ANL/ESD/TM-164

Macroeconomic Impacts of Clean Diesel Engines

Phase 2 Report: U.S.-Produced Clean Diesel Engines and SIDI Gasoline Engines for Selected Light Trucks

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NOTATION

INITIALISMS

AFV	alternative-fuel vehicle
ANL	Argonne National Laboratory
BOP	balance of payments
CAFE	corporate average fuel economy
CPI	consumer price index
DEER	diesel engine emissions reduction
DI	direct injection
DOE	U.S. Department of Energy
DRI	Standard & Poor's Data Resources, Inc.
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
FY	fiscal year
GDP	gross domestic product
GM	General Motors Corporation
HVAC	heating, ventilation, and air-conditioning
NO_x	oxides of nitrogen
OHVT	Office of Heavy Vehicle Technologies
ORNL	Oak Ridge National Laboratory
R&D	research and development
SI	spark ignition
SIDI	spark-ignition direct-injection
SUV	sport utility vehicle

UNITS

bbl	barrel
Btu	British thermal unit
kW	kilowatt
L	liter
mpg	miles per gallon
mph	miles per hour
quad	10^{15} (one quadrillion) Btu
yr	year

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ABSTRACT

Over the past two decades, light trucks (including sport utility vehicles and minivans) have become very popular for personal transportation in the United States. Their share of the U.S. light-vehicle market rose from 20% in 1980 to 46% in 1999. The share is expected to increase slightly over the next 15 years. In 1997, light-truck energy use accounted for 26% of petroleum consumption in the transportation sector. In recent years, the fuel economy of U.S.-manufactured light trucks has been below the corporate average fuel economy (CAFE) standards. About 99% of light trucks use gasoline engines. Recent improvements in advanced direct-injection (DI) diesel engines have made them more suitable for light-duty applications. Diesels now can meet consumer expectations for dependability, low noise, and low vibration. The fuel economy of a light truck equipped with an advanced DI diesel engine is estimated to be about 55% greater than that of an equivalent truck with a gasoline engine (assuming acceleration performance is the same). Advanced diesel engines also are assumed to meet current and future emission standards without any fuel economy penalty. We assess the fuel economy potential and project a market penetration of advanced diesel engines by assuming fuel-efficient spark-ignition direct-injection (SIDI) engines penetrate the market as well. From this, we assess the future light-truck-fleet fuel economy and petroleum consumption over the next 25 years. Next, we project macroeconomic impacts. We analyze four cases with penetration of SIDI engines: (1) business as usual (no clean diesel penetration), (2) medium-cost clean diesel engine, (3) low-cost clean diesel engine, and (4) carbon tax and clean diesel engine. In all three alternative clean diesel cases (Cases 2-4), real gross domestic product (GDP) is projected to increase. The greatest increase is projected from the low-cost diesel engine case. With a carbon tax of $50/ton, we also project a net benefit to the GDP compared to the business-as-usual case. Both micro- and macroeconomic benefits accrue if advanced diesel engines are viable competitors to SIDI engines in the light-duty truck market. Based on our assumptions, a carbon tax would result in a net benefit to the economy if advanced diesel engines were to penetrate the light-duty truck market. The penetration of advanced diesel engines depends on assumed engine cost, fuel cost, and performance, with the assumption that they meet applicable emission standards.

1 INTRODUCTION

In the United States, light trucks (including sport utility vehicles and minivans) have become increasingly popular in recent years. The introduction of minivans and, more recently, the increased demand for sport utility vehicles (SUVs) have primarily contributed to this trend. The sales of light trucks rose from 1.5 million units in 1970 to 2.0 million in 1980 (DRI 1983), 4.4 million in 1990 (DRI 1993), and 6.8 million in 1999 (Heavenrich and Hellman 1999). Their share of the U.S. new light-vehicle market rose from 20% in 1980 (DRI 1993) to 46% in 1999 (Heavenrich and Hellman 1999). Light trucks use more fuel than passenger cars primarily because of their lower fuel economy. Thus, by 1997, the annual energy consumption for the fleet of new and used light trucks had risen to 6.4 quadrillion Btu (6.4×10^{15} Btu, or 6.4 quad), compared with 7.5 quad for cars, according to the U.S. Department of Energy (DOE)/Energy Information Administration (EIA 1999a). This energy use in light trucks accounted for 26% of petroleum consumption in the transportation sector (25.0 quad) and 18% of the total national petroleum consumption (36.5 quad) (EIA 1999b). These shares are expected to increase steadily over the next 15 years as the current stock of passenger cars on the road is increasingly replaced by low-fuel-economy light trucks, such as SUVs. In recent years (since 1995), the fuel economy of U.S.-manufactured light trucks (in which almost 99% of these vehicles use gasoline engines) has been below the corporate average fuel economy (CAFE) standards for light trucks, which are far more lenient than the CAFE standards for cars.

