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Several studies have modeled fuel cell vehicle market penetration and its effect on platinum availability.

Overview of Platinum Availability Studies

Study	g Pt per FCV	FCV Power	FCV Life	FCV Market Penetration
TIAX LLC, 2003	60 g Pt (2005) 15 g Pt (2025)	75 kW	10 year life, plus recycling at 95% efficiency	Two scenarios: 1) 50% penetration in 2050 2) 80% penetration in 2050
Råde Doctoral Thesis Chalmers University of Technology & Göteborg University, 2001	19 g Pt	50 kW	10 year life, plus recycling	100% penetration in 2100 (global) 400 million FCV annual production
Borgwardt U.S. Environmental Protection Agency *Transportation Research Part D* Journal Article, 2001	22 g Pt	50 kW	15 year life, plus recycling	Best case: 100% in 2070 (US fleet growth = 25.3 million FCV/year in 2050)
				Worst case: 100% in 2150 (US fleet growth = 10 million FCV/year in 2150)
Tonn and Das Oak Ridge National Laboratory *Assessment of platinum availability for advanced fuel cell vehicles.* Report, 2001	Low - 5 g Pt	50 kW	Recycling at FCV end of life	Low - 6% in 2030 (US)
	Med - 10 g Pt			Med - 20% in 2030 (US)
	High - 30 g Pt			High - 60% in 2030 (US)
World Fuel Cell Council (Formerly the Platinum Association)	14 g Pt	70 kW	10 year life, plus recycling	Assumes 1 billion FCVs in 2030, Worldwide

Most published studies indicate that platinum availability will be a concern.

Overview of Platinum Availability Studies		
Study	**Resources**	**Conclusions**
Råde Doctoral Thesis Chalmers University of Technology & Göteborg University, 2001	67 Gg in Pt resources	"In the baseline scenario, the demand for primary platinum in the 21st century amounts to 156 Gg, and ***current reserves and identified resources of platinum would be depleted in the 2050's and 2060's***, respectively."
Borgwardt U.S. Environmental Protection Agency *Transportation Research Part D* Journal Article, 2001	47,500 tonnes (47.5 Gg) in Pt resources	Unrestricted US fleet conversion to FCVs would require 66 years and 10,800 tonnes of Pt. If US Pt consumption remains at its current level of 16% of annual world production, fleet conversion would require 146 years and 15,200 tonnes of Pt. "These results imply that, ***without alternative catalysts, fuel cells alone cannot adequately address the issue facing the current system of road transport***."
Tonn and Das Oak Ridge National Laboratory *Assessment of platinum availability for advanced fuel cell vehicles.* Report, 2001	100 Gg in PGM reserves ~50 Gg in Pt reserves[1]	Under the ***worst case scenario, half of known PGM reserves are exhausted before mid-century***. This scenario is characterized by a high demand for new vehicles in the developing countries and high penetration of reformer-equipped fuel cell vehicles with relatively high amounts of PGMs.
World Fuel Cell Council (Formerly the Platinum Association)	1.5 billion troz (47 Gg) in Pt resources	***1 billion car fleet corresponds 450 million troy ounces of platinum.*** With 95% recycling, 2 million troy ounces a year required to maintain global fleet (currently, autocatalyst requires 1.6 million/yr).
Cawthorn University of Witwatersrand *Global Platinum and Palladium Deposits* Review, 2001	4,705 Mozs in PGM deposits ~73 Gg in Pt deposits[1]	"At an increase consumption rate of 6% per year, ***there are adequate indicated resources of PGE in the Bushveld Complex alone to supply demand for the next 50 years***."

[1]TIAX estimate based on 50% Pt in total PGM resources and 31.1 g/oz

Appendix

Summary of Previous Studies

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Platinum Mining

We conducted a series of econometric analyses to model platinum supply, demand and price.

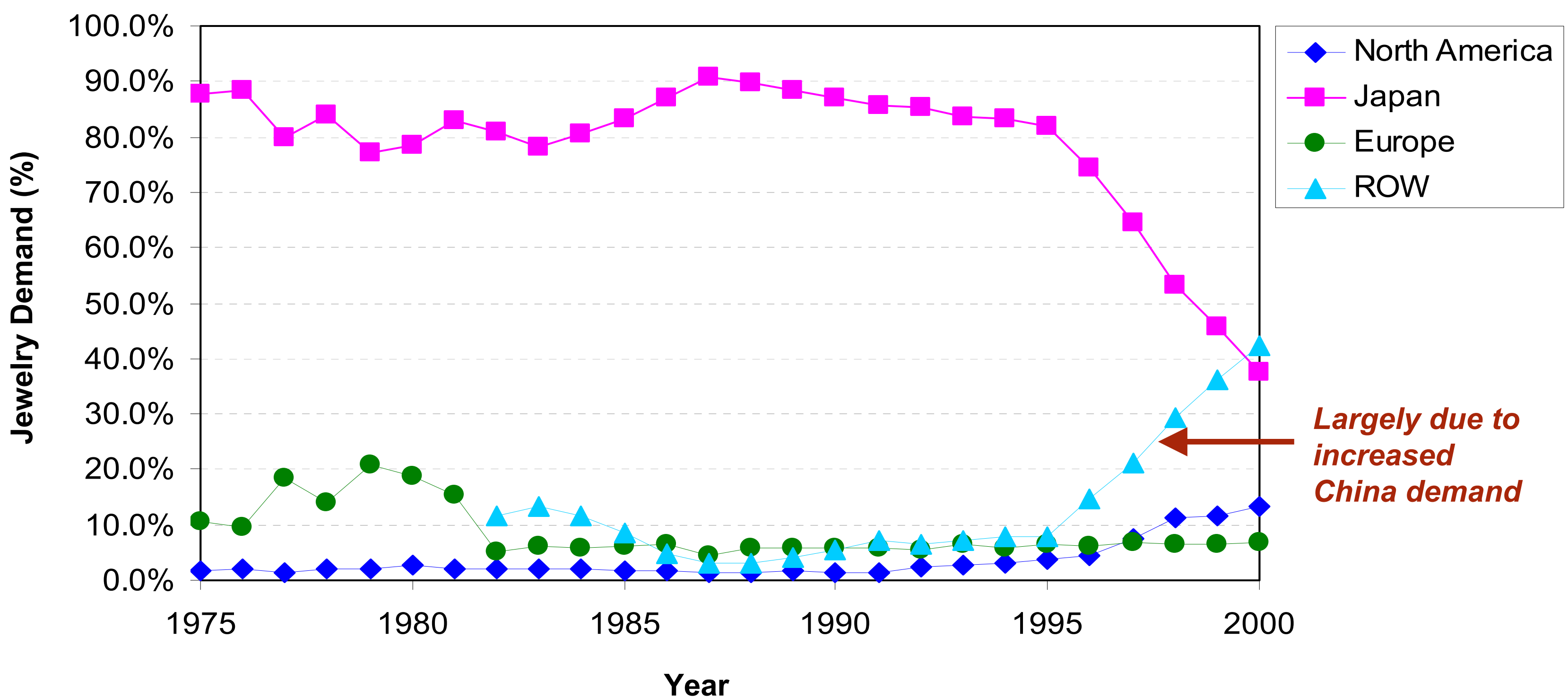
Econometric Analyses

1. ***Platinum Jewelry Demand:*** Both Japan and the world
2. ***Total World Demand for Platinum:*** All uses of platinum
3. ***Platinum Supply***

- World demand for autocatalyst and investment were not modeled separately because:
  - Price elasticity of demand for platinum from autocatalyst is derived from a conceptual model of the general equilibrium derived demand.
    - Autocatalyst use is required by regulation.
    - Autocatalyst accounts for only a very small proportion of total car manufacturing costs.
  - Investment demand for platinum only accounts for a relative small proportion of total demand for platinum.

Platinum Jewelry Demand: Japan has been the largest market for platinum jewelry, but demand has been affected by Japan's economic slowdown. In the meantime, platinum jewelry demand has grown sharply in China, reaching 1.3 million troy ounces (40 Mg) in 2001.

Jewelry Market Share by Region (%)



Source: Johnson Matthey, Platinum 2001.

The predictive power of the jewelry demand model based on the Japanese market can be questioned given Japan's decreasing share in the world platinum jewelry market. However, we believe that the model provided valuable insight into market dynamics.

- The jewelry demand model helps to illustrate the relationship between demand and other economic variables and estimate the potential impact of these variables on the demand for platinum jewelry.
- There are similarities in the development of the platinum jewelry market in Japan and China:
  - Both governments had restrictions on gold ownership that gave an opportunity for platinum to penetrate into these jewelry markets. The subsequent lifting of restrictions allowed more substitution between platinum and gold jewelry.
  - Both countries have experienced rapid economic growth and newly created wealth drives jewelry markets.

The following factors were included in our models of platinum jewelry demand for the world and Japan.

- Quantity of demand for platinum jewelry
- GDP (gross domestic product)
- Price of platinum
- Price of gold
- Inflation
- The amount of promotion (advertising) is also an important factor in this market segment; however, this information was not available for analysis.

The jewelry demand models for the world and Japan were specified as follows:

Demand	Previous Demand	Price Effect	Income Effect	Inflation Effect	Other Price Effect

$$\ln D_{t,j} = \alpha + \beta_1 \ln D_{t-1,j} + \beta_2 \ln P_{t,pt} + \beta_3 \ln GDP_t + \beta_4 \ln infl_t + \beta_5 \ln P_{t,Au} + \varepsilon_t$$

$D_{t,j}$	Quantity of demand for platinum jewelry at time *t*
$D_{t-1,j}$	Quantity of demand for platinum jewelry at time *t-1*
GDP_t	Gross Domestic Product at time *t*
$P_{t,pt}$	Platinum price at time *t*
$P_{t,Au}$	Price of gold at time *t*
$Infl_t$	Inflation at time *t*
α	Quantity of demand for platinum jewelry given other variables are equal to zero

β_1	Impact of previous platinum jewelry consumption on current quantity of jewelry demand
β_2	Price elasticity of demand for platinum jewelry—measures the sensitivity of quantity demanded to a price change
β_3	Income elasticity of demand for platinum jewelry—measures the sensitivity of platinum jewelry consumption to an income change
β_4	Measures the sensitivity of quantity demanded to a change in inflation
β_5	Cross price elasticity of demand of platinum jewelry with respect to gold price—measures the sensitivity of platinum demand to a change in gold price

The world and Japan jewelry demand models produced the following estimated parameters and standard deviations, helping to identify the impact of each factor on the direction and magnitude of platinum jewelry demand.

Demand	Previous Demand	Price Effect	Income Effect	Inflation Effect

$$\lambda n D_{t,j} = \alpha + \beta_1 \lambda n D_{t-1,j} + \beta_2 \lambda n P_{t,pt} + \beta_3 \lambda n GDP_t + \beta_4 \lambda n \inf l_t + \varepsilon_t$$

	α	β_1	β_2	β_3	β_4
World short-run* (std.dev.)	5.39 (1.42)	0.48 (0.13)	-0.33 (0.09)	0.92 (0.25)	0. 20 (0.90)
World long-run* (std. Dev.)	10.37	NA	-0.636 (0.04)	1.77 (0.44)	Insignificant
Japan (std.dev.)	-7.19 (1.07)	NA	-0.62 (0.10)	0.62 (0.10)	0.93 (1.43)

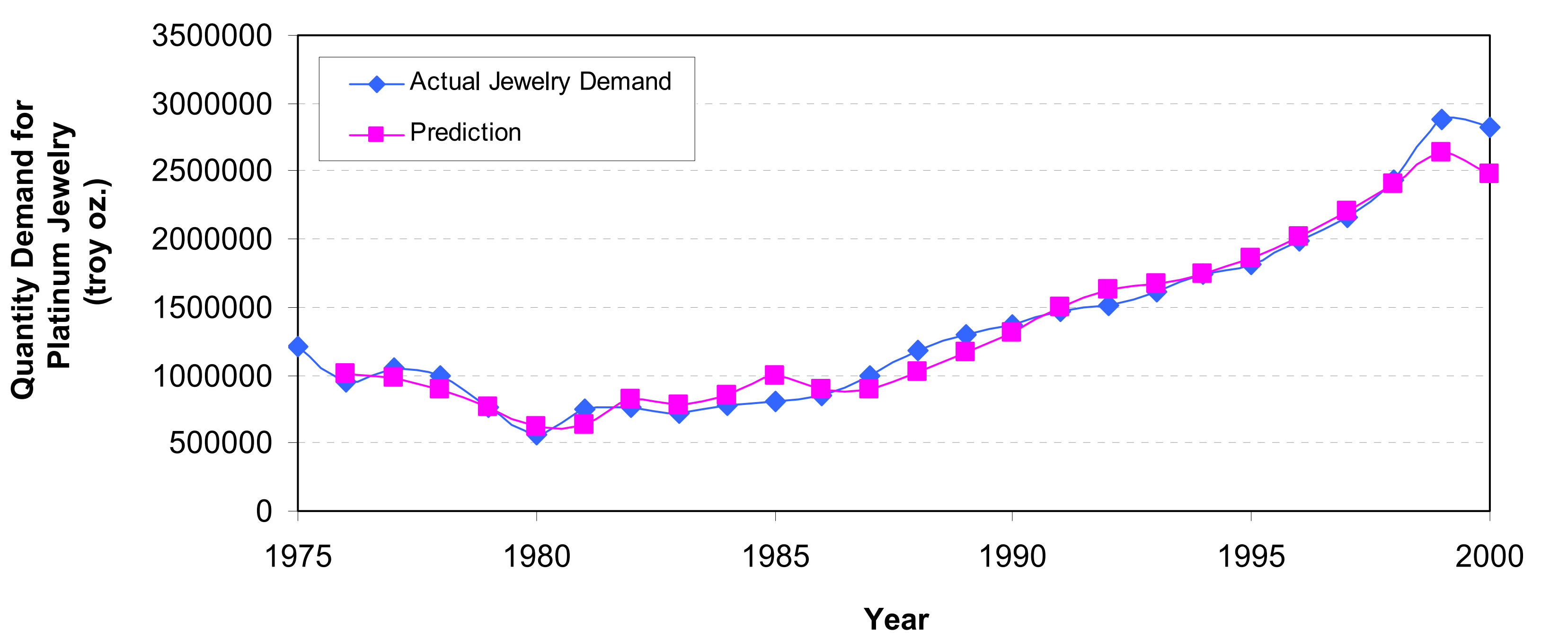
* The chronological definition provided for "short-run" and "long-run" is not precise. The general purpose of the distinction is to differentiate between a short period, where it is impossible for consumers to make adjustments, and a longer period, where consumers have more freedom to make adjustments.

Note: The parameters for the short-run jewelry demand were estimated from the data. Parameters for the "long-run" jewelry demand were derived by adjusting short-run estimates based on the previous year's jewelry consumption.

The predictive power of the world platinum jewelry demand model was verified by predicting the quantity demanded outside the sample period.

- We pretended that the quantity demanded for platinum jewelry was not available from 1999 to 2000 and the model was used to forecast those two years. We then compared the real quantity of demand for platinum jewelry with the model predictions.
- The differences were about 10%.

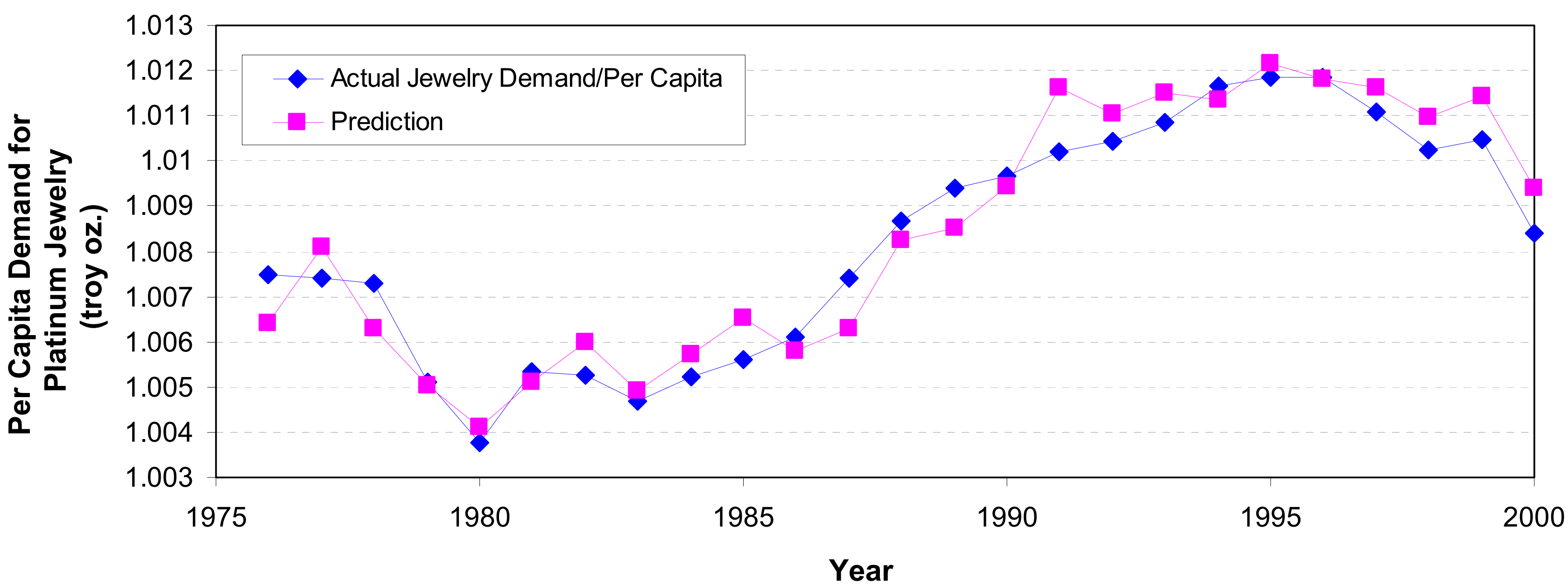
Actual World Jewelry Demand vs. Model's Prediction



The predictive power of the Japan demand model was verified by predicting quantity demanded for platinum jewelry outside the sample period.

- We pretended that the quantity demanded for platinum jewelry was not available from 1999 to 2000 and the model was used to forecast for these two years. Then we compared the real quantity of demand for platinum jewelry with the model predictions.
- The differences were about 0.1%.

Actual Japan Jewelry Demand vs. Model's Prediction



The demand for platinum jewelry is not elastic[1], i.e., even when the price is high the quantity demanded will remain high.

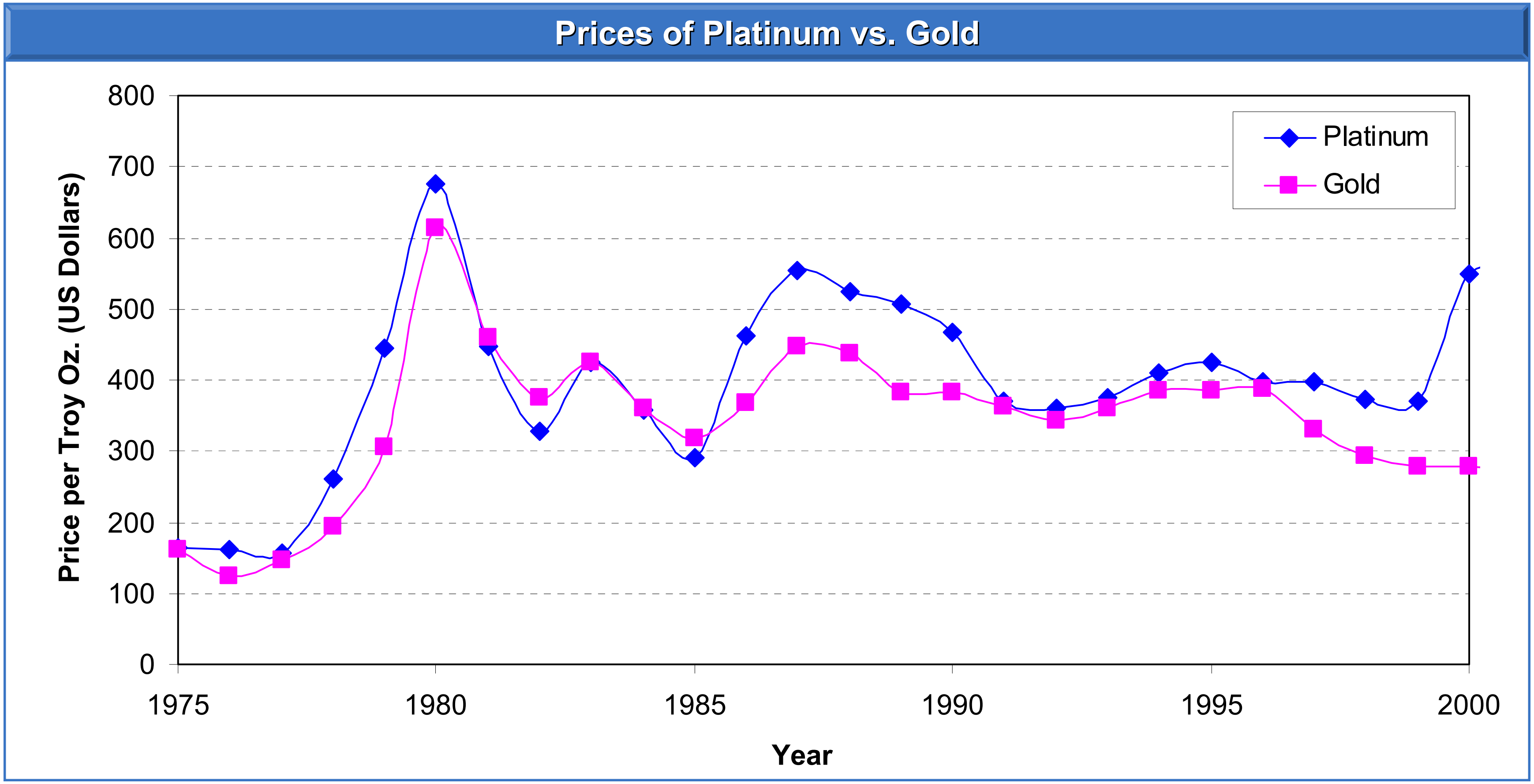
- Both the world's and Japan's price elasticities of demand for platinum jewelry are inelastic (-0.33 and -0.62 in short-run, and -0.63 for the World in long-run). That is, a 1 percent increase in price will result in a 0.33 to 0.63 percent decline in demand.
- Several publications have stated that demand for platinum jewelry is elastic.
  - "Demand for platinum in jewelry, its number one use, is ostensibly fairly elastic in that there are ready substitutes such as gold, white gold, silver and plated precious metal coatings."[2]
- Overstated price elasticity may result from misconceptions rather than data analysis. These authors may believe that platinum jewelry is not a necessity and, therefore, the price elasticity of demand for platinum jewelry would be high.
- The less elastic demand of platinum jewelry can be attributed to the fact that demand is driven by the bridal market, which is less price sensitive since the cost of a wedding ring only accounts for a small share of the wedding cost.

