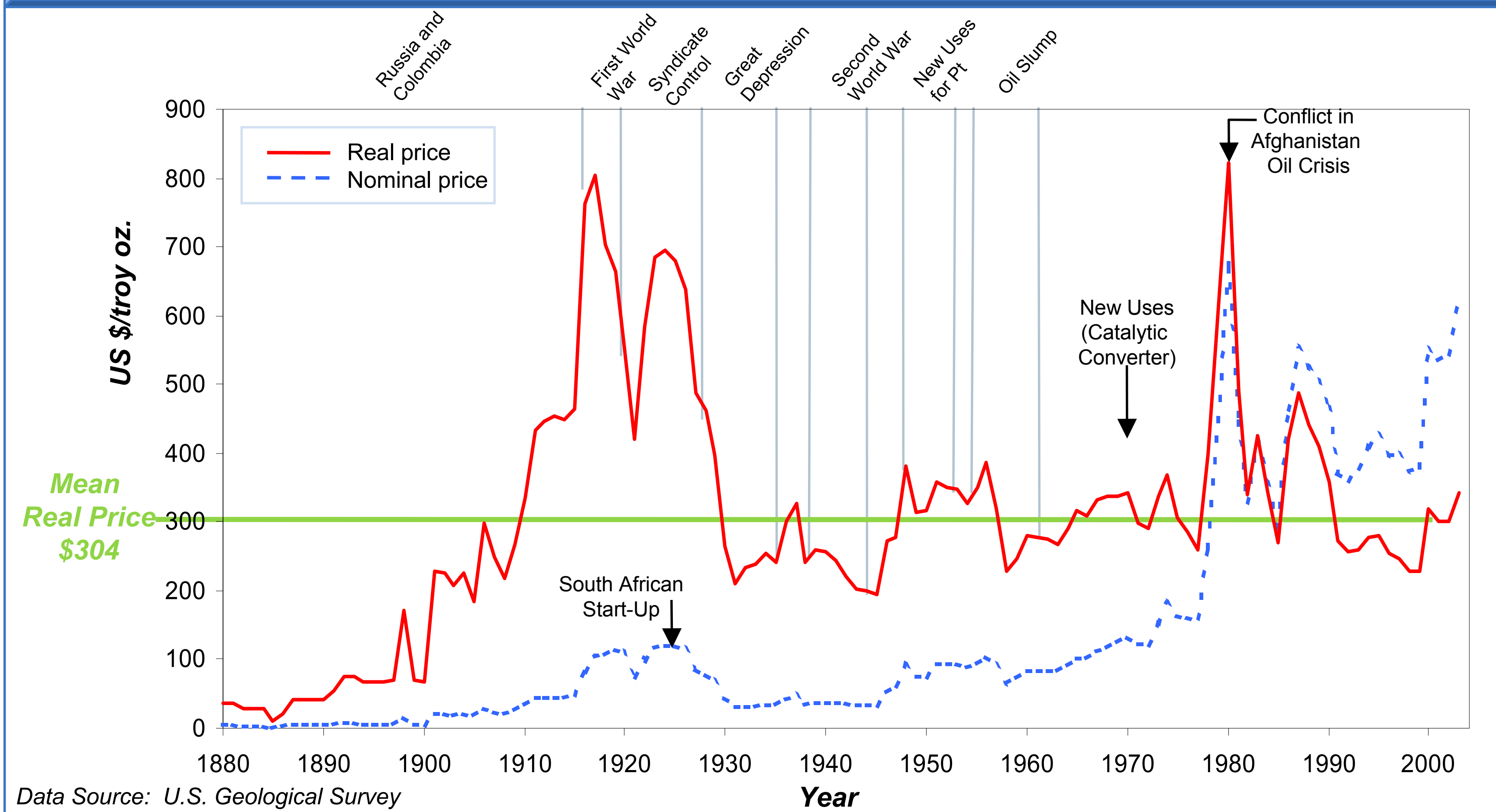
We used three methods to assess whether Hotelling's hypothesis applies to the real price of platinum or if technology advances have been sufficient to maintain a stationary real price.

