Fuel-Saving Technologies and Facility Conversion: Costs, Benefits, and Incentives

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Patrick Hammett, Michael Flynn, and Maitreya Kathleen Sims
Office for the Study of Automotive Transportation (OSAT)
University of Michigan Transportation Research Institute (UMTRI)
2901 Baxter Road
Ann Arbor, MI 48109-2150

Daniel Luria
Michigan Manufacturing Technology Center
47911 Halyard Rd
Plymouth, MI 48170

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Table of Contents

List of Figures

List of Tables

Executive Summary

We, as others in the industry, predict there will be many more hybrids and advanced diesels sold in the United States in five to eight years from now, maybe as many as 1.8 million more. Given Japan's substantial technological and production lead in hybrids and Europe's lead in smaller displacement diesels, offshore-based automakers and suppliers are likely to make the majority of these vehicles and their powertrain components outside the United States. As a result, the United States stands to lose 38,000 to 207,000 jobs depending on the future U.S. market size of hybrids and passenger diesels. These job losses are characterized either as direct losses of existing jobs or as jobs associated with the overseas production of vehicles that will be sold in the United States to meet a growing market demand. To promote the U.S. production of hybrids and passenger diesels, we propose the development of a policy that would provide all automakers and suppliers—foreign and domestic—with a tooling and equipment investment tax credit to be used to convert existing U.S. facilities toward the production of hybrid and advanced diesel vehicles and components.

In this report, we examine the ramifications of a manufacturer tax credit that covers two-thirds of the tooling and equipment investment costs. Our analysis suggests that such a credit would cost the federal government about $1.1 billion over five years from 2005 to 2009. However, our analysis reveals that such a credit could:

- Position the United States to gain share in the hybrid and advanced diesel markets
- Cause half the powertrain components to be made in the United States rather than abroad, resulting in about 10 percent fewer jobs being lost
- Induce one-quarter of the hybrid and advanced diesel vehicles that would otherwise have been made in Europe and Asia instead to be made here, saving another 15 percent of jobs
- Save at least 27,659 barrels, ,and up to 117,265 barrels, of oil per day, assuming that fuel savings will not be cancelled out by manufacturers backsliding in other vehicle segments
- Recoup federal tax incentives over roughly 10 years through increased revenues and new jobs

We believe such credits would prove attractive to manufacturers despite the allure of offshoring labor because at least two-thirds of the value of vehicles and parts sold in the United States are made in the United States. Because this proposed tax credit policy would be made available to both foreign and domestic manufacturers around the world, we also think it is unlikely to run counter to international trade laws. Our research has convinced us that hybrids and advanced diesels will play a substantial role over the next several decades of the auto industry's evolution. A policy such as that proposed clearly states to the world's automakers and suppliers that the United States is seeking to build its capacity and capability in the vehicles of the future and that the U.S. Treasury is prepared to make it significantly less burdensome to do so.

1.0 Introduction

Raising the fuel efficiency of the U.S. light vehicle fleet is a critical strategic option to reduce both the United States' reliance on foreign oil and greenhouse gas emissions. There are numerous ways to raise fuel efficiency in the U.S. vehicle fleet, including making vehicles smaller, utilizing more lightweight materials, and developing more efficient powertrains[1]. The project reported here examines how we may convert motor vehicles and the industry that produces them to one of those alternatives, higher efficiency powertrains. This is a promising alternative to downsizing in terms of consumer acceptance and to major material substitution in terms of technical uncertainty and cost.

To help ease the transition costs to automakers in moving to a more fuel-efficient fleet, a number of stakeholders have proposed federal manufacturer tax credits. This report is intended to provide analysis that should inform and guide manufacturer incentive policies aimed at increasing U.S. production of fuel-efficient vehicles and the powertrain components they require. We provide such an analysis with the following three key objectives in mind:

- Provide incentives for capital investments in new tooling and equipment to convert existing facilities to the production of more fuel-efficient powertrains
- Benefit both automakers and their suppliers
- Cover a "substantial percentage" of the capital investment for vehicles or components that exceed some minimum performance criteria

We have chosen to focus our research on two specific fuel-efficient powertrain technologies: gas-electric hybrids and advanced diesels (HADs). We selected these technologies for three reasons: 1) both are currently in or close to entering the market, 2) advanced diesel vehicles are widely accepted in the European market, and gas-electric hybrids are gaining acceptance in Europe, Japan, and the United States, and 3) beyond incremental improvements to conventional internal combustion engines (ICEs), most analysts agree these two technologies are the most likely near-term solutions to fuel economy and emissions challenges. They have been proven effective and have fuel infrastructures already in place or readily adaptable for use. We hereafter refer to these hybrids and advanced diesels as HADs.

This report is built on separate but complementary analyses designed to answer two key questions. First, what is the potential opportunity cost to the United States in terms of jobs and economic development associated with the future U.S. market for more HADs? Second, what would be the cost of a policy that would effectively encourage U.S. and foreign auto manufacturers to locate new production at existing U.S. production facilities? To answer the first question, the analysis addressed three issues: (1) the likely size of the U.S. HAD market by 2009 and the probable location of production plants for components and assemblies, (2) economic development associated with location of HAD production plants, and (3) losses to U.S. auto

[1] Loosely defined, the powertrain of a vehicle is a label used to group those components that power a vehicle. Traditionally, powertrain components include the engine, transmission, drive axle, and other supporting power electronic subsystems such as an engine control unit. With new technologies such as gas-electric hybrids, motive power may also be provided by an electric motor, thus broadening this traditional component list.

manufacturing from displaced sales and U.S. production of traditional vehicles and their major powertrain components.

To answer the second question, the analysis also targeted three issues: (1) What are the necessary capital investment requirements for assembly plants and for component suppliers to produce HADs?; (2) Assuming a tax credit is designed to offset a "substantial portion" of this necessary capital investment, how quickly would the federal government recoup its investment through increased tax revenues?; and (3) What are the associated oil savings, assuming that manufacturers do not use the fuel economy improvements from these vehicles to offset relaxed fuel economy performance of other vehicles in their fleets?

2.0 Project Approach and Methodology

To conduct an opportunity cost analysis for the first question and the policy analysis for the second, we needed to complete several tasks. These included:

HAD Opportunity Cost Analysis

- Identify a set of fuel-efficient vehicles and illustrative technologies (Section 3)
- Develop market forecasts and explore their implications by production location forecast (Section 4)
- Identify the high-value add HAD powertrain components and provide estimates of their costs (Section 5)
- Develop estimates of the economic benefits and job effects associated with the production of these new vehicles using a broad U.S. economic model (Section 6)

HAD Policy Cost Analysis

- Estimate the potential oil savings associated with encouraging more fuel-efficient vehicles for our various market forecasts (Section 7)
- Estimate the investment required to convert existing powertrain component and assembly manufacturing facilities into HAD facilities (Section 8)
- Recommend effective policies to encourage U.S.-based HAD production (Section 8)

Brief descriptions and approaches for each of these tasks follow.

2.1 Opportunity Cost Analysis – Key Tasks

Fuel-Efficient Powertrains. In considering several fuel-saving technology alternatives, we have chosen to examine hybrids and advanced diesels as illustrative examples. Thus, our intent is not to pick technology winners or suggest that other fuel-saving technologies are not worthy of manufacturer tax credit incentives to encourage their development. Rather, we believe these technologies provide a useful framework for examining the challenges and the potential opportunity gains (or losses) to the U.S. economy associated with a shift toward more fuel-efficient technologies, particularly if the high value-added components and vehicles themselves are produced outside the United States.

Market Forecasts. To explore the potential economic impacts of increased demand for HADs, we develop a baseline and two additional market configurations, or market size and segmentation scenarios, for passenger cars and light trucks, and situate them in calendar year 2009. We believe 2009 allows for a useful analysis. By then, HADs are projected to experience significant increases in demand and availability, though their actual levels still could vary widely due to cost challenges and consumer demand uncertainties. In addition, we believe our analysis results for 2009 would be similar if such consumer purchasing shifts occur any time between 2009 and 2012.

Our 2009 baseline forecast takes into account our projections for the overall economy, as well as a variety of automotive specific factors including underlying consumer demand, shifts in product demand, new product introduction schedules, market shifts among the various manufacturers, and the most likely sales forecast of The Planning Edge.[2] In terms of sales, our 2009 baseline scenario projects that HADs will constitute approximately 2.7 percent of the light vehicle market, up from about 0.5 percent in 2003. This baseline scenario is largely driven by the manufacturers' interest and risk assessment in introducing various HAD technologies to meet their perceived expectation of consumer demand, or as part of their strategy for meeting and/or precluding additional regulatory requirements, such as higher Corporate Average Fuel Economy (CAFE) standards.

Our two additional market forecasts for 2009, which we label as Consumer Shift Low and Consumer Shift High, represent plausible, yet significant shifts in consumer behavior. The Consumer Shift Low forecasts an increase in the market share for hybrids and advanced diesels by approximately 2 percent each or nearly 7 percent total (from 2.7 percent baseline). Our third scenario involves increasing HAD market share another 2 percent each to approximately 11 percent. Any number of factors could account for these consumer shifts. Among them are higher sustained oil prices, greater consumer enthusiasm, or more desirable prices relative to other vehicles. HADs could even become style-lead vehicles, as happened with minivans and SUVs in their early stages.

Production Location. Based on our market forecasts by vehicle model, we also forecast the likely supplier production locations for the key HAD components we studied. These component location forecasts are largely based on where the full vehicles are likely to be assembled and on any historical sourcing patterns for the powertrain components. For example, if we forecast the addition of a hybrid option to a particular model that is currently assembled outside the United States and uses hybrid components produced outside the United States, we assume that this supplier location pattern will not likely change. In generating our production location forecasts, we classify by United States, Canada, Mexico, or Other (e.g., Europe, Japan, etc.).

[2] The Planning Edge is an automotive consultancy that maintains a database and forecasting tool for both U.S. production and sales. It is used by many automotive suppliers and has proved quite accurate. We rely on The Planning Edge forecast rather than developing some arithmetical consensus because its market forecasts can be tied to forecasts of production locations. In addition, one of the project's researchers, Alan Baum, is in charge of maintaining that database for The Planning Edge.

Our production location forecasts also are influenced by existing manufacturing operations. The Japanese manufacturers have led the way with sales of gas-electric hybrid models such as Toyota's Prius and Honda's Civic hybrid, while European manufacturers like PSA Peugeot Citroën and Volkswagen have led the way with advanced diesel models in Europe. As a result, most of the major gas-electric hybrid and advanced diesel components are produced outside the United States.

For example, hybrid components are largely produced in Japan by such companies as Aisin, Denso, and Panasonic. Advanced diesel components also are largely produced outside the United States by suppliers such as Bosch, Faurecia, and Siemens. Even suppliers with a large U.S. manufacturing capability, such as Delphi, produce the majority of their advanced diesel components outside the United States for European-assembled vehicles.

We should note that there is some U.S. production capability for advanced diesel components to support modest volumes of diesel exports (e.g., by DaimlerChrysler) and for medium- and heavy-duty trucks. It is an open question whether this production forms a basis for components for light-duty vehicles, given the largely differing manufacturers in the two vehicle markets.

Component Costs. For our opportunity-cost analysis, we obtained estimates for various component unit costs through a literature review and interviews. We interviewed manufacturers and a range of suppliers, making every effort to secure responses from suppliers that are major producers of key HAD components and systems. Altogether we were able to conduct face-to-face interviews and telephone surveys with 12 individuals representing 12 companies: four manufacturers, seven suppliers, and one forecasting/consulting firm.[3] We compared our interview findings to other sources to identify representative estimates of key hybrid and advanced diesel powertrain components.

We also explored various factors that could affect HAD component cost estimates. These include the powertrain configuration: the number of cylinders and displacement; the amount of electric power and system architecture for hybrids; planning volumes; whether the vehicle is a passenger car or a light truck; and, in the case of advanced diesels, which emission bin standard it meets. While these factors clearly are not all-inclusive, they provide a useful range for analysis purposes.

Economic Opportunity Gains/Losses. We then input our market forecasts, vehicle and component cost data, and production location forecasts into a broader economic model of the U.S. economy, known as the REMI[4] model. This model may be used to track economic effects for the total U.S. economy, and to explore them by region and industry, permitting an assessment of the direct and indirect economic effects of lost U.S. production of conventional gasoline

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[3] We also had more limited and focused conversations with experts who either would not, or could not, agree to a full interview.

[4] The model is built, maintained, and updated by Regional Economic Models, Inc. of Amherst, MA, under the direction of University of Massachusetts economics professor George Treyz. The project team wishes to acknowledge the contribution of REMI staffer Adam Cooper, who spent countless hours tweaking the model to incorporate our incessant changes as the project progressed.

internal combustion engines (ICEs). The model permits estimating the income, employment by industry classification, and fiscal effects of market shifts to HADs.

In assessing the potential opportunity gains and losses associated with a shift toward greater HAD vehicles, we examine the effects of both the addition of new vehicle components (such as hybrid batteries and electric drive motors), and the displacement of other existing powertrain component systems. For example, we assume that advanced diesels replace gasoline engines, and that power-split devices replace automatic transmissions in certain hybrid applications. In examining displaced components, we also estimate the effects for three states (Indiana, Michigan, and Ohio), as they account for nearly 50 percent of U.S. engine production and almost 88 percent of transmission production.