1) For the price to be considered "elastic", a 1 percent increase in price would result in a decline in demand of more than 1 percent.
2) Pearse, Gary H.K., Equapolar Publications, "Platinum Group Metals World Resources Economics of the Future"

The model does not indicate that there is a statistically significant relationship between platinum jewelry demand and inflation.

- Estimates of the impact of inflation on platinum jewelry demand for both the world and Japan yielded positive signs, i.e., the quantity demanded could be positively correlated with inflation.
- However, neither estimate is statistically significant.

We were not able to estimate the cross price elasticity between gold and platinum jewelry because the price of gold and platinum are highly correlated during the period of this study (the coefficient of correlation is about 0.8).



Even though we were not able to estimate the cross price elasticity between gold and platinum jewelry, substitution between platinum and gold* is well known and has been observed by the International Platinum Association.

- “…the recent economic decline in Japan coupled with a widening disparity between the price of gold and platinum together with technical improvements have led recently to increasing substitution of white gold for platinum…”
- “Another element in the success of platinum jewelry in China has been the successful promotion campaign of the Platinum International Guild. However, these campaigns have not yet established the wedding market to anywhere near the same extent as in Japan. Platinum jewelry in China has much more of a fashion element attached to it making it more susceptible to price sensitivity and substitution by white gold than Japan”**

* The price of gold and platinum were highly correlated during the period of the study. The correlation coefficient is about 0.8.

** International Platinum Association, letter from Marcus Nurdin to Eric Carlson (TIAX), 12/13/02.

Total World Demand for Platinum: The objective of our analysis of the world platinum demand was to better understand the relationship between platinum demand and other economic variables across all markets.

- The following factors were addressed in our model of world platinum demand:
  - GDP (gross domestic product)
  - Price of platinum
  - Price of palladium

The model of total world demand for platinum model was specified as follows:

Demand	Previous Demand	Price Effect	Income Effect	Other Price Effect

$$\lambda n D_{t,pt} = \alpha + \beta_1 \lambda n D_{t-1,pt} + \beta_2 \lambda n P_{t,pt} + \beta_3 \lambda n GDP_t + \beta_4 \lambda n P_{t,pd} + \varepsilon_t$$

$D_{t,pt}$	Total world demand for platinum at time *t*
$D_{t-1,pt}$	Total world demand for platinum at time *t-1*
GDP_t	Gross Domestic Product at time *t*
$P_{t,pt}$	Platinum price at time *t*
$P_{t,pd}$	Palladium price at time *t*
α	Total world demand for platinum given other variables are equal to zero

β_1	Impact of previous platinum demand on current quantity of platinum demand
β_2	Price elasticity of demand for platinum—measures the sensitivity of quantity demanded to a platinum price change
β_3	Income elasticity of demand for platinum—measures the sensitivity of platinum demanded to a change in income
β_4	Cross price elasticity of demand for platinum with respect to palladium price—measures the sensitivity of quantity demand for platinum to a change in palladium price

The total world platinum demand model produced the following estimated parameters and their standard deviations.

Demand **Previous Demand** **Price Effect** **Income Effect** **Other Price Effect**

$$\lambda n D_{t,pt} = \alpha + \beta_1 \lambda n D_{t-1,pt} + \beta_2 \lambda n P_{t,pt} + \beta_3 \lambda n GDP_t + \beta_4 \lambda n P_{t,pd} + \varepsilon_t$$

	α	β_1	β_2	β_3	β_4
World short-run* (std. dev.)	4.66 (2.24)	0.70 (0.20)	-0.344 (0.12)	0.25 (0.20)	0. 20 (0.12)
World long-run* (std. dev.)	NA	NA	-1.15 (0.18)	0.83 (0.63)	0.66 (0.12)

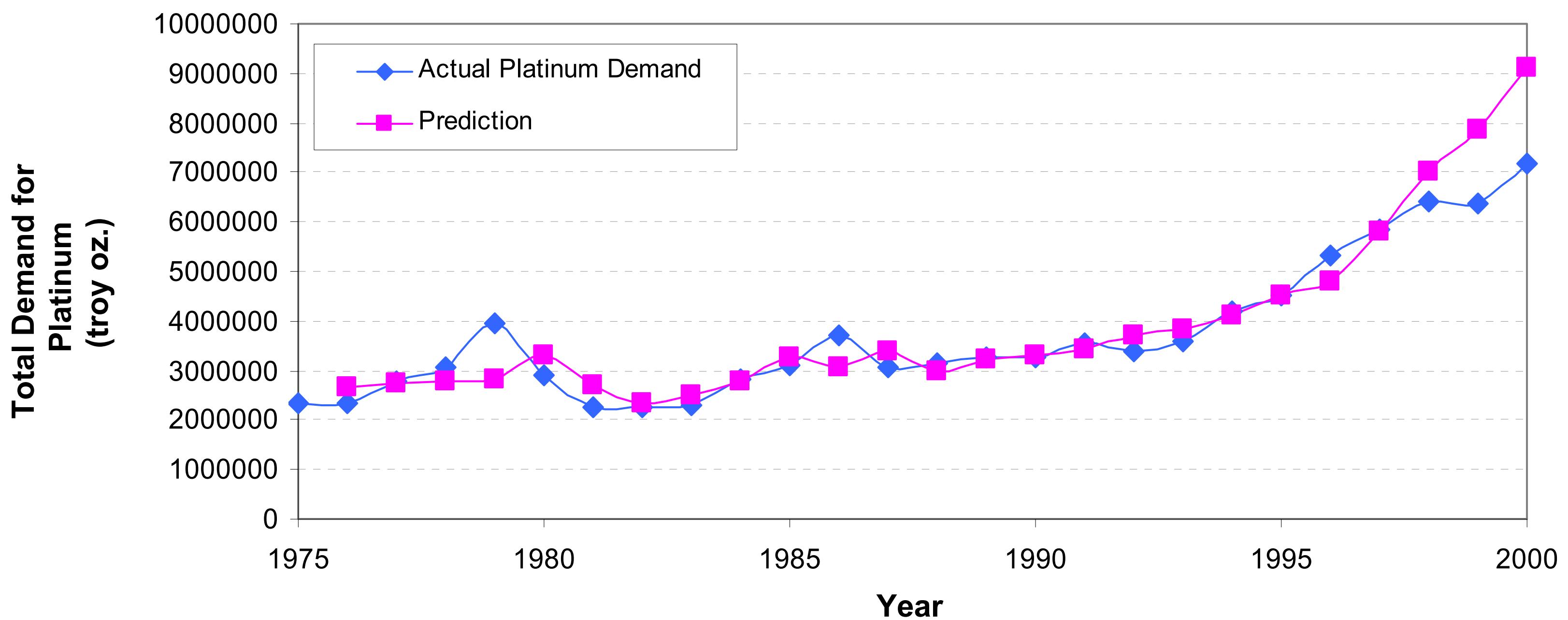
* The chronological definition provided for “short-run” and “long-run” is not precise. The general purpose of the distinction is to differentiate between a short period, when it is impossible for consumers to make adjustments, and a longer period, when consumers have more freedom to make adjustments.

Note: The parameters for the short-run jewelry demand model were estimated from the data. Parameters for the “long-run” jewelry demand model were derived from the short-run parameters by adjusting estimates based on the previous year’s jewelry consumption.

The predictive power of the total world platinum demand model was verified by predicting the quantity demanded outside the sample period.

- We pretended that the total quantity of demand was not available from 1999 to 2000 and the model was used to forecast those two years. We then compared the real total quantity of demand with the model predictions.
- The differences, about 25%, are larger than the differences observed in the predictions of the other two models because of the use of highly aggregated data in this model.

Actual World Total Platinum Demand vs. Model's Prediction

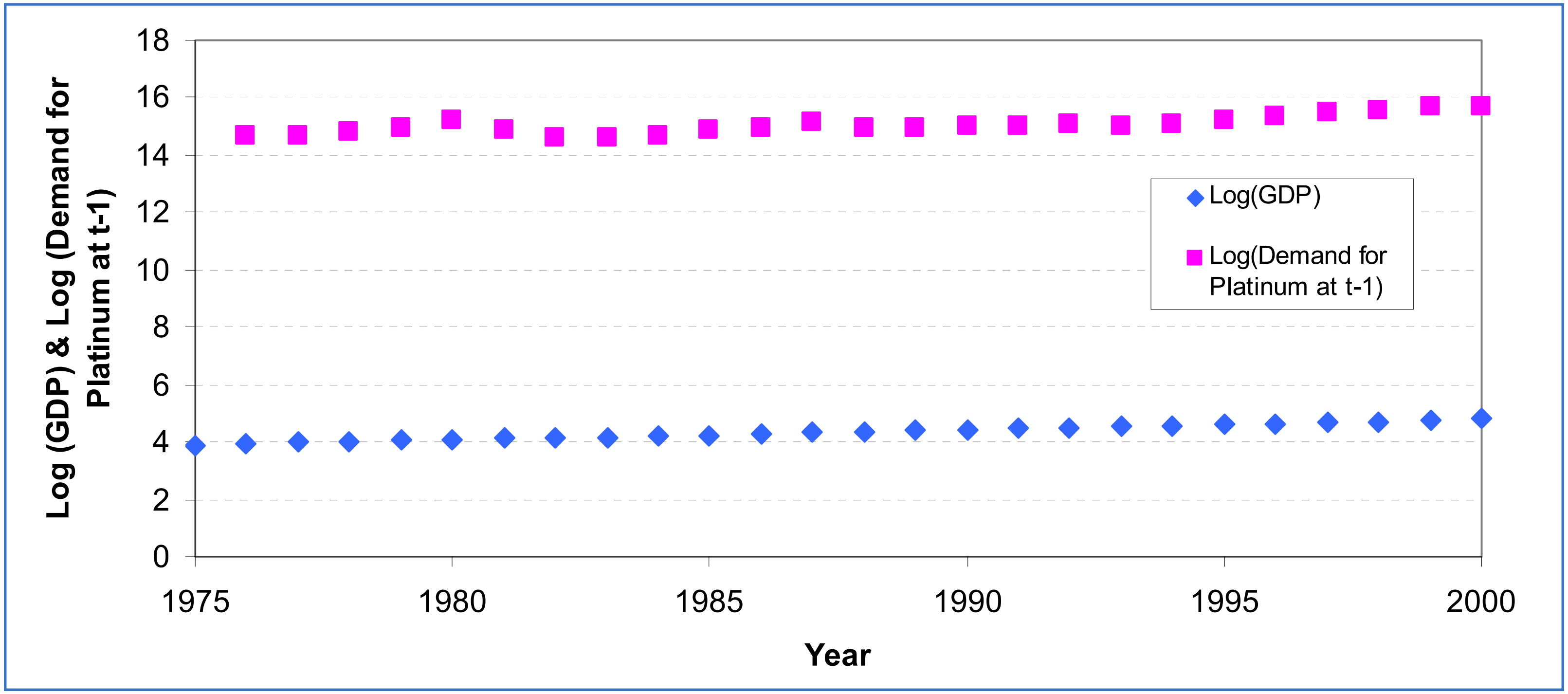


The short-run price elasticity of total world demand for platinum is inelastic; however, the long-run price elasticity is elastic.

- Price elasticity of total world platinum demand has the expected negative sign and is significant (i.e., when platinum price increases, the quantity demanded falls).
- In the short-run, the price elasticity of demand for platinum is not elastic (-0.66). The quantity demanded is not very responsive to a price change, reflecting the reality that it is difficult to find a substitute metal for platinum in the short-run.
- In the long-run, the price elasticity of demand for platinum is elastic (-1.129), indicating that in the long-run, as technology progresses, it is easier to identify substitutes for platinum to respond a price change.

The total world demand for platinum responds positively to the performance of the world economy—the quantity demanded increases as the total income increases.

- However, the two factors that influence the total world platinum demand (i.e., the world GDP index and the total world platinum demand in previous periods) are highly correlated (coefficient of correlation is about 0.85). As a result, the standard error for income elasticity is very large.



The cross price elasticity of platinum with respect to palladium is larger in the long-run than in the short-run.

- Unlike the relationship between platinum price and gold price, platinum price and palladium price are not highly correlated during the period we studied. Therefore, we are able to estimate the cross price elasticity of platinum demand with respect to the palladium price.
- The cross price elasticity has the expected positive sign and is significant, indicating that the two metals are substitutes in some applications, such as catalytic converters.
- In the short run, the degree of substitution is small (0.19), i.e., a 1 percent increase in the price of palladium will result in a 0.19 percent increase in demand for platinum. The low level of substitution is due to time, cost and technical limitations.
- In the long run, the degree of substitution increases (0.65), i.e., a 1 percent increase in the price of palladium will result in a 0.65 percent increase in demand for platinum. The level of substitution is higher because of the time available for users to adopt new technology.

Platinum Supply: The objective of our analysis of platinum supply was to better understand the relationship between platinum price and supply.

- We were not able to develop a structural model for platinum supply because needed information was not available. A structural model would need to include the information described below:
  - Proven reserves
  - Mine and refinery capacity
  - Mine and refinery capacity utilization
  - Production cost
  - Changes in inventory
  - Secondary supply

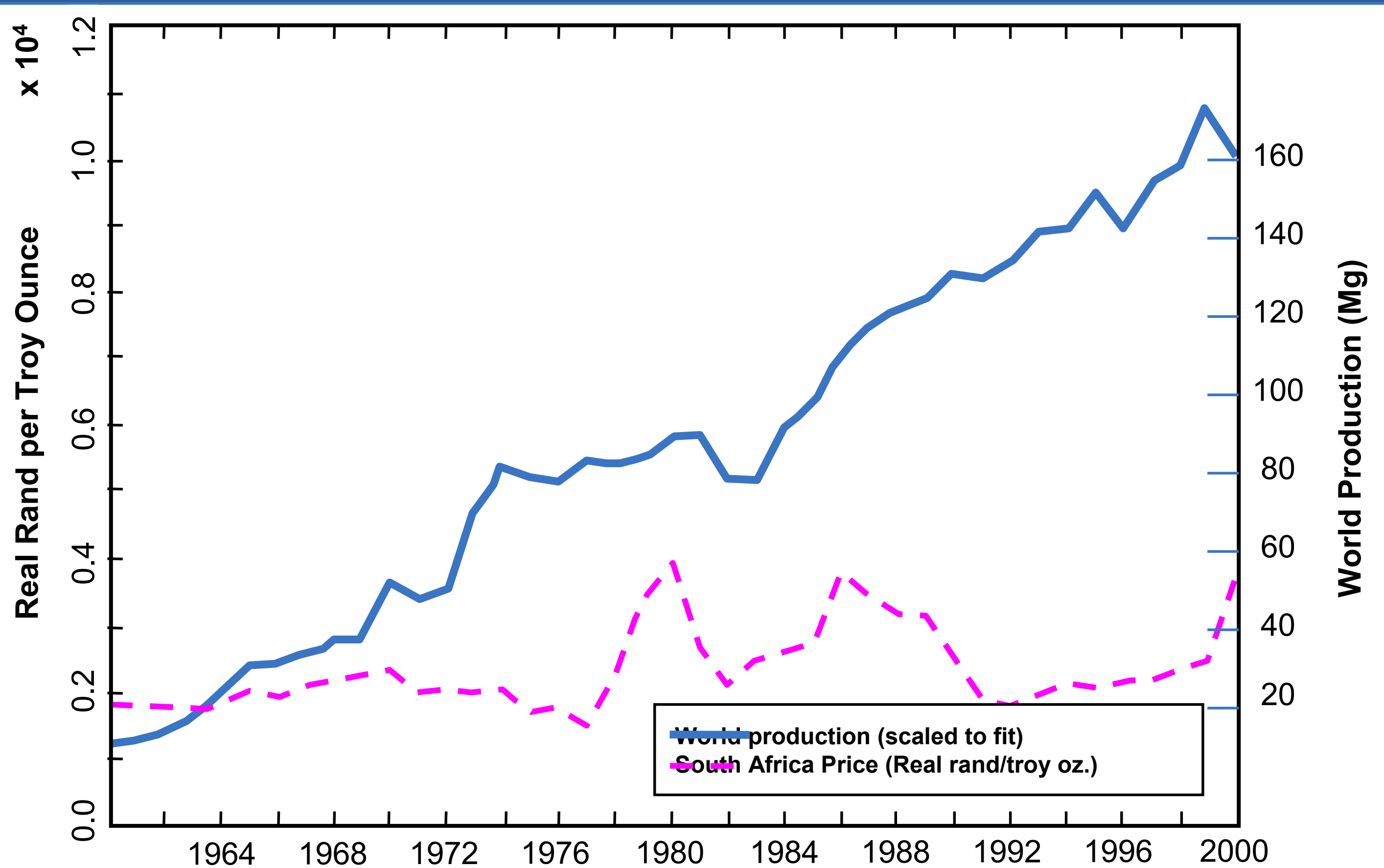
Due to the lack of information needed to estimate a complete structural platinum supply model, two related analyses were pursued.

1. **Analyze the real platinum price on world market.**
   – We conclude that there is no strong evidence that real platinum prices have trended upward during the 20th century. This result suggests that platinum supply is elastic and future increases in demand for platinum can be met without large change in real price.

2. **Estimate a distributed lag relationship between real platinum price series and quantities produced.**
   – An exogenous increase in platinum production is modeled as affecting current platinum price through its effect on the current marginal costs of mining and refining. Such an increase could continue to affect platinum price for some period into the future because of the time required to adjust capital stocks to new levels of price.

While platinum production has trended up for the period of the study, the real price of platinum has been fairly constant.

World Production and Real SA pt Price: 1960-2000



Sources:
Production: *Johnson Matthey*
Price: *U.S. Geological Survey*
South Africa producer price index, South Africa Reserve Bank

An inverse platinum supply function is specified to include the time that the industry takes to increase supplies following an increased, permanent change in demand on the right-hand and the level of price on the left-hand side.

- The response to a permanent change in Q_t (say due to increased fuel cell use) would be a_o in the first year, a_1 in the second year, etc. If it took five years for the platinum industry to arrive at the long run desired production level, then the price effects would be non-zero for five years and zero thereafter.

$$P_t = a_o(Q_t - Q_{t-1}) + a_1(Q_{t-1} - Q_{t-2}) + \ldots + DM_t + \varepsilon_t$$

P_t	Real USGS (dollar-denominated) platinum price multiplied by the South African rand equivalent of the U.S. dollar and divided by the South African Producer Price Index.
$Q_t, Q_{t-1}, Q_{t-2}, Q_{t-1}$	Contemporaneous quantity of world production and its lags.
DM_t	Dummy variable indicating years in which there were supply interruptions. The years in which the supply disruption variable equal one is 1965-1968, 1978-1980, 1986, and 1997-1999. In all, the supply disruption dummy variable equals one for 31% of the 35-year sample period.
a_o, a_1, a_n	Price response to a permanent change in quantity

Because of the lack of sufficient data to estimate a complete structural supply model, a reduced form supply model was estimated.

- The estimated results are weak; however, there is some evidence that:
  - Long-run supply is elastic (supply has been able to meet the demand to keep the real platinum price constant over the last century).
  - An exogenous increase in quantity has a positive effect on platinum price for a short time (2 or 3 year periods) and then the effect fades away.
  - Supply interruption has a larger impact on platinum price.

We simulated the impact of FCV demand on platinum price, using the results from our econometric models, the price elasticity of platinum autocatalyst demand*, and hypothetical FCV demand.

- The simulation model was specified as follows:

$$\frac{dP}{P} = \frac{FC/Q}{\varepsilon_S + \left(Q_A/Q\right)\eta_A + \left(Q_J/Q\right)\eta_J + \left(Q_O/Q\right)\eta_O}$$

Q	Total quantity of Pt sold
$\frac{Q_A}{Q}$	Share of automotive use of Pt
$\frac{Q_J}{Q}$	Share of jewelry use of Pt
$\frac{Q_o}{Q}$	Share of other use of Pt
$\frac{FC}{Q}$	Hypothetical fraction of total Pt consumption by fuel cell use

η_A	The elasticity of demand for Pt in automotive use*
η_j	The elasticity of demand for Pt jewelry
η_o	The elasticity of demand for other use
ε_s	Price elasticity of supply of Pt

This model is the fundamental link among all parts of the simulation model.