Test Methods:
• Visual Inspection of Platinum Price Data (1880-1998) • Slade's Method • Dickey-Fuller Stationary Test

The latter two methods allow us to apply statistical methods to empirically test Hotelling's hypothesis.

The price of platinum has been volatile, spiking in response to increased demand, but it has always returned to its long-term mean, indicating a stationary price.

Nominal versus Real Platinum Prices, 1880–1998



Data Source: U.S. Geological Survey

Source: Vermaak, C.F., *"The Platinum-Group Metals,"* pp. 110

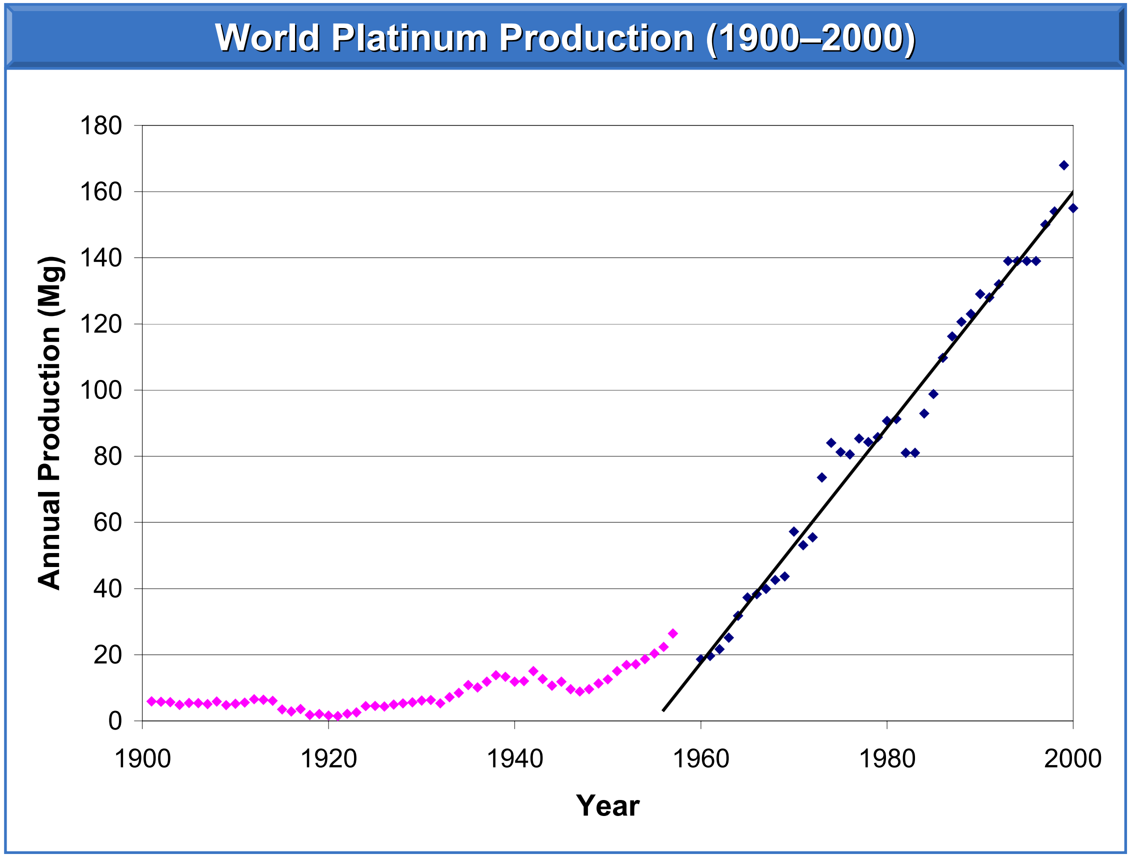
Our statistical tests support a stationary real platinum price over the last century - particularly since the introduction of platinum supply from South Africa.

