Evaluation of a Platinum Leasing Program for Fuel Cell Vehicles

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Abstract

This paper evaluates the feasibility of a platinum leasing program for future fuel-cell vehicles (FCVs) in the United States. By internalizing the residual value of platinum in the vehicle's upfront cost, a platinum lease may offer cost savings to the consumer. These savings were evaluated by estimating cash flows for several platinum leasing scenarios.

The study concludes that under ideal conditions, the upfront price of platinum could be reduced by 40% compared to a no-lease scenario. However, even small increases in the lease rate greatly reduce these savings. The benefits depend on the extent to which lending risks are minimized, and on the vehicle's platinum loading. They will be greatest during initial stages of market penetration, when the technology is less proven and platinum loadings are highest. To ensure low lease rates, governmental support is likely necessary, both to minimize risk exposure and borrowing costs, and to optimize platinum recovery.

Keywords: Fuel Cell Vehicles; Platinum; Leasing

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Nomenclature

DOE – United States Department of Energy
FCV – Fuel cell vehicle
ICEV – Internal Combustion engine vehicle
g – gram
kW - kiloWatt
L – Total value of lease payments over the vehicle life
MEA – Membrane-electrode assembly
Mg - Megagram
OEM – Original equipment manufacturer, refers to large automobile companies
PEM – Proton Exchange Membrane
PGM – Platinum group Metals
P_0 – the initial value of the platinum in a vehicle
P_{Borrow} – Total cost of capital for a lender to finance a platinum purchase
P_f – Total value of the platinum that is recovered from the vehicle at end-of-life
$P_{Overhead}$ – Total of overhead costs on servicing a lease over the life of a vehicle
P_{Rec} – Cost of recovering platinum from a spent fuel cell stack
Pt – Platinum
r_{Borrow} – the lender's borrowing rate, or weighted average cost of capital
r_{Lease} – The lease rate charged by a lender
r_{Lender} – the lender's discount rate
r_{Op} – The portion of the lease rate that covers operating overhead and credit losses
r_{Price} – The portion of the lease rate that covers price risk
r_{Rec} – The portion of the lease rate that covers platinum recovery costs and losses
RPE – Retail Price Equivalent
Tr Oz – Troy Ounce, 31.1 g
WACC – Weighted average cost of capital

1 Introduction

Future fuel cell vehicles (FCVs) fueled by hydrogen have the potential to reduce the environmental footprint of the transportation sector and to reduce reliance on foreign oil in the United States. Hydrogen can be produced from a portfolio of diverse, domestic resources including fossil, nuclear and renewable energy sources. Fuel cell vehicles operating on hydrogen produced from renewable nuclear, or coal (gasified with carbon sequestration) energy resources would result in near-zero greenhouse gas or criteria pollutant emissions on a well-(or source-)to-wheel basis.

Proton-exchange membrane (PEM) fuel cell technology is currently the leading approach for development and demonstration of FCVs. The highly efficient PEM-based FCVs are projected to have greater than twice the fuel economy of the conventional gasoline internal combustion engine vehicle. With the increased fuel economy and ability to produce hydrogen from a variety of domestic resources, foreign oil demand in the US transportation sector could be nearly eliminated.

A potential barrier to the successful commercialization of FCVs is the cost of the fuel cell system itself, which is projected to have a "factory cost"[1] of between $59/kW and $81/kW [1, 2] based on currently achievable PEM technology scaled up for high-volume manufacturing (i.e., 500,000 units/year). To be competitive with conventional internal combustion engine vehicles (ICEVs), the US Department of Energy (DOE) has targeted a high-volume fuel cell system factory cost of $30/kW by 2015 [3].

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[1] The factory cost includes direct materials and labor costs and factor expenses, but does not include factors such as sales expenses, profit, or general corporate overhead.

Presently, the single largest cost driver for automotive PEM fuel cell systems is the platinum catalyst, which enables the electrochemical reaction inside the fuel cell stack. According to 2008 TIAX factory cost projections, platinum catalyst accounts for about 57% of the fuel cell stack cost and 31% of the system cost [1, 5]. Currently, fuel cell research and development activity is focused heavily on reducing the amount of platinum in the system. This goal may be accomplished by increasing the fuel cell stack power density for a given platinum loading, or by decreasing the stack's platinum loading while maintaining stack power density; these improvements must be realized without sacrificing performance, durability, or substituting with other costly materials.

As an alternative method to reduce the upfront cost of fuel cell systems, this paper evaluates the potential benefits of leasing the platinum catalyst in FCVs. Since platinum is recoverable from the fuel cell stack at the end of the FCV's life, a leasing program would help internalize the platinum's residual value in the vehicle's purchase price. To date, the residual value of end-of-life platinum has not been considered in FCV cost analyses. Similar approaches have been discussed with respect to battery technology in automotive applications such as plug-in hybrid-electric and electric vehicles. Although there are many parallels to these battery-leasing business models, a platinum lease differs insofar as that the platinum is not readily separable from the vehicle itself, and in that it maintains a larger fraction of its initial value at end-of-life. The separability issue could be addressed by leasing the entire fuel cell stack or even the entire vehicle.

In a FCV market where the platinum is leased, a lender – such as a catalyst manufacturer, an automaker, or a financial lending institution – would maintain ownership of the metal throughout the life of the vehicle. The lender would receive a monthly or yearly usage fee from downstream user of the metal. At the end of the vehicle's life, the lender would take physical possession of the metal and sell it to a reprocessor at the current market price of the assayed metal minus cost of extracting and reselling the platinum for a profit.

To be successful, a platinum leasing program would need to:

1.) Provide significant initial savings to the consumer
2.) Establish reliable infrastructure and institutional (i.e., legal) support for end-of-life recovery
3.) Deliver a reasonable risk-adjusted rate of return to the lender

2 Background

Platinum is one of several metals (including palladium, rhodium, ruthenium, etc.) classified as a Platinum Group Metal (PGM). About 70% to 80% of the world's platinum supply of approximately 200 Mg/year comes from South Africa. Russia supplies much of the rest (10% to 25%), with the United States and other countries supplying the balance. An additional 27 Mg per year of platinum is recycled. Recent estimates suggest that worldwide platinum resources (i.e., platinum in the ground) are about 76,000 Mg [5]. Currently, the largest consumer of platinum is the autocatalyst industry (52% of demand), which produces catalyst for the catalytic converters used on ICEVs. Non-automotive industrial users of platinum, such as electronics manufacturers, glass manufacturers, and oil refiners, are the second largest consumers (26%); the jewelry industry consumes much of the balance (21%) [6].

Commercialization of FCVs would dramatically alter the global balance of platinum supply and demand. According to light-duty transportation fleet models developed for the DOE as an adjunct to this study [7], if half of all new vehicles sold in the year 2050 are FCVs, they would become the dominant consumer of platinum. To meet this new demand, annual primary platinum supply (i.e., platinum from the mines) would need to double to 400 Mg/year by 2050; in parallel, secondary supply (i.e., recovery of platinum from spent FCVs and other sources) would also need to reach about 400 Mg/year – a fifteen fold increase over present-day levels. This transition would consume 17% of the known reserves, and would require mines to expand capacity at rates as high as 13 Mg per year (Figure 1)[2]. While this rate of expansion is about twice that at which suppliers have expanded capacity in recent history, discussions with industry representatives indicate that mines have established plans to expand at approximately this rate [8]. Hence, although a rapid transition would require aggressive expansion of the current infrastructure, such a transition would not be fundamentally constrained by either platinum reserves or supply capacity.

A transition to a hydrogen economy is further complicated by the high price volatility of platinum. Platinum metal prices have risen sharply since 2002 when the DOE factory cost targets for fuel cell systems were originally set (Figure 2). In March 2008, the spot price of platinum reached an all time high of about $2,200/tr. oz, driven largely by power shortages and heavy rains flooding mines in South Africa [9]. This spike in prices was not expected. Just a few months prior to the spike, industry analysts were forecasting that the price would not rise much

[2] Primary platinum demand levels off starting in 2040 due to the growing supply of secondary platinum that is recovered from retired fuel cell vehicles.

above $1,600/tr. oz. in 2008 [10, 11] and would remain between $1,050/tr. oz. and $1,475/tr. oz. through early 2010 [12]. These economic forecasts suggest that the current price spike is a transient event[3]. However, this event highlights weaknesses in South Africa's industrial infrastructure that should not be overlooked and which will likely influence future prices if not adequately addressed. More broadly, it highlights the risk associated with depending on just a few regions for the world's platinum supply.