Although not explicitly modeled, we do explore two kinds of job loss. First, there is the actual loss of current jobs where the manufacturer of traditional vehicles and powertrain components fall as HAD sales rise. This could result either through a loss of U.S. vehicle assembly volume or displacement of current powertrain components such as conventional gasoline engines and transmissions. Second, there are the opportunity job losses if the United States fails to capture production for a growing HAD market share.

2.2 Policy Cost Analysis – Key Tasks

Fuel Savings. Next, we use our market forecasts to estimate the potential benefits in terms of fuel savings. Here, we apply conventional assumptions regarding typical usage and fuel savings for our various HAD types. We should note that while the purpose of the producer policy examined in this report is largely aimed at affecting production location sourcing decisions, the overall justification for such a policy is clearly related to the potential environmental benefits resulting from reduced fuel consumption and emissions. Hence, such a policy might incorporate a provision designed to discourage manufacturers from using the CAFE-positive performance of HADs to support increasing the CAFE -negative performance of other vehicles in their fleets.

Tooling and Equipment Investment Costs. Our next task involved estimating the tooling and equipment investment costs for converting existing facilities to HAD production facilities. As described earlier with obtaining component cost data, we used both a survey and a structured interview to identify the tooling and equipment investment requirements for key HAD powertrain component systems. Similar to component costs, these investments are highly dependent on numerous factors including production volumes and degree of automation. For purposes of our analysis, we asked interviewees to provide representative numbers based on past experience with both conventional production facilities and HAD production facilities overseas.

Effective Policy Recommendations. Using the various market volume and location forecasts, and the analysis of the economic effects of such forecasts, we conducted a policy analysis for a manufacturer tax credit. The capital investment tax credit we propose is based on the tooling and equipment investment information for converting existing automotive assembly and component plants into HAD production facilities. We use this investment cost data and our opportunity cost analysis to consider the potential costs and benefits to federal and state treasuries for greater U.S.

production of key HAD powertrain components and their assemblies. Hence, we put some parameters on the actual public cost of various conversion credits to accelerate production of HADs into U.S. manufacturing plants.

Figure 1 summarizes the data flow within our various tasks toward our policy analysis. In the following sections, we present the analysis and findings for each of the tasks.

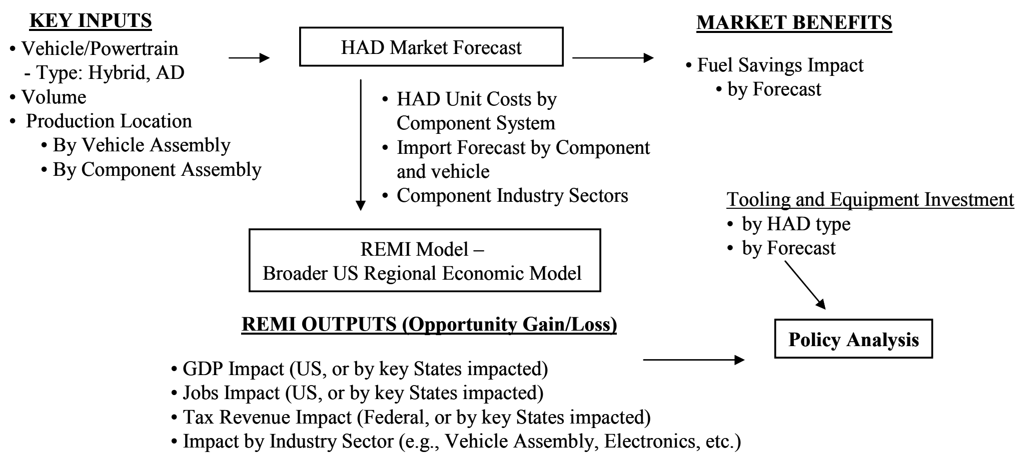

Figure 1. Project data flow chart

3.0 Gas-Electric Hybrids and Advanced Diesels

To effectively forecast and model the impact of hybrids and advanced diesels, we first stratified these technologies into subsystems. These subsystems provide high-level groupings to help distinguish significant differences in likely volumes, unit cost, or tooling and equipment investments. We use the following classifications for these subsystems:

- Minimal hybrid
- Medium hybrid
- Full hybrid
- Advanced diesels (Note: costs developed for three sample engine configurations)

We classify minimal hybrids, like the planned GM Silverado, as those that perform efficiently by using stop/start capability and regenerative braking, and require significant changes to the electrical system architecture (e.g., 42-volt versus 12-volt electrical system). These minimal hybrids typically boost fuel economy by approximately 10 to 15 percent. Some industry-specific names for these systems include Integrated Starter Alternator Damper (ISAD) and Integrated Starter-Generators (ISGs). Importantly, these hybrid types rely on the internal combustion engine to provide motive power and require fewer new components. Thus, they have lower incremental costs when compared with a non-hybrid option of the same vehicle model. We've chosen to include minimal hybrids in our report because the changes to the electrical system carry significant cost and because ISGs represent a major market introduction strategy by GM; however, not all analysts consider ISGs true hybrid electric vehicles (Lipman and Hwang, 2003). Similar to minimals, medium hybrids do not provide all-electric drive. These hybrids, like the Honda Civic hybrid, provide acceleration boost, rely less on their internal combustion engines, and can therefore perform even more efficiently. Medium hybrids generally utilize higher voltage systems and require larger electric motors and greater battery power (e.g., 144 V nickel metal hydride battery packs). These systems also require more sophisticated power inversion and control electronics. In terms of fuel economy, medium hybrids such as the Integrated Motor Assist system used by Honda may boost fuel economy by approximately 20 to 30 percent.

In comparison, full hybrids provide some all-electric power using electric motors. These full hybrid systems, such as in the Toyota Prius, are projected to be more costly than minimals or mediums as they involve more substantial changes in terms of the powertrain and electrical system architecture changes. However, they may boost fuel economy by 30 to 40 percent (Greene, Duleep, and McManus, 2004).

We should note that other hybrid technologies exist, and that yet others are still evolving. For example, systems have been developed to provide basic stop/start capability and electrical power to non-motive components. These systems may boost fuel economy by approximately 5 percent. However, they generally do not involve significant changes to the electrical system architecture and require less investment. In addition, there is not widespread acceptance among industry experts as to whether these systems should be classified as gas-electric hybrids. Thus, we do not consider them in this analysis.

In addition to hybrids, we also examine "advanced" or "clean" diesels. We use the term advanced diesels to represent diesel-powered passenger vehicles capable of meeting Tier II, bin 5 emission levels and which require the low-sulfur fuel due in the market in 2006 (Kliesch and Langer, 2003). We acknowledge that existing diesels do not meet these requirements, but we assume manufacturers will be able to meet these criteria by 2009 and beyond, at which time improvements in diesel fuel (i.e., lower sulfur content) and engine emission systems are assumed to occur. In terms of fuel economy, advanced diesels typically are 25 to 30 percent more fuel-efficient than the conventional engines they replace, but provide lower greenhouse gas benefits because of the higher carbon content in diesel fuel.

4.0 Market Forecasts

In this section, we present our market forecasts for calendar year 2009 that will be used to study the potential economic impacts of HADs. One challenge in developing such forecasts is vehicle weight classification. Most policies draw a distinction for light vehicles based on a Gross Vehicle Weight Rating[5] (GVWR) less than 8,500 pounds. This categorization is particularly important for an analysis of passenger diesel vehicles as the large majority of their existing applications is in vehicles with GVWR over 8,500 pounds. Table 1, below, indicates that approximately 95 percent of calendar year 2003 diesel sales were for such vehicles.

[5] Gross Vehicle Weight Rating represents the vehicle weight plus rated cargo capacity.

Similar to other studies, we have chosen to exclude sales of vehicles with GVWR greater than 8,500 pounds. In doing so, we are not suggesting that such vehicles have minimal economic impact or are unlikely or inappropriate candidates for the application of fuel-saving technologies. Clearly, tremendous opportunities exist for the increased use of advanced diesel and hybrid technologies for these applications. However, since our primary purpose is to examine the potential usefulness of manufacturing facility tax-credit incentives for producing light vehicles (passenger cars and light trucks) utilizing more fuel-efficient powertrain systems, we consider these particular vehicles outside the scope of this study.

Table 1. Diesel production and sales, 2003

	Units	% Diesels Sold	Vehicle models (*n*)	Avg. volume per model
US Diesel Sales	567,998		10	56,800
GVWR > 8500	538,114	95%	7	76,873
GVWR < 8500	29,884	5%	3	9,961

After excluding passenger vehicles with GVWR over 8,500 pounds, we project total U.S. sales figures for calendar year 2009 of 16.6 million, up from 15.5 million in 2003. Table 2 summarizes our HAD forecasts within these total market sizes, showing the number of CY2003 hybrids and diesels (none of which are "advanced" in 2003, but all of which are expected to be in CY2009), and projecting them for our three 2009 scenarios. Our first scenario calls for a penetration of 2.7 percent in a 16.6 million market (2.1 percent hybrids, 0.6 percent advanced diesels), the second for an increase in HAD market share to 6.9 percent, and, finally, a HAD share of 11.1 percent (6.3 percent hybrids, 4.8 percent advanced diesels). The development of the Consumer Shift Low and High scenarios is fairly straightforward. We consider a 2 percent increase in sales (or about 350,000 units) a consumer shift in demand. Thus, in our Consumer Shift Low scenario, we add 700,000 HADs (350,000 hybrids and 350,000 advanced diesels) to our baseline forecast. Thus, the Consumer Shift High adds another 700,000 hybrids, resulting in a total projection of 1.84 million HADs.

Table 2. U.S. market configuration forecasts for HADs

		Hybrids					
Market configuration	Units sold (in millions)*	Full	Medium	Minimal	Total hybrids	Diesels	Total HADs
2003	15.5**	24,627	22,897	0	47,524	29,884	77,408
2009							
Baseline	16.6	213,200	81,800	55,000	350,000	93,400	443,400
Consumer Shift Low	16.6	428,300	176,700	95,000	700,000	443,400	1,143,400
Consumer Shift High	16.6	670,380	252,620	127,000	1,050,000	793,400	1,843,400

* Excludes vehicles with GVWR > 8500

** ~70% are assembled in U.S.

Various other industry reports have made projections for the growth of hybrids and advanced diesels in both the relatively near term (2008-10) and longer term (2012-15). For example, in a study by the Oak Ridge National Laboratory, Greene, Duleep, and McManus (2004) forecast a hybrid market share of 2.5 percent (about 400,000 units) for 2008. In terms of diesels, the report cites a projection by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) of about 179,000 light-duty diesels (i.e., those with GVWR less than 8,500 pounds) in 2010, or about 1 percent in a sales market of 18 million). However, this same report projects a rapid increase thereafter. By 2012, they estimate hybrids at 10 to 15 percent and advanced diesels at 4 to 7 percent (or 14 to 22 percent HADs).

In comparison to these estimates, our baseline forecast is more conservative for both hybrids and advanced diesels, although within a reasonable margin of error. Similarly, our forecasts for the Consumer Shift Low and High scenarios, while possibly a stretch for 2009, also may be viewed as conservative relative to other projections. We forecast a HAD market share of 11 percent in our Consumer Shift High scenario which is toward the lower end of their 2012 projection (14 to 22 percent). Differences in forecasts are not surprising given the inherent risk and uncertainties of introducing new technologies with unknown consumer acceptance. Thus, we will summarize our economic analysis on a per-100,000-units basis to allow for some scaling to our various market projections, or to other sources.

In generating our market scenarios, we also provide forecasts for specific vehicles and/or market segments (e.g., midsize cars, crossover utility vehicles, etc.). These detailed forecasts are important to our analysis because they influence projections for the likely manufacturing locations of vehicles and their high value-added powertrain components.[6] Japanese manufacturing plants are currently the leading producers of small to midsize hybrids, and European assemblers have the lead in the production of diesel passenger cars[7]. U.S. manufacturers have some existing capability for advanced diesel trucks, though currently in the medium- and heavy-duty classifications. Thus, a consumer shift in demand toward midsize hybrid or advanced diesel cars would more likely be filled by imports versus an increase in advanced diesel light-duty pickup trucks.

The production location forecasts for vehicles and key powertrain components drive growth and/or shifts in jobs and income based on whether the production location is inside or outside the United States. We further distinguish production location outside the United States by Canada, Mexico, or Other (mainly Europe and Asia). We do this for several reasons. First, vehicles imported from within North America, whether Canada or Mexico, have considerably higher U.S. supplier content than vehicle imports from other countries. Thus, the potential economic multiplier to the United States is smaller for these vehicles. Second, the production location region of the major powertrain component systems shipped to vehicle assembly plants historically correlate with vehicle assembly location. In other words, vehicles assembled in North America are more likely to have high value-added powertrain components produced in North America. Furthermore, vehicles assembled outside North America in, say, Japan or Europe,

[6] High value-added powertrain components represent those components or modules supplied to vehicle assembly plants that reflect the large majority of the total unit cost related to our diesel and hybrid classifications. See the section in this report on Major Diesel and Hybrid components for a more detailed discussion.
[7] In Europe, diesels account for approximately 40 percent of passenger car sales.

traditionally obtain their high value-added powertrain components from manufacturing locations in their respective regions. For example, the high value-added components for the Toyota Prius, such as the battery and power split transmission device, are produced in Japan where the vehicles are assembled. Consequently, the potential economic loss associated with the displacement of a U.S.-assembled vehicle is higher if that import comes from outside North America, and we reflect this in our broader models of the U.S. economy.