Over the years, the DOE Office of Heavy Vehicle Technologies (OHVT), under its Light-Truck Clean Diesel Engine Program, has sponsored extensive research on a number of technologies that have the potential to make these engines even more efficient and clean. The goal of the Light-Truck Clean Diesel Engine Program is to meet all future emission standards, although the standards were uncertain at the time this study was conducted. The current federal 10 years/100,000 miles emission standards for light trucks are reported in a U.S. Environmental Protection Agency (EPA)/Office of Air and Radiation summary report (EPA 1998). However, at the time this study was conducted, the emission standards were undetermined for model year 2004 and beyond. The results of this DOE-sponsored research related to the clean diesel engine, plus the results from many other studies throughout the world, have made it possible to develop a new generation of diesel engines that might be introduced into the market in the next few years. These new, very efficient and clean engines are expected to be far more advanced than the current generation.

Recent market developments are noted here for some advanced diesel engines for light trucks. These advanced diesel engines, however, have not yet reached the level of the clean diesel engine discussed above. In a news release on March 5, 1998, Navistar International Corporation (1998) reported that Ford Motor Company had selected it to supply diesel engines for light trucks that meet consumer expectations for fuel economy, low noise, and environmental friendliness. The Cummins Engine Company and Detroit Diesel Corporation have separately developed a small engine for light trucks (Cummins 1998). Also, General Motors Corporation (GM) and Isuzu Motors, Ltd., have formed a joint venture (with combined capital of more than $300 million, constant 1998 dollars) to build a new generation of diesel engines for pickup trucks

(GM 1998). According to GM, this is also one of the world's cleanest-burning diesel engines (GM 1998).

The U.S. manufacturers and many foreign companies with a long history of manufacturing diesel engines for light vehicles are vying for leadership in the production of clean diesel engines for light trucks. If the companies attempt to introduce clean diesel engines in the United States, they may decide either to manufacture or to import them. The impacts are expected to be far-reaching and would affect several sectors of the economy differently. Under the Phase 1 research study of this project, the economic impacts of clean diesel engines over conventional gasoline engines for the selected light trucks were estimated for several cases involving U.S. or foreign production of clean diesel engines (Teotia et al. 1999). The economic gains (as measured by changes in the real gross domestic product and other macroeconomic indicators) were found to be higher under a clean diesel engine domestic production case as compared to a corresponding engine import case. Furthermore, the model results also demonstrated that the economic activity was highest for the High (Clean Diesel Market Penetration) Case with U.S.-produced clean diesel engines. Specifically, the cumulative real gross domestic product surplus over the Base Case over a 22-year period after introduction of clean diesel engines was estimated to be about $56 billion (constant 1992 dollars) under that assumed high U.S. dominance case.

Under this Phase 2 research study, the authors assumed that the gasoline-powered engines also are likely to improve. As the new diesel engine technology will employ a direct-injection technique, a similar technique is also proposed for gasoline-powered engines, called spark-ignition direct-injection (SIDI) technology. The SIDI engine is expected to be about 15% more energy-fficient than the conventional gasoline engine, but slightly more expensive. Under this Phase 2 study, the original Base Case macroeconomic scenario is modified to incorporate the penetration of SIDI engines in selected light trucks, termed the Enhanced Base Case. The economic analysis presented here provides estimated impacts of clean diesel engines for selected light trucks, including SUVs, pickup trucks, and large vans, under three alternative cases of domestic production of clean diesel engines. The authors assume that the technical hurdles in developing a small-size, low-emission, energy-efficient clean diesel engine will be overcome by U.S. or foreign companies.

This study provides estimates of direct and indirect economic effects under each of three clean diesel engine scenarios, which were generated by solving the Standard & Poor's Data Resources, Inc. (DRI), U.S. economy model (DRI 1998). The model was used to estimate changes in gross domestic product, total civilian employment, total fuel savings, balance of payments, and the federal government surplus under alternative scenarios. The cost/benefit of emissions changes resulting from the clean diesel engine was not evaluated by this macro model, however, because it was not a focus of this study.

2 METHODOLOGY

The domestic economic impacts of the energy-efficient clean diesel technology could be significant, even assuming market penetration of SIDI gasoline engines in light trucks. The impacts can be put in two categories. First, any commercialization of clean diesel engines in trucks will result in “direct impacts,” such as capital expenditures on engine plants and fuel savings. Second, market penetration of the new clean diesel engine could have significant “indirect impacts,” such as a reduction in crude oil imports and an increase in jobs. In order to measure the direct and indirect impacts, a four-step approach was used, as described below.

2.1 ALTERNATIVE SIDI AND CLEAN DIESEL ENGINE CASES

A set of alternative cases was developed for analysis. A case representing the possible improvements in the spark-ignition (SI) technology served as an enhanced Base Case against which the clean diesel technology alternatives would compete. Three U.S.-produced clean diesel cases representing possible performance, cost, and regulation levels were developed. The cases covered a range of technological, affordability, and regulatory changes that would influence the level of market penetration by the clean diesel technology. Alternative market penetration estimates for these cases were developed through the application of a market penetration model that evaluated benefits and costs of conventional, together with improved, spark-ignition and clean diesel technologies and projected market shares. However, improved drivability and performance of clean diesels compared with that of traditional diesels could spur additional, consumer-driven demand. The possibility of a consumer-driven increase in demand for more fuel-efficient and equal-performance advanced diesel technology is evident from the European experience. The share of light-duty diesel vehicle sales in Europe was 28% in 1999. In a few European countries, such as Belgium, France, and Spain, the sales shares were the highest at 54%, 44%, and 52%, respectively. These sales shares have been achieved from a less than 5% share in the late seventies. It is likely that a smaller price differential between gasoline and diesel fuels in the United States may not spur a very high 1-in-2 sales share. However, sales shares of 22–23%, which are similar to those achieved in Germany and Netherlands, are very plausible. Therefore, our estimates of market penetration may be conservative.