Effective substitutes (notably palladium) for platinum in many industrial and automotive applications, as well as a somewhat elastic jewelry market, provide a long-term check on high platinum price[4]. Perhaps the most important control on platinum prices is substitutes for the FCV *technology itself* in automotive applications. While there are currently no viable substitutes for platinum catalyst in fuel cells, there are viable substitutes for FCVs (e.g., ICEVs, biofueled vehicles, electric vehicles, plug-in hybrid vehicles) that offer similar benefits in terms of reducing petroleum use and/or greenhouse gas emissions. However, once the public and industry has invested in a completely new vehicle and fuel (i.e., hydrogen) infrastructure, substituting for FCVs could have disastrous effects on the economic viability of the new infrastructure. This risk highlights the need for a solid understanding of the stability of platinum price before undertaking such an investment.

If the technical and economic challenges of commercializing FCVs are resolved, this new vehicle technology will represent a large market for platinum producers. Unreasonably high platinum prices would make the technology untenable, even at relatively low loadings. To

[3] As of November 2008, platinum spot prices had dropped to less than $900 per troy ounce
[4] The impact of substitution has already been demonstrated to dramatic effect in the jewelry market, which saw its platinum market share dip from 40% in 2003 to 21% in 2007.

ensure access to this potentially large market, platinum producers would need to align their production capacity to meet the anticipated demand. Once FCV demand requirements are clear, platinum producers would likely implement plans to increase supply to meet that demand at a price where FCV technology remains viable.

In addition to uncertainty over platinum price and supply, it is unclear how much platinum will be required in a FCV. In 2008, fuel cell systems were estimated to require between 0.35 and 0.48 g Pt per kW of rated stack power [1, 2]. For a vehicle with an 80 kW_{net} fuel cell system – the DOE benchmark for a passenger vehicle – the 2008 loading estimate equates to 32 to 45 g of Pt per vehicle[5]. To meet long-term commercialization goals, the DOE has identified a 2015 target of 0.2 g Pt/kW of rated stack power.

To account for uncertainty with respect to current and future estimates of platinum loading, we bracket our analysis using a "high" and a "low" platinum loading scenario based on levels that are +/- 50% of the present-day estimate (Table 1). The "high" scenario assumes a loading of 0.6 g/kW of rated system power (48 g per vehicle). We chose a loading that is higher than present-day estimates to reflect the fact that current state-of-the-art stack technology has not yet been deployed in on-road applications under real-world driving conditions over a ten to fifteen year vehicle life. The "low" scenario assumes a loading of 0.2 g/kW of rated *system* power (16 g per vehicle); this loading level is slightly lower than the 2015 target, which is 0.2 g/kW of *stack* power.

[5] The 2008 system characterization estimates that an 80 kW_{net} system requires a 90.3 kW fuel cell stack. Note the distinction between "rated *stack* power", which reflects the stack power output only; and "rated *system* power", which reflects the stack power less the system's parasitic power requirements

The uncertainty associated with both FCV platinum loadings and platinum prices means that the retail price equivalent (RPE) for platinum in a fuel cell could plausibly range from a few hundred to several thousand dollars. To characterize this uncertainty, the RPE of platinum in a FCV stack was estimated using both current estimates and target loading values over a range of potential platinum prices (Figure 3) and other assumptions summarized in Table 2.

As shown in Figure 3, in a low loading scenario, the platinum RPE seen by the consumer ranges from $500 - $1,600. In the high loading scenario, this range varies from $1,400-$5,000. Hence, even under low loading conditions, the RPE of platinum may be high enough to justify the establishment of a leasing program. Conversely, under the best-case scenario (low platinum price, low loading), leasing offers a far lower value proposition. Under the high loading, high price scenarios, the FCV may not be cost competitive; however, a leasing program could offer an opportunity to defray costs for early adopters and help drive initial commercialization efforts.

3 Platinum Leasing Scenarios

To identify key stakeholders and operational characteristics of a platinum leasing program, a base case and two operational scenarios were considered. The two scenarios vary based on who owns the metal during the life of the vehicle. As is the case with many automotive components, we assume that vehicle original equipment manufacturers (OEMs) will assemble fuel cell systems from a series of upstream component suppliers. Hence, the fuel cell stack's membrane-electrode assembly (MEA), which houses the platinum catalyst would be manufactured by an external supplier. It is not yet clear how this upstream supply chain will be integrated: the MEA could plausibly be assembled by either a catalyst manufacturer (examples include Johnson-

Matthey and Umicore), or by a membrane manufacturer (e.g., Dupont or Asahi). While there could be minor differences in how costs are passed through to the OEM, for the purposes of this analysis, the details of how the upstream suppliers are integrated are immaterial (Figure 4).

- *Base Case:* Platinum is not leased. In this scenario, the consumer purchases the vehicle (including the platinum). At the end of the fuel cell stack life, the vehicle owner recovers a portion of the residual platinum value when the vehicle or stack is sold to a vehicle reclaimer.

- *Scenario 1 ("Platinum Leased to OEM"):* In this scenario, an upstream lender leases the platinum, or a fully manufactured MEA, to the OEM. The lender (i.e., the owner of the platinum) could be a MEA manufacturer, a catalyst fabricator, bank or similar organization. The OEM pays a monthly/annual platinum lease fee to the lender, and sells the vehicle outright to a consumer. At the end of the vehicle's life, the FCV owner would need to return the vehicle to an established FCV reclaimer. At that point the lender would receive payment from the reclaimer for the assayed value of the platinum in the vehicle.

- *Scenario 2 ("Platinum Leased to the Consumer")*: A downstream lender loans platinum directly[6] to the consumer. The consumer purchases (or finances) the vehicle and leases the platinum as part of a single transaction through the car dealership. The lender could be a bank or an automotive financing company. Again, at the end of the vehicle's life, the FCV owner would need to return the vehicle to an established FCV reclaimer, who would then pay the lender for the assayed value of the platinum in the vehicle.

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[6] This "direct" loan to the consumer is not to be confused with "direct" vs "indirect" lenders who currently participate in consumer vehicle financing; in this context, both would be considered "direct".

The base case and the two leasing scenarios each provide likely benefits and challenges to consumers and other organizations in the supply chain. The benefit of the base case is its simplicity. The consumer owns the vehicle and the platinum. Also, the FCV purchase process is identical to the current process for ICEVs, so upstream organizations do not need to implement new systems for financing and managing platinum. At the end of the FCV's life, the owner benefits from the higher value of the vehicle based on the residual value of the platinum. However, this approach provides no relief to the consumer from the likely high initial cost of the FCV. If the value of the platinum in the vehicle is low, it may not impact the consumer's purchase decision, but if the value is high some relief may be necessary. The prospect of benefiting from the higher value of the vehicle in ten or more years at the end of the vehicle's life is unlikely to be considered a significant benefit to most consumers.

The first scenario (i.e., leasing platinum to the OEM) is based on the idea that a lender could purchase platinum (or more likely MEAs or fuel cell stacks containing platinum) and lease it to the OEM at a lower price than if the OEM were to buy the material outright. The lender can charge this lower rate because it has a lower cost of capital and is able to internalize the value of the residual platinum that it will reclaim at the end of the vehicle's life. In this scenario, the FCV purchase price is reduced if the expected lifetime cost of leasing the platinum is less than the OEM's cost of capital. Based on conversations with platinum fabricators and precious metal lenders, this scenario is most viable if a bank or similar organization acts as the lender. Fabricators focus on adding value and selling a product. As a general rule, they are not structured to hold inventory and manage the risks associated with leasing metal. To a bank, on the other hand, the business of leasing metal is comparable to leasing other assets [15, 16]. Two challenges of this scenario are structuring a reliably low lease rate and ensuring that the lender receives the platinum at the end of the FCV's life. Both of these issues are discussed in greater depth below.