Test	Finding
Visual Inspection	• The real price of platinum appears constant (i.e., there is no trend). • The price spiked during WW I (due to military demand for platinum), introduction of catalytic converters for cars, and the oil crisis. • Following each spike, the real price returned to its long-term mean.
Slade's Hypothesis	• The results for platinum are quite different from those found by Slade for other commodities. There is no evidence of a U-shaped pattern and virtually no support for an upward trend in real platinum price.
Stationarity Test	• 1880–1998: Not conclusive about stationarity of real platinum price series • 1910-1998: Some support that platinum real price is stationary • 1925–1998: Strong evidence that platinum real price is stationary

- Interviews with Englehard, Johnson Matthey and South African geologist, Grant Cawthorn, confirmed our observation of a stationary real platinum price. It is in the best interest of mines to maintain a stable price to prevent end users from substituting other metals for platinum and ultimately destroying the platinum market.

A stable price has been maintained due to steadily increased supply by producers.

- In anticipation of the introduction of catalytic converters in the 1970s in the United States and the 1980s in Europe, South African mines expanded production to meet demand.
- In 1980-1990s, South African mines continued to increase supply to meet increasing demand for platinum jewelry from Japan and China.



Data Sources: 1901-1957 Die Metallischen Rohstoffe Heinrich Quiring, pp 98-99
1963 -1983 Mineral Facts and Problems, U.S. Bureau of Mines
1986-2000 Mineral Yearbook, U.S. Geological Survey

Based on this analysis, we have several key expectations for the impact of fuel cell commercialization on platinum price:

Shorter Timeframes	*Prices can be volatile—increasing with the introduction of fuel cell technology.*
"Longer " Timeframe	*The real platinum price will tend to return to its long-term mean following increased supply and material substitution.*

To project the impact of future platinum supply and demand on price, we developed a set of econometric models for platinum supply and demand.

- We developed econometric models of three sectors of the market:
  1. Platinum Jewelry Demand: For both Japan and the world.
  2. World Demand for Platinum: For all uses of platinum.
  3. Platinum Supply

- The models provided the following insights:
  – The world demand for platinum jewelry is relatively inelastic (i.e., a 1 percent increase in price will result in only a 0.6 percent decline in demand).
  – In the short run, world demand for all platinum is inelastic, but in the long-run, the demand becomes more elastic (i.e., in the long-run a 1 percent increase in price will result in a decline in demand of 1.1 percent).