In some instances, we forecast differences in the production region location of the powertrain components versus the vehicle assembly, i.e., we allow for imported components into U.S.-assembled HAD vehicles. While this may occur for either hybrids or advanced diesels, we consider it more likely in the case of advanced diesels and thus we project fewer advanced diesel *vehicle* imports relative to hybrid vehicles. One reason for this projection relates to current availability. Since more U.S. assemblers already utilize existing diesel engines and powertrain components for similar models sold in the European market, we would expect them to meet initial demand for specific vehicles (say, less than 30,000 units) using imported components from largely existing facilities. In the case of hybrids, which involves more new powertrain components, we predict that the production location of the high value-add suppliers will more closely follow the assembly location. Of course, if U.S. production volumes increase for component manufacturers either to supply a particular vehicle or a family of vehicles with similar requirements, this sourcing assumption may change. We explore this issue later in our tooling and equipment investment costs analysis and our policy analysis.

4.1 Hybrid Vehicle and Powertrain Forecast

In generating our forecasts, we classified hybrids into three categories: minimal, medium, and full. Recall that our minimal hybrid classification involves significant changes to the drivetrain power electronics, and that minimal hybrids are expected to boost fuel economy by 10 to 15 percent. This classification is important in considering our forecast as the total number of hybrid vehicles would be significantly higher if we included any vehicle using a basic hybrid-related technology such as start/stop capability.

Table 3 provides estimates for the number of U.S. hybrid sales and the projected number of vehicle models by type for our various market configurations. Through 2003, only three hybrid models have been sold (Honda Insight and Civic, and Toyota Prius). However, given the announced and probable future hybrid models, we expect a significant increase in this number from three to 18 by our baseline calendar year 2009 forecast. Our Consumer Shift Low and High forecasts project even larger increases, to 28 and 35 models, respectively. For these scenarios, we project that most of this growth will be toward full hybrids. These hybrids tend to have wider appeal across all major manufacturers whereas medium and minimal hybrids appear to be more manufacturer specific, with Honda emphasizing mediums and GM minimals.

Table 3. U.S. hybrid vehicle sales and number of projected models

Market configurations	Volume**	Hybrid vehicle models (n)*				Average volume per model	Engine Platforms	Average volume per platform
		Full	Medium	Minimal	Total			
2003	47,524	1	2	0	3	15,841***	3	15,841***
2009								
Baseline	350,000	11	3	4	18	19,444	15	23,333
Consumer Shift Low	700,000	17	6	5	28	25,000	23	30,435
Consumer Shift High	1,050,000	22	6	5	33	31,818	28	37,500

* 2003 actual sales; 2009 forecasted sales

** Composite of full, medium, and minimal

*** If exclude Honda Insight, average sales per model in CY03 was ~23,000

In April 2004, these three vehicles accounted for 6,700 sales in the United States, or half a percent of total light vehicles sold. These sales figures are more than twice those posted in April 2003.[8] Although we would not expect these growth rates to continue on a per-vehicle basis, we do forecast sales per-announced hybrid model to increase in addition to the number of model offerings with a hybrid option. Interestingly, if we exclude the Honda Insight, the average 2003 volume of the Prius and the Civic is approximately 23,000. Thus, our baseline configuration actually projects a slight decline in sales volume per model as nearly all manufacturers have plans to become "hybrid" producers. However, if a consumer shift toward more hybrids develops, we would expect the average volumes per vehicle model to reach closer to 32,000 units. We should note that a few of the models in our forecast share a common platform with another model. Thus, the table above also provides estimates of average volumes per platform. Although higher, we still expect average volumes to remain relatively low at 37,500 per platform.

Although certain vehicles, such as a Honda Civic (or Camry, if Toyota begins offering a full hybrid version), may sell in larger volumes (e.g., more than 60,000), we expect the majority of vehicles to have low to modest per-model sales volumes. These projections are significant because the leading Japanese OEMs currently are producing their hybrid versions of existing models outside the United States and likely would continue to do so given relatively modest growth forecasts on a per-vehicle model basis. Even in the case of vehicles with higher potential volumes such as the Camry, Toyota currently sources about 10 percent of its U.S. sales from Japan (Automotive News, 2004). Thus, we believe it is reasonable to expect that if Toyota begins selling a hybrid Camry in the United States, it still may draw initially from imports to meet demand because its manufacturing experience currently resides in Japan, both in terms of vehicle assembly and component production.[9]

Our projections by particular hybrid vehicle model nameplates are further detailed in Table 4. Here, we provide a list of likely candidates for hybridization in our Consumer Shift Low and/or

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[8] From J.D. Power & Associates, U.S. Hybrid Sales History 2004.

[9] This projection is purely a speculation by the authors of this report and is not based on any discussions with representatives of Toyota.

High scenarios. This list is based primarily on announced (or likely) plans and current offerings. Our forecasts also provides for an “unassigned vehicle” category. Here, we project volumes for a market segment without assigning them to a specific vehicle nameplate.

Table 4. List of potential hybrid vehicles for Consumer Shift Low and/or High scenarios

Company	Type	Name plate (model)	Type	Segment	Baseline	Likely vehicle assembly location	Likey powertrain manufacturing location
Chrysler	Truck	Ram Pickup	MEDIUM	Pickup Truck	*	US	US
Ford	Truck	Escape	FULL	Crossover Utility Vehicle	*	US	US
Ford	Car	Futura	FULL	Midsize Car	*	Mexico	Mexico
Ford	Truck	Mercury Mariner	FULL	Crossover Utility Vehicle	*	US	Mexico
GM	Truck	Equinox	MINIMAL	Crossover Utility Vehicle		Canada	Canada
GM	Car	Malibu	MINIMAL	Midsize Car	*	US	US
GM	Truck	Saturn VUE	MINIMAL	Crossover Utility Vehicle	*	US	US
GM	Truck	Sierra	MINIMAL	Pickup Truck	*	US	US
GM	Truck	Silverado	MINIMAL	Pickup Truck	*	US	US
GM	Truck	Tahoe	FULL	Sport Utility Vehicle	*	US	US
GM	Truck	Yukon	FULL	Sport Utility Vehicle	*	US	US
Honda	Car	Accord	MEDIUM	Midsize Car	*	Japan	Japan
Honda	Truck	Acura MDX	MEDIUM	Crossover Utility Vehicle		Canada	Canada
Honda	Truck	Acura RDX	MEDIUM	Crossover Utility Vehicle		Canada	Canada
Honda	Car	Civic	MEDIUM	Small Car	*	Japan	Japan
Honda	Truck	Pilot	MEDIUM	Crossover Utility Vehicle		Canada	US
Mazda	Truck	Tribute	FULL	Crossover Utility Vehicle	*	US	US
Mercedes	Car	Mercedes S-class	FULL	Large/Luxury Car		Europe	Europe
Nissan	Car	Altima	FULL	Midsize Car	*	US	Japan
Toyota	Car	Camry	FULL	Midsize Car	*	Japan	Japan
Toyota	Truck	Highlander	FULL	Crossover Utility Vehicle	*	Japan	Japan
Toyota	Car	Prius	FULL	Small Car	*	Japan	Japan
Toyota	Truck	RX400H	FULL	Crossover Utility Vehicle	*	Japan	Japan
Toyota	Truck	Sienna	FULL	Van	*	US	US
Toyota	Truck	Tundra	FULL	Pickup Truck		Japan	Japan
Unassigned	Car	Crossover Utility Vehicle		Crossover Utility Vehicle		Non US	Non US
Unassigned	Truck	Large/Luxury Car		Large/Luxury Car		Non US	Non US
Unassigned	Truck	Midsize Car		Midsize Car		Non US	Non US
Unassigned	Car	Pickup Truck		Pickup Truck		Non US	Non US
Unassigned	Truck	Small Car		Small Car		Non US	Non US
Unassigned	Car	Sport Utility Vehicle		Sport Utility Vehicle		Non US	Non US

Note: * indicates vehicle in CY09 baseline forecast

The reason for an “unassigned vehicle” category is that in the event of an initial shift toward hybrids, we expect demand to be met by adding hybrid options to existing vehicle models. Thus far, the manufacturers that have announced hybrid plans have made the technology optional, rather than standard (Brooke, 2003). For instance, Ford and Honda chose to add hybrid versions to their existing Escape and Civic models rather than build entirely new hybrid-only models. GM plans to offer hybrid versions of its largest SUVs, like the Chevy Avalanche and Cadillac Escalade, starting in 2007 (Kiley, 2003). The Prius—a vehicle that is exclusively hybrid—appears to be the exception to this strategy, but going forward even Toyota will likely add hybrid options to existing nameplates rather than introducing new hybrid-only option vehicles.

We should further note that the intended volumes for these hybrid versions are expected to account for relatively small percentages of the total volume for a given vehicle model or nameplate. For example, the hybrid version of the Ford Escape is expected to represent only about 12 percent of total sales (about 20,000 of 165,000) (O'Dell, 2004). Thus, even in this unassigned category, we project that hybrid demand will be met largely by relatively low-volume hybrid options of 20,000 to 40,000 units spread over a number of vehicle nameplates.

Although it is difficult to predict actual hybrid options by vehicle nameplate, given Toyota's and Honda's current lead in hybrid technology, we expect that these volumes will likely be met by additional imports, at least over the next five to eight years. For example, increased hybrid demand would likely result in Honda providing Acura MDX hybrids to compete in the Crossover Utility Vehicle category. Of course, General Motors, Ford, and DaimlerChrysler could also increase hybridization, but given Toyota's and Honda's relative position in hybrid technologies, we believe they are more likely in the near term to be met by imports.

In terms of our economic opportunity cost analysis, the specific vehicle model and its assigned volumes are actually less important than the production location for full vehicles and key hybrid components. For example, in the case of Toyota, the number of hybrid vehicles that it would likely produce outside the United States is actually more important to our economic modeling of jobs and tax revenue than is the number of units for a particular nameplate.

Figure 2, below, displays the total hybrid sales forecast for each of our three scenarios and their projected market share. Again, we project total hybrid sales to rise from 2.1 percent in our baseline scenario (CY09-Baseline) to 6.3 percent in Consumer Shift High (CY09-High).

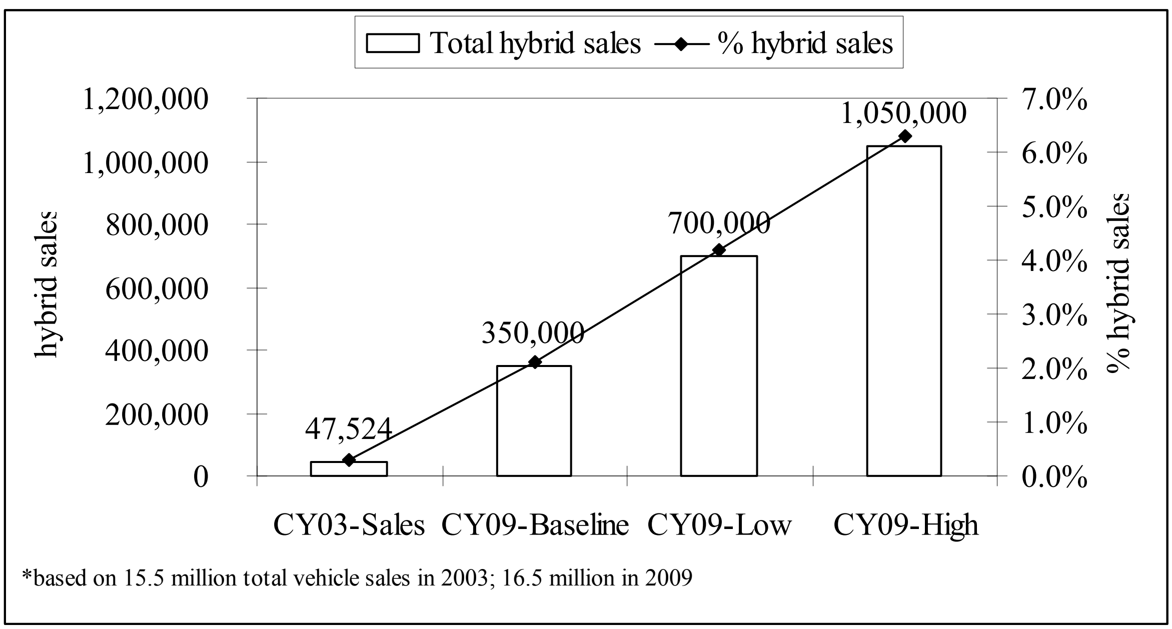

Figure 2. U.S. hybrid sales, 2003 and 2009 projections

Table 5 further stratifies the hybrid vehicle forecasts by their likely manufacturing locations (United States; Canada/Mexico; Other). We project that imported hybrid vehicles (from Canada, Mexico, or Other) will represent nearly 60 percent of hybrid sales in the 2009 baseline scenario.

More importantly, we forecast this import percent to increase to nearly 75 percent in the Consumer Shift High scenario. In particular, we forecast Toyota and Honda as the leading importers in a Consumer Shift High scenario based on their current positioning and hybrid production operations. While these manufacturers could shift some of their hybrid production to U.S. facilities, we predict they will initially meet most of this demand through non-U.S. production facilities. Based on analyses by The Planning Edge, these two manufacturers currently import over 1 million units for U.S. sales and some hybrid imports would likely offset other imports for similar models. In addition, several manufacturers are exploring the possibility of assembling gas-electric hybrids (Tierney, 2004).