Scenario 2 is similar to a standard car loan or lease, where the consumer pays for using the platinum through monthly payments to the platinum lender over the life of the lease. Compared to Scenario 1, this approach results in a larger reduction in the initial cost of the FCV to the consumer, but it would also lead to higher monthly payments for the consumer over the life of the lease. Due to several institutional advantages, it is likely that "captive" financing companies (i.e., financers owned by specific OEMs such as GMAC, Ford Motor Credit, Toyota Financial Services, etc.), as distinguished from banks and credit unions who currently offer automotive financing, would be the dominant lenders. These captive organizations are better positioned to develop and maintain infrastructure that ensures end-of-life recovery than would unaffiliated lenders. Moreover, the captive financers dominate auto lease markets, with over 80% market share [17]. Vehicle financing and payments would be managed in an analogous fashion to present-day automotive financing arrangements. Depending on the length of the platinum lease compared to the car loan/lease, there is potential for separate ownership of the metal and the vehicle. This dual title issue presents a problem any time there is a change of title. While this issue could be managed, it adds a layer of complexity and inconvenience to both the consumer and the lender.

In either of the two lending scenarios, the government could take on the role of the leasing organization. With the ability to offer low-interest loans (or leases) for programs of strategic interest, the government could conceivably offer the reliably low lease terms to the OEM or the consumer. The potential benefits of involving the government in such a leasing program are discussed later in this paper.

4 Pricing a Platinum Lease

The price of a platinum lease must be structured to offer a high enough risk-adjusted rate-of-return to justify the opportunity costs of the lender's capital investment. Based on discussions with stakeholders [15, 16] and analysis of present-day automotive and metal leasing markets, we identified several significant sources of risk exposure and capital investment to the lender that would be priced into a lease:

Expenses:

- **Borrowing Cost of capital (P_{Borrow})**: The cost of capital needed to finance the purchase of catalyst at the current market rate.
- **Operating and Administrative Expenses ($P_{Overhead}$):** Costs associated with the overhead of managing lease contracts.

  Recovery Cost (P_{Rec}): Costs incurred during the process of recovering, disassembling, and extracting the metal content from a spent stack.

Risks:

- **Price Risk (P_f-P_0)**: A hedging cost imposed by the volatility of metal markets. This risk accounts for the possibility that the future metal price (P_f) is less than its purchase price (P_0).

- **Credit Risk:** Costs incurred due to delinquent payments and inadequate securitization of the metal once it has left the lender's possession and before it enters the platinum recovery loop at the end of the stack's life.

In turn, these expenses and risks are counter-balanced by two sources of cash flow:

Cash flow:

- **Lease payments (L)**: The cumulative payments received by the lender over the duration of the lease.
- **Value of platinum at the end-of-life (P_f)**: The value of the platinum that is economically recoverable from the vehicle at end of life:

To recoup the capital investment and any revenue loss due to the risk factors identified above, the lease payments received over the life of the vehicle must cover the difference between the lender's financing costs (P_{Borrow}), overhead costs ($P_{Overhead}$), plus any difference between the final, recovered value of platinum and the initial value at time of purchase:

$$L = P_{Borrow} + P_{Overhead} - [P_f - P_0 - P_{Rec}] \qquad \text{(Eq 1)}$$

To meet this profitability threshold, a prospective lender would fix the lease rate to equal the cost of capital, plus a premium to account for the risk and recovery expenses identified above:

$$r_{Lease} = r_{Borrow} + r_{Rec} + r_{Op} + r_{Price} \qquad \text{(Eq 2)}$$

Where r_{Rec} is the lease premium that accounts for the costs and efficiency of platinum recovery; r_{Op} is the lease premium that accounts for operating expenses and credit loss; and r_{Price} is the lease premium that accounts for price risk. By estimating plausible values for the expenses, risks, and cash flow defined above, the individual terms that determine the lease rate in Equation 2 may be calculated without regard to the actual price of platinum. The subsequent sections will describe the process used to estimate these values and perform sensitivity analysis on individual parameters to quantify the lease rate needed to adjust for the costs and risks that have been identified. Actual calculations were performed using an Excel-based financial spreadsheet model.

Borrowing Cost:

The borrowing cost (r_{Borrow}) for a firm is estimated by calculating the firm's weighted average cost of capital (WACC). This cost varies by firm and by sector, with riskier industries and firms incurring higher borrowing costs; one recent analyses of WACC for different firms is available in [18]. Our analysis considers three different potential lenders, each of whom would need access to capital to finance a leasing operation: the government, a bank, or an automotive finance company. Of these, the federal government, which can issue debt at low rates of interest, has access to the lowest cost of capital. Auto companies have the highest cost of capital, and banks typically borrow at a rate that lies between the two[7]. To reflect this variability, we conduct analysis on platinum leases with borrowing costs ranging from 5% to 12%. While there is no single correct value for these borrowing costs, most firms will lie within this range.

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[7] The recent financial crisis (Fall 2008) has significantly altered the landscape of credit markets, particularly in the banking and automotive sectors. For example, current borrowing costs for both banks and auto companies are much higher than historic levels (9% to 12%, compared to historic levels of 6% to 9%); on the other hand, the federal government is issuing short-term debt at much lower rates of return. For this analysis, we have applied a range of borrowing costs, but in general assume that over the long run, credit markets will revert to their more stable, historic behavior.

Operating Expense and Credit Loss:

"Operating expense" accounts for costs associated with managing a lease; "credit loss" refers to losses incurred by the lender when the borrower defaults on a payment or the metal is lost during the vehicle's life due to factors such as catastrophic failure of a stack that renders the platinum unrecoverable, vehicle theft, or export to other countries.

When an OEM lends directly to a consumer (our "Scenario 2"), these factors are similar to the expenses and risks that an auto lender faces on a vehicle lease. A lender typically requires that a borrower insure against damage or theft (so called "gap" insurance); and in cases of default, the metal owner can recover the vehicle and sell it at auction to recover a portion of the lost cash flow. Because the cost of insurance will be passed on to the borrower, in this analysis we include insurance within expenses due to credit loss.

Lending Scenario 2 could be structured to lease the entire vehicle, the fuel cell stack, or just the constituent metal itself. If the entire vehicle is leased, these credit losses are easier to manage and would likely be similar in magnitude to the magnitude of credit loss seen by current motor credit companies. However, if only the stack or the metal is leased, these losses may be harder to control. The fact that the metal is commingled with all of the other value-added components of a FCV could be problematic, as could the extended, open-ended duration of a platinum lease (upwards of 10 years). This is because it may be hard for a lender to track the metal over longer durations and to recover it if the vehicle owner and the stack/metal owner are two different entities. Theft may also be an issue if the value of the platinum is significant.

In a survey of several automotive credit companies, it was found that the combination of credit loss and operating/administrative expenses averaged between 15% and 20% of total financing revenue on a year-to-year basis [20, 21]. Platinum leasing may present higher credit risk than automobile leasing, although if the entire vehicle or the stack is leased as a single unit, the risk may not be appreciably different. In light of these differences, the combined credit loss and operating expense is assumed to range from 15% to 30%. The higher threshold is roughly 1.5 times the credit loss associated with the high end of current auto leases, and accounts for the potential of heightened credit risk. Substituting this range of values into Equation 12 for borrowing rates that range from 5% to 12% indicates that the operating expense/credit loss term (r_{Op}) adds between 2% and 6% to the lease rate.

In an upstream leasing scenario (our "Scenario 1"), the lender's credit loss risk exposure comes from the possibility that a large borrower (OEM) defaults on lease payments, and from the OEM's lack of control of the borrowed metal. The risks incurred by an "indirect" leasing model, in which an OEM relinquishes control of the metal for an extended period of time, are difficult to characterize because this leasing model lies outside the realm of experience.

The viability of such a leasing scenario hinges on near-universal adoption of platinum lease and both the risk-pooling and recovery infrastructure that these high levels of acceptance would enable. Experience shows that end-of-life recovery for a durable good can be quite effective given a combination of (1) concentrated ownership; (2) high residual value; and (3) appropriate regulatory, legal, and financial framework. For example, recovery rates of platinum in closed loop processes[8] (such as in industrial catalysis applications) are upwards of 98%, (not including process losses) [22, 23]. In this case, recovery is aided by the concentrated ownership and the high residual value of the metal. In an automotive context, regulation has enabled highly efficient (>99%) recovery of car batteries in the United States [24]. More generally, it is estimated that 90% to 95% of end-of-life vehicles are recycled to some extent in the United States; the remaining 5-10% are sold abroad (typically Mexico and Eastern Europe).