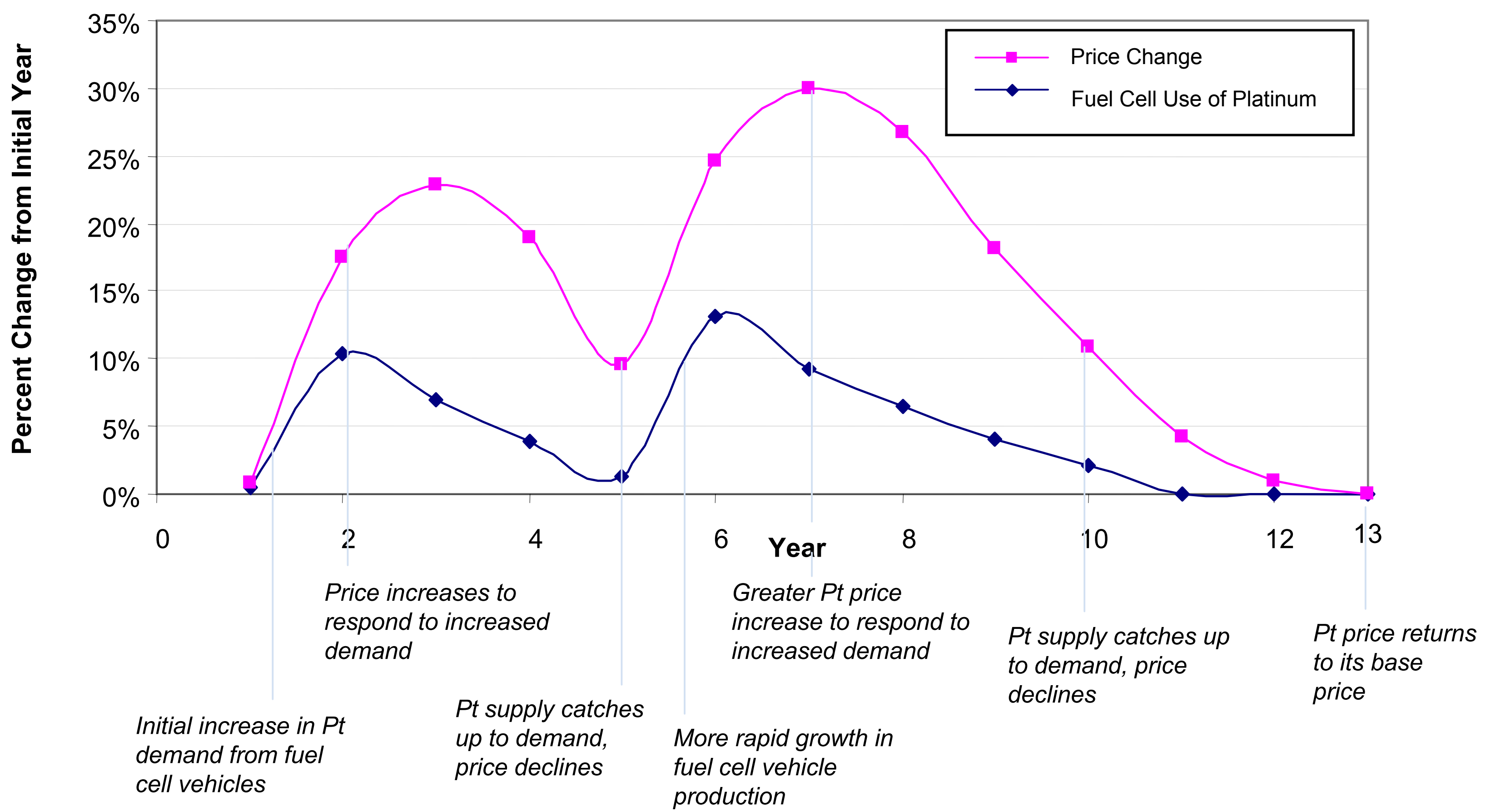
* Obtained from a conceptual model of the general equilibrium derived demand. Derivation is available upon request.

We used a hypothetical demand scenario for FCVs to assess the impact of increased demand for platinum on price.

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 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.

Other factors outside the scope of our models could have an even more significant impact on platinum price than new FCV demand.

- For example, even without demand from FCVs the 12/17/03 platinum price was $840/oz (53% higher than the long-term mean) as a result of a supply/demand imbalance and other market factors.

Appendix

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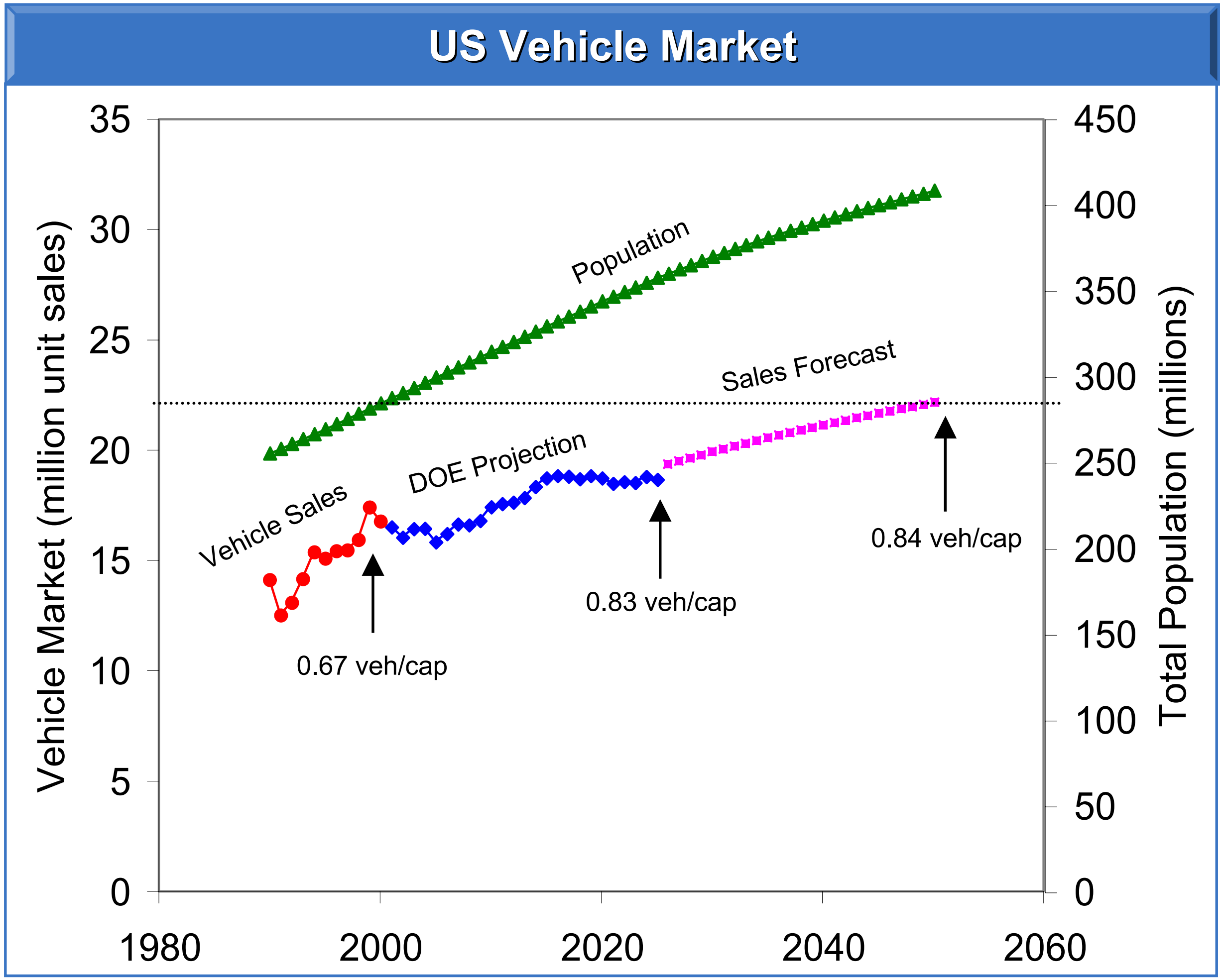
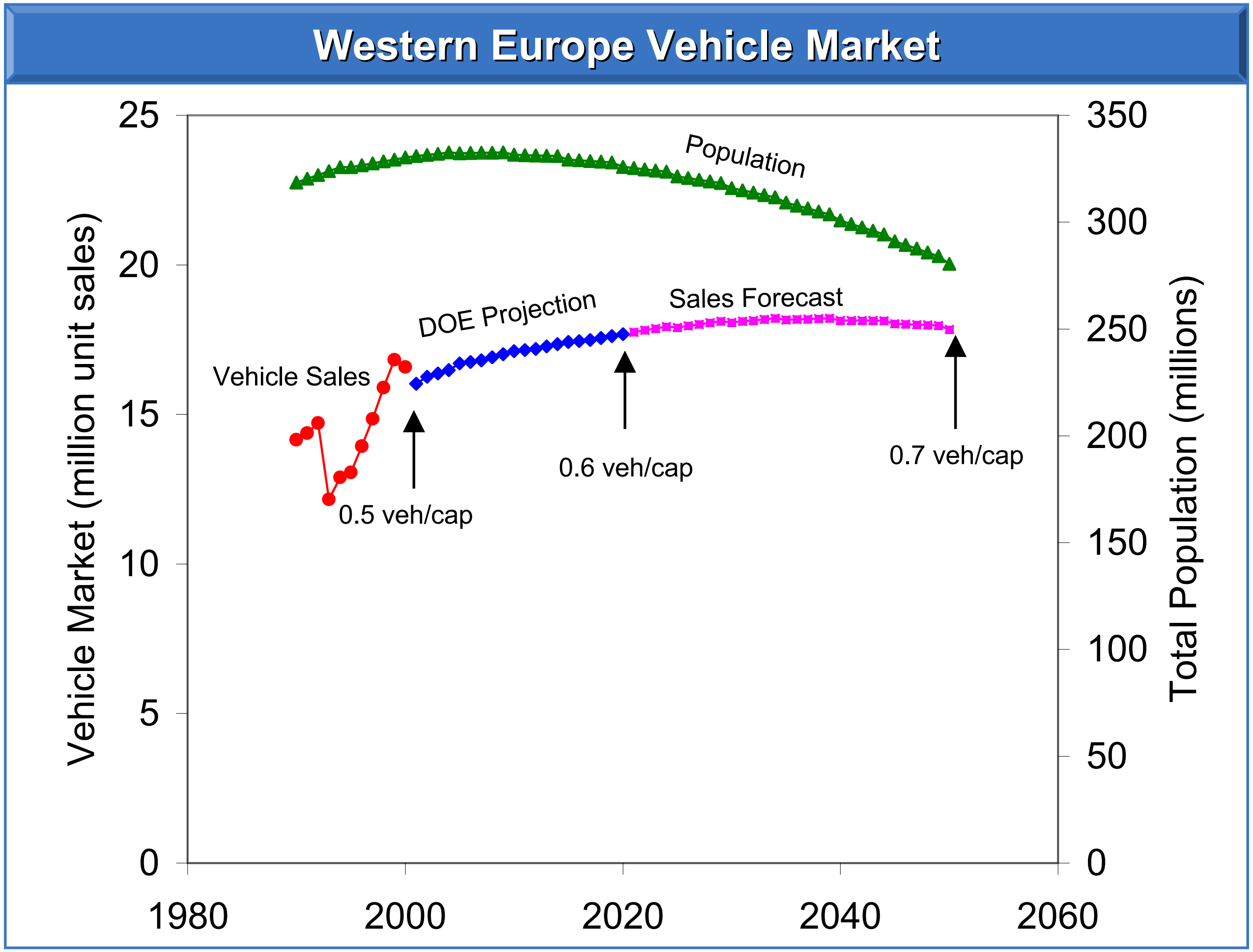
An increasing population in the US leads to increasing vehicle sales in a mature market.



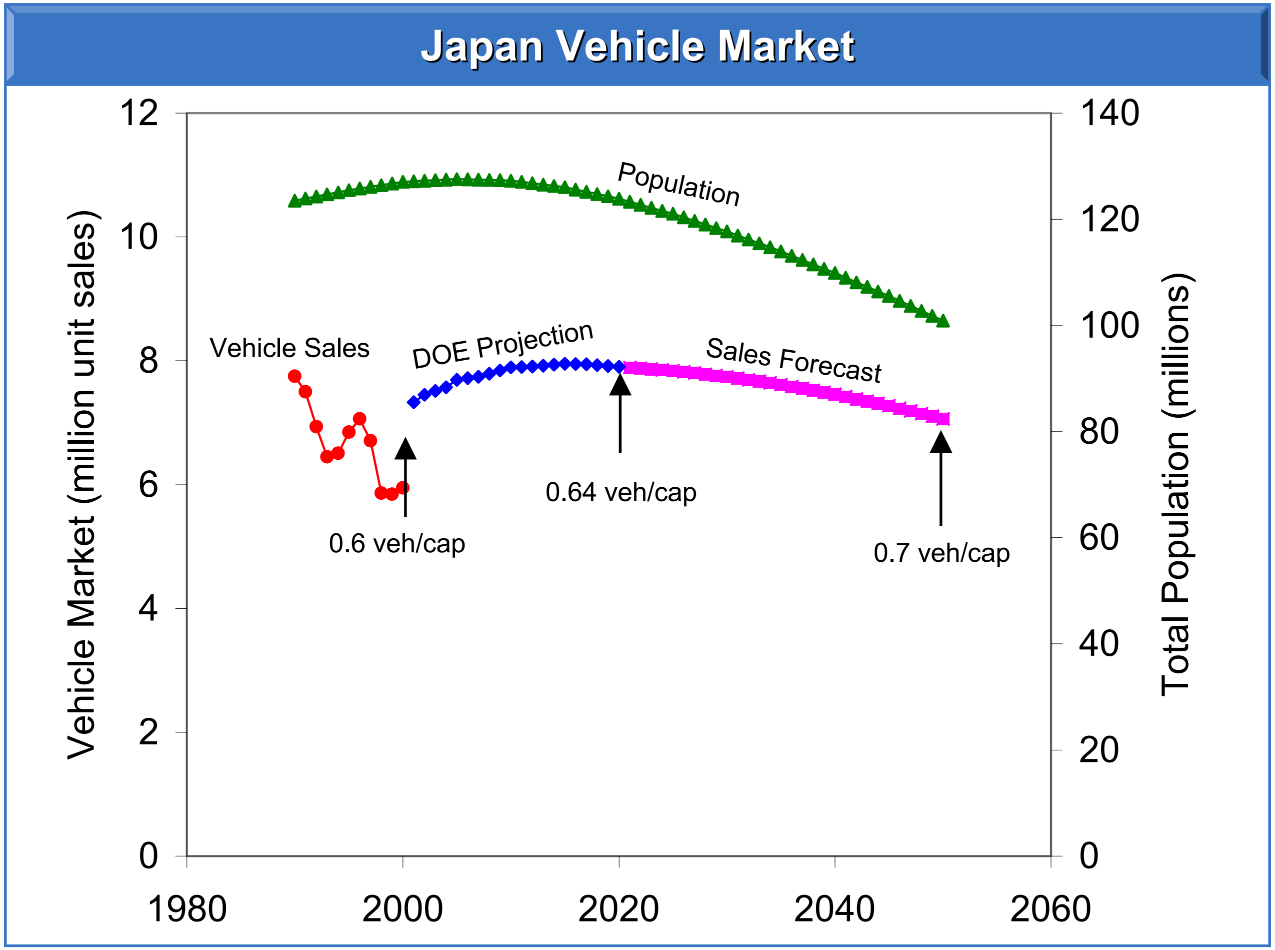
Sources: United Nations, Ward's, DOE Energy Information Administration
** Vehicle Turnover Period = 15.5 years*

The Western European market is mature, but the rise in vehicle per capita ownership offsets the effect of a projected decrease in population.



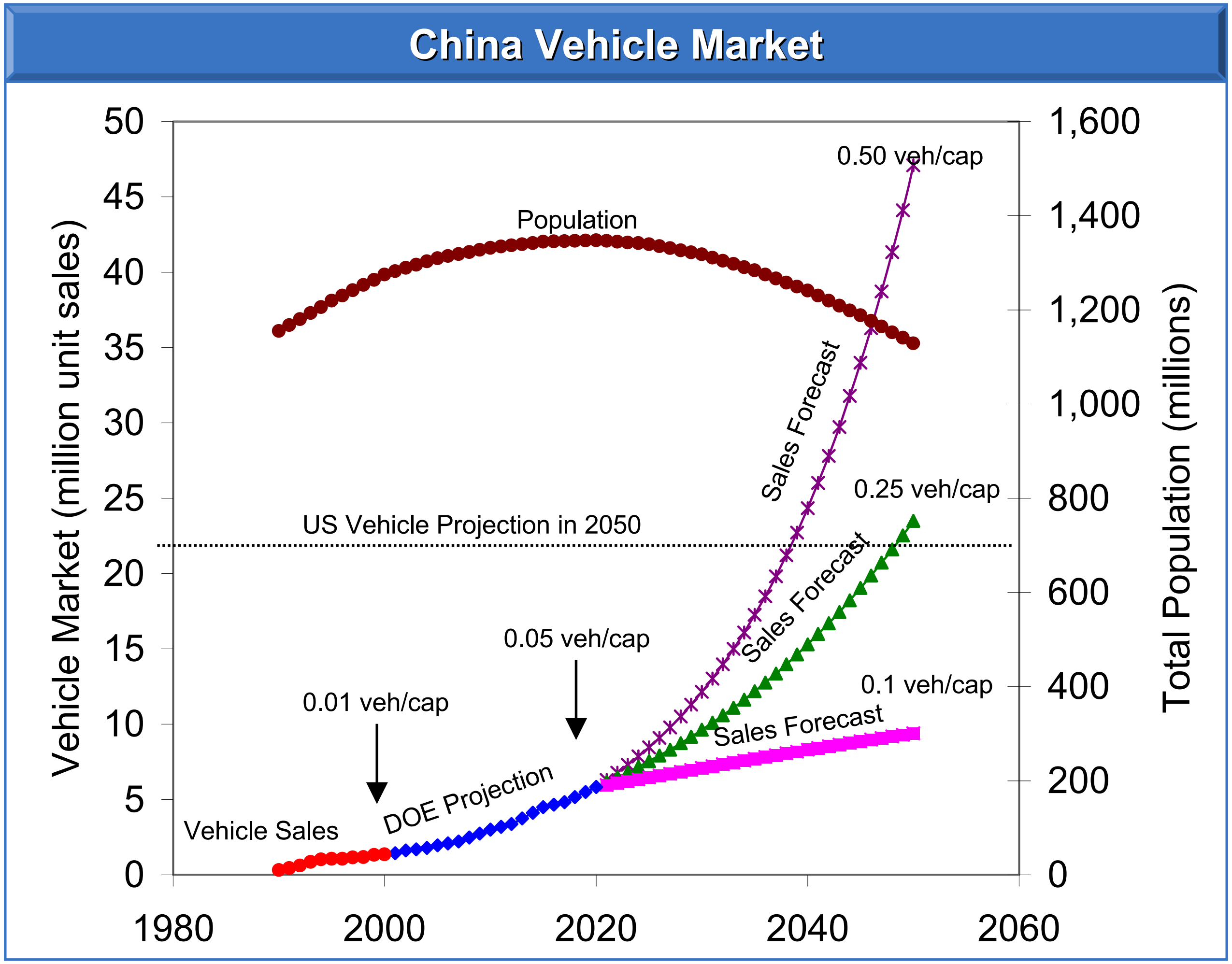
Sources: United Nations, Ward's, DOE Energy Information Administration
** Vehicle Turnover Period = 11.5 years*

The Japanese market trend is similar to Western Europe in our vehicle sales estimate.



Sources: United Nations, Ward's, DOE Energy Information Administration
** Vehicle Turnover Period = 10 years*

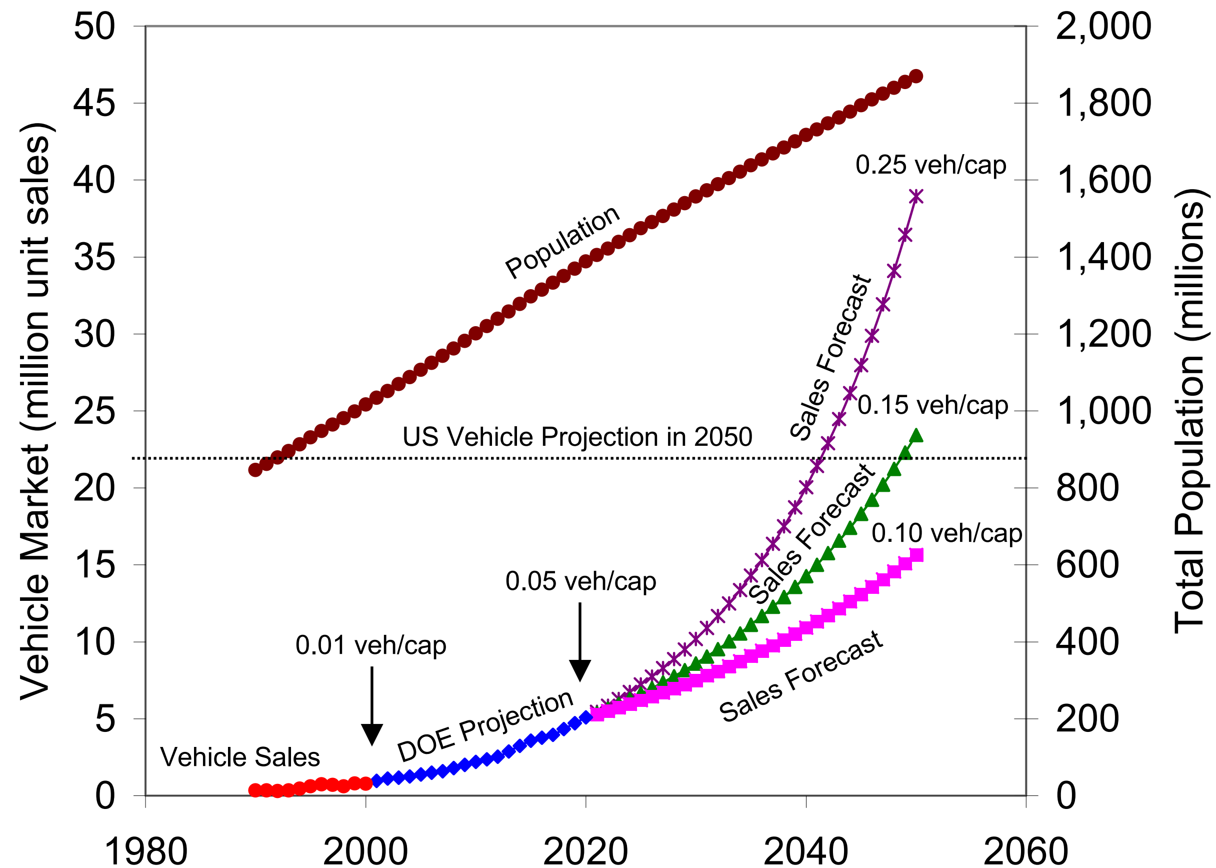
The Chinese market has the potential to surpass the United states assuming vehicles per capita continues to rise with increasing GDP.