Table 5. U.S. hybrid vehicle sales by likely vehicle assembly production location

	CY03 Sales		CY09-Baseline		CY09-Low		CY09-High	
	n	%	*n*	%	*n*	%	*n*	%
Total hybrid sales	47,524	100	350,000	100	700,000	100	1,050,000	100
U.S. assembled	0	0	150,000	43	217,500	31	271,500	26
Other assembled								
Mexico and Canada	0	0	10,000	3	30,000	4	46,000	4
Non-North America	47,524	100	190,000	54	452,500	65	732,500	70
Subtotal	47,524	100	200,000	57	482,500	69	778,500	74
Total	47,524	100	350,000	100	700,000	100	1,050,000	100

Although the Consumer Shift High scenario constitutes a significant total volume increase, we expect that the volumes per model will continue to remain relatively modest and probably insufficient to spur U.S. investment. We maintain that this trend is especially likely if Toyota, Honda, and perhaps Nissan capture the majority of this market because their component production facilities and manufacturing experience largely reside in Japan. Of course, historical patterns in terms of converting imports to U.S.-siting would suggest that if hybrid demand reaches higher levels (perhaps 100,000 units for a specific model or vehicle platform), then the percentage of U.S.-assembled hybrid vehicles would likely increase. A later section of this report explores the potential impact in terms of jobs and tax revenues should such scenarios materialize.

Some additional considerations in our hybrid forecasts relate to market segment mixes. In the case of hybrids, we project the majority of initial hybrid growth will occur in passenger cars (primarily small and midsize cars) and crossover vehicles like the Ford Escape (see Table 6). Here, we project that the majority of hybrids will fit vehicles with 4- and 6-cylinder engines and displacements in the 1.5 to 4.0 liter range.

Table 6. Hybrid forecasts by vehicle segment

		Calendar Year 2009				
	CY03-Sales	Baseline	Consumer Shift Low	Low vs. Baseline (Δ)	Consumer Shift High	High vs. Baseline (Δ)
Small car	47,524	53,000	98,100	45,100	149,180	96,180
Midsize car	0	142,000	253,400	111,400	342,520	200,520
Large/Luxury car	0	0	10,000	10,000	38,000	38,000
Total car	47,524	195,000	361,500	166,500	529,700	334,700
Pickup truck	0	25,000	55,600	30,600	100,080	75,080
Van	0	20,000	30,000	10,000	38,000	18,000
Crossover Utility Vehicle	0	85,000	218,500	133,500	325,300	240,300
Sport Utility Vehicle	0	25,000	34,400	9,400	56,920	31,920
Total truck	0	155,000	338,500	183,500	520,300	365,300
Total	47,524	350,000	700,000	350,000	1,050,000	700,000

The spread of hybrid volumes over many manufacturers and models reflects realistic market analysis, but it has a downside production corollary. While domestic production of hybrids increases across our three scenarios, the percent of total hybrids that are imported also increases. We believe that the market share for hybrids will be more concentrated at lower levels, perhaps leading to a fairly early production shift for one or perhaps two manufacturers. As the market for hybrids grows, additional sales will be more dispersed over models and manufacturers, and it could take considerably longer for another manufacturer to reach scale.

It is difficult to predict at what point any given manufacturer would bring hybrid production to the United States. Those with more flexible manufacturing capabilities may move production at lower volumes, fitting the hybrid line into an existing assembly plant with other vehicles. Others may need to wait until volumes grow substantially. But, in either case, the chance of production being U.S.-sited increases with higher volumes per model, especially if a comparable ICE model is already built in a U.S. facility.

Discussions with vehicle assemblers and component manufacturers suggest that shifting production to the United States is more volume-sensitive for components than for vehicles. In terms of plant tooling and equipment, adding a hybrid (or advanced diesel) option in a vehicle assembly plant is relatively minor relative to the total vehicle tooling and equipment cost. Body shop tooling and equipment costs represent the large majority of assembly plant tooling and equipment investment costs for a new vehicle model, particularly when a new model is added to an existing assembly plant. Thus, to add a hybrid version, assembly plants only need to allow for a few additional assembly stations and some increased logistical demands associated with multiple models. Still, plants routinely handle numerous vehicle options in their general assembly areas and thus this is not considered a major challenge.

In contrast, decisions by suppliers of key hybrid components about where to locate production facilities are more heavily influenced by sales volumes. For example, many hybrid component manufacturers have already established operations in Japan where most hybrid vehicles are assembled. As volumes increase initially, these manufacturers will likely expand capacity at those existing facilities, particularly if the vehicles continue to be assembled there. Some companies indicated that they would need U.S. production volumes (i.e., vehicle assembly orders) to reach 200,000 to 250,000 units before they would likely shift and/or expand production operations to the United States for their hybrid components.

However, these volume requirements are by component family (a collection of particular components for different models at one manufacturer), and not necessarily for a specific vehicle. Thus, U.S.-siting could occur faster if multiple vehicle models require particular components of similar specifications. For example, a particular nickel metal hydride battery pack might, with minor alterations, serve multiple vehicle models, either within or across vehicle manufacturers. For example, a hybrid battery for a Ford Escape may, with some minor modification, also be used for a Mazda Tribute. As the total U.S. volume requirements for a component family increase, the likelihood of investing in a U.S. production facility also would increase.

Although these consumer shift configurations forecast a large percent of imported hybrid *vehicles*, we do consider the potential impacts of hybrid *components* produced outside the United States, and assembled into vehicles in U.S. facilities. Section 6.0 provides estimates of the economic impact on a per-100,000-unit basis for the key components in the various hybrid classifications. These estimates may be used to assess the potential impact of losing high-value-added components regardless of their vehicle assembly location.

4.2 Advanced Diesel Vehicle and Powertrain Forecast

Again, we have chosen to exclude vehicles with GVWR over 8,500 pounds. Using this criterion, the number of diesels sold in the United States in 2003 was only about 44,000 units. These vehicles were largely sold by Volkswagen (Beetle II, Golf, and Jetta) and Mercedes (E-Class). Some additional models (e.g., Chrysler PT Cruiser and Mercedes M-Class) have diesel options that are assembled in North America but the cars are exported. These particular models are of interest to note as they represent likely candidates for future advanced diesel sales should significant consumer shifts occur.

Although we exclude vehicles with GVWR over 8,500 pounds, we believe it merits mention that several of them, including the Dodge Ram, Ford F-Series, and GM Silverado/Sierra, sell versions above and below the 8,500-pound cutoff. Interestingly, they all sell versions with GVWR above 8,500 pounds in a diesel option, but their models under 8,500 pounds all use conventional gasoline engines. Still, these models represent natural candidates for advanced diesels in light-duty truck applications.

Table 7 provides estimates for the number of advanced diesel vehicles sold for our various market configurations. In comparison to hybrids, our baseline forecast for advanced diesels is much lower, at 93,400 versus 350,000 for hybrids. In addition, while we expect a modest increase in sales from calendar year 2009 versus our baseline forecast, we expect only 27 percent of HAD vehicles to be assembled in the United States, with all of the engines imported. Even as the sales forecasts grow in the Consumer Shift Low and High scenarios for U.S.-assembled vehicles, we still project the majority of engines to come as imports (e.g., 62 percent of engines forecasted as imports).

Table 7. Advanced diesels sold in the United States

	Sales volume	Engine platorms (*n*)	Avg. volume per platform	Vehicles assembled and sold in U.S. (%)	with engines produced in U.S. (%)
2003	29,884	1	29,884	0	0
2009					
Baseline	93,400	9	10,378	27	0
Consumer Shift Low	443,400	28	15,836	43	33
Consumer Shift High	793,400	33	24,042	58	38

One reason for our lower projections for advanced diesels relates to our interview discussions. Manufacturers and suppliers are cautious with their advanced diesel projections partly due to concerns about the costs necessary to meet passenger-vehicle emission standards. Most diesel vehicles produced in the United States are work vehicles with over 8,500 GVWR and are not required to meet the stringent emission standards required of passenger vehicles. The "advanced" characterization of diesels in this study is associated with bringing diesel-powered vehicle emissions up to the emissions performance of gasoline-powered passenger vehicles. Of interest, while diesel passenger-vehicle manufacturers currently are not meeting advanced standards (e.g., Tier II, bin 5), there is general acceptance that these standards can be met, particularly with the expected rises in the quality of diesel fuel. However, the likely additional costs for diesels to meet future emission standards increase uncertainty in predicting consumer demand. In Europe, where diesel vehicles now represent over 40 percent of passenger cars, consumers face a wider gap in prices at the pump than do U.S. consumers, due to differences in European fuel taxes between diesel and conventional gasoline blends. This wider disparity in pump prices makes diesels more attractive when comparing their higher initial prices to their payback in fuel savings.

Interestingly, the challenge for current U.S. assemblers to increase their sales mix of diesel engines is probably less burdensome than in the case of hybrids. Diesels are variants of a known and well-understood technology and require comparatively less re-design effort than hybrids to "drop-in" or integrate into an existing vehicle platform. In addition, most vehicle manufacturers have diesel versions in Europe of similar U.S.-sold models. For example, the Opel Vectra sold in Europe shares a similar platform as the General Motors Malibu which is produced and sold in the United States. Thus, while our projections for advanced diesels in the baseline case are lower than for hybrids, the ability to quickly respond to consumer shifts in the near term is actually higher for advanced diesels.

Some important uncertainties related to advanced diesels are the likely production locations for vehicles and those key powertrain components that make them advanced, as well as the vehicle segments that they would likely target. In Table 8, we project that the number of diesel *vehicle* imports is likely to decline with increased volumes though *component* imports are expected to remain high, in contrast to our projections for hybrids where we project high imports for both cases. Again, a fundamental driver here is that many vehicles currently assembled in the United

States have similar diesel versions in Europe (at least more so than is likely to be the case with hybrids), and these vehicles can be made "advanced" by importing engines and components.

Table 8. U.S. advanced diesel vehicle sales by likely vehicle assembly production location

	CY03 Sales		CY09-Baseline		CY09-Low		CY09-High	
	n	%	*n*	%	*n*	%	*n*	%
Total advanced diesel sales	29,884	100	93,400	100	443,400	100	793,400	100
U.S. assembled	0*	0	25,300	27	188,800	43	462,320	58
Other assembled								
Mexico and Canada	29,884	100	49,600	53	109,200	24	156,880	20
Non-North America	0	0	18,500	20	145,400	33	174,200	22
Subtotal	29,884	100	68,100	73	254,600	57	331,080	42
Total	29,884	100	93,400	100	443,400	100	793,400	100

Note: There are U.S. built diesels that are exported

Another reason for forecasting more U.S.-assembled advanced diesel vehicles with imported components when compared to hybrids relates to our vehicle segment sales forecasts. Our interviews with manufacturers and diesel suppliers indicate that they expect stronger growth in the light-truck market (particularly sport utility vehicles and pickup trucks) for vehicles with 6- and 8-cylinder engines with displacements in the 4.0 to 6.0 liter range. Thus, for advanced diesels, we assign a significantly larger demand for pickup trucks and sport utilities (see Table 9) than for hybrids which we project as more proportionately passenger cars (reference Table 6 on page 15). Here, we consider U.S. vehicle assembly manufacturers better positioned to respond to future advanced diesel demand in this light-truck market, even if they import the key powertrain components. So, while we project nearly 74 percent hybrid vehicle imports in Consumer Shift High, we forecast 40 percent advanced diesel vehicle imports with 62 percent of the key components imported. Of note, since many European advanced diesels have strong brand recognition, we still would expect a significant level of imports (about 20 percent for Non-North America) to remain, even in the Consumer Shift High forecast.

Table 9. Advanced diesel forecasts by vehicle segment

		Calendar Year 2009					
	CY03-Sales	Baseline	Consumer Shift Low	Low vs. Baseline (Δ)	Consumer Shift High	High vs. Baseline (Δ)
Small car	29,884	46,000	75,000	29,000	98,200	52,200
Midsize car	0	0	85,000	85,000	159,720	159,720
Large/Luxury car	0	14,500	20,000	5,500	46,400	31,900
Total car	29,884	60,500	180,000	119,500	304,320	243,820
Pickup truck	0	0	75,000	75,000	175,000	175,000
Van	0	0	0	0	20,000	20,000
Crossover Utility Vehicle	0	10,400	65,000	54,600	102,680	92,280
Sport Utility Vehicle	0	22,500	123,400	100,900	191,400	168,900
Total truck	0	32,900	263,400	230,500	489,080	456,180
Total	29,884	93,400	443,400	350,000	793,400	700,000

4.3 Vehicles Versus Component Imports

While our projections for the number of advanced diesel vehicle imports are lower than for hybrids, we do expect a similarly high number of key component imports. For example, due to relatively low current U.S. diesel vehicle production, most existing advanced diesel components (such as engines, advanced turbochargers, and diesel particulate filters) are produced outside the United States for sale in other markets. In addition, even if volumes are shared across multiple vehicle lines, the total volumes for component suppliers still are likely to be insufficient for U.S.-siting as interviews with component manufacturers suggest they generally require volumes over 100,000 for engines and more than 200,000 for most other components to make an effective business case for retooling an existing facility or building a new U.S. facility. Of course, we recognize that these import trends, particularly for engines, could change if different assumptions are invoked (e.g., government incentives).