Under the above scenario for U.S.-produced clean diesel engine cases, domestic manufacturers would dominate the light-duty clean diesel engine market. In fact, the United States is the leader in heavy-duty diesel engine manufacturing. The U.S. diesel engine manufacturers have designed engines to meet more stringent emissions regulations than are found in most of the world. The expertise gained earlier by U.S. diesel engine manufacturers in the area of heavy-duty engines will provide the base for the development of clean diesel engines for light trucks. The engine manufacturers would enter into commercial arrangements with domestic light-duty vehicle manufacturers for production of the new clean diesel engines.

2.2 MARKET PENETRATION

Alternative market-penetration trajectories for clean diesel engines were developed, as described in this section. Several alternative methods are available to evaluate a new technology not yet in the market and to project its market penetration. These alternatives include stated preference surveys, Delphi surveys, and the use of an analogy to the historical market penetration elsewhere. Both the stated preference and Delphi surveys require careful planning and execution of a detailed survey instrument. They are time- and cost-intensive, and they require additional model development efforts.

A new technology has attributes that define its usefulness to potential buyers. By using a national survey (Tompkins 1998), Argonne National Laboratory (ANL) has developed models that project light-vehicle market shares by various competing technologies, including the conventional technology. These models evaluate such vehicle characteristics as initial cost, operating cost, performance, seating capacity, cargo capacity, safety, and other items of interest to consumers. They also evaluate such buyer attributes as buying capacity, desired cargo and seating capacity, type of use, and intensity of use in terms of annual miles driven. The models, which project market shares for competing technologies on the basis of this evaluation, employ survey data that reflect consumer preferences, but they do not include questions specifically for diesels. Because questions specific to diesel technology were not asked, these models may not be suitable to project the extent of market penetration by the new diesel technology, which differs substantially from conventional diesel technology. A separate model suitable for projecting market shares for the new diesel technology, as it competes with only the gasoline technology, was developed. This model was applied to project the market penetration profiles for each alternative case.

Earlier analysis assumed that the new clean diesel technology would compete with the conventional gasoline engine technology. Unlike the earlier analysis, this analysis assumes that the gasoline-powered engines also are likely to improve. As the new diesel engine technology will employ the DI technique, a similar technique is also assumed here for gasoline-powered engines. The new gasoline technology is called SIDI technology. The SIDI technology would improve fuel economy of the gasoline-powered engines and, when mass-produced, would cost only $250–300 more. Though the SIDI technology has the potential to boost gasoline engine fuel economy by 22–24% (Cole, Poola, and Sekar 1998, 1999), it is not likely to meet the emission standards without emission control equipment that requires frequent regeneration. When fuel consumption for regeneration is accounted for, the gain in the fuel economy is estimated to be 8–10% (Stovell et al. 1999). Even with the lower fuel economy gain, the SIDI technology is estimated here to be a superior technology with relatively low cost. The technology, most likely, would replace the conventional SI technology within 10–15 years after introduction. Thus, for a realistic analysis, the new diesel technology should compete against the SIDI technology for the light-truck market share. An Enhanced Base Case involving rapid penetration of SIDI technology was developed first.

Three cases involving the clean diesel technology were developed. The first such case, the clean diesel engine case, involved an estimation of market penetration by light trucks equipped with clean diesel engines. The new diesel technology would make the diesel-powered light trucks more desirable than those powered by the old indirect-injection technology. The new technology is projected to have very high efficiency, thus making its fuel economy considerably higher (by 55%) compared to the conventional SI engines. The SIDI engine fuel economy gains would be 8–22%, depending on how emissions control is deployed. We assumed the SIDI engine to have a 15% higher fuel economy than a conventional SI engine. The market penetration model was applied and year-by-year market shares for the clean diesel engine case were developed. The procedure used for developing these shares is described in the next chapter.

The second diesel case, the low-cost clean diesel engine case, involved market penetration projection for light trucks equipped with low-cost diesel engines. The DOE sponsors research and development (R&D) programs aimed at reducing the price premium for light-duty clean diesel engines. One of the goals of these R&D programs is to cut the price differential between the gasoline and diesel engine from $20/kW to $10/kW. The diesel price premium was reduced accordingly, and year-by-year market shares for this alternative case were developed through the model.