Sources: United Nations, Ward's, DOE Energy Information Administration
** Vehicle Turnover Period = 12 years*

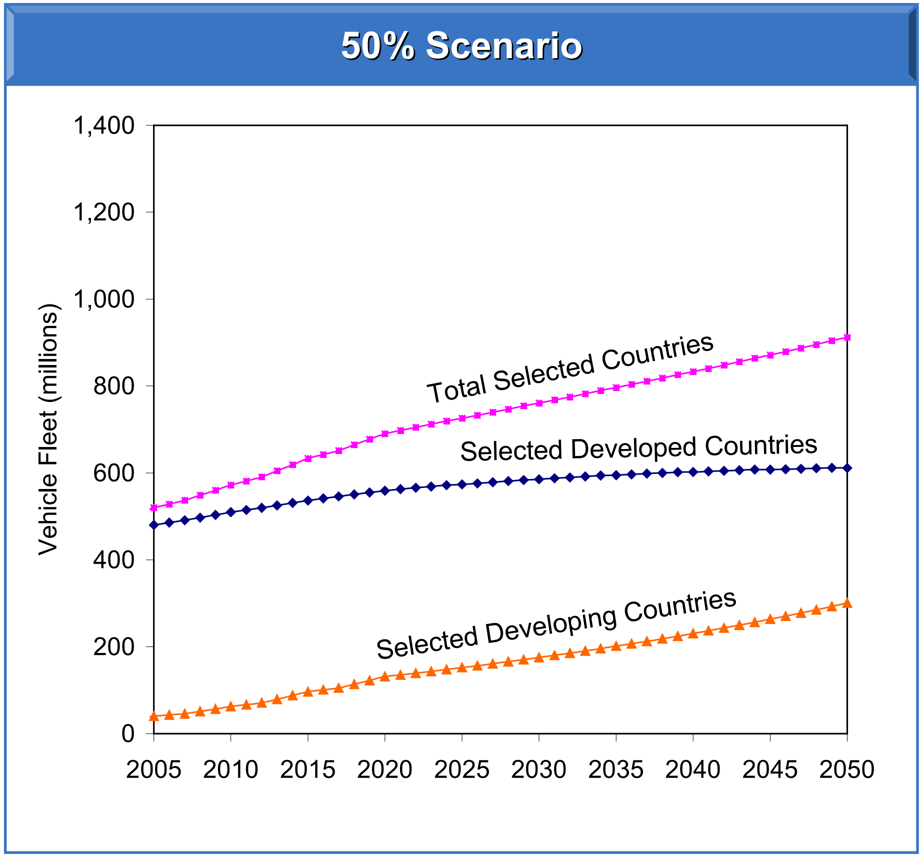
The combination of increasing population and increased vehicles per capita leads to potentially the largest vehicle markets in India.

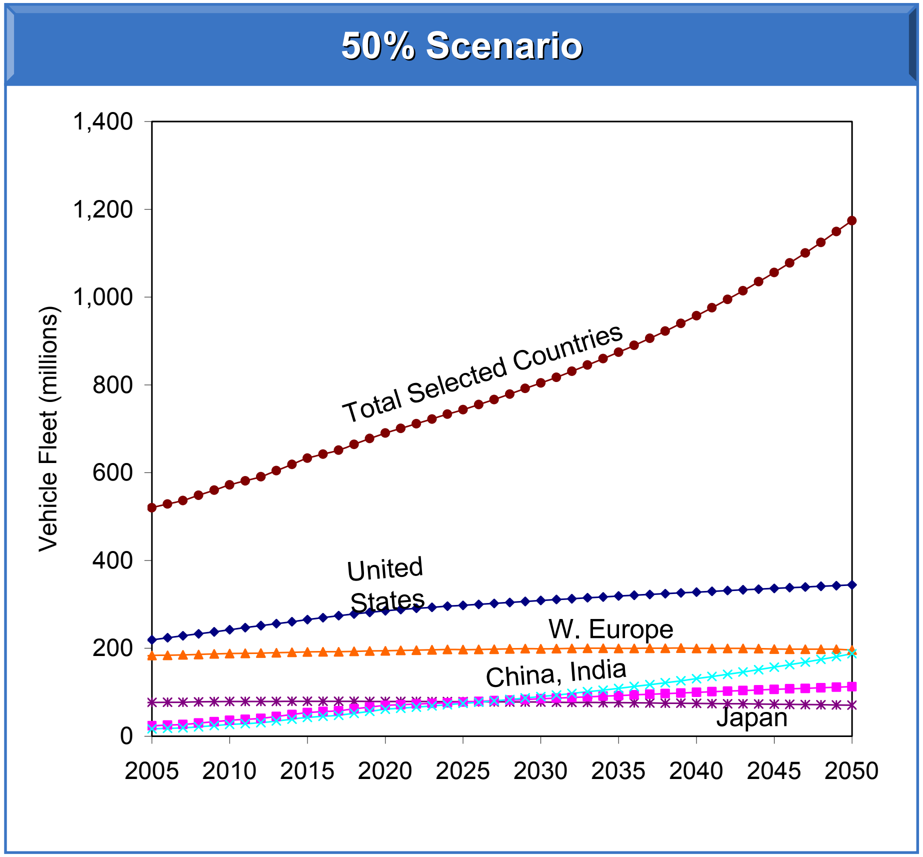
India Vehicle Market



Sources: United Nations, Ward's, DOE Energy Information Administration
** Vehicle Turnover Period = 12 years*

The 50% Scenario shows that the world vehicle fleet will significantly increase as Developing Countries increase their vehicles per capita.

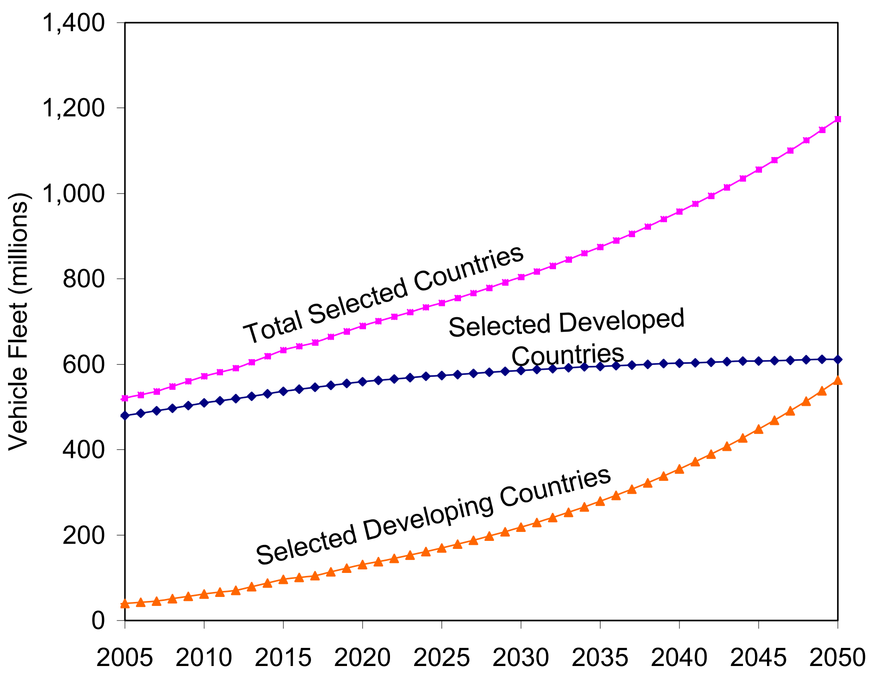




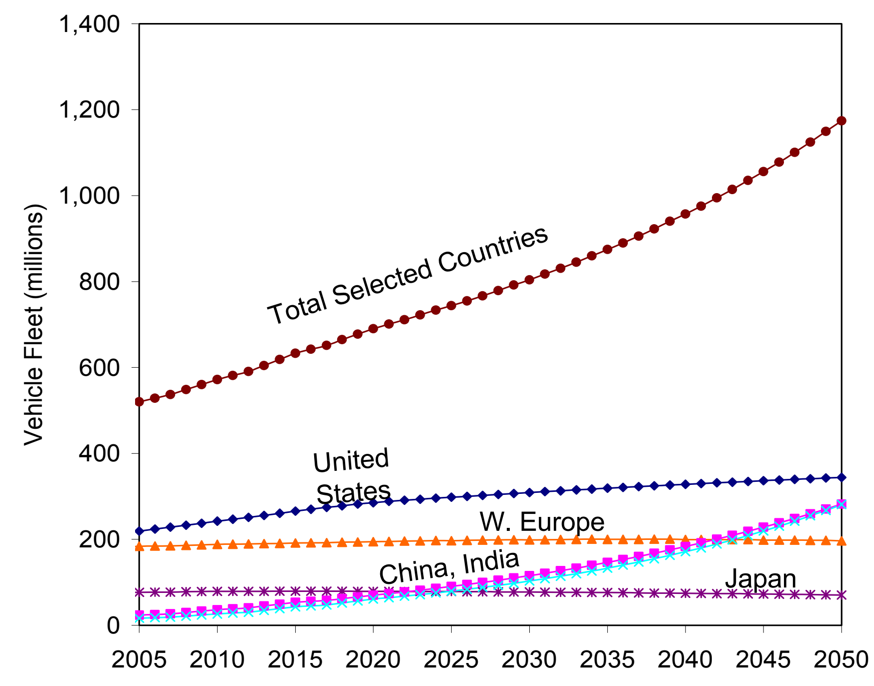
Sources: United Nations, Ward's, DOE Energy Information Administration
** Rest of world may add 20% to vehicle sales based on 2000 statistics*

The 80% Scenario shows that the world vehicle fleet will significantly increase as Developing Countries increase their vehicles per capita.

80% Scenario



80% Scenario



Sources: United Nations, Ward's, DOE Energy Information Administration
** Rest of world may add 20% to vehicle sales based on 2000 statistics*

Appendix

Previous Studies

Econometric Analyses

Vehicle Forecasts

Stationary Fuel Cell Markets

Platinum Mining

We evaluated stationary global PEMFC markets for the scenario in which PEMFC achieves success in transportation applications.

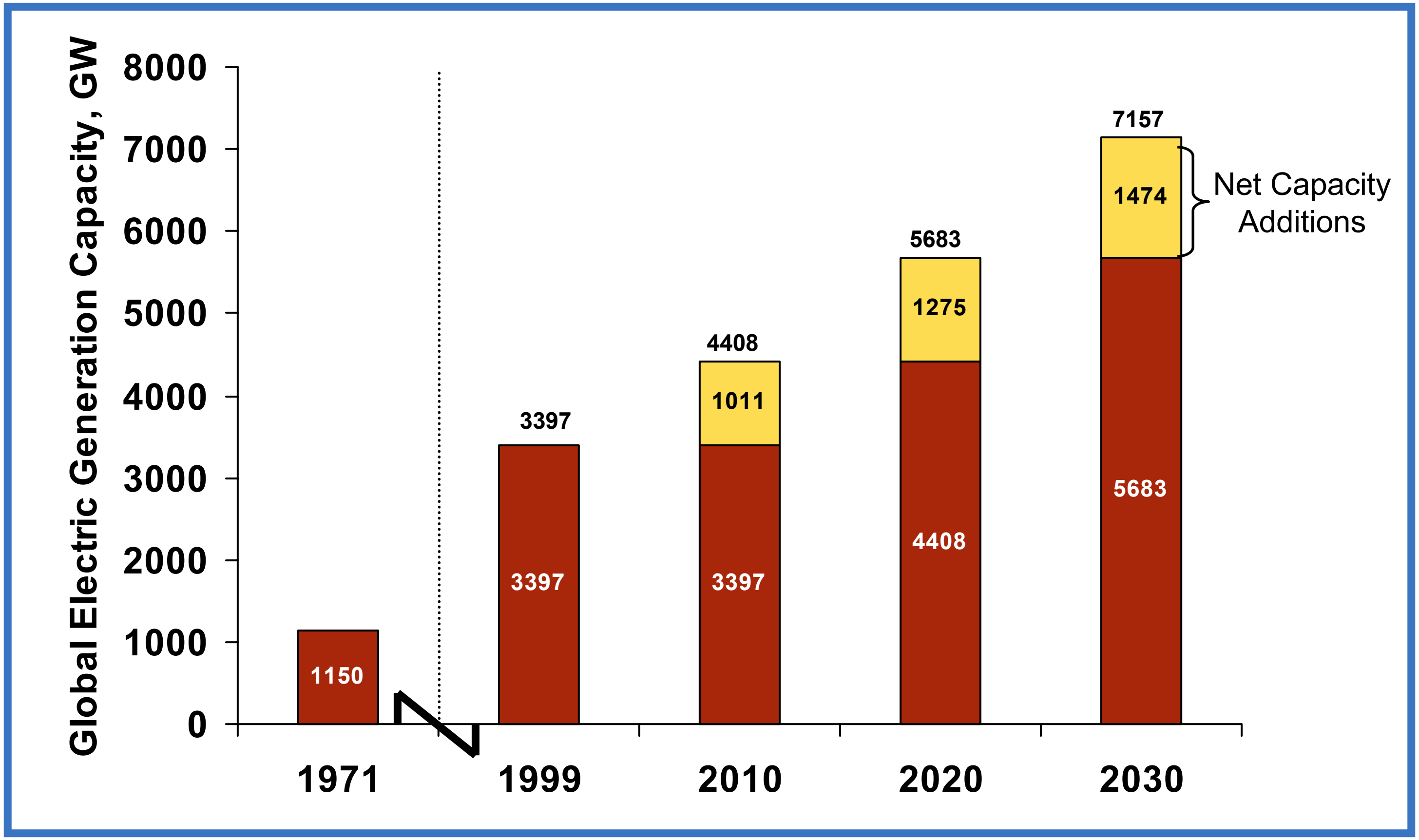
Success Scenario

- Stationary PEMFC cost and performance characteristics are consistent with the cost/performance needed for success in transportation applications.
- Achieving these cost performance characteristics will make PEMFC the distributed generation technology of choice in stationary applications for distributed generation plant capacities under 1 MW.

We used several simplifying assumptions for a scenario-based evaluation of the future stationary PEMFC market through 2050.

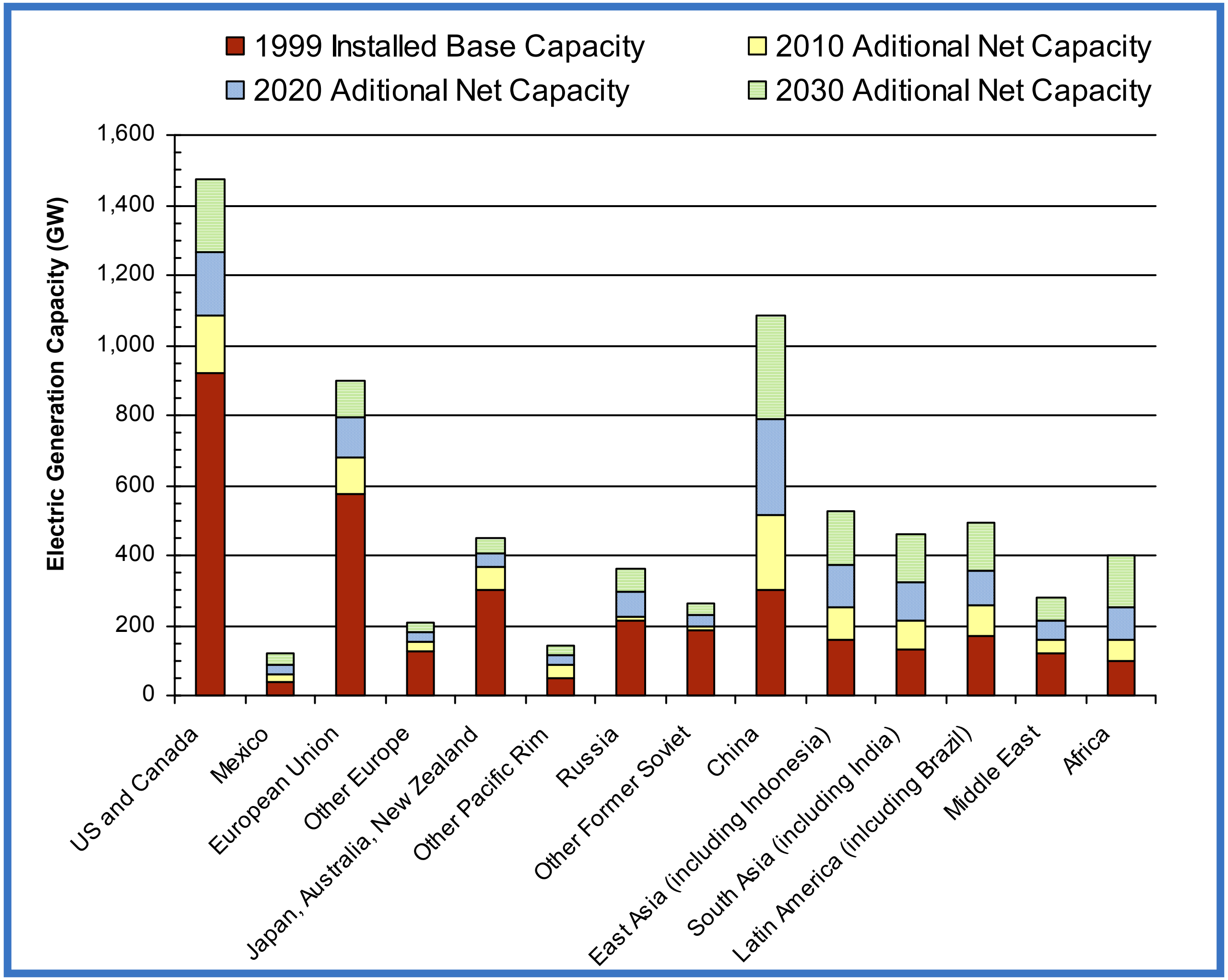
- Global projections of new additions of electric generation capacity (from the International Energy Agency), with some adjustments, are a reasonable proxy for the target market.
- IEA generation capacity projections can be extrapolated from 2030 to 2050 using global Gross Domestic Product projections.
- Consistent with findings from previous TIAX studies, the simple payback period of stationary PEMFC in the U.S. are reasonably representative of the simple payback period in most significant global markets.
- Energy-cost savings at the end-use site will be the primary motivation to install PEMFC.
- PEMFC distribution chain markups will be at the low end of markups typically seen in the HVAC and Appliance industries.

The IEA projects global electric generation capacity to more than double by 2030.



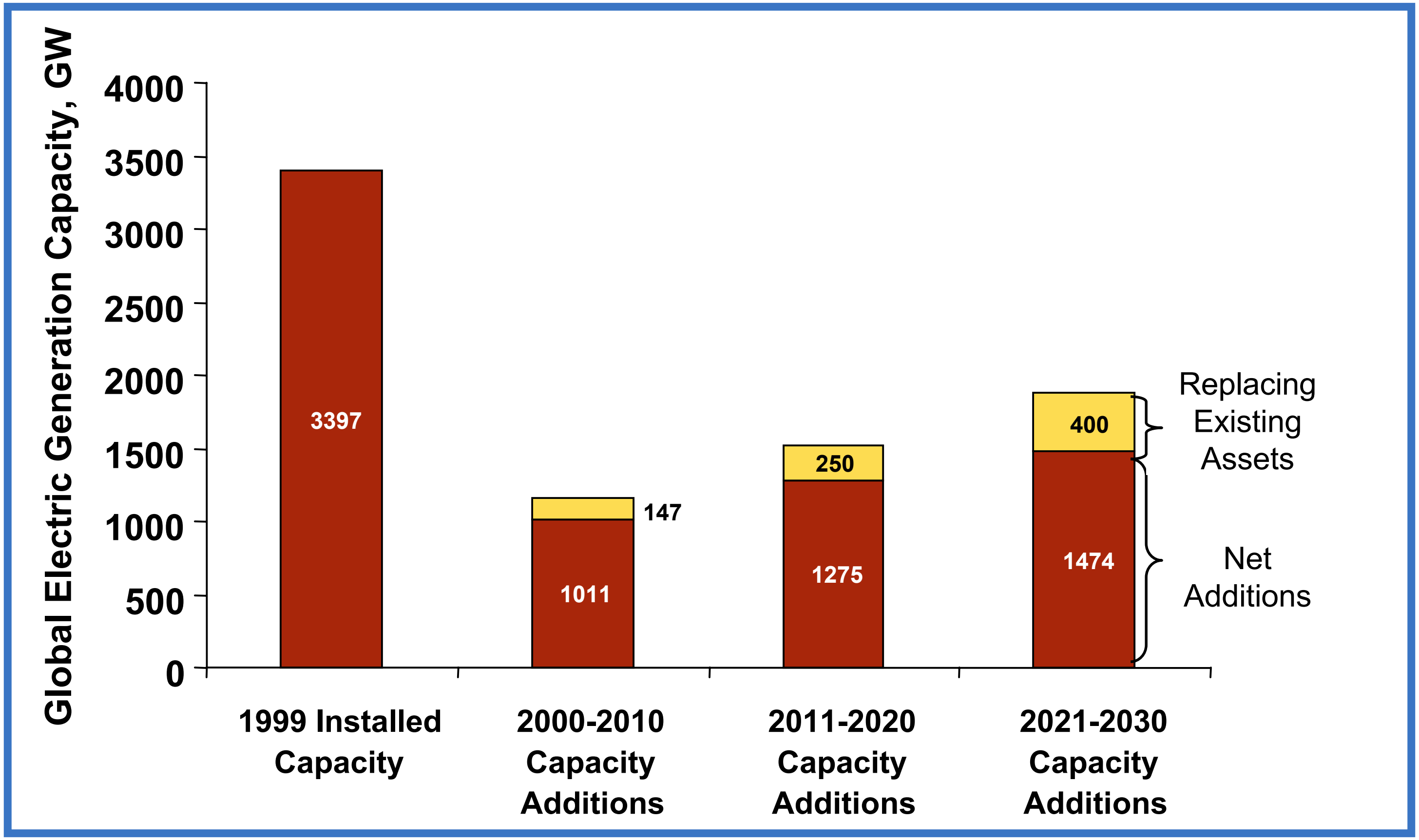
Source: World Energy Outlook 2002; International Energy Agency; pp. 411, 424-498.
1971 installed base derived from EIA consumption data (5,250 TWh), and the 1999 Capacity Factor (0.52).