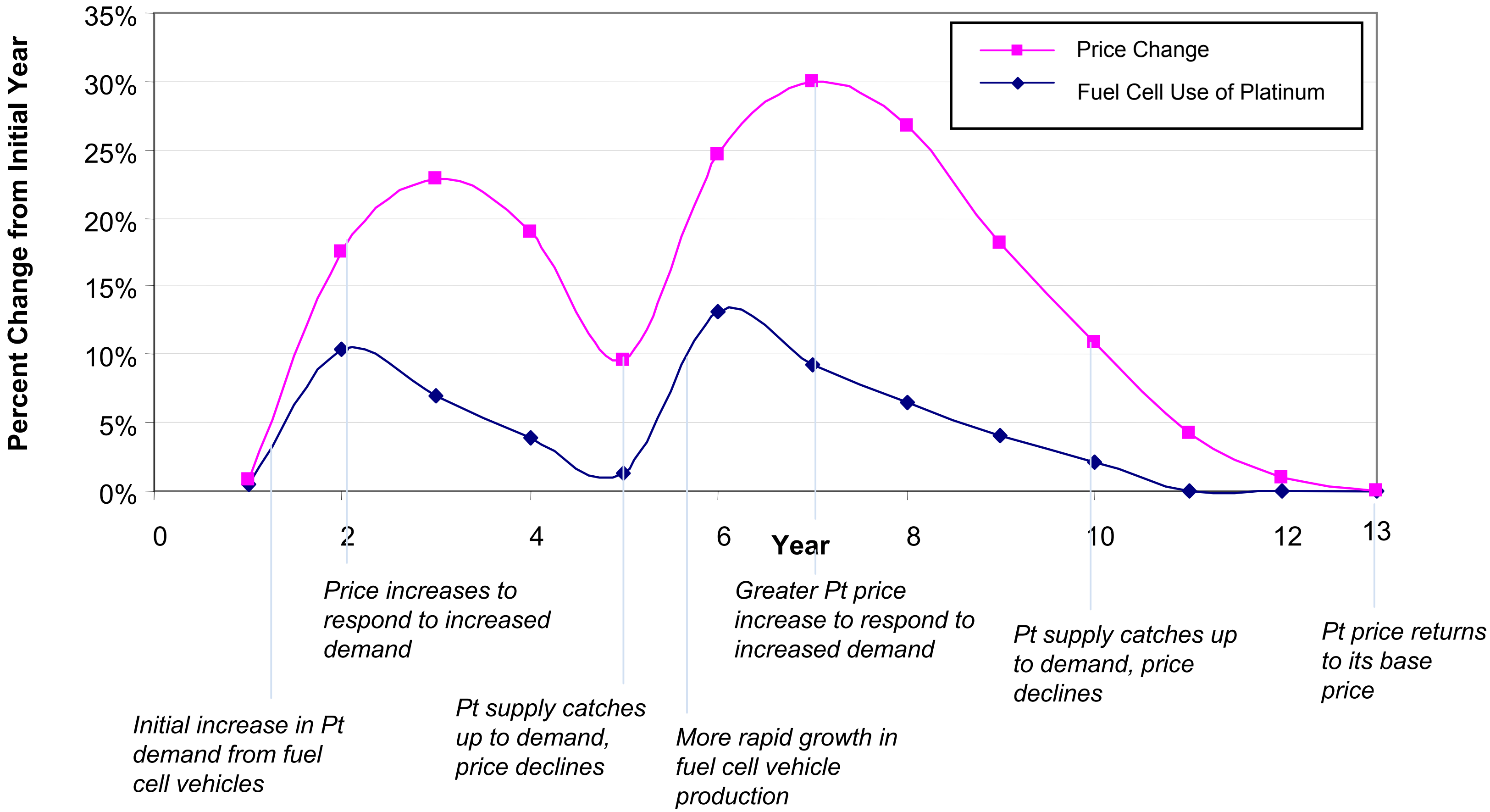
We then developed a model to simulate the impact of hypothetical FCV platinum demand on platinum prices over a thirteen-year period.

Year of fuel cell vehicles introduced	Fuel cell vehicle production (million)	Pt demand (g)/vehicle	Fuel cell use of Pt (million Troy oz)	Increased fuel cell use of Pt in total Pt consumption	Pt price changes
1	0.01	100	0.03215	0.50%	0.81%
2	0.25	88	0.7034	10.35%	17.46%
3	0.50	75	1.206	7.02%	22.89%
4	0.75	63	1.507	3.94%	18.90%
5	1.00	50	1.608	1.26%	9.63%
6	1.80	46	2.662	13.09%	24.61%
7	2.60	42	3.511	9.32%	29.94%
8	3.40	38	4.154	6.46%	26.78%
9	4.20	34	4.592	4.12%	18.10%
10	5.00	30	4.823	2.10%	10.92%
11	5.00	30	4.823	0.00%	4.21%
12	5.00	30	4.823	0.00%	0.99%
13	5.00	30	4.823	0.00%	0.00%

- The simulation model was based on the results obtained from the econometric analyses and the conceptual model of autocatalyst demand.

The simulation illustrates that increased platinum demand will increase the price in the short-run, but in the long-run the price will return to its base level once supply catches up with demand.

Simulation 2: Volatile Platinum Demand



The simulation model helps to highlight the following issues related to the impact of future FCV demand for platinum on price.

- Future demand for platinum from FCVs could drive up the price of platinum by 20 to 30 percent over its base price.
- A gradual adoption of fuel cell technology would minimize the pressure on platinum market and minimize the impact on platinum prices.
- Price declines over time are due to more elastic long-run supply and demand. The supply side has enough time to increase production and capacity and the demand side has the time to improve technology, to reduce platinum loading, or find alternatives.

Table of Contents