The third diesel case involved analysis of a regulatory scenario under which all fuels would be taxed on the basis of their carbon content. Data for the “9 Percent above 1990 Levels” case, from an EIA report, were used for developing fuel prices for this clean diesel case (EIA 1998b). The selected EIA’s carbon emissions case represents a reasonable middle ground and balances environmental and economic concerns resulting from carbon taxes and other regulatory actions necessary to reduce carbon emissions and maintain economic growth. The EIA’s report used fuel prices from its 1998 energy projections (EIA 1998a). Because the analysis in this report uses EIA’s 1999 projections (EIA 1999a), a method was developed to separate carbon tax amounts and add them to the 1999 energy prices. The resulting fuel prices were used in the model to project year-by-year clean diesel market penetrations. The 1999 EIA projections reported gasoline price (per gallon) as $1.17 in 2003 and increasing to $1.28 by 2025. The corresponding diesel prices (per gallon) were $1.12 and $1.18. With the carbon taxes, the gasoline price (per gallon) increased to $1.31 in 2003 and $1.52 in 2025. The corresponding diesel prices (per gallon) were $1.28 and $1.46.

2.3 DIRECT ECONOMIC IMPACTS

For each level of penetration of the SIDI engine under Case 1 and the clean diesel engine under Cases 2 to 4, we derived the direct economic impacts, such as fuel savings. Some of the key assumptions made are discussed below.

To estimate annual fuel savings under each case, we assumed that a clean diesel engine would have a 35% higher fuel economy (miles per gallon), compared to a light-truck SIDI engine. To estimate additional consumer and business expenditures on light trucks with the SIDI engine (Case 1) or clean diesel engine (Cases 2 to 4), we assumed that about 75% of the new light trucks are sold to residential customers, and the remaining 25% are sold to commercial customers (Teotia 1999). To estimate additional capital expenditures on manufacturing plants for engines/light trucks under each of the cases, we assumed that, for competitive reasons, initially one clean diesel engine plant with a capacity of 300,000 units and one SIDI engine plant with a capacity of 320,000 units would be introduced in 2003, 2005, and 2007 by one of the Big Three automobile/truck manufacturers. Subsequently, new engine capacity was assumed to be added by these and/or other producers whenever plant utilization exceeded an 80% level. The construction cost of a 300,000-unit clean diesel engine plant or 320,000-unit SIDI engine plant was assumed to be $500 million (constant 1996 dollars).

2.4 INDIRECT ECONOMIC IMPACTS

The indirect impacts of clean diesel engines and SIDI engines were estimated by using the Standard and Poor’s Data Resources, Inc., model of the U.S. economy. The DRI model is an econometric model that incorporates more than one thousand economic variables. Among the economic variables of the model, one of special interest to us is the potential gross domestic product (GDP), which is a measure of the ability of the economy to produce goods and services. The potential GDP is estimated by a Cobb-Douglass production function with four inputs — labor hours, capital stock, energy, and the stock of research and development capital (Eckstein 1981). The input values of the labor hours/capital stock exclude any hours/stock used in production of energy. Because clean diesel engines and SIDI gasoline engines are more energy efficient than conventional gasoline engines, market penetration by clean diesel engines under Cases 2 to 4, and SIDI engines under Case 1 to lesser extent, will result in substitution of capital for energy, thus increasing the potential GDP. In addition, the potential GDP will also increase dollar-for-dollar with any expected decrease in net energy imports. All else being equal, any increase in potential output (GDP) would result in increased actual output.

For the Enhanced Base Case (Case 1 with SIDI engines), variables were changed in the DRI model to accommodate increased levels of capital expenditures on engine/light-truck manufacturing plants, fuel savings, and consumer and business expenditures on light trucks with SIDI engines. No export of light trucks with SIDI gasoline engines was assumed to occur. For Cases 2 to 4 (with clean diesel engines), variables were changed in the DRI model to accommodate various levels of capital expenditures on engine/light-truck manufacturing plants, fuel savings, consumer and business expenditures on light trucks with clean diesel engines, and exports of light trucks with clean diesel engines. Details of these changes to the model are provided in the Appendix (Sections A.1 to A.4).

Macroeconomic projections were obtained by solving the DRI model for each of the above four cases (Section 4 for Case 1, and Section 5 for Cases 2 to 4). The indirect economic impacts of clean diesel engines were measured by comparing the projections under Cases 2 to 4 with the Case 1 (Enhanced Base Case) projections derived from Standard and Poor’s Data Resources, Inc., Base Case projections (DRI 1999). National impacts associated with commercialization of a clean diesel engine over a SIDI engine were measured by examining changes in such key economic indicators as real GDP, total civilian employment, total fuel savings, balance of payments, and federal government surplus (Section 5.2).

3 MARKET PENETRATION PROJECTIONS

Light-duty automotive diesel engines were introduced in Europe in very modest quantities in the late 1930s, mostly as power plants for taxicabs. After World War II, such engines — introduced again by Mercedes-Benz and Peugeot — found a small but steady market in taxicabs, salespeople's cars, and other high-mileage light vehicles. The bigger, higher-power automotive diesel engines quickly obtained a relatively large market in heavy and medium trucks used for over-the-road transport and distribution. However, light-duty engines occupied only a small niche until well into the 1970s. As a result, most of the technical development in automotive diesel engines addressed the larger, heavier-duty type, and light-duty engines remained relatively unrefined for many years. However, the energy crisis of the early and late 1970s stimulated a wider use of light-duty diesel engines, and many new diesel-powered vehicles were introduced in that period. Between 1973 and 1985, 25 new-vehicle manufacturers, mainly in Europe and Japan but also in the United States, started offering diesel options on passenger cars and light trucks; previously, only three manufacturers in Europe and one in Japan had done so. Diesel-powered passenger cars did not find widespread, lasting acceptance in the U.S. market for a number of reasons, but they became widely accepted in Europe (about 20% penetration), Japan (about 10%), and many other parts of the world.