U.S./Canada, the European Union, and China combined account for about 50 percent of current and projected future generation capacity.



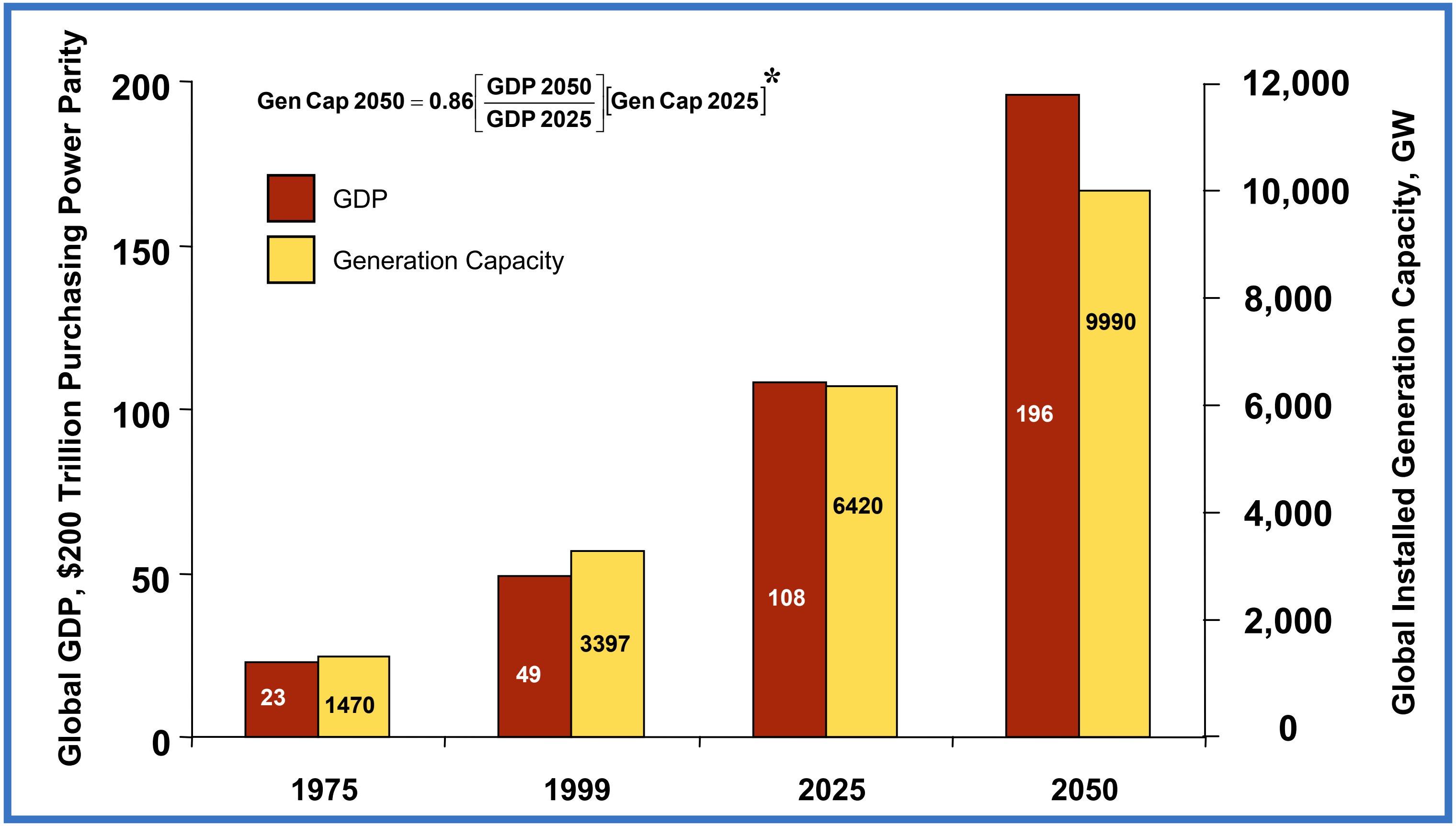
Source: World Energy Outlook 2002; International Energy Agency; pp. 424-498.

Projected total capacity additions include significant portions that will replace current aging assets.



Source: World Energy Outlook 2002; International Energy Agency; pp. 123-132, pp. 410-497, and Table 3.11.

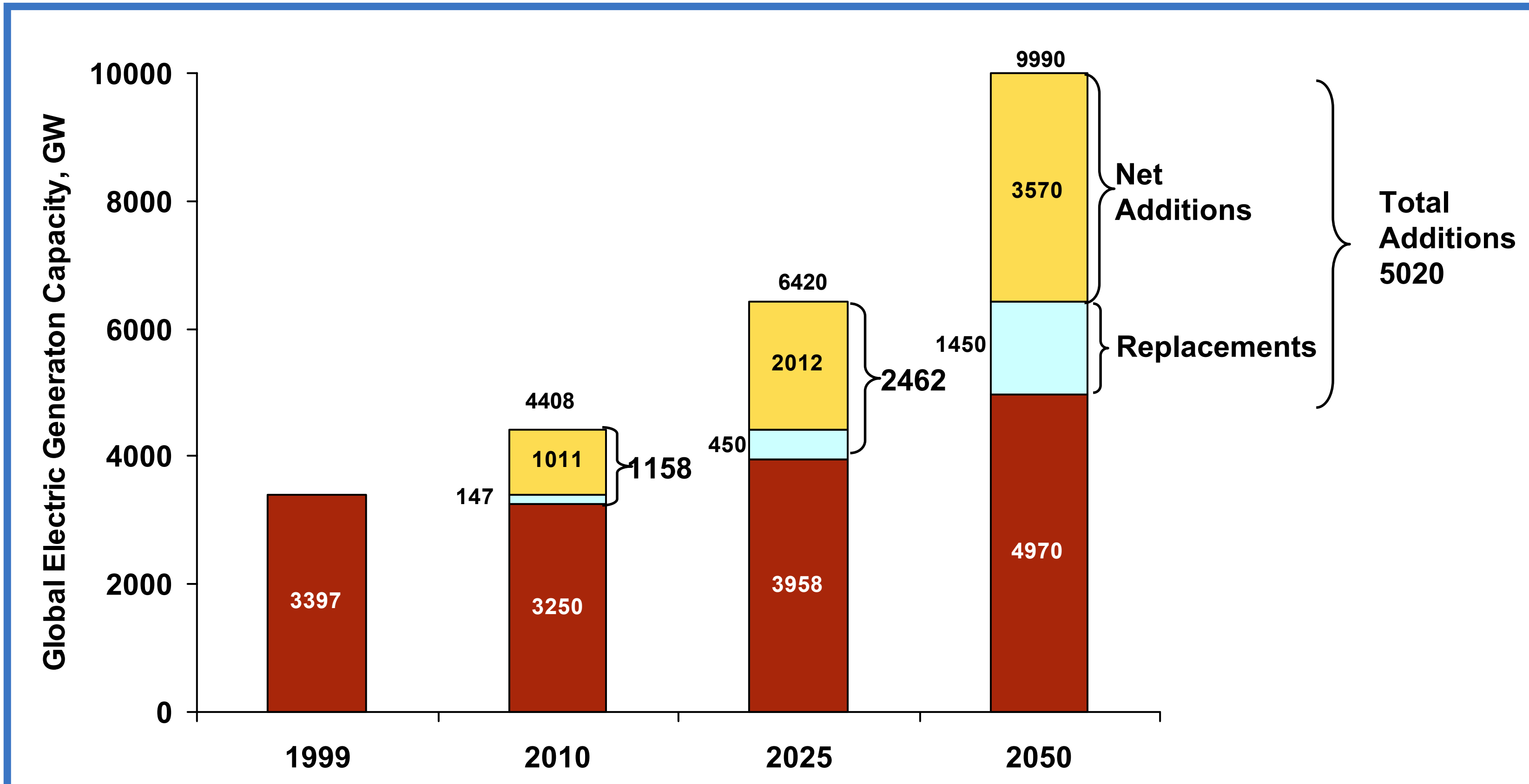
We extrapolated IEA generation capacity projections to 2050 using global GDP projections.



Sources: Generation Capacity: IEA data. 1975 and 2025 values from interpolation. GDP: Exploring the Future: Energy Needs, Choices and Possibilities – Scenarios to 2050; Global Business Environment, Shell International 2001; p.60.

* 0.86 factor calculated from 1999/2025 values

We then extrapolated IEA's projections for total additions of generation capacity to 2050.



Source: IEA data. 2025 from interpolation. 2050 Replacements from extrapolation of data for 2020 and 2030.

Stationary PEMFC cost and performance characteristics were estimated from the requirements for a successful transportation PEMFC market.

Requirements for a Successful Transportation Market	
System Cost	$50/kW
Efficiency	35% (LHV*)

* Lower Heating Value

Net generation efficiency in stationary applications will be slightly higher than for transportation applications.

Performance Projections		
Transportation	**Stationary 2010+**	**Stationary 2025+**
35% (LHV)	40% (LHV)	

Rationale

- Rated at 0.75 to 0.80 volts/cell for stationary applications, vs. 0.65 to 0.70 volts/cell for transportation, to optimize efficiency (rather than power density)
- This efficiency benefit is adjusted down slightly to account for power-conditioning losses associated with stationary PEMFC.
- We assumed the upper end of the efficiency range for stationary applications would be achieved.

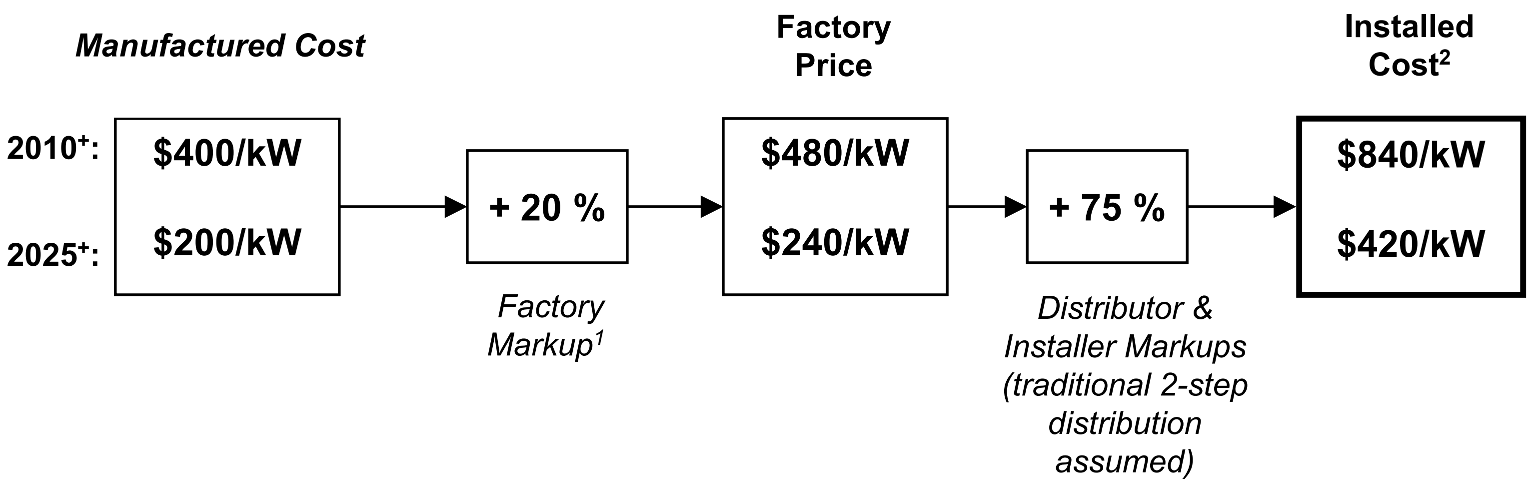
The manufactured cost of stationary PEMFC will be 4 to 8 times the cost for transportation applications.

Performance Projections		
Transportation	**Stationary 2010⁺**	**Stationary 2025⁺**
$50/kW	$400/kW	$200/kW
Rated at 0.65 to 0.70 volts/cell	Rated to 0.75 to 0.80 volts/cell	

Rationale – Additional Requirements for Stationary PEMFC

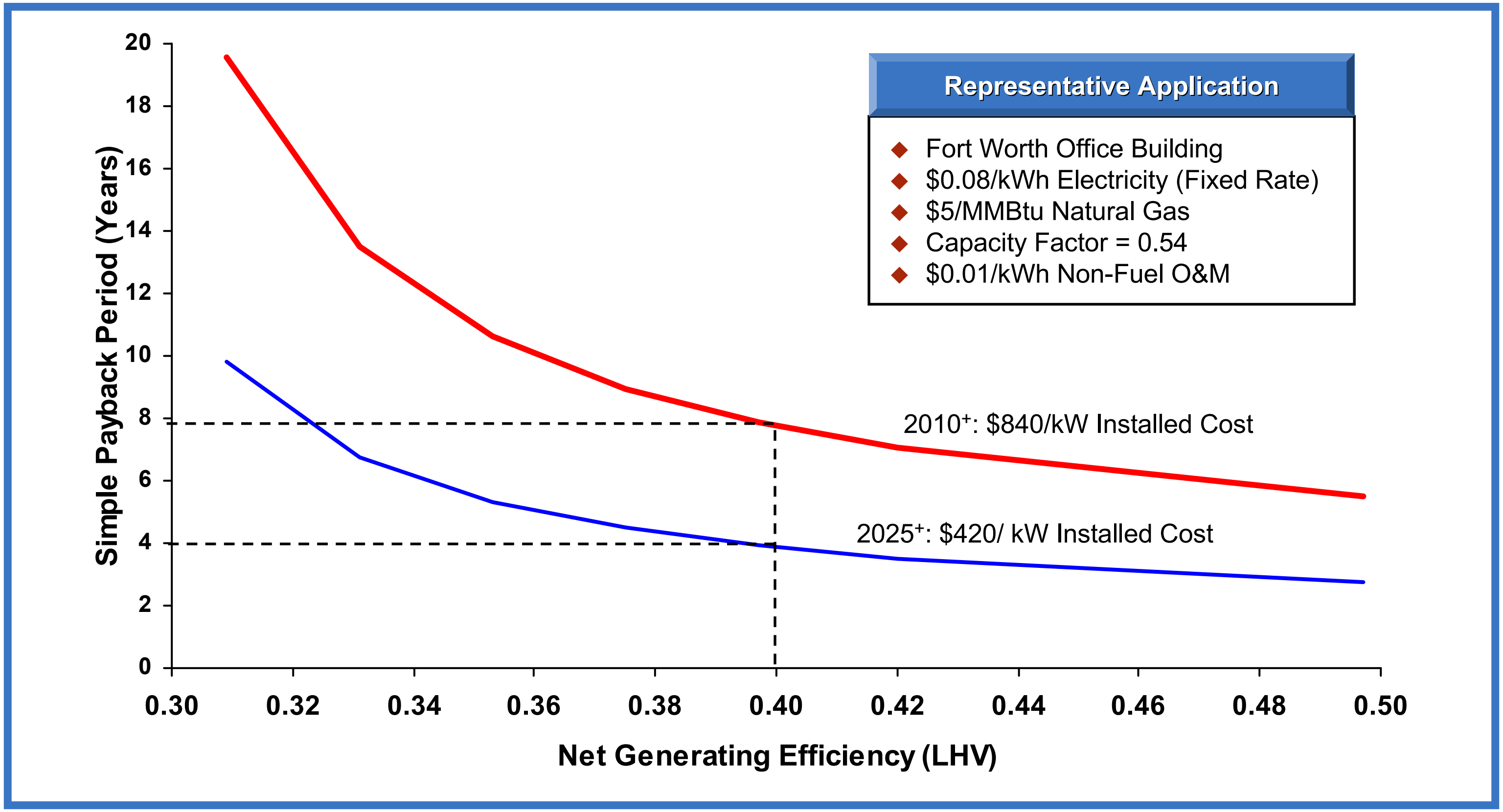
- Power conditioning subsystems to produce alternating current at the required voltage and frequency
- Utility interface subsystems (including electric grid interconnection)
- Packaging (the vehicle provides the packaging for transportation applications)
- More robust components (40,000 hour life required for major subsystems vs. 5,000 hours for transportation):
  - Higher catalyst loadings in fuel-cell stack
  - Thicker, more robust, membrane structures
  - More robust electromechanical equipment (pumps, blowers, valves, etc.)
- Different cell voltage rating to optimize efficiency (rather than power density)
- Fuel processor subsystem to operate on natural gas or other fossil fuel

We estimated distribution chain markups based on the low end of mark-up ranges for appliances and HVAC equipment.



[1] Low end of 20-40 percent range.
[2] Assumes straight forward installation and simple, standardized grid interconnection requirements.

For this scenario, using TIAX analytical tools[1], we estimate a simple payback period of about 8 years in 2010, improving to 4 years in 2025.



[1] Developed for the U.S. Department of Energy under UT-Battelle Subcontract No. 4000008858; completed April 12, 2002.

Simple payback period is often used as an initial screen of energy-saving technologies.

Simple Payback Period (Years)

- Defined as: $\frac{\textbf{Installed Cost}}{\textbf{Net Annual Savings}}$
- Accounts for:
  - Installed Cost
  - Electricity Cost Savings
  - Fuel Cost
  - Non-Fuel O&M
- Does NOT Account for:
  - Cost of Capital
  - Product Life, Salvage Value, or Replacement Cost
  - Non-energy-saving Benefits

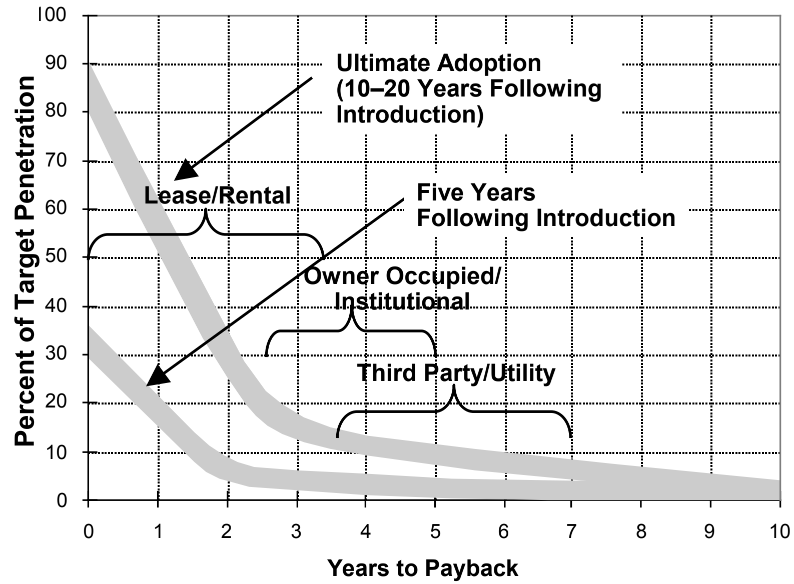
TIAX has developed simplified relationships to predict market penetration based on payback period.

Customer-Owned (Residential/Commercial)

TIAX Market Penetration Curves for Residential and Commercial Buildings

- Based on field interviews, consumer surveys, and market data on adoption of efficient technologies
- Useful as guidelines for market acceptance rates
- General observations:
  - threshold payback is 4-5 yrs
  - large market penetration occurs at <3 yrs

Market Penetration Curves for Efficient Technologies in Commercial Buildings



Sources: TIAX estimates, based on HVAC market penetration experience

We increased the resulting market penetrations to account for other factors, based on TIAX experience.

Time Period	Installed Cost	Simple Payback	Unadjusted Market Penetration[1]	Adjusted Market Penetration[2]
2010+	$840/kW	8 years	2%[3]	3%
2025+	$420/kW	4 years	12%[4]	15%

Examples of Other Factors
◆Power quality/reliability ◆Fuel flexibility ◆Energy security ◆Additional savings from cogeneration in some applications ◆Transmission and distribution system support

1) Based on energy-cost economics alone
2) Includes Other Factors.
3) Based on market penetration curve for “5 years following market introduction”.
4) Based on market penetration curve for “ultimate adoption”.

We adjusted the target market to account for end uses that cannot be addressed by PEMFC.