In the case of a platinum lease, concentrated interests (i.e., large lenders and large borrowers) would have a legal right to the metal at end-of-life, and a direct financial stake in recovery. As such, an upstream lending scenario lends itself to highly efficient centralized recovery. This recovery process would likely entail returning the vehicle or stack to a centralized collection facility. For example, OEMs might directly collect spent stacks from consumers through their dealership network or vehicle dismantlers by offering a small return fee. Several OEMs are using this type of model to facilitate recovery of nickel-metal hydride batteries in hybrid vehicles [25, 26, 27]. Although this type of "cradle to grave" recovery process is quite different from current end-of-life recovery mechanisms in the United States, in which material is recycled by independent salvagers, recent regulation in the EU and Japan requires OEMs to collect vehicles from consumers at no cost [28].

As one point of reference, if we assume that the borrower (in this case, the OEM), faithfully makes lease payments over an average vehicle lifetime, the lender can absorb fairly significant attrition in the amount of (future, discounted) metal that is actually recovered: for example, to

[8] A closed loop process is typically characterized by (1) material be used for an industrial *process* rather than a consumer durable; and (2) the platinum user owns a substantial amount of catalyst

absorb losses of 30%, lease rates would need to go up by 2.5%. In reality, we would expect attrition to be significantly lower based on prior experience with durable goods. The lease would also need to protect against the credit risk associated with lending to an auto manufacturer; lenders could potentially be shielded from this risk if leases are packaged as an asset-backed security. Doing so would protect the lender's assets from the OEM's bankruptcy risk. On balance, it appears that while the nature of the risk exposure due to credit loss is different for the two leasing scenarios (i.e., upstream lender and downstream lender), it is not clear that one is inherently more risky than the other. As such, without evidence to the contrary, we have assumed credit losses incurred by an upstream lender will lie within the 2% to 6% range that was estimated for a downstream lender.

Platinum Recovery:

The viability of a platinum lease is predicated on the notion that the fuel cell stack retains significant residual value at end-of-life. As such, both leasing scenarios require efficient, low-cost end-of-life recovery operations. The residual value of the platinum recovered at end-of-life is dictated by the following factors:

1.) In-use loss of platinum during the vehicle's operational life.

2.) Process loss of platinum during recovery operations.

3.) Operational costs incurred during recovery

4.) The relative difference between the initial and final platinum price.

With the exception of the relative price difference (#4), which is discussed below (under "Price Risk"), these costs are estimated primarily by analogy with autocatalyst recovery. However there are key differences between fuel cell platinum recovery and autocatalyst platinum recovery that will be highlighted.

The "in-use loss" refers to the fraction of platinum in a new fuel cell stack that is no longer recoverable when the vehicle reaches its end of life. This includes the trace amounts of platinum that may dissolve out of the MEA and exit the system in the exhaust stream. In catalytic converters, platinum is emitted from the vehicle exhaust at a rate of 1 to 3 micrograms per mile; this loss mechanism renders about 10% of the platinum unrecoverable by the end-of-life [22, 23]. In contrast, the primary mechanisms for fuel cell stack degradation are agglomeration of platinum catalyst sites within the MEA, and poisoning of these catalysts with impurities such as carbon monoxide. Neither of these failure mechanisms should affect the recoverability of the platinum itself. Preliminary testing from Los Alamos National Labs indicates that loss of platinum in the effluent water is quite low – estimated at 0.35%, although there is a great deal of uncertainty in these measurements [29]. As such, we estimate the in-use losses in a fuel cell stack to be less than 1% -- significantly lower than that seen in catalytic converters.

End-of-life platinum recovery in FCVs must absorb two major costs: platinum that is physically lost or unrecoverable during the recovery process ("process losses"); and actual costs of the recovery operation. Recovering platinum from a catalytic converter entails a complex process: first, catalytic converters are aggregated from auto salvage yards by collectors; they are then "decanned" to remove the PGM substrate from the steel canister in which is housed; at this point, the substrate is shredded and crushed, then smelted, then refined. The autocatalyst recovery industry is fragmented, and the costs and losses are not tracked particularly closely until the later stages of the supply chain (smelting and refining). However, several sources [30, 22] estimate that a typical salvage yard would expect to sell a catalytic converter for 70% to 75% of the value of the bulk platinum resident (i.e., the autocatalyst supply chain nets about 70% to 75% of the platinum value).

There is reason to believe that for FCVs, more platinum may be economically recoverable, and recovery costs may be lower. A study of the autocatalyst recovery process in Hageluken [30] indicates that during autocatalyst recovery, about 5% of the PGM is lost during the collection stage due to mishandling of material, and "dust losses" that arise from the brittleness of the catalytic material; an additional 5% is lost during the decanning stage – this is a brute force process that is also subject to significant dust losses. During the smelting and refining processes, between 95% and 98% of the material is recoverable. On balance, it is estimated that 12% to 15% of PGM is lost from the time a catalytic converter is removed from a vehicle to the time the catalyst is reprocessed. Given that catalyst salvagers receive \$0.70 to \$0.75 on the dollar for a catalytic converter, we assume that the remaining 15% to 18% of the platinum value reflects the costs of the recovery process and profit margins for the various stakeholders in the supply chain[9].

There are several candidate processes for recovering platinum from a fuel cell. Although these processes are still in the development stages, current analysis suggests that they will be simpler and offer higher yields than autocatalyst recovery. While autocatalysts lose a substantial fraction of material to the "dust losses" discussed above, a fuel cell stack may be removed, shipped, and

[9] In fact, these recovery costs are more accurately represented as a cost per ounce of material, as distinguished from a percentage of the total platinum resident. The reason for this adjustment is that the costs of the recovery process should not float with the market price of the metal. Given that, at the time these estimates were made, platinum costs were on the order of \$1,000 per troy ounce, recovery costs would then range from \$150 to \$180 per ounce.

disassembled largely intact. Once at a recovery plant, the recovery rates for PGM from a fuel cell stack are estimated at somewhere between 95% and 98% [28, 31, 32]. Without real-world experience with a fuel cell recovery supply chain, the extent to which the process losses may be mitigated is unknown. However, if we assume that dust losses are on the order of half that estimated for autocatalysts (i.e., 5% instead of 10%), the total process loss for fuel cell PGM recovery would be 8% to 10%.

The fuel cell platinum recovery process is also likely to be cheaper than that of the autocatalyst due to several factors:

1.) The high concentration of platinum in a fuel cell stack, which decreases the platinum recovery cost per unit mass of platinum recovered. This is because many aspects of the recovery process scale with the number of units to be processed, not with the mass of the recovered material.
2.) The ease of recovery of PGM from a stack relative to that of a catalytic converter. The process of disassembling a fuel cell for recovery is more straightforward than decanning a catalytic converter, which is quite labor intensive [22, 28].
3.) The high residual value of platinum in FCVs and the potential for a more centralized recovery process could pave the way for refiners and collectors to vertically integrate, streamline operations, and drive cost reductions through improved economies of scale [30].

Given these opportunities for improved operational efficiency of fuel cell platinum recovery, but limited real-world experience, platinum recovery costs might range anywhere from a level that is slightly below the low-end for autocatalyst recovery to a level that is significantly lower. Our calculations assume that these costs could plausibly range anywhere from $75 to $150 per troy ounce.

In sum, fuel cell stack recovery process costs plus process losses are estimated to comprise between 13% and 25% of the initial value of the platinum (Table 3). Substituting these estimates into Equation 12 for borrowing costs ranging from 5% to 12% implies that the lease premium for recovery (r_{Rec}) ranges from 1% to 2% on a 10-year lease.

Price Risk:

In present-day metal leasing markets, lease rates are driven by the lender's borrowing cost – a function of metal supply and demand – and by the price risk incurred by market volatility. As such, the metal lease rate is equivalent to the cost of: (1) borrowing money; (2) purchasing metal; (3) selling a forward contract for the metal for settlement upon lease expiration. This type of transaction is used primarily as a hedging instrument by investors or by industrial users who hope to shield themselves from the price risk of owning the metal [15].