In the meantime, the key forcing factor that ultimately affected automotive diesel engine development worldwide was the introduction of ever-tightening exhaust emissions regulations in the United States, which affected both heavy- and light-duty diesels. However, these regulations had an impact primarily on the heavy-duty engines used in large numbers in U.S. heavy and medium trucks. The net result was a series of important new technical developments such as electronic controls, very-high-pressure fuel injection, and improved turbocharging and intercooling. These technical advances made modern heavy-duty diesel engines far cleaner; lighter; more economical, powerful, and compact; and more competitive relative to other power plants. These new developments were introduced first in heavy-duty diesel engines, specifically in the U.S. market, to satisfy the tough heavy-duty emissions regulations introduced in 1991 and 1994. In general, most light-duty diesel engines were manufactured abroad and were not offered in the United States. At that time, U.S. light-duty vehicle emission standards for the diesel were quite strict compared to European and Japanese standards. The light-duty diesels remained relatively undeveloped until tougher European and Japanese exhaust emissions regulations started forcing a more rapid pace of development. Ironically, these tighter standards — which would normally be considered detrimental to the diesel — led to the introduction of technology previously adopted in heavy-duty diesels. The new technology began to make diesels more attractive, especially to European consumers. Sales volumes went up, rather than down, after the standards were tightened. Now the volume of light-duty diesel production in Europe is relatively high. Manufacturers can now afford to make significant investments in research and development, and the state of development of the light-duty diesel is catching up with and even surpassing that of heavier diesels. As a result, diesels have been reintroduced in the United States by Volkswagen and model lines expanded by Mercedes. Domestically, light-duty diesels have expanded market share in heavy pickup trucks (class 2b and 3), but these are not yet clean enough to be marketed widely in class 1 and 2a, where emissions regulations and test procedures are most difficult.

Market penetration projections, in terms of year-by-year share of new light trucks using the new technology, were necessary for our analysis. The projections, when used with total light-truck sales, would provide estimates of the number of clean diesel truck sales annually. The year 2003 was selected as the introductory year for the new technology. Projections for the Enhanced Base Case representing the SIDI technology and the three clean diesel cases were developed.

Future light-duty truck sales were derived from the DOE/EIA 1999 Annual Energy Outlook (EIA 1999b). The EIA document provides Base Case projections for fuel prices, fuel consumption, light-truck sales, and gasoline light-truck fuel economy. The light-truck sales are further subdivided by six truck types: (1) small pickup, (2) minivan, (3) small sport utility, (4) large pickup, (5) large van, and (6) large sport utility. The EIA projections extend through the year 2020; the growth rate during the last five years of the projections was used to extrapolate sales to 2025. Households own a majority of the minivans and SUVs used for personal travel. An ANL survey showed that minivan-owning households are less likely to adopt new technologies readily (Tompkins et al. 1998). Also, the owners of minivans (which are classified as light trucks) treat them as larger station wagons. Consequently, minivans were excluded from the population of new light trucks that were projected to be equipped with advanced diesel engines.

The fuel savings from the use of clean diesel technology would be substantial. The conventional gasoline engine’s peak efficiency is in the range of 27–31%, while the current turbocharged, direct-injection diesel engine’s peak efficiency is close to 44%. The most efficient gasoline engine, Honda’s VTEC, is said to have an efficiency of 31.7%. On the basis of peak efficiency alone, the current turbocharged diesel is 38.8% more efficient. Also, a gallon of diesel fuel contains 11.5% more energy (128,700 vs. 115,400 Btu) than does a gallon of gasoline (Davis 1997). Based on these rough estimates, the most efficient current diesel engine would provide 55% more miles per gallon of fuel than the most efficient current gasoline engine with SI technology. The advanced diesel technology is projected to increase peak engine efficiency to 50%, a 13.6% increase. The gasoline engine with SI technology would also improve its fuel economy. Assuming that future improvements would increase the conventional SI technology gasoline engine efficiency to 36%, we kept the fuel economy gain at 55%. We also evaluated an Enhanced Base Case involving SIDI technology. The SIDI vehicles were assumed to have 15% higher fuel economy than the conventional SI technology. Thus, three engine technologies for each of the light trucks were included in the analysis: (1) conventional SI, (2) SIDI, and (3) clean diesel. The assumed fuel economies for the five light trucks are shown in Figures 3.1 and 3.2.

The following sections describe the assumptions and procedures used in developing market penetration estimates under the alternative cases.