	Central Generation	PEMFC	Market Adjustment Factor[1]
Capacity Factor	0.52[2]	0.54[3]	1.0[4]
Fraction of Load Supplied[5]	1.0	0.74[3]	0.74
Applicable End Uses[6]	Residential (35%), Commercial (33%), Industrial (31%), Transportation (1%)	Residential (35%) and Commercial (33%)	0.68
		Total Adjustment Factor:	**0.5**

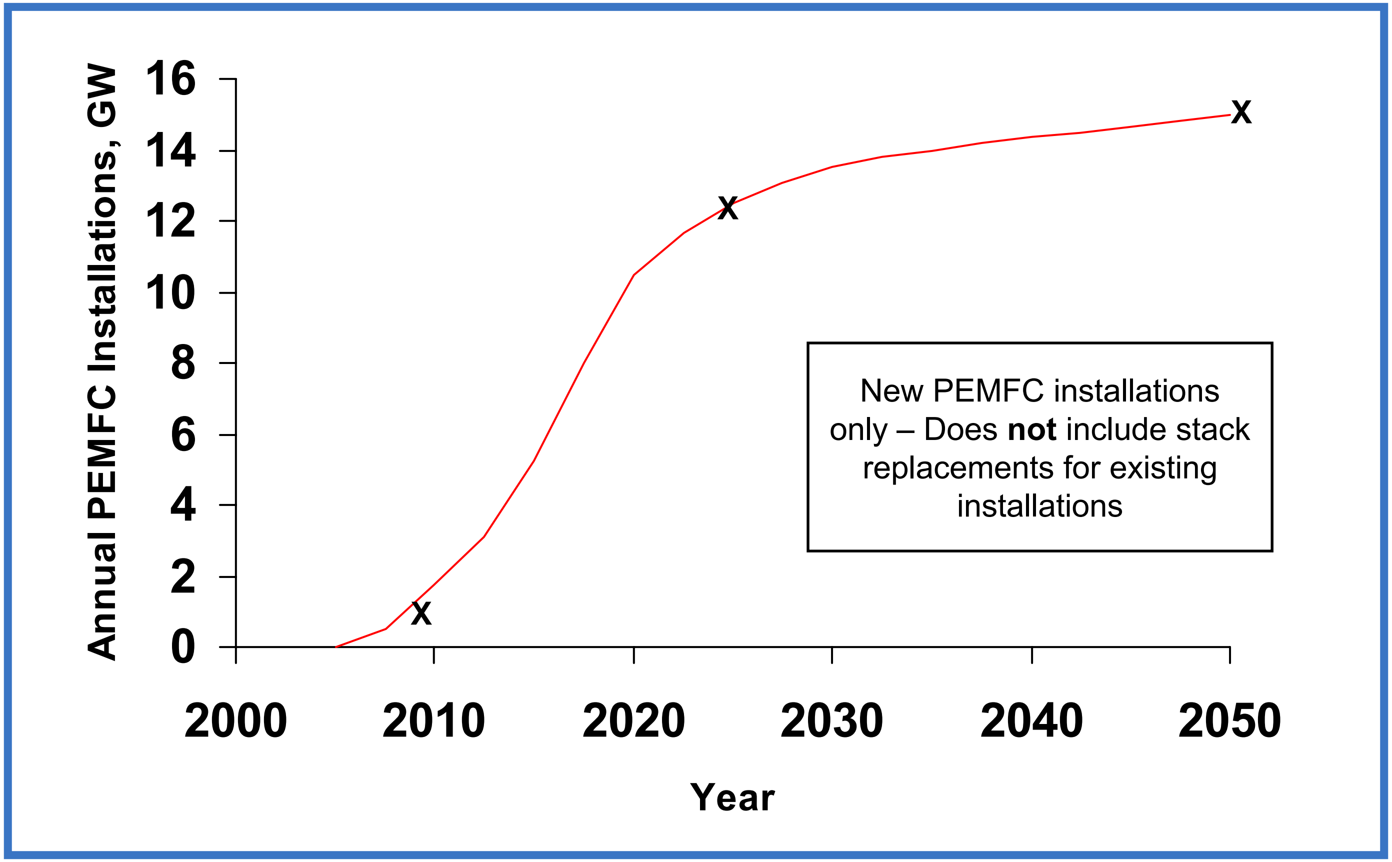
1) Fraction of stationary end uses that are addressable by PEMFC
2) Based on IEA global data for 1999: 3397 GW generation capacity and 15,391 TWh consumption.
3) Typical value for office building application with fuel cell sized to match 50% of peak load – from previous TIAX analyses.
4) Difference between central generation and PEMFC is well within range of uncertainty – no adjustment factor is justified.
5) For a typical end use, the fraction of annual electricity consumption supplied divided by the total consumption
6) Using a 1 MW maximum PEMFC plant size, and approximating end uses requiring >1 MW plants as all industrial applications. Based on end-use splits for the U.S. for 2000 (2002 Buildings Energy Databook, DOE/EERE, Table 1.1.3).

We used the preceding projections to evaluate the stationary PEMFC market for three discrete future years (2010, 2025, and 2050).

Time Period	Total Capacity Additions, GW	Avg. Annual Capacity Additions, GW	Market Adjustment Factor[1]	Projected PEMFC Market Penetration	Avg. Annual PEMFC Market, GW
2000-2010	1158	105	0.50	3% (2010^+)	1.5 (for 2010)
2011-2025	2462	164		15% (2025^+)	12 for (2025)
2026-2050	5020	200			15 (for 2050)

1) Adjusts for portion of market that cannot be addressed by PEMFC. See previous slide.

We generated a reasonable penetration curve based on the 2010, 2025, and 2050 market penetrations.



Appendix

Summary of Previous Studies

Econometric Analyses

Vehicle Forecasts

Stationary Fuel Cell Markets

Platinum Mining

PGMs are mined in only a few locations throughout the world, with more than 90% of platinum production concentrated in South Africa and Russia.

- PGMs are localized in mafic to basalatic magmatic complexes
  - Layered: Bushveld (South Africa), Stillwater (United States), Great Dyke (Zimbabwe)
  - Massive: Norlisk (Russia), Sudbury (Canada)
    - Associated with nickel-copper deposits
- Placer deposits (alluvial)
  - Urals, Alaska

Layered deposits account for 75% of platinum production and resources and massive deposits account for the balance.

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

PGMs

- Platinum
- Palladium
- Rhodium
- Iridium
- Osmium
- Ruthenium

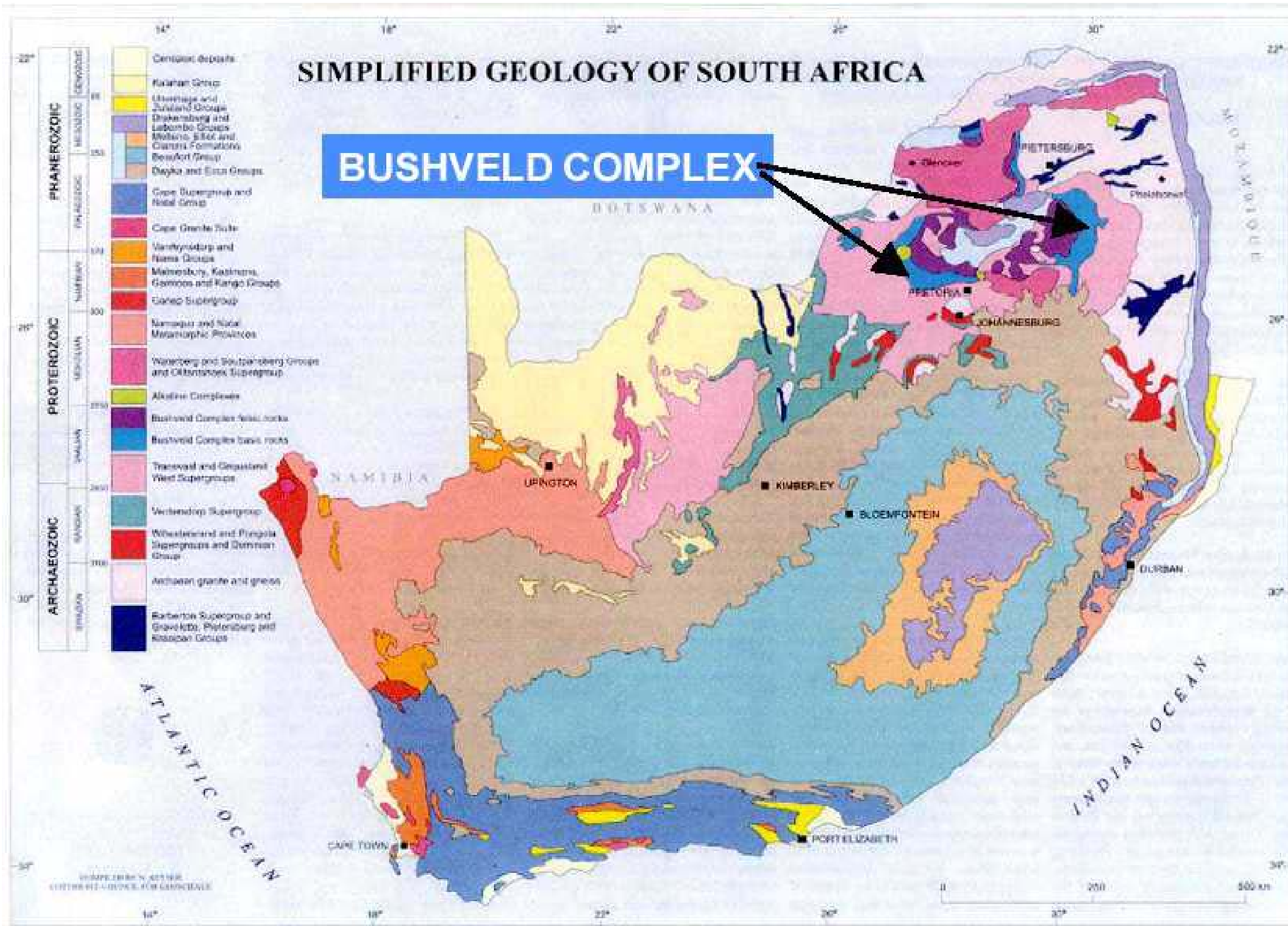
Base Metals

- Nickel
- Chromium
- Copper

Precious Metals

- Gold
- Silver

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



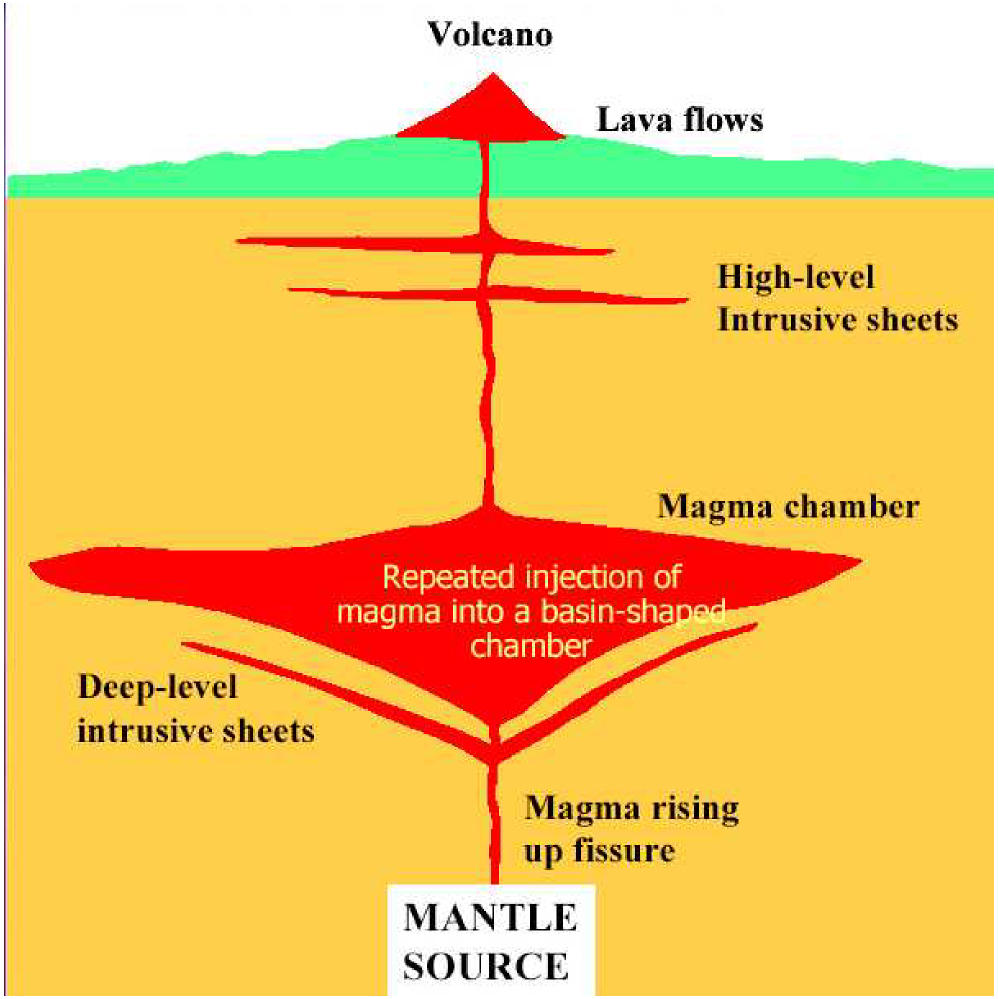
Source: Lonmin Platinum, Geology of the Bushveld Complex, 2003.

The Bushveld Complex contains an estimated 75% of the world's platinum resources.

- The 3 most important PGM mineralized layers are:
  - Merensky Reef
  - UG2 Chromitite layer
  - Platreef
- Mafic portion of the complex is 2 billion years old
- PGM mineralization was discovered in 1924 on the eastern limb by Merensky and Lombard.
- The Complex is the largest layered intrusion in the world:
  - Continuous over 300km
  - Aerial extent of over 65,000km^2 (350 x 185km)
  - Depth of 7 to 9km

The Bushveld Complex was created as the result of repeated injections of magma from a source in the earth's mantle.

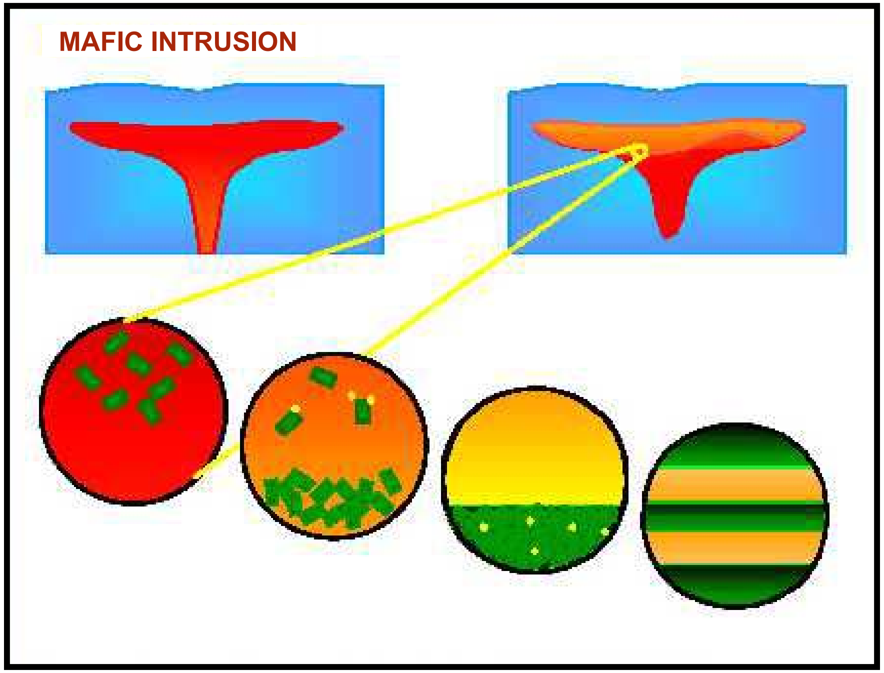
- The pressure from the rising magma created high level pockets that are made accessible through mining.



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

The stratification of the mineral layers in the Bushveld Complex was created by the continual crystallization of magma from within the earth's mantle.

- Enormous volumes of magma developed layers (stratification)
- Minerals crystallized as the temperature fell
- These minerals accumulated into sub-horizontal layers, building up from the base of the magma chamber
- Intermittent replenishment of the chamber by hotter magma led to a repetition of this crystallization sequence, leading to concentration of minerals in layers of chromitite and magnetite

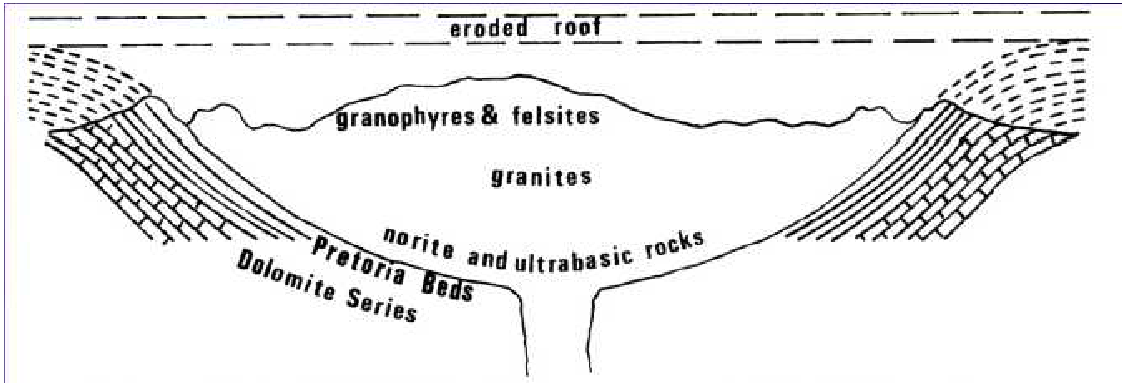


Source: Lonmin Platinum, Geology of the Bushveld Complex, 2003.

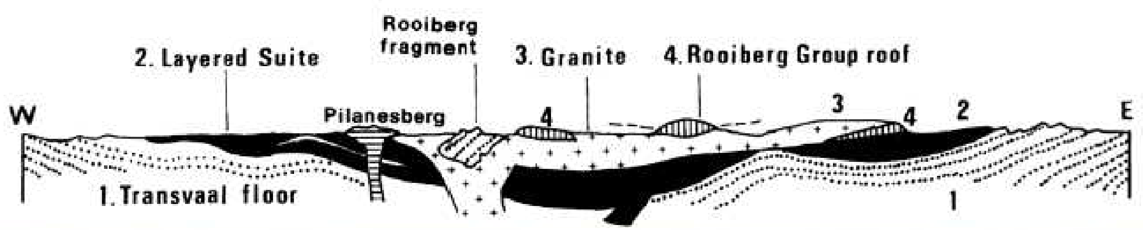
This process led to a 1000 fold increase in PGM concentration.

The Bushveld geology is more complicated than the idealized layered deposit.

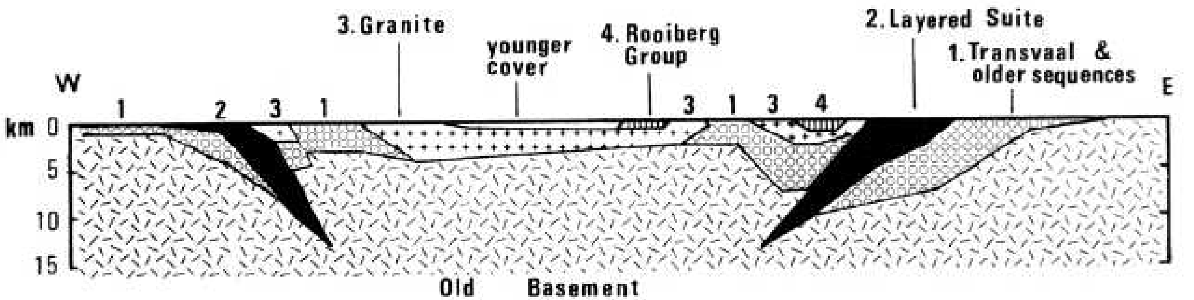
Idealized Platinum section
(Molengraaf—1905)



East–West section
(Du Toit—1954)

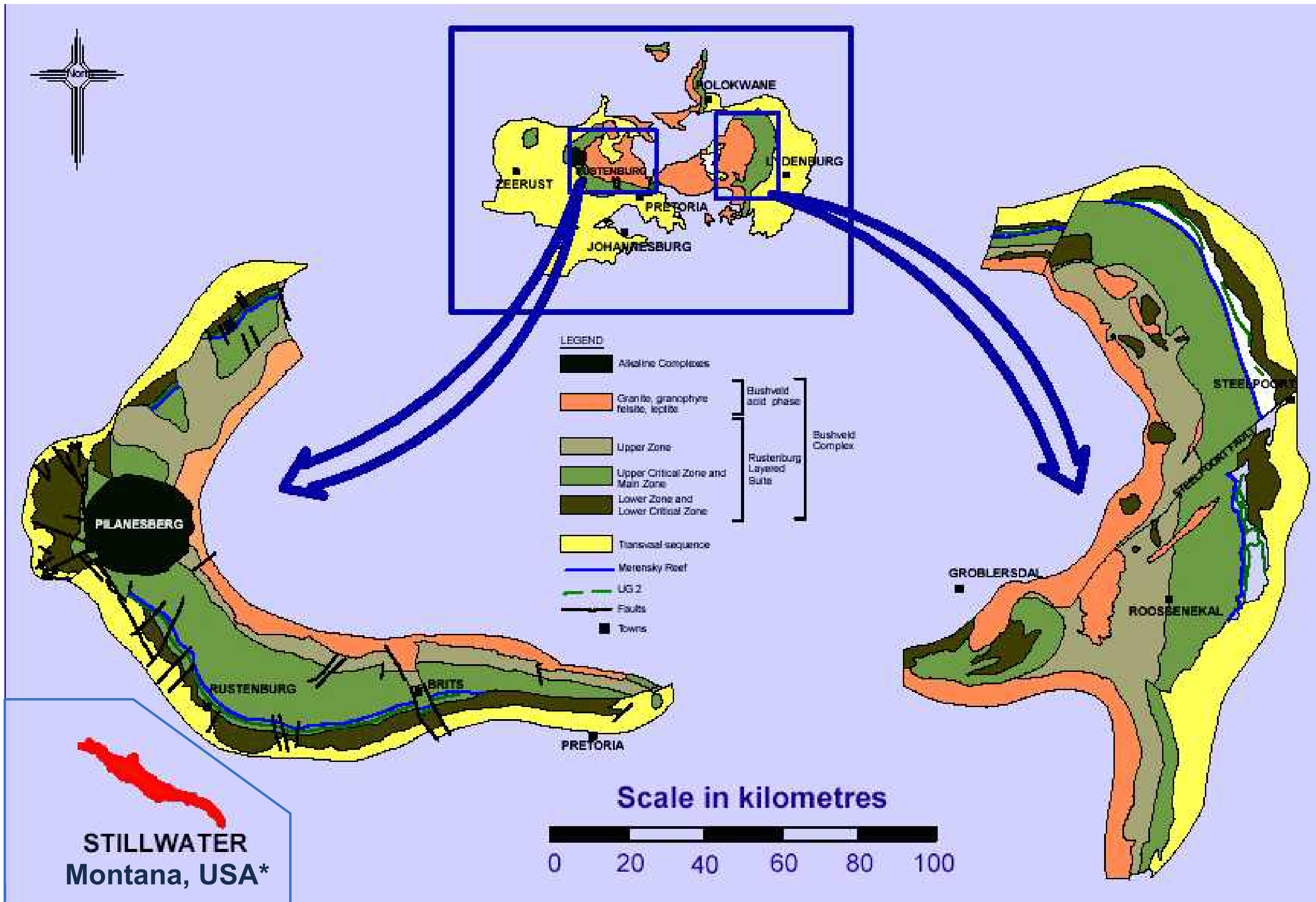


East–West section
(Meyer & De Beer—1954)