Table 10 displays our projections for the number of import vehicles and HAD components. By combining imported components for both U.S. and imported vehicles, we project that nearly 80 percent of our forecasted 1.8 million HAD sales will involve *imported* HAD components. The large number of component imports relative to vehicles is critical in our subsequent policy analysis as our manufacturing tax credit policy analysis would apply largely to component manufacturers where the large majority of tooling and equipment expenditures are necessary.

Table 10. HAD component imports versus vehicle assembly location

	CY03 Sales	CY09-Baseline	CY09-Low	CY09-High
Total HAD vehicles	77,408	443,400	1,143,400	1,843,400
U.S. assembled HAD vehicles	0	175,300	406,300	733,820
Imported components for U.S. vehicle assemblies	0	135,300	200,700	355,740
Non-U.S. assembled HAD vehicle imports	77,408	268,100	737,100	1,109,580
Total HAD components imported	77,408	403,400	937,800	1,465,320
% HAD components imported	100	91	82	79

5.0 HAD Major Components

In determining which components to include in our opportunity cost analyses, we first identified those key components or subsystems that define a hybrid or advanced diesel (i.e., which powertrain components are necessary in order for a vehicle to be described as a hybrid or advanced diesel). We further examined those components that carried a significant cost as they yield the majority of influence in economic modeling. In many cases, we tried to group various individual parts into major component modules or systems. These component modules or groupings made it easier for interviewees to estimate cost information. The lists below summarize these components (or modules):

Gas-Electric Hybrid Components Studied:

Full Hybrid Components

- *Battery.* The battery pack in a hybrid vehicle acts as an energy storage unit through which the generator stores energy and the electric motor draws energy. Batteries can be made from a variety of compounds, but nickel-metal hydride (NiMH) is the most widely used compound particularly for full and medium hybrids.

- *Electric Motors/Generators.* An electric motor/generator supplements the power provided by the internal combustion engine. The motor supplies power to the engine by drawing energy from the battery, and the generator returns power to the battery.

- *Power Control Unit.* The power control unit controls the power electronics of the system. For instance, it contains an inverter that converts DC from the battery into AC to drive the electric motor. Two common types of technology used in power electronics are Insulated-Gate Bipolar Transistors (IGBTs), which are often used in full- and medium-hybrids, and Metal Oxide Semiconductor Field Effect Transistors (MOSFETs), which are used in minimal hybrids.

- *Power-Split Device.* The power-split device in a full hybrid replaces the conventional transmission. The device acts as a gearbox between the engine, electric motor, and generator. It allows the electric motor and engine to power the vehicle separately or together.

Medium Hybrid Components

A medium hybrid involves many components similar to a full, including an advanced hybrid battery, motor/generator, and a power control unit. However, it requires lower performance levels (e.g., a smaller battery) as its components do not provide all motive power. One significant difference is that medium hybrids do not involve switching between electric motor and conventional drivetrain, and thus use a conventional transmission (as opposed to a full hybrid's power-split device).

Minimal Hybrid Components

A minimal hybrid uses even fewer and less sophisticated components. It essentially requires an integrated starter-generator (ISG), a power control system, and a small hybrid battery. The ISG replaces the conventional starter and alternator. It functions as both an electric motor to start up the combustion engine and as a generator to power non-motive energy-consuming systems such as lights, air conditioning, radio, etc. An ISG also allows the engine to shut off and start again at idle. It does not provide motive power.

Major Advanced Diesel Components Studied:

- *Base Engine.* We loosely have defined the base engine as the engine system, which is similar to a conventional gasoline engine, excluding its more sophisticated diesel fuel injection system and advanced turbocharger.

- *Fuel Injection System.* The two most commonly used injection systems are direct injection and common rail fuel injection. Both compress the fuel-air mixture so intensely that it combusts to provide engine torque.

- *Turbocharger.* Turbochargers are centrifugal compressors used to improve engine power by boosting the charge air pressure.

- *Aftertreatment System.* In addition to the base engine (see above), advanced diesels require an aftertreatment system to meet emission standards. These systems work to eliminate harmful diesel exhaust emissions by trapping and "cleaning" them. For the purposes of our study, we consider an aftertreatment system to include an oxidation catalyst, a diesel particulate filter, and a NOx adsorber. Filters particulate matter from the exhaust stream and then "clean" it through the oxidation of the captured particles. A NOx adsorber traps and adsorbs nitrogen oxides. Although numerous technologies exist for these aftertreatment systems, they all provide similar basic functions.

Given the wide disparity in specific hybrid and advanced diesel technologies used by manufacturers and suppliers, we identified basic specifications to obtain approximate cost estimates for key HAD components. We asked interviewees for estimates by hybrid type rather than by engine size. For full hybrids, we specified a 65 kW system with 300V; for medium hybrids, a 20 kW generator with a 144V electrical system. For minimal hybrids, we assumed the use of an 8 kW generator and 42V electrical system.

For our advanced diesel cost estimates, we identified three basic configurations: an I4 cylinder configuration with 2.0 liter displacement, a V6 cylinder configuration for a 3.0 liter engine, and a V8 configuration for a 5.3 liter engine, all with automatic transmissions.

We used these basic specifications to allow us to model some variation in cost by HAD type. Clearly, the specifications used across our various vehicle forecasts vary from these and thus our cost estimates should be viewed as more general than detailed. Still, since most of these components represent new technologies or have yet to be produced in large volumes, we believe that trying to identify cost estimates in greater detail would have been overly speculative and, in any case, unnecessary to perform our broader economic analyses.

In developing our cost estimates, we initially used existing literature and then confirmed the findings via surveys and interviews with knowledgeable industry executives. Each interviewee was asked to provide cost estimates for key HAD components from the standpoint of an assembler buying powertrains and components from suppliers. Hence our estimates include supplier profit margins as well as capital and manufacturing elements, but not necessarily markups between the vehicle manufacturer and end customer.

Tables 11 and 12, below, describe the cost of each HAD component and approximate costs for any traditional components being displaced. Not surprisingly, the NiMH battery has the highest hybrid component cost. This component cost is one of the biggest hurdles facing manufacturers and suppliers in creating hybrid appeal.

Table 11. Cost of hybrid components and displaced ICE components

Component system	Full	Medium	Minimal
Electric Motor/Generator	$ 900	$ 500	
Power Split Device	$ 1,000		
Displaced component (transmission)	$ (900)		
Power Control Unit (controller/inverter)	$ 500	$ 400	
Power Controls			$ 300
Integrated Starter Generator (ISG/ISA)			$ 750
Displaced starter alternator			$ (150)
Nickel-metal hydride Battery	$ 2,025	$ 1,725	$ 375
Total	$ 4,425	$ 2,625	$ 1,425
Net	$ 3,525	$ 2,625	$ 1,275

Table 12. Cost of advanced diesel components and displaced ICE components

	Cylinders		
Component system	3/4	5/6	8+
Diesel engine module			
Diesel base engine	$ 2,000	$ 2,400	$ 3,000
Displaced component (gas engine)	$ (1,000)	$ (1,200)	$ (1,500)
Turbocharger	$ 300	$ 310	$ 360
Fuel injection system	$ 550	$ 650	$ 750
Total	$ 2,850	$ 3,360	$ 4,110
Aftertreament system (with particulate filter and NOx reduction systems)	$ 900	$ 1,000	$ 1,100
Total	$ 3,750	$ 4,360	$ 5,210
Net	$ 2,750	$ 3,160	$ 3,710

Various other sources provide costs for hybridization or diesel engine options (e.g., Lipman and Delucchi, 2003; Greene, Duleep, and McManus, 2004; Science Applications International Corporation, 2003; Lienert and Lienert, 2004; and Markus, 2004). Not surprisingly, these sources often differ widely based on experiences of the interviewee, specifications used in estimating costs, and other assumptions related to production locations and volumes. Still, most sources predict incremental costs in the $2,000 to $4,000 range for hybrid or advanced diesel options versus the conventional applications they replace. Thus, we consider our estimates representative based on these sources, as well as our surveys, interviews, and private communications with industry experts. Most importantly, we believe our estimates provide a sufficient level of precision for the REMI model to effectively study the effects of HAD components at a fairly high aggregation level.

We should also note that our various survey respondents and interviewees often provided different estimates for the same components. This, of course, is not surprising given that neither manufacturers nor suppliers have significant pricing experience with many of these components. In addition, the costs associated with HAD production will almost certainly fall as the industry increases its volumes and gains production experience. Increased volumes almost always mean lower component and investment costs per unit, and continuous improvement efforts to lower costs with experience is typically a reality, not just an industry slogan. Still, since most vehicle manufacturers will have low HAD volume expectations, they still face major uncertainties in estimating the mature production costs.

Although we forecast low volumes for most specific vehicle models, we do expect some component manufacturers to capture scale economies in investment, materials, and manufacturing by spreading volumes over multiple applications (e.g., across different manufacturers or over multiple models within a manufacturer). HAD technologies are relatively new to the industry, and suppliers may well find opportunities to combine components into systems or modules that capture a higher value share and permit them to travel down the cost curve. The higher the value, the more readily a component can be exported, offering suppliers the opportunity to build volumes through supplying even one customer at multiple locations. And these are high-value components. Finally, simple part consolidation might let some suppliers gain a greater share of the HAD business and build their production volumes over multiple parts.

6.0 Domestic Economic Impacts

In this section, we now use our various market and production location forecasts along with the component cost estimates to examine U.S. economic impacts. Again, while we have chosen our consumer shift scenarios for calendar year 2009, we should recognize that this is primarily to allow for effective comparisons. We would expect the potential impacts in terms of jobs, tax revenue, and fuel economy to be similar if such consumer-purchasing shifts occur sometime between 2009 and 2012.

To understand and estimate the size of the economic impacts, we utilized a well-respected and often-used economic model from Regional Economic Models, Inc. (REMI).[10] The REMI model is based on the pairing of two complicated sets of data. The first is the latest version of the national input-output matrix that links the output of every final goods industry (e.g., cars and light trucks) with inputs from every other industry. The second is the latest edition of the Census of Transportation, which measures the flow of products into and out of the United States from and to any other country. By mating these two sources of information, REMI can answer questions such as "If more washing machines are made in the United States, how many more jobs will there be in the electric motor industry in North Carolina, and how much more state taxes will be collected there?" This modeling capacity is perfectly suited to our inquiry here: We want to know how much GDP, how many jobs, and how much tax revenue hinges on the U.S.-versus-non-U.S. mix of the HADs sold in the United States in and after 2009.[11]

We began by having REMI run baseline scenarios for 2003 and 2009. Because the industry groups that include the sectors making HADs and their components are sometimes part of broader industries (e.g., the electric motors used in full and medium hybrids are not the only electric motors, and electric motors dominate, but are not the only product in, motors for the sector SIC 362), the study team worked closely with REMI to customize the model to make it reflect what we knew about the current location of HAD- and other auto-related component manufacturing. Thus, while we have no idea where in the United States the power-split devices that replace conventional transmissions in full hybrids will be made (if they are made in the United States at all), we do know where current transmissions are made (e.g., 43 percent are made in Ohio). Thus, we know that if full hybrids take market share from conventionally-powered cars and trucks in 2009, Ohio is likely to lose out unless it can capture a like share in power-split devices (see Table 13). We also know that, because the vast majority of advanced

[10] Organizations such as the State of Michigan and various industry associations use the REMI model to understand the role of different industries in the economy of a state, region, or the nation and the effects of different policies upon them. OSAT has used the model on a number of projects for different clients.

[11] For the convenience of the reader, we have updated REMI's 1996 dollars to 2004:Q2 dollars using the U.S. DOC, BEA's GDP: Implicit Price Deflator series.

diesels sold in 2009 and beyond will replace gasoline engines, Indiana's dominant position in current diesels (68 percent) is likely to make it a winner *if* the advanced diesel share rises, and those diesel powertrain suppliers currently making components for vehicles with GVWR over 8,500 pounds expand their engine production capability for light vehicle application.

Table 13. Geographic distribution of U.S.-made vehicle and powertrain production, 2003

Location	Vehicles (%)	Gasoline Engines (%)	Transmissions (%)	2003 diesel engines (%)*	2009 diesel engines (%)**
Michigan	23.29	27.31	24.20	7.97	5.31
Ohio	15.86	19.75	42.99	12.04	8.03
Indiana	6.08	3.61	20.31	67.98	45.32
Total	45.23	50.67	87.50	87.99	58.66
Other U.S. Locations	54.77	49.33	12.50	12.01	41.34

*For vehicles less than 10,000 lb GVWR

**For vehicles less than 8,500 lb GVWR

Because the REMI model uses analogous functions for adding and subtracting U.S. production scenarios, we can interpret REMI results to tell us what the United States (and particular states) could gain from more U.S. production and what they stand to lose if that production is instead done elsewhere. Further, because the REMI model is linear in the relevant range, we may simulate the impacts per 100,000 units of vehicles, hybrid powertrains of various types, and advanced diesel powertrains. Thus, we may then think of the three different market configurations as scalars, or multiples, of these per-100,000 figures. Table 14 presents economic impacts on this per-100,000-unit basis.