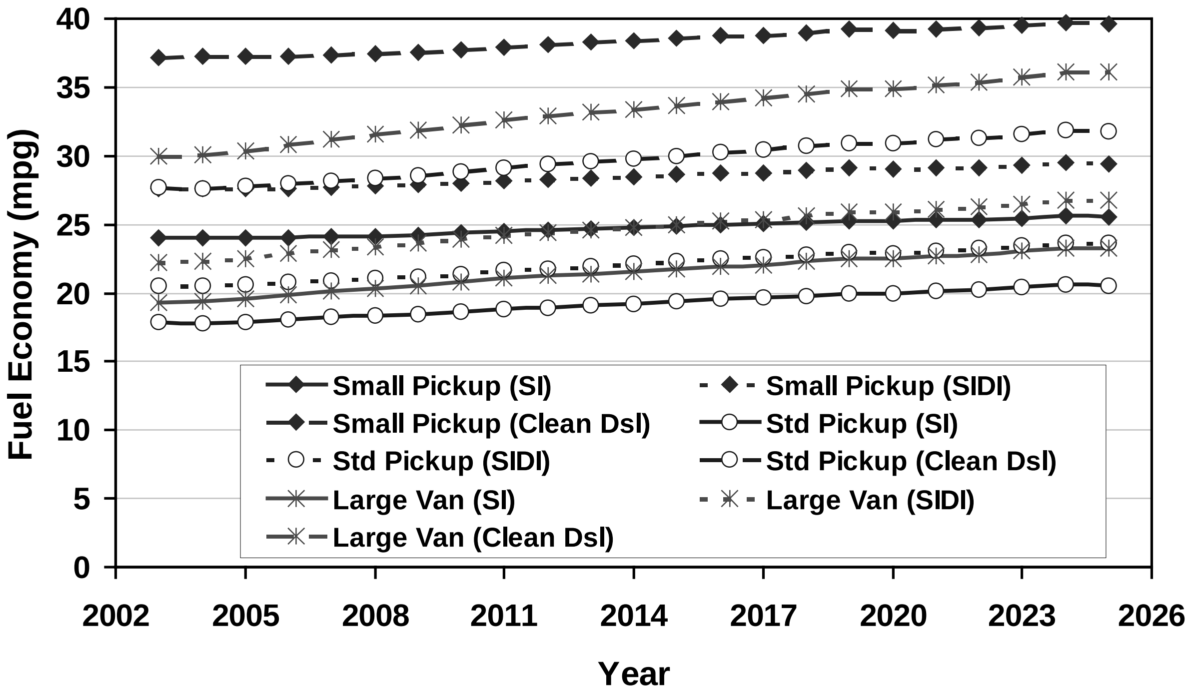

FIGURE 3.1 SI, SIDI, and Clean Diesel Fuel Economies of the Small Pickup, Standard Pickup, and Large Van

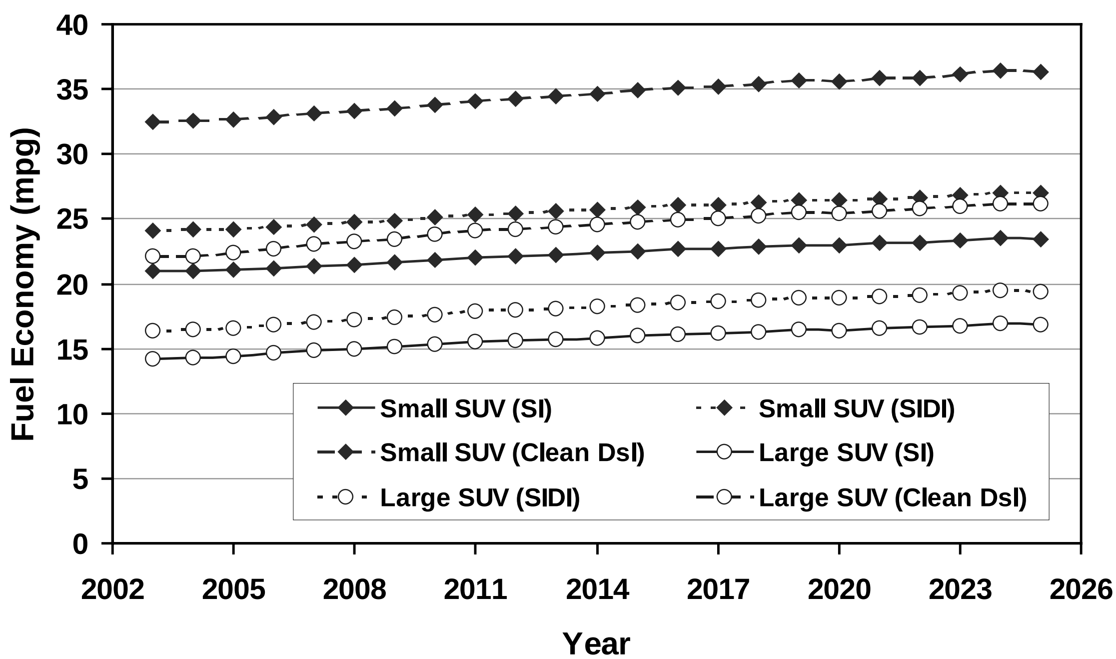

FIGURE 3.2 SI, SIDI, and Clean Diesel Fuel Economies of Small and Large SUVs

3.1 ENHANCED BASE CASE (CASE 1)

Under the Enhanced Base Case, the SIDI technology would be introduced in 2003. The technology is superior and cost effective. It will eventually replace the conventional SI engine. The market penetration profile for the SIDI technology was developed by applying a technology substitution model.