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

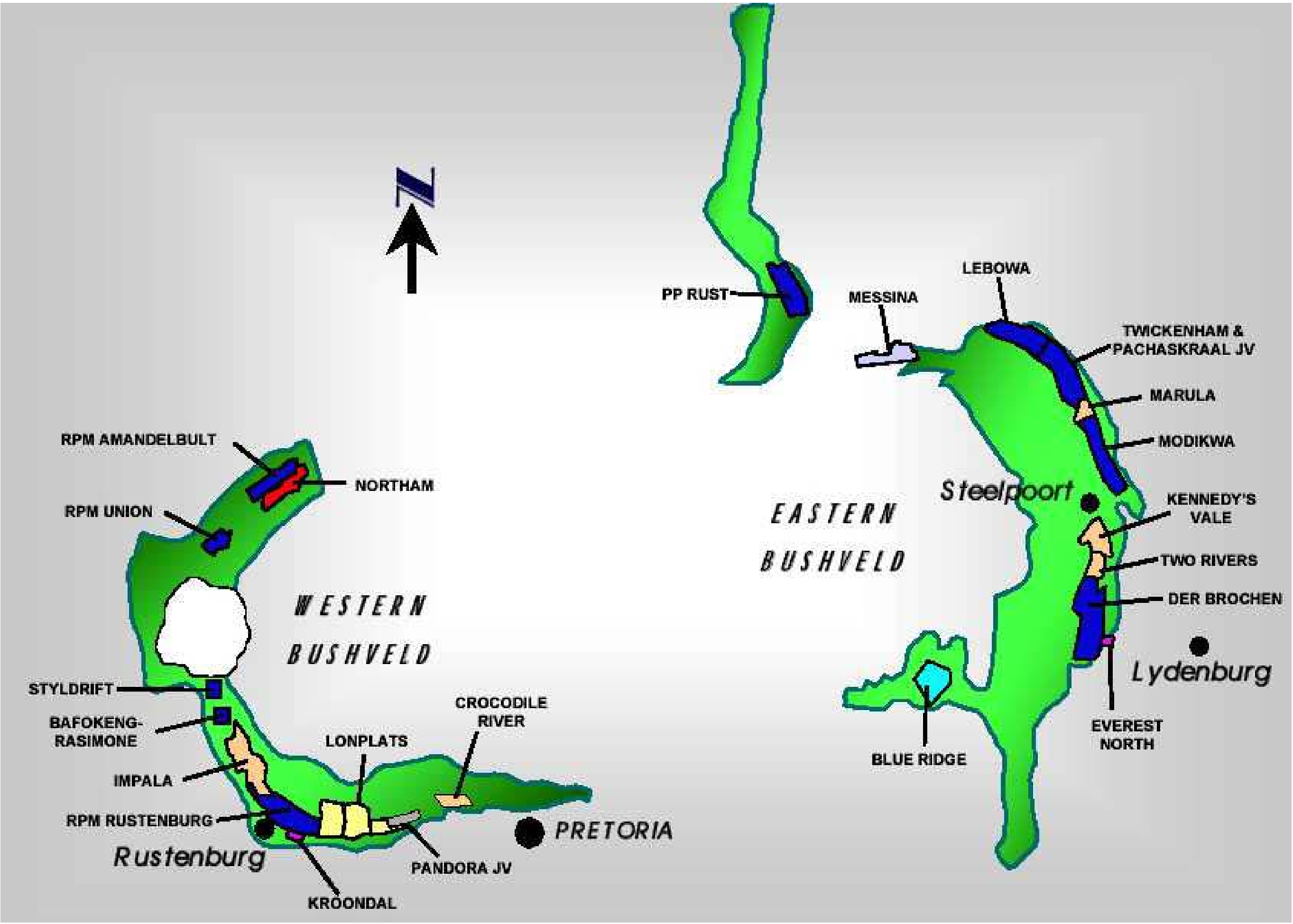
The Complex is divided into an Eastern and Western location



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

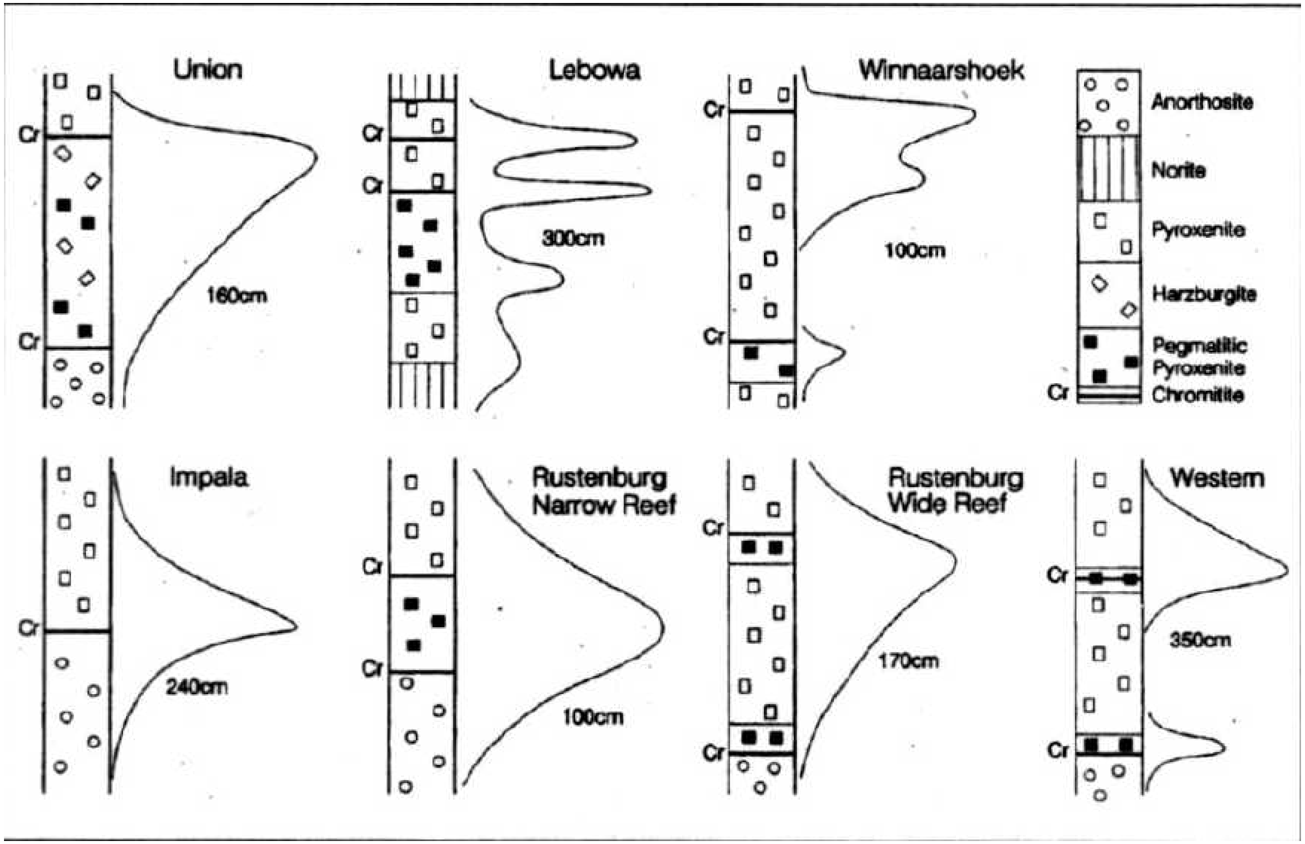
* For size comparison with Bushveld Complex

The Western Bushveld is more heavily developed than the Eastern limb. Open pit mining occurs at PR Rustenberg.



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

Within the layered deposits, concentration profiles vary depending on the local conditions during formation.



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

This data influences site selection and how each deposit is mined.

Platinum dominates the valuable elements of the Merensky, UG2, and Platreef ores.

Percent of PGM and Gold				
Parameter	**Merensky Reef E&W Limbs**	**UG2 Western Limb**	**UG2 Eastern Limb**	**Platreef**
Pt	55–59	46–52	39	44
Pd	25	23–27	39	44
Rh	3–4	7.5–8.5	7	2.7
Ru	6–8	8.5–16	9	3.3
Ir	0.8–1.3	2–3	4	0.9
Os	0.5–1	1	1.5	0.8
Au	4–5	0.6–1.5	0.9	4.9

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

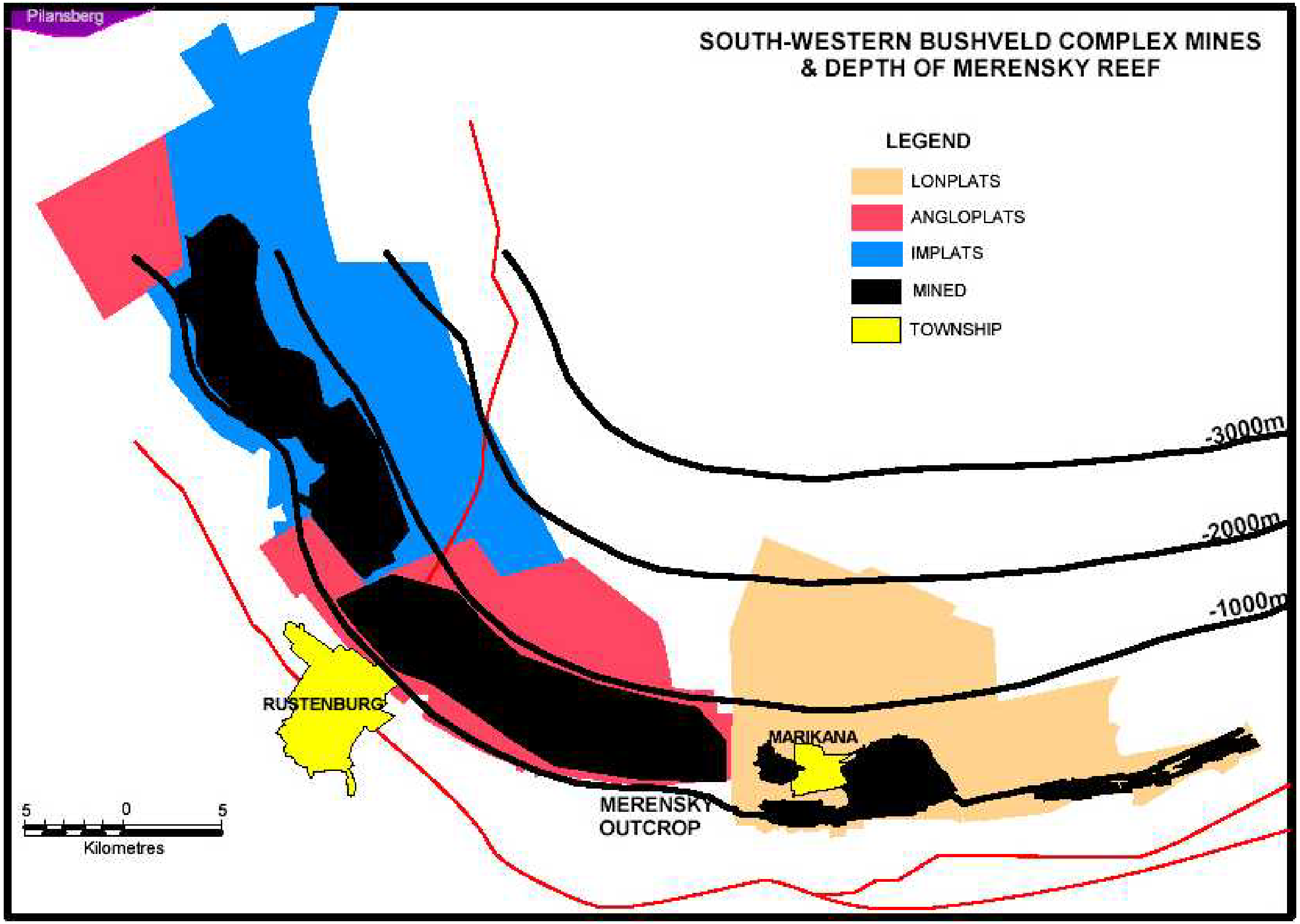
* $\% = (W_{metal_i} / (\Sigma W_{PGMs} + W_{Au})) \times 100$
W = Weight

The composition of the ores varies across the Bushveld Complex.

Parameter	Merensky Reef	UG2	Platreef
Rock Type	Pyroxenite	Chromitite	Pyroxenite
PGE Content	4–10 g/t	4–10 g/t	4–5 g/t
Ni Content	0.13%	0.07%	0.36%
Cu Content	0.08%	0.02%	0.18%
BMS Content	1–10%	<1%	N/A
BMS Grain Size	Up to 10 mm	30 um	N/A
PGM Grain Size	Up to 350 um	Up to 10 um	N/A
Density	3.2 g/cm^2	4 g/cm^2	N/A

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

Currently the shallower deposits, less than 1,000m, are being exploited.



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

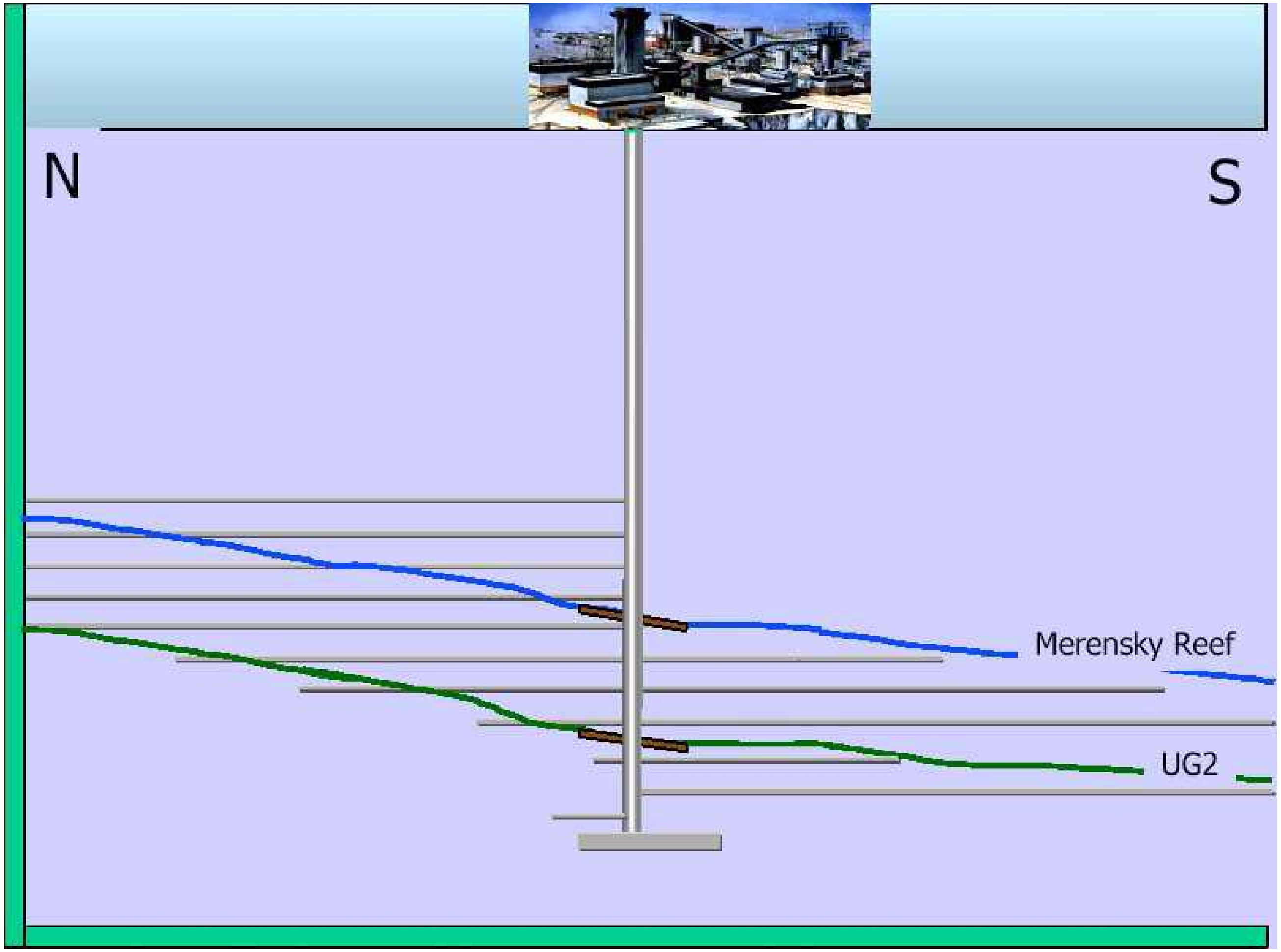
There are three types of mines.

- Incline (trucks can drive in and out)
- Deep shaft
- Open pit

Open Pit Mine—
PR Rustenberg Angloplatinum

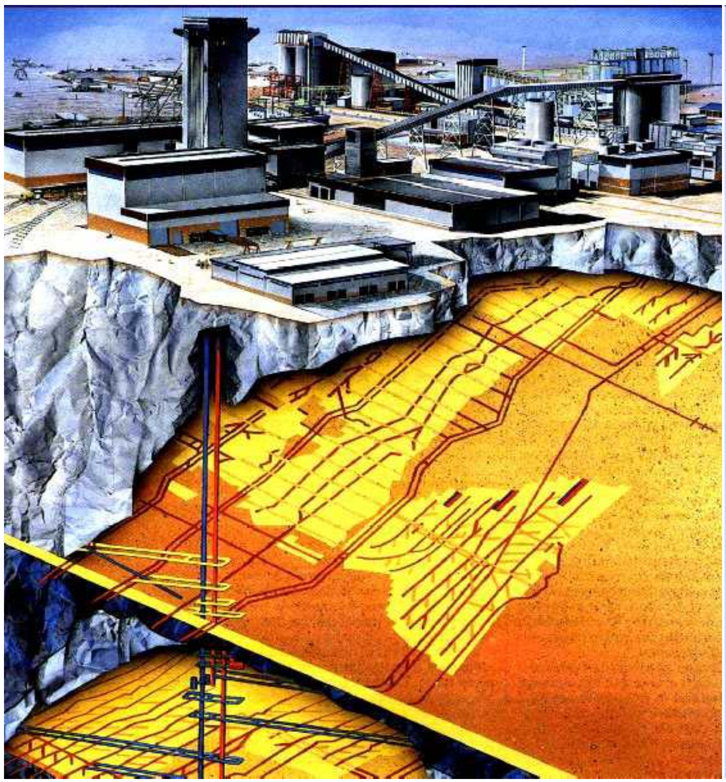
Implats Shaft Mine Head

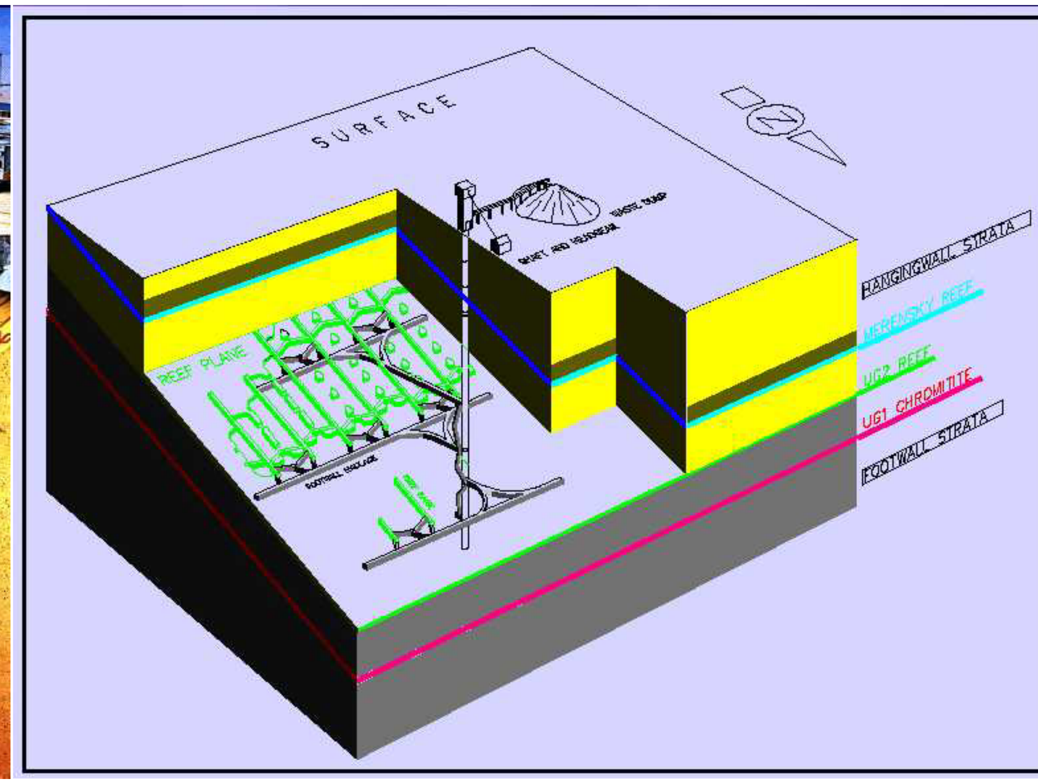
Today, the deepest mine shafts extend 2 km below the surface.