For an extended duration (>10 year) platinum lease, a forward market currently does not exist; as a result, the uncertainty is too great to quantify. However, due to the extended lease duration, the price risk is less significant for an automotive platinum lease than a conventional metal lease. This is because the lengthy lease duration allows the lender to receive cash flow throughout the vehicle lifetime based on the metal purchase price. Moreover, this volatility can also work in the lender's favor should the metal value appreciate.

Sensitivity calculations show that a twofold decrease in platinum price over a ten-year vehicle life can be protected against with a 3% lease premium. However, given that the price may also appreciate, we estimate that a lender would set a lower price volatility risk premium; we estimate 1% to 2%.

Total Lease Cost:

Estimates for the different components of the platinum lease (r_{Borrow}, r_{Price}, r_{Op}, and r_{Rec}) are summarized in Table 4. As shown, there is a wide band of uncertainty surrounding how to price a platinum lease. Depending on the lender's ability to minimize risk and overhead expenses, the lease premium (i.e., the level above the firm's borrowing cost) may range anywhere from 4% to upwards of 10%. Depending on the lender's cost of capital, Equation 9 suggests that lease rates could range anywhere from 9% to 22% per year.

5 Results / Analysis

To assess the level of cost savings that could be achieved for FCVs through a leasing program, we conducted analysis of the two leasing scenarios (upstream and downstream lender), with and without government participation. As discussed above, we assume the government can offer lower lease rates than commercial entities due to its low cost of capital and the fact that it may be best-positioned to minimize ownership risks and establish efficient recovery loops.

In general, the two scenarios incur similar types of risks and have similar overhead costs, but can differ markedly depending on the relative cost of capital of the lender and the borrower. As such, our quantitative analysis focuses on this difference in cost of capital. Table 5 summarizes the range of values that were assumed for various borrowers / lenders. In this table, the "Lease Rate" is the sum of cost factors described in Table 4 and "Discount Rate" refers to the *borrower's* cost of capital[10].

To compare the proposed lending scenarios to the base case (in which platinum is purchased outright), the total cost of leasing platinum, on a present-value basis, was compared to the cost of purchasing the metal outright. In general, leasing would be an attractive value proposition if the present value of the platinum lease[11] is less than the purchase price of the metal in the base case scenario.

To illustrate the combinations of lender lease rate and borrower discount rate in which leasing would be attractive to a consumer, the price of a platinum lease relative to the price of purchasing the metal outright was calculated as a function of the lease rate (Figure 5). In this figure, the y-axis represents the relative price (in present dollars) paid by a borrower to lease platinum over a 10-year vehicle life for a given lease rate; the three lines corresponds to different borrower discount rates. Note that in these calculations, the relative platinum price is estimated in relation to the *purchase price* of the metal; it does not account for the residual value that a car owner would be able to recover at end-of-life if he or she sold the vehicle. In effect, in exchange for assuming the risk of owning metal over the life of the vehicle, the lender retains rights to the metal at end-of-life.

[10] Note that to this point, we have only discussed the lender's cost of capital; the borrower's cost of capital will dictate how attractive it is for a potential lessee to borrower money.
[11] The present value of the platinum lease is the sum of the expected future cash flow from leasing the metal.

In Figure 5, a "Relative Platinum Price" of 1.0 (horizontal dashed line) indicates that the present value of the leasing scenario is equal to the initial value of the platinum in the FCV. The lease rate/discount rate combinations that exist below that line indicate that a platinum lease has the potential to reduce the lifetime cost of ownership of the platinum in a FCV. The grey circles indicate plausible ranges of lease rates and borrower discount rates for different lender/borrower combinations. The range of lease rates reflects both variations in the lender's cost of capital (which depends on the specific lender and the market conditions), and uncertainty in the "risk premium".

As shown, the scenarios that involve lending to the consumer (either through the OEM or through a government program) are less favorable due to the relatively low discount rate that has been assumed. However, as discussed previously, this type of lending may prove easier to implement than an arrangement in which the OEM borrows from an upstream financier: direct lending to the consumer ensures reliable end-of-life recovery and it takes advantage of current automotive financing and leasing institutions. In a similar vein, lenders with a higher cost of capital offer less favorable lease terms.

The savings offered by a platinum leasing program vary depending on the vehicle's platinum loading and the price of platinum. For example, the savings to the consumer for the favorable set of lease conditions marked by an "A" in Figure 5[12], which yields a relative platinum price of 0.61 compared to the no-lease scenario, is illustrated in Figure 6. Raising the cost of the lease from 9% to 13% (while holding the borrower discount rate constant at 10%) raises the relative

[12] Lease rate = 9%; borrower discount rate = 10%

platinum price to 0.88 times the “no lease scenario”; the savings for this higher cost lease are shown in Figure 7[13].

Under low-cost lease conditions (Figure 6), the savings for a low-loading scenario range from $170 to $650. Under a high-loading scenario, these savings range between $520 and $1,900. For the mid-range lease case shown in Figure 7, the high-loading case reduces the vehicle purchase price by $200 to $600; the low-loading case offers less than $100 savings.

As these calculations illustrate, the benefits of a platinum leasing program are highly dependent on (a) the price of platinum; (b) the loading assumptions; and (c) the degree to which the lender’s risk exposure can be controlled. Using 2008 DOE platinum loading and price estimates [1][14], savings range from $225 to $730 (or $1.90/kW to $6.00/kW) as lease rates are decreased 12% to 9% for a borrower discount rate of 10%.

Because a platinum leasing program adds a level of complexity and additional transaction costs to the vehicle purchase process, these results suggest that there is a threshold cost below which the overhead and logistics would not justify establishing a leasing program. In a similar vein, it is unlikely that FCVs could be successfully commercialized under the high-loading, high-cost scenario. Even with favorable leasing conditions, the cost of the platinum to the consumer would still be several thousand dollars. Hence, there is an “window” of platinum market conditions and fuel cell technology status within which the vehicle platinum cost is high enough to consider establishing a leasing program, but not so high as to make the technology

[13] This increase in lease rate increases the relative price of platinum to 0.9 times the no-lease case, marked by a “B” in Figure 5.
[14]0.4 g/kW and $1,100/Tr Oz, respectively

impractical. While consumer research would be needed to quantify the upper and lower bounds of this cost savings window, the authors suggest that the bounds may be between $1,000 and $5,000 platinum retail price equivalent. Within this envelope, consumer savings per vehicle would range from $400 to $2,000 under favorable lease conditions.

The base case results illustrated in Figures 5, 6, and 7 reflect the estimated costs for a 10-year lease. While this duration may reflect the expected lifetime of a FCV during early-stage development and deployment, current ICE-based technology lasts significantly longer, with median vehicle lifetime ranging from 12 to 15 years. Extending the lease duration outward has a negligible impact from the lender's perspective, since the lender continues to receive lease payments throughout the life of the vehicle. However, from the borrower's perspective, leasing becomes much less attractive. Figure 8 illustrates the effect of extending the ownership duration from 10 to 15 years for a borrower with a discount rate of 10%. At this discount rate, the longer lease adds 12% to the present value cost of the lease. The lease rate would have to decrease by about 1% to compensate for the additional five years. Conversely, the lease on a shorter duration term of vehicle ownership (due to an accident or other premature end-of-life) could protect the vehicle owner by limiting the duration of their lease payments. This relative impact is inversely proportional to the borrower's discount rate, meaning that a borrower with a lower discount rate would see a greater increase in the value of a lease.

6 Conclusions

Platinum represents a large portion of fuel cell system manufacturing costs. By establishing a platinum leasing program, the end-of-life value of the platinum could be internalized into the manufacturing cost, thereby reducing the initial cost of the system to the consumer. Such a program could be attractive, particularly if high platinum prices and/or high loadings persist.

A key challenge to successfully commercialization of a platinum leasing program is establishing platinum lease rates that are significantly below the borrower's discount rate. The uncertainties associated with a leasing program drive significant risk to the lender, leading to high lease rates. These uncertainties include consumer acceptance, efficiency of end-of-life recovery, average length of vehicle ownership, volatility in platinum metal markets, and risk of default. For a lender to enter into such a program, these risks would need to be better understood and quantified in a real-world context prior to implementing a leasing program on a large scale.