To reflect the fact that vehicles assembled in Canada and Mexico contain, on average, much more U.S.-made-parts content than models assembled in Europe and Asia, we also have been able to make the REMI model distinguish between the impact of vehicles imported from our North American neighbors and those from elsewhere (see Table 14). For example, vehicles lost to Mexico or Canada represent about 10,600 jobs, whereas vehicles lost outside North America may result in about 21,000 fewer jobs per 100,000 vehicles.

Table 14. Economic impact per 100,000 units imported

	Vehicle Production		Hybrid Powertrain			Advanced diesel powertrains
	Non-North America	Mexico or Canada	Full	Medium	Minimal	
Gross Domestic Product ($04 millions)	2,296	1,148	462	344	168	367
U.S. Employment	21,270	10,635	3,219	2,375	1,188	2,141
Federal Tax Collections ($04 millions)	290.0	145.0	49.0	36.1	18.0	26.6
3-State Employment	6,959	3,485	193	365	158	633
3-State tax collections ($04 millions)	69.74	34.88	1.64	3.18	1.41	6.23

6.1 REMI Results for the Three Market Configurations

As explained earlier in this report, the study team has looked at three configurations of the 2009-and-later U.S. market for cars and light trucks with GVWR under 8,500 pounds. For each, we have made careful estimates of where both HAD vehicle assemblies and powertrains are likely to be produced. While the U.S. share of HAD powertrains is forecasted to rise from essentially zero today to roughly 40 percent by 2009, the 60 percent import share of these components is well above the overall import share, and thus poses a risk to U.S. production. Of even more concern, we forecast that the U.S. share of many vehicles containing HAD powertrains would be lower than that 40 percent.

Table 15, below, shows the economic impact of this anticipated rise in import HAD vehicles and powertrains. We believe that in 2009 the U.S. GDP would be from -$4.25 billion to -$22.77 billion lower per year, because relative to 2003:

- between 176,000 and 1,018,000 more HAD-equipped vehicles will be imported into the United States (i.e., full vehicle and HAD powertrain imported), and
- between 135,000 to 356,000 HAD powertrains-without-vehicles will also be imported.

While even the latter figure is a small proportion of a $12 trillion economy, it is not a small number in absolute terms, representing something like 38,000 to 207,000 U.S. jobs, between the Baseline and Consumer Shift High scenarios, respectively.

Table 15. Economic impact across three HAD scenarios

		2009			
	2003	REMI	Baseline (Δ)	Consumer shift low (Δ)	Consumer shift high (Δ)
Gross Domestic Product ($04 million)	$11,356.82	$14,022.37	$4.25	$14.37	$22.77
Federal Tax Collections ($04 million)	$2,226,575	$2,393,588	$523	$1,793	$2,829
U.S. Employment	165,493,953	175,501,969	38,046	131,039	207,055
3-State Employment	15,478,020	16,282,136	11,634	41,752	66,308

These employment impacts, and the resulting drop or lack of growth in federal and state tax collections, would furthermore be concentrated in the three states—Michigan, Ohio, and Indiana—that make a disproportionate share of cars, light trucks, engines, transmissions, and other auto parts. These three states today are host to 45 percent of U.S. light vehicle assemblies, 51 percent of gasoline and 88 percent of diesel engine production, and 88 percent of transmission production (reference Table 13 on page 25). Thus any large increase in imports, HAD or otherwise, would hit these states particularly hard, as shown in Table 16 (vehicles) and Table 17 (powertrains), below. Nearly one in three of the jobs that hang in the balance of the U.S.-versus-imported decision are represented in one of these three states. Their stake in a higher U.S. market share in HADs is thus obvious, even though they are unlikely to capture the same shares of HAD vehicles or components that they enjoy today in conventional vehicles and powertrains.

The job losses are large, ranging from approximately 38,000 to just over 207,000, depending on the market configuration. Again, these estimates include two kinds of job losses, the loss of actual existing jobs as traditional vehicle and component production falls in the face of increasing HAD production, and the opportunity loss, the failure to capture production and jobs associated with HADs. We explore this distinction at the end of this section.

Table 16. Job losses associated with vehicle imports by industry and location per 100,000 units

		Non-North American Full Vehicles			Canada/Mexico Full Vehicles		
SIC	Sector Description	U.S.	3 States	47 States	U.S.	3 States	47 States
371	Final assembly, ICEs, transmissions & power-split devices, most parts	3,603	1,581	2022	1,802	791	1,011
351	Diesel engines & parts	12	4	8	6	2	4
362	Motors	20	4	17	10	2	9
367	Electronics, including controller/inverter	128	9	119	64	5	60
369	Batteries, other engine electricals	28	5	23	14	3	12
	Subtotal	3,791	1,603	2189	1,896	802	1,095
	All Other Sectors	17,478	5,366	12112	8,739	2,683	6,056
	Total	21,270	6,969	14301	10,635	3,485	7,151
	% of Total		32.8				

Table 17. Job losses for powertrain imports by industry / location per 100,000 units

		Full Hybrids			Medium Hybrids			Minimal Hybrids			Advanced Diesels		
SIC	Sector Description	U.S.	3 States	47 States	U.S.	3 States	47 States	U.S.	3 States	47 States	U.S.	3 States	47 States
371	Final assembly, ICEs, transmissions & power-split devices	39	-75	114	14	1	13	7	1	6	-165	-116	-49
351	Diesel engines & parts	2	0	2	1	0	1	1	0	1	240	108	132
362	Motors	47	12	35	36	9	27	17	4	14	11	1	11
367	Electronics, including controller/inverter	296	25	271	226	19	207	110	8	102	71	2	69
369	Batteries, other engine electricals	65	15	50	50	12	38	24	5	19	16	1	14
	Subtotal	449	-23	472	327	41	286	160	18	142	173	-4	177
	All Other Sectors	2,770	216	2,554	2,048	324	1,724	1,028	140	888	1,968	637	1,331
	Total	3,219	193	3,026	2,375	365	2,010	1,188	158	1,030	2,141	633	1,508
	% of Total		60.0%	40.0%		15.4%	84.6%		13.3%	86.7%		29.6%	70.4%

Of interest, if the other 47 states would suffer less from more imported HADs, they also stand to gain much more than the three current core automotive states from more U.S. HAD production. Referring again to Tables 16 and 17, the 47 less auto-dependent states stand to gain between 70 and 94 percent of the jobs if more HAD powertrains are made in the United States. This simply reflects the current location of the facilities in the industries that include most of the other HAD powertrain components. For example, a higher proportion of power electronics jobs are currently located outside these three states, resulting in greater opportunity for job growth.

In short, the United States—and especially its three core auto states—faces large losses if many more HADs are sold in and beyond 2009 than today. The United States—and especially its 47 non-auto-producing states—could reap large gains if more of the HADs sold in 2009 have powertrains made in the United States. Beyond these powertrain jobs and their economic spin-offs lies the possibility that more U.S. production of these components could function as the "tail" that wags the "dog"—that by becoming a powerhouse in HAD powertrain production, global automakers might decide to assemble more HAD-equipped cars and light trucks in the United States as well. Since HAD powertrain component system jobs only represent 8 to 30 percent of the value of a complete vehicle[12], winning more U.S. production of the full vehicle has to be a high priority.

6.2 REMI Results: Opportunity Jobs versus Direct Job Losses

An increase in HAD vehicles and their associated key powertrain components could affect U.S. jobs in multiple ways. It could involve nothing more than "lost opportunity" jobs if future HAD market demand can be fully accommodated by the normal market growth expected between 2003 and 2009. Alternatively, actual job losses could occur if future HAD vehicle imports displace existing U.S.-made vehicles. Although it is difficult to predict the mix, we can offer some plausible scenarios and provide a spectrum of possibilities.

One scenario is that our future HAD import projections in the Consumer Shift High scenario may consist entirely of opportunity jobs (or lack of job increases). The number of imported HAD vehicles, even in the Consumer Shift High forecast, amounts to just about 1.1 million units (and 1.47 million key component sets as referenced in Table 10 on page 20). But 1.1 million units is relatively minor when compared to market growth and the current number of imports. Specifically, we expect the market to grow by over 1 million units by 2009, and U.S. sales already include over 4.5 million units from Canada, Mexico, and the rest of the world (Automotive News, 2004). Thus, one could argue that all of the jobs associated with HADs merely represent lost opportunity rather than loss of already existing jobs. Instead of importing about 29 percent of the vehicles sold here (4.5 out of 15.5 million) as it did in 2003, by 2009 the United States would import about 5.9 million (29 percent of 16.6 million, plus 1.1 million HADs), or about 36 percent.

But it is probably more plausible to expect that at least some HAD imports will displace actual jobs, and not merely reduce the opportunity for future U.S. jobs. Although determining the extent of displacement is speculative, a reasonable starting point would be to expect new HAD imports to displace vehicles in approximately the same proportion as the current sales/production mix. Thus, since about 70 percent of vehicles currently sold in the United States are built in the United States (Automotive News, 2004), we would expect about 70 percent of the losses to incur in the United States. On the other hand, since hybrids and advanced diesels are a growth segment, we believe this 70 percent figure is probably too high.

[12] While we have modeled a full vehicle at a value of three to 12 times that of a HAD powertrain, this datum is somewhat misleading. The typical U.S.-assembled car is only on the order of two-thirds American in value:

- Europe- and Japan-based automakers assembling cars and light trucks in the U.S. make some of their engines, most of their transmissions, and about half of their other parts outside the U.S.
- At least 20 percent of the value of the traditional domestic vehicles assembled in the U.S. by GM, Ford, and the Chrysler part of DaimlerChrysler is produced in Mexico, Canada, or offshore.

Another, less severe and arguably more plausible, scenario suggests that U.S. job losses could occur if growth is attributed to a shift in market share away from the traditional "Big Three." For example, our forecast of imported HAD vehicles projects a greater rise in hybrid sales for Toyota and Honda, and in advanced diesel sales for manufacturers such as Volkswagen and Mercedes. Given that these manufacturers already have HAD manufacturing capability outside the United States, it is plausible that these additional imports may start to involve U.S. job losses, particularly if sales are not large enough to justify U.S. expansion. If we consider our vehicle import forecast for these manufacturers and attribute volumes over 30,000 as likely candidates for U.S. job losses, we might predict that HAD growth will result in about 20 percent actual job losses and 80 percent lost opportunity jobs (i.e., absorbed by normal market growth or by displacing current imports).[13] This 20 percent figure is the one that the study team feels is the most credible estimate of actual job displacement.

7.0 Fuel-Saving Benefits

Although fuel savings would result from more hybrid and advanced diesel vehicles regardless of their production location, a manufacturer tax credit policy could also be viewed as a means to foster or accelerate a shift in U.S. HAD demand from say our Baseline to Consumer Shift High scenario, or to even higher levels as discussed earlier.

To estimate the potential oil savings associated with encouraging more fuel-efficient vehicles for our various market forecasts, we may apply some conventional assumptions regarding current fuel usage and expected improvements for the various HAD technologies considered. Regarding general fuel usage, we assume that the average light vehicle gets approximately 20 miles per gallon, is driven 15,000 miles per year, and has a useful life of approximately 120,000 miles. Determining the fuel saving improvements by HAD technology clearly depends on many factors including vehicle size and driving conditions (e.g., mix of city versus highway driving). Still, we may assume some standard improvements to estimate fuel savings. For our study, we assume a 10 percent fuel savings for minimal hybrids, 30 percent for medium, and 45 percent for full. For advanced diesels, we assume a 30 percent savings.

Using these assumptions, Table 18 provides an estimate of the oil saving benefits for our various market configurations. These estimates examine our market forecasts projected over a 10-year period from 2009-2018[14] relative to a fleet with no HADs over the same period. In addition, we assume that fuel savings for future HAD offerings will not be cancelled out by manufacturers backsliding in other vehicle segments. Based on these assumptions, the U.S. should save from four to 18 billion gallons (or 117,000 barrels per day) between our Baseline and Consumer Shift High scenarios.

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[13] Actual job losses are estimated by using the total forecasted volume of HAD vehicles that are non-North American built, not made by the "Big Three," and have HAD volumes projected above 30,000 (~400,000/1,843,000 HADs).

[14] For estimation purposes, we assume a constant demand rate for the subsequent years beyond 2009, and that vehicles will cease to be driven after 120,000 miles.

Table 18. Estimated fuel savings with a HAD-enhanced fleet

Configurations modeled (2009)	HADs sold in U.S. per year 2009-2018	Over 10 Years	Fuel savings* Billion gallons	Barrels/day
Baseline	443,000	4,434,000	4.24	27,659
Low	1,143,000	11,434,000	10.57	68,947
High	1,843,400	18,434,000	17.98	117,265

*Fuel savings vis-à-vis all ICE fleet over a ten-year period

In addition to the above mentioned fuel-saving benefits, we should recognize that hybrids allow for higher torque at low speeds (e.g., a 15 to 20 percent improvement). In some cases, we might expect manufacturers to even downsize an existing engine application with hybridization and still achieve performance similar to a larger conventional gasoline engine. Thus, even greater fuel savings than shown above could occur with engine downsizing (e.g., downsize a V6 conventional engine with a 4-cylinder full hybrid).

8.0 Investment Requirements and Policy Analysis

Americans generally recognize the environmental and security problems associated with our consumption of fossil fuels; however, there is less recognition that these problems could also lead to significantly reduced economic activity in the U.S. automotive industry.