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

A network of shafts spread horizontally from the main shaft to gain access to PGM rich deposits.

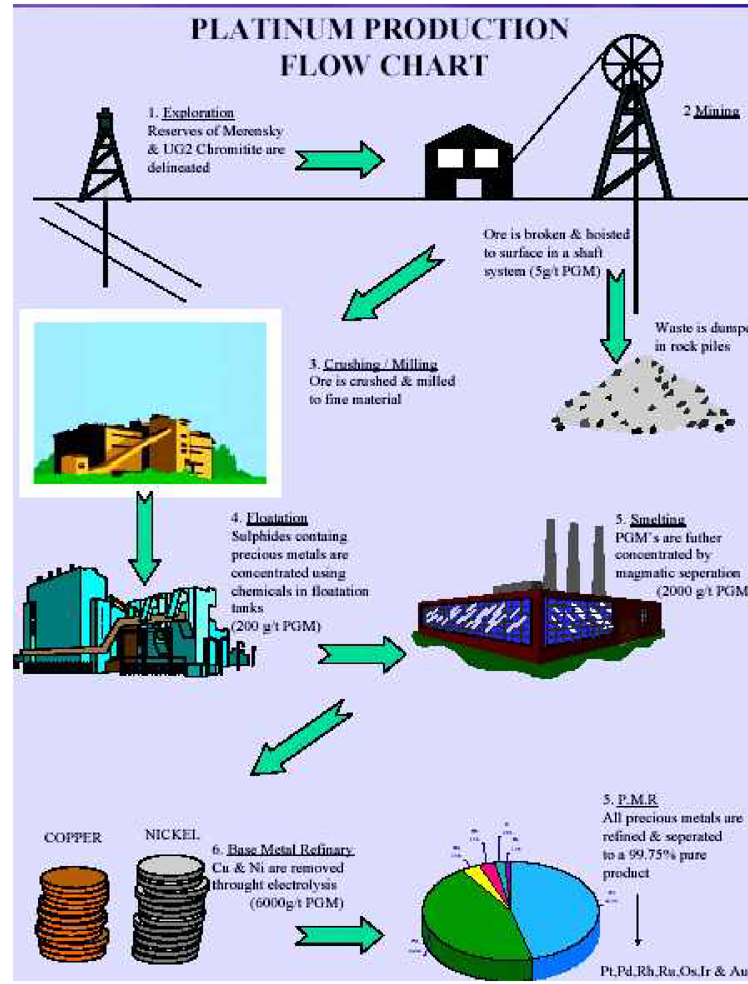




Source: Lonmin Platinum, Geology of the Bushveld Complex, 2003.

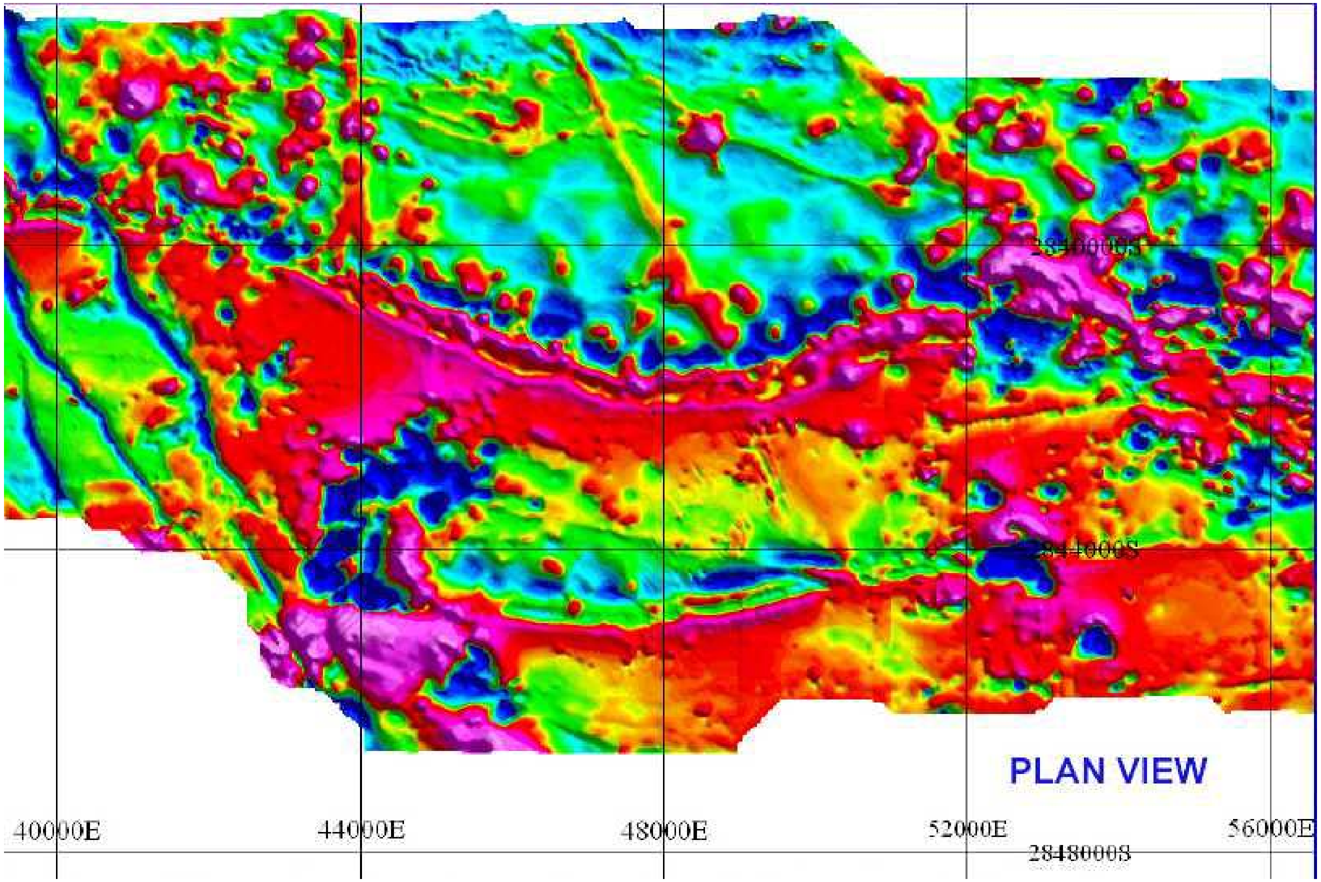
Refining PGMs from the raw ore is a capital intensive process.

1. The area is surveyed for PGM rich deposits.
2. The ore is mined. (5 g/t PGM)
3. The raw ore is crushed and milled.
4. PGM is concentrated through flotation. (200 g/t PGM)
5. PGM is further concentrated through smelting and conversion processes. (2000 g/t PGM)
6. Base metals are removed through electrolysis. (6000 g/t PGM)
7. Precious metals are refined and separated to a 99.75% pure product. (solvent extraction)



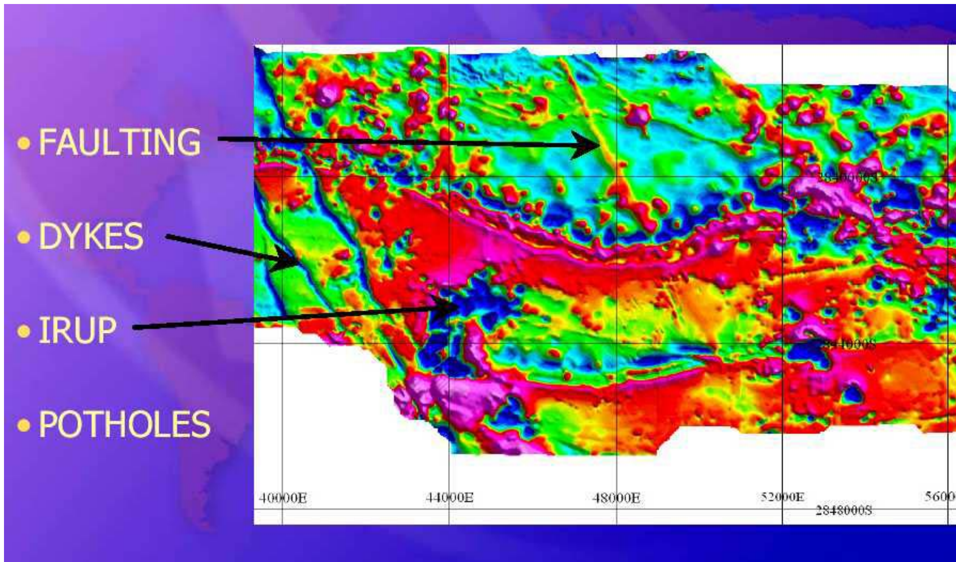
Source: Lonmin Platinum, Geology of the Bushveld Complex, 2003.

Aerial magnetic surveys are used to located PGM rich locations.

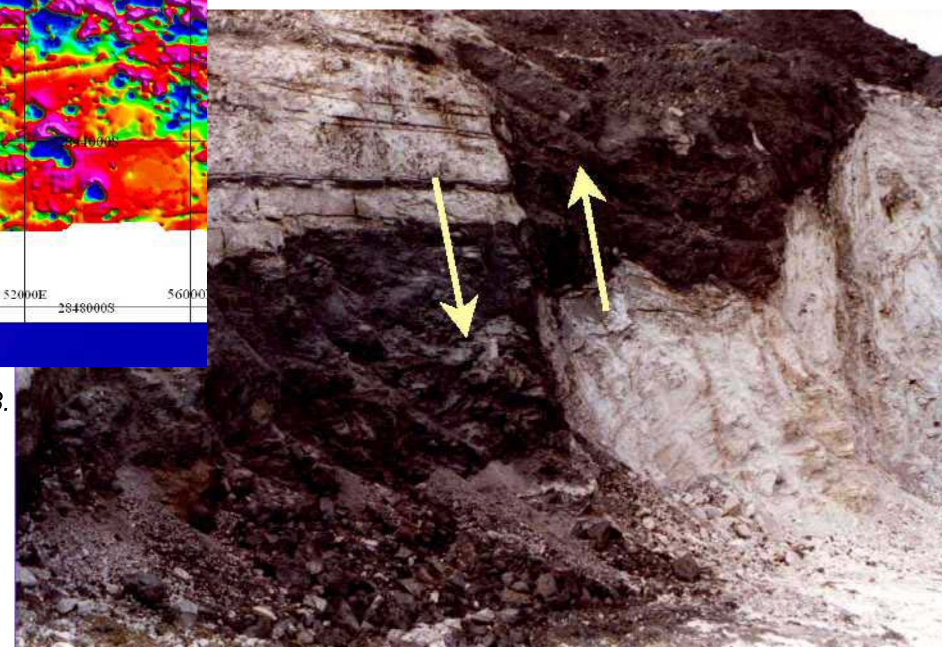


Source: Lonmin Platinum, Geology of the Bushveld Complex, 2003.

Geological disturbances degrade recovery efficiency and uniformity of the deposits.



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

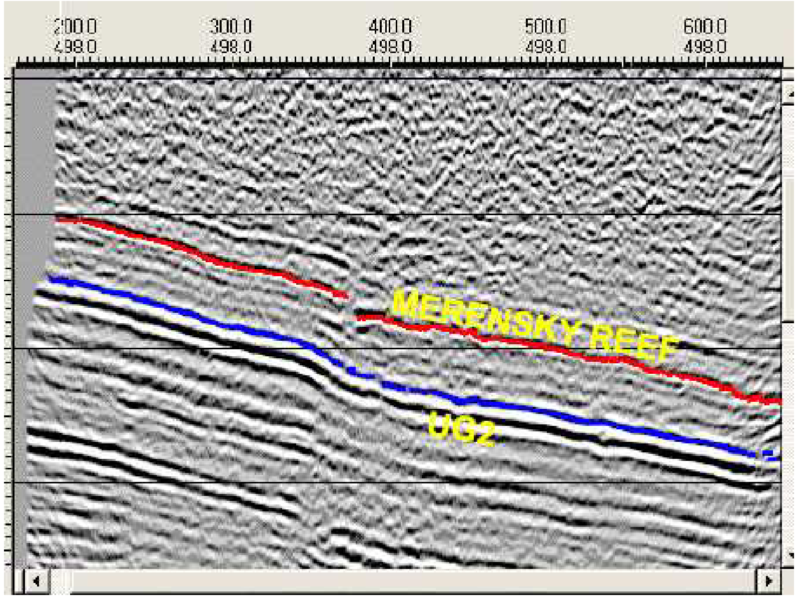


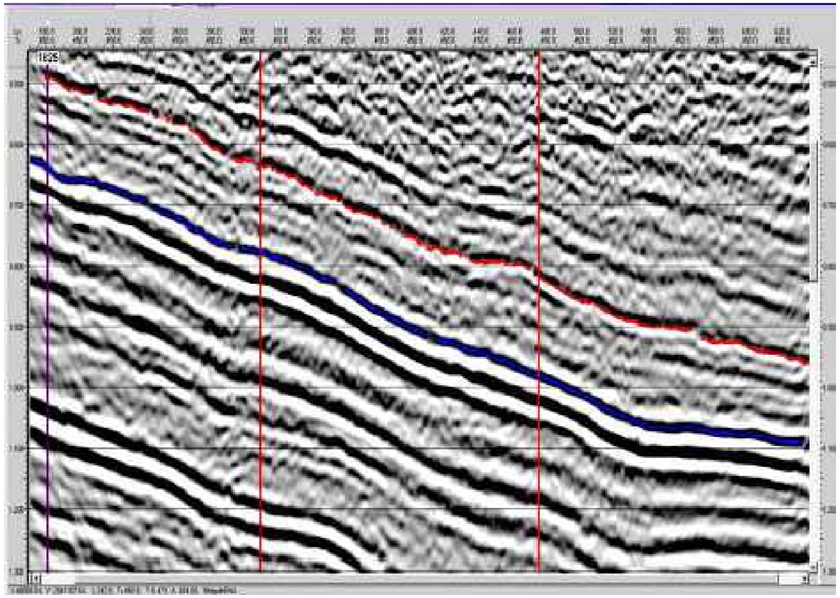
The impact of these disturbances is evident in this photo and magnetic survey.

Potholes are large, saucer shaped deformities that greatly distort the structure of the ore body and cause disruptions to the mining operations.

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

3D seismic surveys are conducted to map the layered structure of a region.





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

Drilling rigs are used to extract core samples from the ground in order to quantify PGM concentrations and actual deposit geology.

Drilling Ring

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

Core Samples

Conveyors and hopper cars are used to extract the loose ore from the mine.

Conveyer belt for ore transportation

Hopper used to remove ore from a shaft mine

In an incline mine, workers can use mechanized drills to prepare the mine face for blasting.

Workers Drilling

Mining technology is moving to reduce the height of equipment in order to reduce the amount of tailings that need to be processed.

Roof Anchor

Excavating Ore

Workers drill into the mine face in preparation for blasting. The height of the shaft is kept to a minimum to reduce the amount of excess material.

Area mapped for blasting in an incline mine

In a shaft mine, drilling is done by hand

Shaft mining relies heavily on manual labor, while the incline mining process is more mechanized.

In open pit mining, large quantities of material are removed to expose the valuable PGM layers.

Non-ore material removed to expose the PGM layer

PGM layer to be processed

In open pit mining, large quantities of material are removed to expose the valuable PGM layers. (continued)

Formation of a New Pit

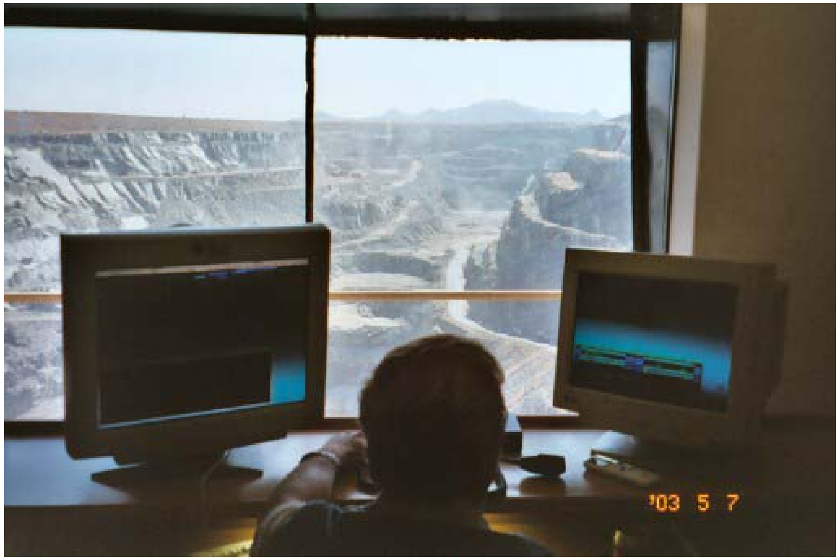
PGM face

Removal of Non-Ore

Sophisticated controls are used to monitor material flow, traffic, and the condition of the equipment.

Truck Used to Haul Ore

Monitoring Station



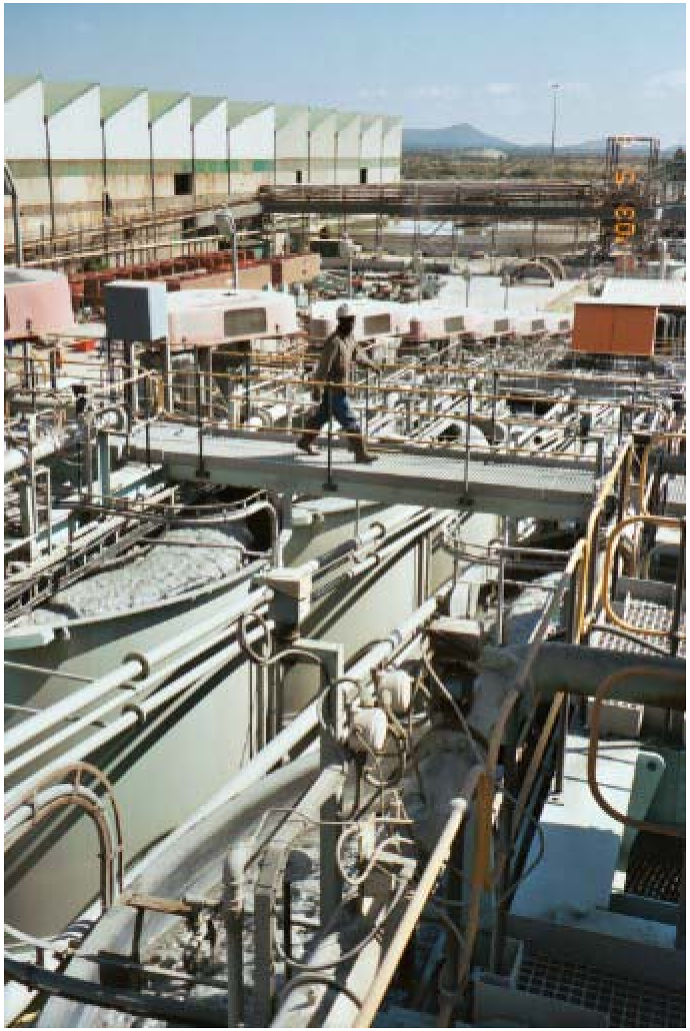
The ore is first crushed and moved into the processing plant. Additional milling forms a fine powder for the flotation separation process.

Crushed Ore

Processing Plant

The powder is then moved through a series of flotation tanks.

- The powder is mixed with water and special reagents.
- Air is pumped through the mixture, causing a PGM rich matte to float to the surface.
- The matte rises over the rim of the tank and flows to the next floatation tank.
- The process continues through several more tanks, each increasing the PGM concentration.



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

Smelters are used to further concentrate the flotation concentrate in the ore and recycled catalytic converter materials.

Impala Smelter

Rowland Shaft, Concentrator, and Smelter

The material is smelted in an electric furnace at temperatures over 1500ºC.

Tapping the smelter

Filling a ladle to transport to the converters

Material is loaded into the converters where air is periodically blown through the molten material to remove the iron and sulfur.

Converters

Cooling the converters

The final two stages of the process involve separation of the metals.

- At the base metals refinery, the base metals are removed using electrolysis techniques.
- The PGMs are refined through a combination of solvent extraction, distillation, and ion exchange techniques.
  - Processes are proprietary.

Water used in the refining process is treated and reused, as it is a precious commodity in South Africa.

Wastewater Treatment Plant

Mining is the major component of platinum production costs.

Parameter	Mining	Commun-ication & Flotation	Smelting & Converting	Base Metal Refining	Precious Metal Refining	Total
Percent of Total Cost	65–75	9–12	6	7	4–5	100
PGE Grade (g/t)	5–6	100–600	640–6000	30–65%	>99.8%	N/A
PGE Recovery %	N/A	80–90	95–98	>99	98–99	75–85
Grade Ration Increase	N/A	30–80	20	75	2	200,000
Processing Time (Days)	N/A	2	7	14	30–150	Up to 170

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