If loss mechanisms are controlled and end-of-life recovery is efficacious, lenders could lease platinum at a rate of 9% to 10%; for a borrower with a 10% discount rate, this would reduce the upfront price of platinum by about 40% compared to a no-lease scenario on a present-value basis. Under these conditions, there is a significant value proposition in platinum leasing – particularly under higher platinum loading or cost scenarios. Using platinum loading and price assumptions that are consistent with the DOE Hydrogen Program's 2008 cost analysis conducted by TIAX and Argonne National Labs[15] [1], such a lease would reduce the specific cost of a fuel cell system by $6/kW (or 10% of the total fuel cell system factory cost projection $59/kW), which translates to a savings of $730 on the purchase price of a vehicle. Over the full range of platinum price and loading assumptions that were examined, these savings range from $1.40/kW to $16/kW, or $170 to $1,900 per vehicle.

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[15] Assumptions are: $1,100/Tr Oz pt (+ $110/Oz prep cost), and 0.4 g/kW. 0.4 g/kW is based on 0.25 mg/cm^2 Pt and a power density of 715 mW/cm^2 for a 90.3 kW stack (gross power).

On the other hand, even a small increase in the risk premium charged by a lender greatly reduces these cost savings. For example, if the lease rate is increased to 13%, the cost reduction offered by leasing platinum is only 12% below that of the no-lease scenario. Using the same 2008 loading and price levels, such a lease would reduce the specific cost by $1.90/kW (or 3% of the total fuel cell system factory cost projection), which translates to a purchase price savings of $230 per vehicle. Over the range of price and loading assumptions that were examined, savings would range from $0.35/kW to $4/kW ($40 to $500 per vehicle). It should be noted that lease rates could be even higher if lenders are not able to secure access to low-cost capital, or if the risk of leasing platinum is determined to lie at the high end of our range of estimates. Under these circumstances – i.e., for lease rates above 12% to 13%, leasing platinum does not offer a value proposition.

These findings highlight the importance of minimizing the risk to the lender. One way to do so is to integrate platinum leasing into a broader fuel cell stack or vehicle lending program. A number of stakeholders – including both car makers and catalyst manufacturers – indicated that while the uncertainties associated with a large-scale platinum leasing program are currently too high for such a program to be effective, a small-scale vehicle or stack leasing program could be a valuable tool in an early-stage FCV commercialization strategy. With just a limited number of vehicles to manage, a small-scale program would reduce the lender's risk exposure and would give valuable real-world experience related to vehicle performance, efficacy of recovery, and risk management. In addition, by focusing on a more modular vehicle component (the stack) or the vehicle itself, a leasing program can leverage institutional knowledge and experience with normal automotive leases.

From the consumer's perspective, this lease would defray the high prices that are likely to prevail during early-stage FCV commercialization. Moreover, depending on how it is implemented, a stack or FCV lease agreement could offer the vehicle owner protection against early stack failure, or allow the owner to trade-up for next-generation versions of what will likely be a rapidly improving technology. These features of a fuel cell lease could make early-stage adoption significantly more attractive to a consumer.

In addition, by concentrating ownership of the metal, a leasing program could greatly enhance the efficacy of vehicle or stack recycling programs – which would be of great societal benefit. In the scenarios examined, a government-financed lease appears to offer both financial and logistical advantages. In addition, discussions with commercial stakeholders suggested that they would be unlikely to take on the levels and investment and risk that such a program would incur. With government involvement, such a program could be plausibly implemented using either an upstream financing model, in which platinum is leased to an OEM; or directly to a consumer in a downstream model. Both of these arrangements incur different types of risk exposure and financing costs. At present, the uncertainty surrounding such a program makes a large-scale platinum leasing program too risky to be effectively implemented. Experience from an initial program to lease the whole FCV or the fuel cell stack is needed to better understand if the benefits of such a program outweigh the implementation risks.

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Figure Captions:

Figure 1: Projected primary platinum demand, FCV sales, and FCVs on the road to achieve 50% market penetration in the year 2050[16] [7].

Figure 2: Yearly average platinum price, 1900 through 2008 [9].

Figure 3: Estimated retail price equivalent (RPE) of platinum in a fuel cell vehicle (Includes markup + catalyst preparation costs) for high and low Pt loading scenarios.

Figure 4: Fuel-Cell Primary and Secondary Supply Chain.

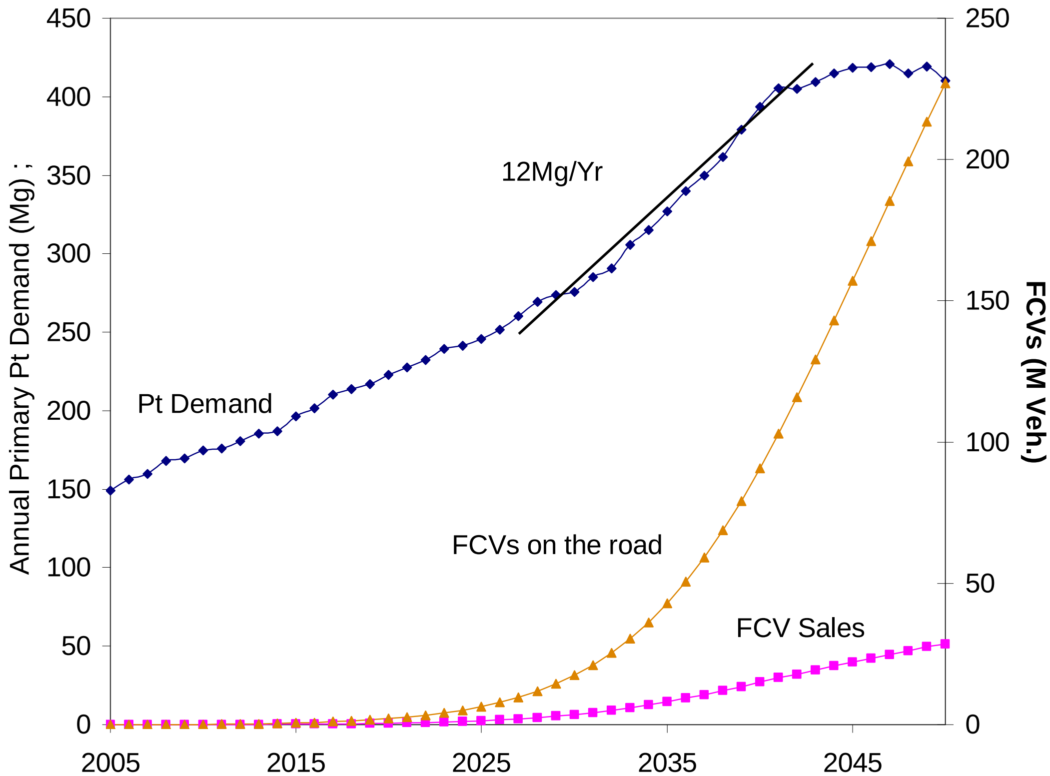
Figure 5: Present Cost of a Platinum Lease as a Function of Lease Rate and Discount Rate, 10-year lease.

Figure 6: Estimated Reduction in Vehicle Purchase Price for favorable lease conditions (Relative Pt Price = 0.61).

Figure 7: Estimated Reduction in Vehicle Purchase Price for mid-range lease conditions (Relative Pt Price = 0.88).

Figure 8: Impact of Vehicle Life on Savings due to Leasing Platinum.

[16] Platinum demand projections assume that platinum loadings remain constant at 0.2 g/kW after 2015.