We believe that there is a cost-efficient, effective policy initiative that can sharply increase HAD powertrain and HAD-equipped vehicle production in the United States. As discussed earlier, body shop tooling and equipment costs represent the large majority of assembly plant tooling and equipment investment costs for a vehicle model. Thus, in terms of examining the tooling and equipment investment requirements for more HAD powertrain production, we focus our analysis of the component requirements as a basis for a policy initiative. Of course, a policy to lower the investment risk for component suppliers also clearly benefits the manufacturers in terms of their costs to end customers.

For our policy analysis, we first need to estimate the tooling and equipment investment requirements for a conversion of existing component facilities to HAD facilities. Next, we examine the effects if a policy that could switch imports to the United States. Finally, we explore the timing of expenditures should the United States adopt such a policy.

8.1 Tooling and Equipment Investment Requirements

Recall that in our discussions with suppliers, the interviewees indicated that they would likely require that volumes reach 200,000 to 250,000 units to justify adding new production lines for components in the United States. These units would likely represent multiple customers or vehicles. Of course, manufacturers might begin adding U.S. capacity at lower volumes if they expect volumes to ramp up quickly. Tables 19 and 20 provide estimates of the tooling and equipment investment needed for 100,000 and 200,000 units of each component system. Collecting these estimates was challenging. Most of these components are not currently produced at high volumes, so our interviewees based their estimates on their experience with both conventional production facilities and HAD production facilities overseas.

Table 19. Estimated tooling and equipment investment for advanced diesel components (in 2004 millions of U.S. dollars at mature production levels)

	Number of units	
Component system	100,000	200,000
Motor/Generator	$ 20	$ 30
Powersplit Trans	$ 50	$ 90
Power Control Unit	$ 30	$ 50
ISG	$ 30	$ 50
Battery	$ 90	$ 160
Total (Full)	$ 190	$ 330
Total (Medium)	$ 140	$ 240
Total (Minimal)	$ 90	$ 153

Table 20. Estimated tooling and equipment investment for advanced diesel components (in 2004 millions of U.S. dollars)

	Number of units	
Component system	100,000	200,000
Engine	$ 65	$ 110
Fuel system	$ 50	$ 80
Aftertreatment system	$ 30	$ 50
Total	$ 145	$ 240

In Table 21, we indicate that the one-time tooling and equipment investment necessary to create capacity for 100,000 HAD powertrains using the HAD mix contained in our Consumer Shift High scenario is about $144 million. Clearly, this estimate provides an aggregate view of the required tooling and equipment investment requirements for modeling purposes. Actual cost could easily be higher as manufacturers would likely need to build initial excess capacity in anticipation of rising demand. In other words, if demand for a particular component across several manufacturers were only say 80,000 units, they still would likely invest in tooling and equipment capable of higher production levels. Thus, while our investment costs may not be accurate in a specific case, we believe they are sufficient to explore the potential benefits if the U.S. Treasury chose to enact a policy that would reduce such investments made to increase the U.S. stake in the production of future HAD powertrains.

Table 21. Estimated one-time tooling and equipment investment

60% Hybrids: Of which: 60% Full, 25% Medium, 15% Minimal	**40% Advanced Diesels:**
Investment Cost ~ $144 million per 100,000 HAD Units Note: ~ Weighted Average of 100K & 200K Units by HAD Mix	
Federal Treasury Opportunity Revenue (versus imported HAD powertrains) **~ $35 million per 100,000 HAD units** (weighted average of federal tax revenue)	

Table 21 also provides a weighted average estimate of having U.S.-built HAD components versus imported powertrains in terms of tax collection revenue. From our REMI results presented earlier, we may estimate the opportunity revenue in terms of tax collections for every 100,000 units at approximately 35 million. This revenue may be used to estimate the payback period in terms of years of production for a one-time investment in tooling and equipment capacity. Note, the opportunity revenue in this table is for the powertrain components only. In the next section, we consider the potential impact and policy payback for both powertrains and full vehicle assemblies.

8.2 Manufacturer Investment Tax Credit Policy Analysis

While we have not attempted in this study to address every possible detail of a manufacturer investment tax credit policy, we believe that we have explored it enough to satisfy ourselves, and hopefully our readers, that it can be designed in legislation and implemented in the real world. The policy would have the following key features:

- Producers of HAD powertrains and their identifiable components would be able to reduce their corporate tax liability by a certain percentage of their expenditures for the tooling and equipment (T&E) associated with launching or adding to HAD capacity.
- In order to avoid having the transition from conventionally- to HAD-powered vehicles add to the problem of excess capacity in the automotive sector, and to help address local concentrations of manufacturing job loss, the credit would be tied and limited to T&E investments made after a certain date in manufacturing facilities built prior to a specific date.

We leave it to the legislative development process to fill in full credit design details. What are important are the principles of tying tax relief to lumpy, easily measurable up-front capital outlays, and to induce both component suppliers and the assemblers they supply to prefer U.S. over non-U.S. production siting for their HAD capacity. Because *this credit would be available to any manufacturer, based anywhere in the world*, and because it does not favor companies currently operating in the United States over companies not yet producing here that could rent or buy existing factory facilities, it is likely not to run counter to international trade laws.

We believe that this approach should be attractive to all Americans that wish to reconcile the nation's interests in saving fuel and stemming manufacturing decline. Because these are both *public* interests even more than they are private ones, it strikes us as only fair that the federal government help to underwrite some of the cost of the transition to a more HAD-intensive U.S. capacity mix.

Whatever its details, the usefulness of a policy of this kind depends, of course, on the extent to which it actually causes component suppliers and assemblers to change their behavior; in this case, to produce in the United States more of the HADs they expect to sell in the United States. Much as we might like to treat this as a simple question with an easily researchable answer, it is not. Tooling and equipment costs make up no more than half, and usually less than that (perhaps one-fifth), of the total investment costs of launching new capacity. (The additional investment costs are for items such as research and development and product and process engineering.) Would a policy that promised to reduce these investment costs by, say, two-thirds—and therefore unit HAD costs by something between 5 percent and 15 percent—be enough to change producers' behavior? Would such a savings be enough to make up for labor costs in the United States that are multiples of those in Mexico, and an order of magnitude higher than in China?

We believe that such a policy could well be effective. Despite the apparent attractiveness of cheaper, non-U.S. labor, at least two-thirds of the value of the vehicles and parts sold in the United States are made in the United States. Despite market share losses in recent decades by the traditional Detroit-based automakers, there is more assembly capacity in the United States today than there was a decade ago. Automotive part-sector employment was essentially unchanged in 2003 from its 1978 peak, even as other sectors shed four million factory jobs in the same 25-year period. Europe-, Japan-, and Korea-based assemblers continue to add U.S. capacity, as do their foreign-based first-tier suppliers. A large and unyielding U.S. trade deficit may portend a lower U.S. dollar in the decade ahead, which may further tilt the economics in favor of U.S. production. Thus the question of a producer tax credit's effectiveness really comes down to whether, on the margin, tax relief for HAD-related investment makes it more likely that global automakers and their suppliers will place in the United States a larger proportion of their large, and growing, investment in HADs.

Our work for this study convinces us that HADs will play a large and perhaps fast-growing role in the next 10, 20, and 50 years of the auto industry's evolution. Even if we are wrong and a HAD producer tax credit policy has no effect on the absolute level of U.S. production or even production capacity, if it only makes more of the capacity *HAD capacity*, then it will still pay off. The United States will be a producer, and not merely a passive consumer, of vehicles embodying core advanced powertrain technologies. Such a policy states clearly to the world's automakers and suppliers: "The United States is seeking to build its capacity and capability in the vehicles of the future. It is your decision, but if you plan to build such vehicles, or supply automakers that plan to build them, then the U.S. Treasury will make it significantly less burdensome for you to do so."

Despite our conviction that a producer tax credit for HAD investment would be effective, we have no way to predict precisely *how* effective. We have chosen to model the impact of the credit on two assumptions:

1. It is set at the 67 percent level, so that the Treasury would reduce the tax liability of a manufacturer making eligible investments by two-thirds of their allowable tooling and equipment expenditures.
2. It is effective enough to induce 50 percent of the powertrains that would otherwise be imported from outside the United States instead to be produced here.

Because the REMI model is linear in the relevant range, it is a simple matter to think about the implications if the credit is, instead, set at 33 percent or 100 percent, rather than 67 percent, or if it is 25 percent or 75 percent, rather than 50 percent, effective. (The cost of the credit is likewise proportional to its effectiveness: If it is 100 percent rather than 50 percent effective, then its cost doubles, but so do its benefits.)

We must acknowledge, however, that as with all tax expenditure policies, some companies will be paid to make some investments that would have been made without a credit. This classic opportunism problem actually turns out to be something of an advantage in this case: Producers of HADs and their components are rewarded for their "base investments," increasing their ability and inclination to add on to existing investment plans and drive toward volumes at which economies of scale, which are needed to permit the unit cost reductions on which a larger HAD market share will depend, can be achieved.

Table 22, below, summarizes the credit we propose. Over the period of years—presumably 2005-2009—during which manufacturers would be investing $348 million to $1,599 million in the tooling and equipment with which to make more HAD powertrain components in the United States, the U.S. Treasury would forego $233 million to $1,072 million in corporate income tax receipts (67 percent of investment cost) in order to induce the switch of 201,700 to 732,660 HAD powertrains from imported to U.S.-made.[15] These switched powertrain components would cause the United States not to lose the 4,999 to 18,158 jobs that it otherwise would lose, at an apparent cost of just under $59,000 per job.[16]

[15] Careful readers will note that a comparison of Tables 10 and 22 suggests that a 50 percent effective powertrain credit would actually result in switching more than 100 percent of the powertrain component packages that would otherwise be imported. This reflects the fact, which we discuss beginning just after Table 22, that the credit also results in some full HAD vehicles being re-sourced from Europe and Japan to the U.S.

[16] Estimated by the cost to the Treasury of $1,072 million for 18,158 component-related jobs

Table 22. Powertrain component credit summary (in millions of dollars)

Configurations modeled (2009)*	HAD powertrain components** Planned U.S.	Switched to U.S.	US Jobs Gained***	Investment ($)****	Cost to treasury ($)****	Annual gain in revenue to treasury in tax collections ($)
Baseline	40,000	201,700	4,999	348	233	72
Consumer Shift Low	205,600	468,900	11,621	971	651	165
Consumer Shift High	378,080	732,660	18,158	1,599	1,072	259

*Based on powertrain components

**Per year over entire product lifecycle

***U.S. jobs gained due to switched HAD powertrins. Jobs assumed over entire product lifecycle.

****One-time investment spread over several years (2005-2009). Cost to treasury assumed at 67% of manufacturer investment.

As we noted earlier, there is a credible prospect that a larger U.S. role in HAD powertrain production could be the "tail that wags the dog," inducing some automakers to locate more of their HAD-equipped vehicle assembly here. Just as we illustrated the likely impact of our HAD powertrain component credit by assuming it would be 50 percent effective at inducing the switch of imported, we can gauge the potential impact of switched imported vehicles by assuming 25 percent effectiveness. (Readers may wish to double, or halve, the resulting impacts if they object to the 25 percent assumption.)

We assume that the vehicles switched are from outside North America, as it would largely be Europe- and Japan-based automakers that might be tempted by the emerging U.S. hybrid market and powertrain role. We recognize, however, that even switching such vehicles to the United States would not switch 100 percent of their content. Based on the fact that the 75 percent of light vehicles assembled in the United States by the U.S.-based manufacturers have approximately 80 percent U.S. content, while the 25 percent assembled here by foreign-based automakers have about 40 percent U.S. content, we get a weighted average content of 70 percent. We can apply this 70 percent to the 21,270 jobs the United States foregoes per 100,000 vehicles imported, yielding a content-corrected figure of 14,889.[17] Thus, in our Consumer Shift High scenario, switching 25 percent of the imports would equate to 41,301 jobs and an annual Treasury gain of $565 million (Table 23). In comparing potential job benefits for components versus vehicles (reference Tables 22 and 23), we may observe that switching even one vehicle in four results in about twice the number of jobs as does switching one of every two HAD powertrain component sets.

[17] It is not necessary to net out the weighted average 2,478 jobs per 100,000 powertrain packages from the 21,270 jobs per 100,000 vehicles. The 21,270 is for a conventional ICE-powered car or light truck; each 100,000 HAD vehicles are associated, on average, with 21,270 + 2,478 = 23,748 jobs.

Table 23. Economic effects by projected vehicle assembly location (in millions of dollars)

Configurations modeled (2009)*	HAD vehicle assembly switched**	Jobs gained***	Annual gain to treasury in tax collections ($)
Baseline	67,025	9,979	137
Consumer Shift Low	184,275	27,436	374
Consumer Shift High	277,395	41,301	565

*Based on HAD vehicles

**HAD assembly switched to U.S. assembly plants. Assume 25% of imports are switched.

***U.S. jobs gained due to switched HAD full vehicle assemblies (excludes powertrain jobs shown in prior table). Jobs assumed over entire product lifecycle.

Next, we consider the combined effect of a 50 percent imported powertrain and 25 percent imported vehicle switching over roughly the 10-year period that the powertrains and vehicles produced would result from a credit-induced investment. Under these assumptions, over 10 years, the net Treasury gain could be between $1.86 billion and $7.17 billion (see Table 24). In terms of jobs, the result would be to preserve between 14,978 and 59,459 jobs that would otherwise be lost to imported HAD vehicles and powertrain components. Instead of foregoing between 38,000 and 207,000 jobs (see Table 15 on page 26), with the credit the U.S. foregoes a much more modest 23,000 to 147,600 jobs, winning for the nation 15,000 to 59,500 jobs it otherwise would not have.