3.1.1 Assumptions

The Enhanced Base Case represents lower fuel consumption by the light truck sector, as the new SIDI technology would have higher fuel economy. The SIDI engine would increase the light-truck price by $300 initially and decrease to a $250 increment in 10 years, irrespective of light-truck type. The technology would be very cost effective since it is assumed to increase the light truck fuel economy by 15%. As explained earlier, laboratory tests have shown the SIDI technology to provide 22–24% higher fuel economy (Cole, Poola, and Sekar 1998, 1999). However, because it would not meet the emission standards without an emission control system that needs frequent regeneration, laboratory tests have shown the effective fuel economy gain lowered to 8–10% (Stovell et al. 1999). We assumed that a middle ground would be reached by the time the SIDI technology reaches the market and assigned a 15% fuel economy gain over EIA's projected fuel economies. The fuel economies are shown in Figures 3.1 and 3.2.

The new SIDI technology is assumed to completely replace the SI technology in 15 years. Some new technologies have substituted an existing technology in less time. For example, the historical market penetration by the electronic fuel injection technology in the U.S. has taken less than 15 years. However, the new emissions regulations were behind that dramatic rate of technology substitution. A sustained price escalation that lasts for several years, doubling or tripling the fuel prices, could cause rapid market domination by the SIDI technology in a period shorter than 15 years. Historically, such a sustained fuel price rise has not occurred. Therefore, a period shorter than 15 years for the SIDI technology to replace the SI technology in the light-truck market is not justified.

3.1.2 U.S. Markets

Introduction of the new SIDI technology represents a case in which a superior technology substitutes an existing (SI) technology. Marketing professionals use mathematical models for projecting the level of technology substitution. Work by many researchers has shown such substitution to follow an S-shaped curve under normal circumstances (Mansfield 1961; Blackman 1974; Paul 1979; Teotia and Raju 1986). A formulation in which functions $F_o\{t\}$ and $F_n\{t\}$ define the market shares of old and new technologies at time t, respectively, was used for projecting SIDI shares. Since only two technologies are competing, $F_o\{t\}$ equals $1 - F_n\{t\}$. For the market penetration profile, the following functional form, from earlier work by Santini (1989), was used:

$$t = \delta + \beta \ln[F\{t\}/(1 - F\{t\})] + \mu$$

Here, δ and β are coefficients that determine the shape of the market penetration curve, and μ is the error term. The term δ defines the midpoint in time for the symmetric market penetration curve represented by the above equation, while β determines the rate at which the new technology would penetrate the market.

We estimated values of δ and β such that the new SIDI technology would replace the SI technology in 15 years. The nonlinear regression procedure in the SHAZAM econometric software (McGraw-Hill 1997) was used for this purpose. The resulting market penetration profile is shown in Figure 3.3.

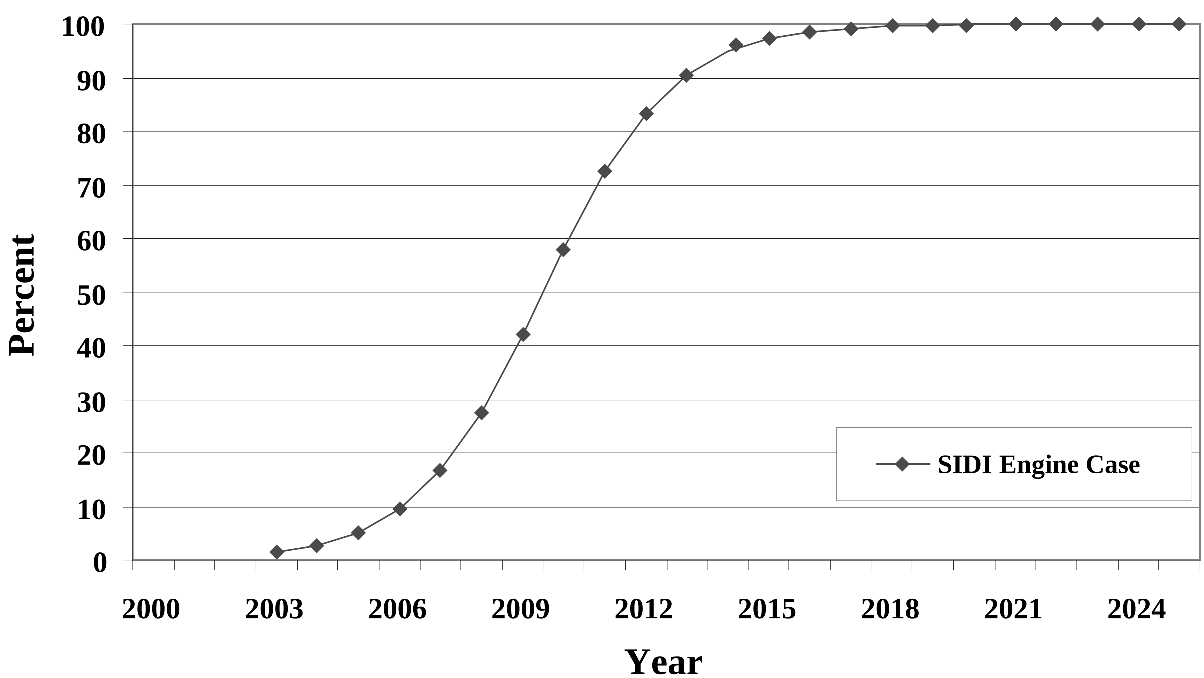

FIGURE 3.3 Market Share of New Light Trucks with SIDI Engines under the Enhanced Base Case