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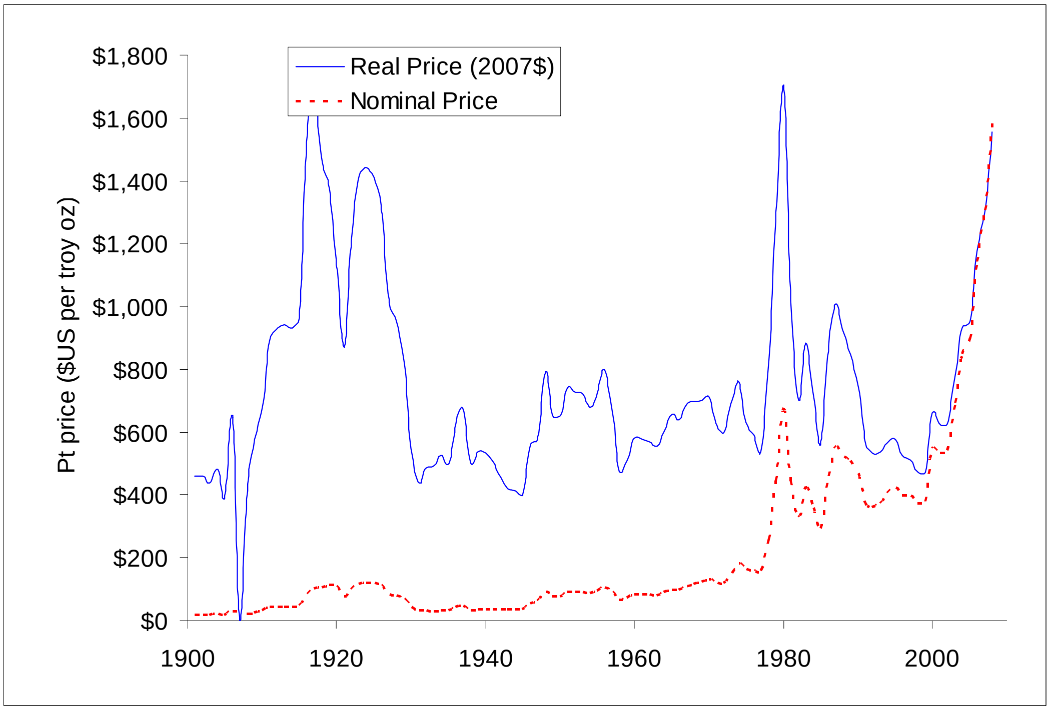

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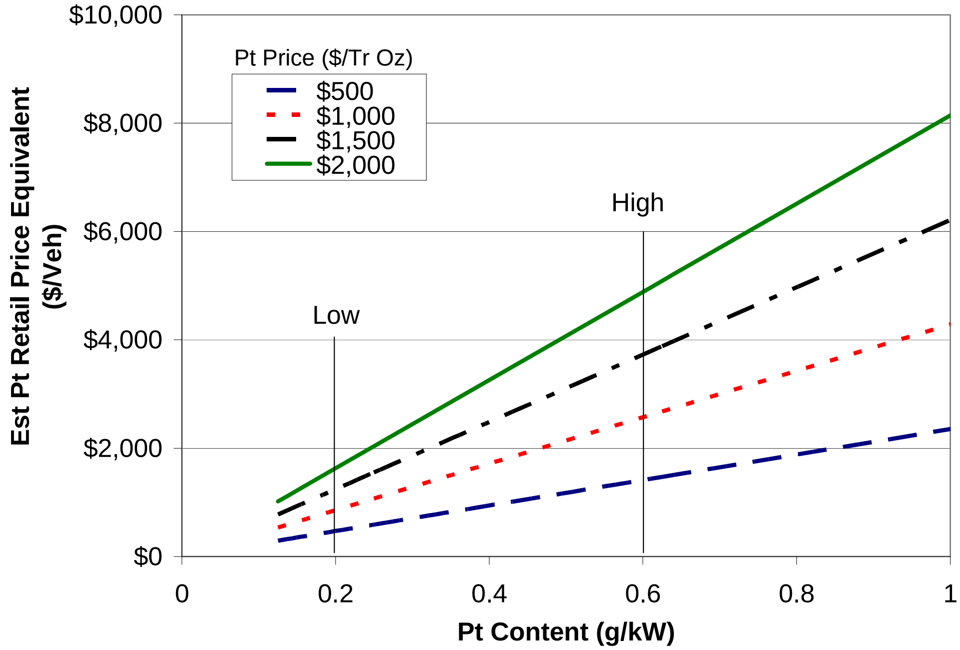

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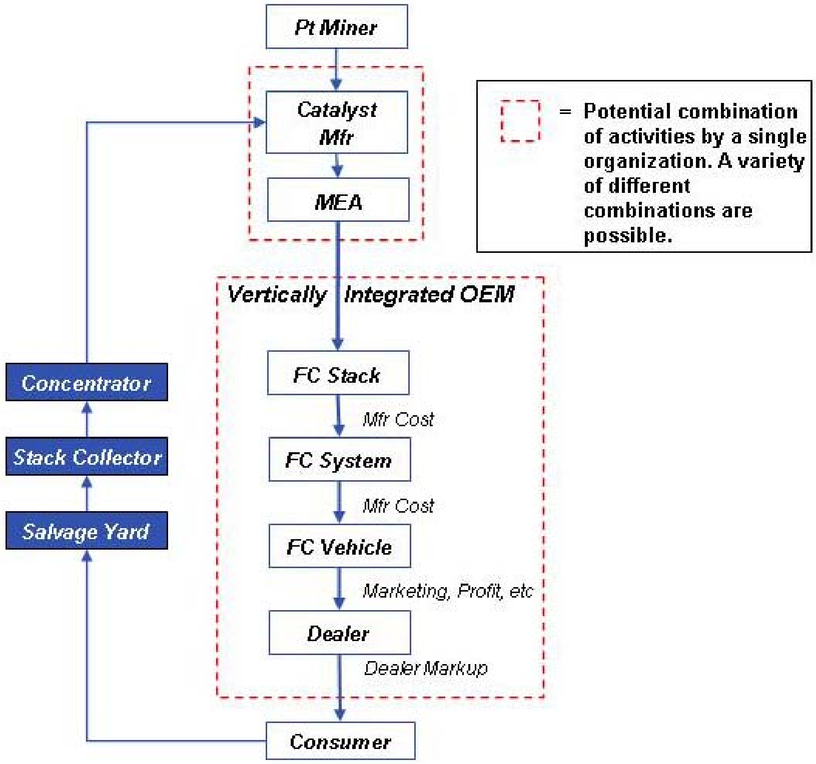

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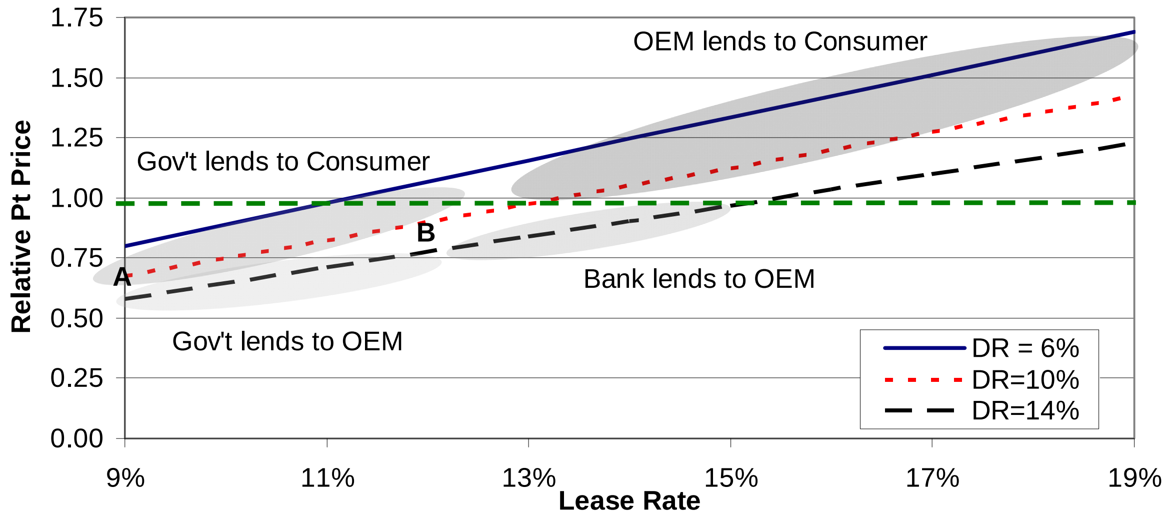