We should note that under a 50 percent switching of powertrains with only a 25 percent vehicle assembly switch, the U.S. could become a net exporter of HAD powertrains. We believe this is plausible when considering that we forecast around 200,000 HAD vehicles in Consumer Shift High to be assembled in Mexico and Canada and we would expect this number to increase more with U.S. HAD component production switching.

Table 24. Ten-year impact of producer credit policy (in millions of dollars)

Configurations modeled (2009)	10-Year gain in tax collections For Switched Components	Cost to treasury*	10-Year net gain For Switched Components	Additional 10-Year gain For Switched Vehicles	10-Year net gain Components + Vehicles	Jobs gained Components + Vehicles
Baseline	718	233	485	1,370	1,855	14,978
Consumer Shift Low	1,653	651	1,002	3,740	4,742	39,057
Consumer Shift High	2,588	1,072	1,516	5,649	7,165	59,459

*One-time investment spread over several years (2005-2009). Cost to treasury assumed at 67% of manufacturer investment.

8.3 Investment Timing Policy

The timing of investment policy is often important. By combining our investment cost estimates for each type of HAD and the Consumer Shift High market configuration, we may approximate an expenditures timeline based on reasonable assumptions related to how manufacturers would likely introduce fuel-saving powertrain technology options.

Figure 3, below, provides a projected timeline for investment expenditures based on the following assumptions:

- Most future hybrid and advanced diesel applications would be introduced as options to vehicles with conventional gasoline engines (e.g., Ford Escape).
- Expenditures for particular option applications would likely coincide with the launch year of a major model and/or platform change. Component tooling and equipment investment payments usually begin six to 18 months prior to the start of regular production, but final payments and investment costs often are not complete until the final six months.
- Expenditure level per 100,000 vehicles is approximately $144 million.
- Expenditures for projected switched HADs (as opposed to those already planned for U.S. production facilities) would have a lower policy usage rate. As discussed above, we assume a 50 percent policy usage rate in projecting expenditures.
- Although we chose 2009 for comparison purposes, recall that this introduction date is somewhat arbitrary and could as easily occur in 2010 to 2012. Thus, for the projected consumer shift in 2009, we spread its usage over 2009 and 2010 for illustrative purposes.

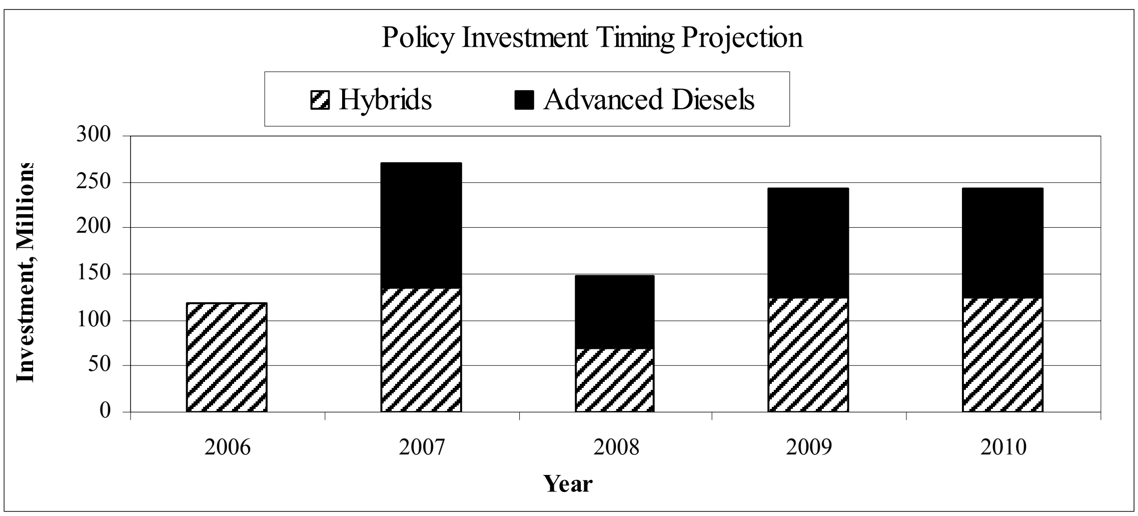

Figure 3. Timing of projected policy investment expenditures

Overall, we expect yearly expenditures from $300-$600M based on our above assumptions and current timing plans of new vehicle introductions for hybrids and advanced diesels. One should not react to the apparent dip in 2008 in the figure above. This simply reflects the fact that fewer actual vehicle announcements for HADs currently are scheduled for this calendar year. In addition, the larger expenditures in 2009 and 2010 simply reflect the typical time needed for developing production plans for new vehicle models. In other words, should a policy be enacted in 2005, we would expect that manufacturers would require a few years to ramp up to the levels of a Consumer Shift High scenario.

8.4 Policy Extension Considerations

We have studied the possible impact of a generous tax credit applied to the tooling and equipment investments associated with U.S. production of more hybrid and advanced diesel powertrains and their components that would otherwise be made in other countries. We estimate that between 5,000 and 18,200 jobs (see Table 22) would be preserved for component manufacturers by such a credit, depending on HAD market penetration late this decade. We have also estimated that, if such a policy also were to induce even one imported HAD vehicle in four instead to be made in the United States, an additional 10,000 to 41,300 jobs (see Table 23) could be saved, raising the total number of jobs preserved to between 15,000 and 59,500 (see Table 24).

If our assumptions are realistic, this would mean that roughly one in four jobs placed at risk by the rising import share likely to be associated with a rapid increase in HAD penetration could be kept in the United States rather than lost. We estimated this from our job preservations of 59,500 out of our total potential opportunity job loss of 207,000 in our Consumer Shift High scenario (see Table 15 on page 26). We also think, though we have not studied this closely, that many of the other jobs could plausibly be preserved if more vehicles could be switched to the United States where, after all, they are to be sold. There are, no doubt, a number of options for extending our approach beyond powertrains in an effort to induce more vehicle-switching. For example, the Treasury could offer automakers a credit for the total tooling and equipment investments in their *assembly plants* for a new HAD vehicle model if, and to the extent that, those plants make HAD-equipped vehicles. Since some of those plants might have full-hybrid vehicles achieving 40 percent better fuel economy that account for 50 percent of their output, while others might have minimal-hybrids achieving only 10 percent better mileage for 20 percent of their output, the credit should be scaled. The 50 percent full-hybrids plant might deserve a large percentage credit, while the 20 percent minimal-hybrids plant might rate a lower percentage credit.

In light of the cost-effectiveness of the proposed producer credit, it might also make sense to keep it on the books beyond 2009. The Oak Ridge National Laboratory study discussed earlier forecasts that HAD market share in the United States could be as high as 22 percent by 2012. Extending the credit by three more years could help shift more than a million more HAD powertrains annually to the United States than even our 2009 Consumer Shift High configuration. While the cost of the credit would rise from less than $1.1 billion to about $3.45 billion, the benefits in terms of U.S. jobs and long-term Treasury collections would amply repay the difference. In principle, policy makers could simply put the credit in place and have it expire in 2012 or when an agreed-upon level of "claims" against the credit (e.g., $2.5 billion) had been made.

Not only are the economics such that a producer credit of this type would prove over time to be revenue-neutral or better, we also believe that this is precisely the right moment to consider enacting such a policy. As Americans approach a second year of much more expensive gasoline, more of them than ever before are entertaining the possibility that prices may remain high. Residual values of low-mileage vehicles have dropped, imposing a negative "wealth effect" on their owners. There is bipartisan agreement that the gains to the United States in reduced oil imports, emissions, and greenhouse gases may justify tax-advantaging consumer decisions to purchase high-mileage HAD vehicles that, at current prices, many might not consider. Thus the odds of much higher U.S. HAD sales are clearly improving.

On the producer side, the technologies involved are still immature, favoring advanced-technology countries such as the United States, Japan, Germany, and France. Establishing a strong position early could help the United States capture R&D as well as manufacturing capacity. Japan, and especially Toyota and the companies working with it, enjoys a clear early advantage in some hybrid designs. Ford, which has courageously invested in the first full-hybrid SUV but had to go offshore for its key hybrid drive components, has publicly warned of the impact to the U.S. economy of our technical backwardness. Europe has a lead, though smaller, in the smaller diesel engines that will power sub-8,500-pound vehicles in and beyond 2009. But in both cases, there are capable U.S.-based suppliers looking for a signal, and customers waiting for those suppliers to wade deeper into the fray. Europe- and Japan-based auto suppliers have a large and growing U.S. presence that does not, but easily could, include HAD components. These suppliers, and others that will join them, *will* build these powertrains and their components ... somewhere. We believe that the producer tooling and equipment tax credit proposal we have evaluated would materially increase the proportion of that production that is done in the United States.

9.0 Conclusion

This report is explored two fundamental questions. First, what is the potential opportunity cost to the United States in terms of jobs and economic development associated with the future U.S. market for more HADs? Second, what would be the cost of a policy that would effectively encourage U.S. and foreign auto manufacturers to locate new production at existing U.S. production facilities? These questions resulted in an opportunity cost analysis which fed into a policy analysis of a proposed manufacturer tax credit incentive toward tooling and equipment investments in the conversion of existing facilities to produce hybrid and advanced diesel vehicle assemblies and components.

For our opportunity cost analysis, we forecasted a most-likely scenario for 2009 and then developed two contrasting scenarios that could represent 2009 to 2012. Our baseline scenario calls for a modest consumer interest toward HADs resulting in a forecast of just under 450,000 HAD-equipped light vehicles per year in a market of 16.6 million vehicles, compared with about 90,000 vehicles in 2003. We compare this with a significant, but not huge, consumer shift that increases HAD sales to some 1.14 million units. We then consider an even larger consumer shift, such as might result from sustained higher fuel prices, increased environmental concerns, and/or a generous consumer tax credit. In this high growth scenario, we explore the effects of HAD sales reaching 1.84 million units (or about 11 percent of the market).

While the United States would realize significant benefits in terms of fuel savings from such significant shifts toward these levels of HAD vehicles, negative economic consequences would occur if this demand were largely met by imports. Our forecast predicts that the first 700,000 additional HAD vehicles would likely be primarily imports, with an estimated 70 percent of hybrids and 55 percent of advanced diesel vehicles imported. Moreover, we predict that 82 percent of HAD powertrains will be produced outside the United States, and thus many U.S.-assembled HADs vehicles will still contain imported high value-add powertrain components. We forecast that the imported hybrids will come largely from Japan, and diesels largely from Mexico, and other non North-American markets (e.g., Europe). We further explore the effects of another 700,000 increment. Here, we believe that these vehicles would still be substantially import-supplied, but some automotive OEMs would begin building U.S. HAD powertrains and sourcing more vehicles from the United States.

These projections for increasing HAD sales could result in a loss (likely some combination of direct jobs and lost opportunity jobs for missed growth) to the United States of as many as 207,000 jobs and $2.8 billion per year in federal tax receipts. Moreover, job and tax losses would be concentrated, affecting some states much more than others. Three states (Michigan, Ohio, and Indiana) would be especially hard-hit.

These losses could be ameliorated by policies designed to encourage more U.S. HAD production. For example, a tooling and equipment investment tax credit for HAD components made in existing U.S. plants could help mitigate these potentially large and concentrated adverse job and tax effects. Indeed, the gains from higher HAD production would be spread quite broadly across the states.

Specifically, in the event of a major consumer shift that raises the HAD share from levels of less than one percent in 2003 to 11 percent by 2009, or about 1.8 million vehicles, a 67 percent investment tax credit that was 50 percent effective at switching projected imports to U.S. production would cost just under $1.1 billion spread out from 2005 to 2009. However, that credit could save almost 18,000 U.S. jobs and increase federal tax collections over a future 10-year period by almost $2.6 billion. If this same credit were also to have a positive effect on the production location of related HAD vehicle assemblies, the public benefits would increase substantially. For example, if it were effective at switching 25 percent of the projected vehicle assembly imports presented here, then the Treasury could, over the same 10-year period, gain an additional $5.65 billion in tax revenues and preserve an additional 41,300 jobs.

Appendix:

Project Team

This project is a cooperative one involving OSAT and the Michigan Environmental Council (MEC) represented by the Michigan Manufacturing Technology Center (MMTC) and The Planning Edge. Two groups guided the activities of the project. First, a working group was drawn from the above organizations along with other representatives from interested organizations. Second, a more formal advisory board of industry experts was organized as well. This board was comprised of representatives from two vehicle manufacturers, three supplier organizations, and one industry consultant. The authors wish to thank the members of this advisory board for their contributors and insights. We have chosen to leave their names off this formal report to protect their confidentiality.

HAD Project Working Group

Alan Baum
Director, Automotive Forecasting
The Planning Edge

Michael S. Flynn, Research Scientist
Director, OSAT

Charles Griffith
Automotive Project Director
Ecology Center

Patrick Hammett
Associate Director, OSAT

Roland Hwang
Senior Policy Analyst
Natural Resources Defense Council

Drew Kodjak
Program Director
National Commission on Energy Policy

Daniel Luria
Vice President, Strategy & Measurement
Michigan Manufacturing Technology Center

Brad Markell
International Representative
Research Department, UAW

Maitreya K. Sims
Research Associate, OSAT

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