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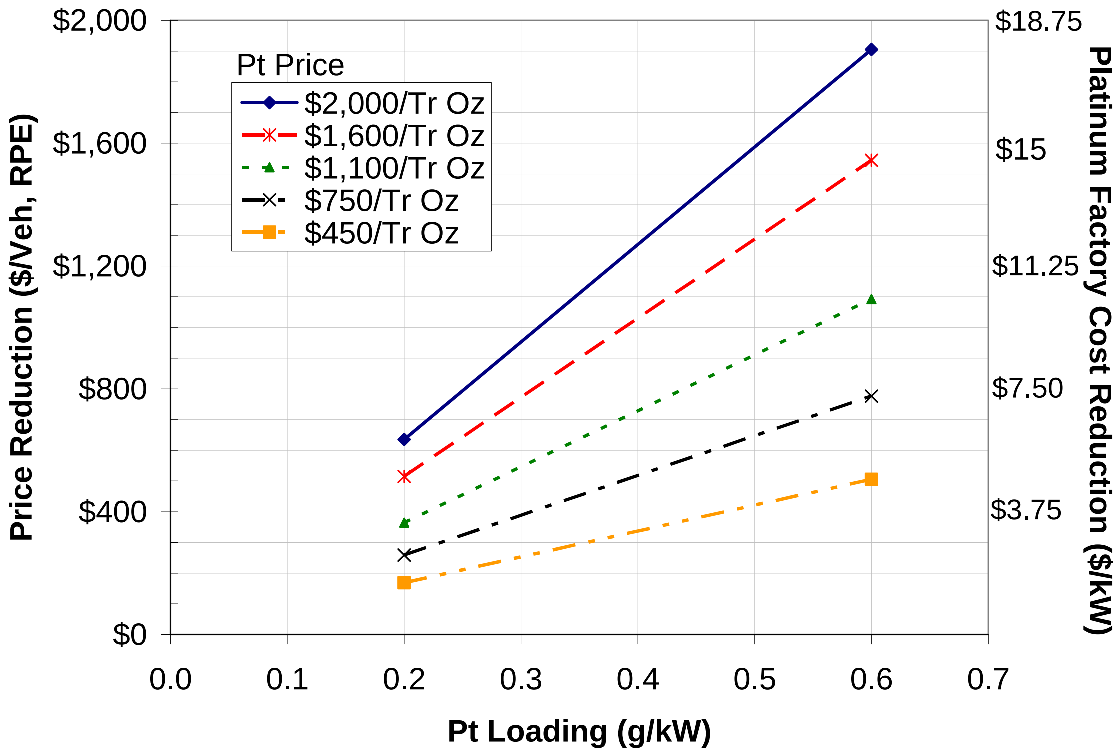

Figure 6: Estimated Reduction in Vehicle Purchase Price for favorable lease conditions (Relative Pt Price = 0.61).

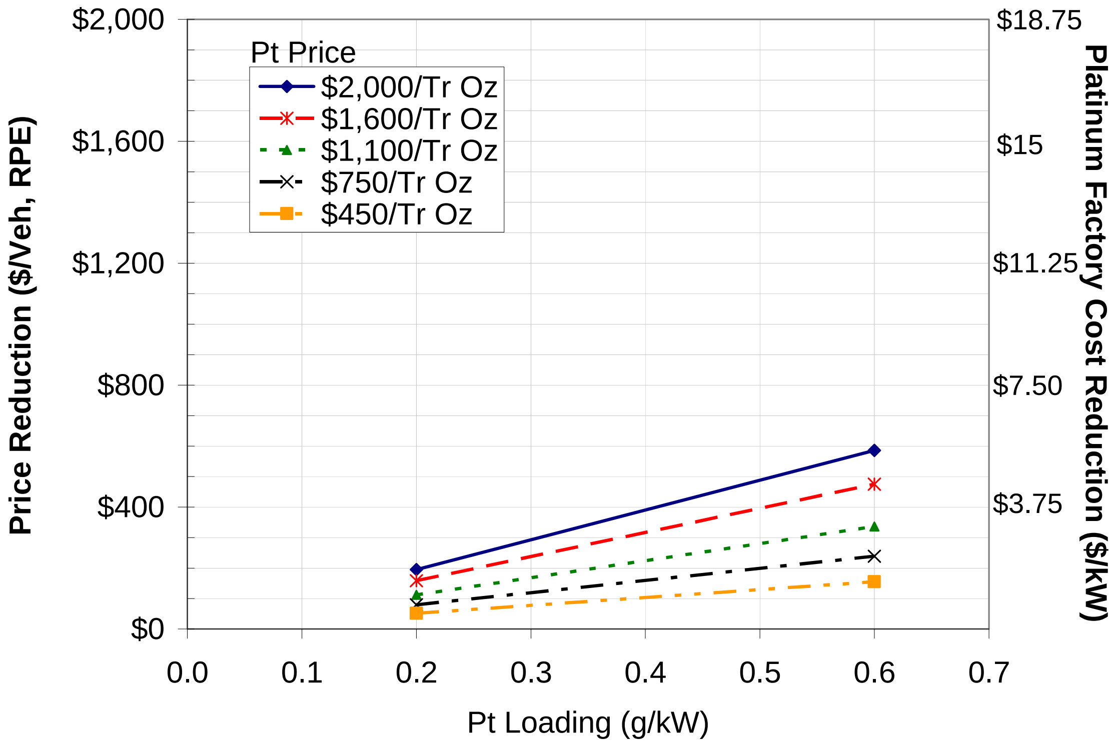

Figure 7: Estimated Reduction in Vehicle Purchase Price for mid-range lease conditions (Relative Pt Price = 0.88).

Figure 8: Impact of Vehicle Life on Savings due to Leasing Platinum.

Table 1: Platinum loading estimates and assumptions

Scenario	Pt Requirement (g/kW, system)	Loading (mg/cm^2)	Power Density (mW/cm^2)
High	0.6	0.40	750
Low	0.2	0.20	1,000

Table 2: Fuel Cell Loading and Cost Assumptions

	Value	Source
Pt Loading	0.2 – 0.6 g/kW	[2,3]
Pt Price	\$450 - \$2000/tr. Oz[a]	[9]
Catalyst Prep. Cost	\$110/tr. oz	[4]
Supply Chain Markup[b]	1.5	[13]
FC Net Power	80 kW_e	[14]

[a] 31.1 g per troy ounce; Range reflects historical fluctuations in constant 2008 US$

[b] Markup includes corporate overhead, distribution, marketing, dealer support/discount, dealer profit, and manufacturer profit. It reflects the difference in between the price paid by an auto maker for platinum catalyst and the retail price equivalent seen by a consumer.

Table 3: Summary of fuel cell stack recovery process

Loss Mechanism	Description	Key differences from autocatalyst recycling	Estimated Cost[a]
In-Use Loss ($\gamma_{Process}$)	Platinum degradation in the fuel cell stack	- Catalyst degradation mechanisms generally do not entail catalyst loss	~1%
Process Loss ($\gamma_{In\text{-}Use}$)	Metal losses in the secondary supply loop	- Higher yield recovery process	8% to 10%
Recovery costs (β)	Cost of recovering metal from end-of-life vehicle	- Higher concentration of platinum and less labor-intensive process reduces unit cost of recovery - Potential for streamlining operations	4% to 9%[b]
Total			13% to 20%

[a] As a fraction of the platinum price, P_0

[b] This estimated cost is expressed in terms of a percentage for the sake of consistency with other values. The low end represents the $75/Troy oz recovery cost as a percentage of platinum at $2,000 per troy ounce; the high end represents the $90/Troy oz recovery cost as a percentage of platinum at $1,000 per troy ounce.

Table 4: Estimate of Lease Rate

Factor	**Annual Lease**	**Range of lease costs reflects…**
Price Risk (r_{Price})	1% - 2%	Decline in the value of Pt between 20% and 40%
Operating Costs (r_{Op})	2% - 6%	Operating costs ranging from 15% to 30% of revenues
Recovery Costs (r_{Rec})	1% - 2%	Recovery costs plus platinum loss ranging from 15% to 25% of the residual Pt value
"Risk Premium"	4% - 10%	Sum of r_{Price}, r_{Op}, and r_{Rec}
Cost of Capital (r_{Borrow})	5% - 12%	Borrowing costs for government vs industry
Total	**9% - 22%**	

Table 5: Estimated lease rate and discount rates for key stakeholders

	Discount Rate (Borrowing)	Lease Rate (Lending)
Consumer	6% - 10%	N/A
OEM / Auto Finance	8% - 12%	12% - 22%
Government	N/A	9% - 15%
Upstream Bank	N/A	10% - 18%