3.2 DOMESTIC CLEAN DIESEL ENGINE CASE (CASE 2)

ANL conducted a 47-state stated preference survey of vehicle owners by collecting exhaustive information on preference for various vehicle attributes (Tompkins et al. 1998). The data from the ANL survey were merged with a similar survey conducted by the University of California's Institute of Transportation Studies in the state of California. A consumer choice model was developed for this project. The model, a multinomial logit model, was used for projecting the clean diesel technology market shares.

The survey data provided information relating to various vehicle attributes that would affect a vehicle technology's market penetration. The selected model evaluated vehicle price, fuel cost per mile, annual maintenance cost, time required to accelerate from a stop to 30 mph, fuel availability in terms of diesel service stations as a percent of gasoline service stations, and top speed. The following multinomial logit equation was applied:

$$P_i = \frac{Exp\left(\sum_{j=1}^{6} C_j \bullet X_{ij}\right)}{Exp\left(\sum_{j=1}^{6} C_j \bullet X_{1j}\right) + Exp\left(\sum_{j=1}^{6} C_j \bullet X_{2j}\right)}$$

In this equation, C_j represents the model coefficient, and X_{ij} represents the variable values for the two technologies: (1) combined SI and SIDI and (2) clean diesel. Table 3.1 lists the model coefficients.

3.2.1 Assumptions

Aside from the lower fuel consumption, the usual, well-designed diesel engine has other advantages, too. It has lower maintenance and longer life. The gasoline engine and gasoline fuel itself have the advantage of better low-temperature starting and operating characteristics and

TABLE 3.1 Vehicle Choice Model Coefficients

Variable	Coefficient
Vehicle price (1995 dollars)	-5.0000E-4
Fuel cost (1995 cents per mile)	-4.2900E-1
Annual maintenance cost (1995 dollars)	-2.7500E-3
Acceleration time for 0–30 mph (seconds)	-7.1201E-2
Fuel availability (% of gasoline stations)	4.6038E-2
Top speed (mph)	6.0599E-3

established refueling and maintenance infrastructure. The DOE/OHVT sponsors several research projects aimed at improving performance, operational aspects, and costs of heavy-vehicle power plants. The current research on the clean diesel engine is anticipated to bring such characteristics as poor starting, smell, noise, vibration, and harshness equivalent to those of the SI engine. Considerable success in improving these characteristics has been demonstrated in European diesel engines. Consequently, such characteristics need not be quantified for the market penetration analysis. Data necessary to execute the model were developed for each of the five truck types: (1) small pickup, (2) large pickup, (3) small sport utility, (4) large sport utility, and (5) large van.

Price information from the *Automotive News Market Data Book* was used to estimate gasoline and diesel truck prices (Automotive News 1999). A representative vehicle or an average of two or more representative vehicles was used for each truck type. The conventional (SI) gasoline truck prices were increased to account for the SIDI premium and its market share. Though OHVT also sponsors research aimed at bringing cost equality for mass-produced diesel engines, we assumed diesel engines to cost more. We assumed a cost premium, over conventional (SI) gasoline trucks, of $20 per kW in 2003, linearly decreasing to $17/kW by 2013. The diesel truck price was reduced by a factor of 0.95 to account for its longer life. A diesel truck is assumed to last 30% longer than a gasoline truck and be useful for 17% more vehicle-miles. The benefits of this increased life were assumed to occur after 15 years. We used a 5% discount rate to arrive at a diesel price adjustment factor of 0.95.

The year-by-year diesel fuel prices were obtained from the EIA's summary tables supporting the *1999 Annual Energy Outlook* (EIA 1999b). The Base Case EIA-projected gasoline prices (per gallon) ranged from $1.17 in 2003 to $1.28 in 2025. The corresponding values (per gallon) for diesel were $1.12 to $1.18. A factor of 1.55 was applied to the EIA-projected gasoline truck fuel economies to arrive at diesel fuel economies (shown in Figures 3.1 and 3.2). The gasoline truck fuel economies were then increased to reflect SIDI technology market shares, thus creating a set of market share weighted fuel economies. The resulting fuel economies were used for computing fuel costs.

The annual maintenance costs include routine and unscheduled maintenance. The routine maintenance relates to lubrication, oil, and filter changes at regular intervals; replacements of tires, battery, and belts; upkeep of the heating, ventilation, and air-conditioning (HVAC) and engine cooling systems; periodic spark plug replacement and tuning; and other maintenance such as replacement of lights. The unscheduled maintenance includes replacement of the water pump, alternator, starter, gaskets, one or more fuel injectors, and shock absorbers. The average annual maintenance cost was estimated as $547 for the small pickup, $560 for the small sport utility, $629 for the large pickup, and $711 for the large sport utility and large van. The diesel maintenance cost at the time of introduction was assumed as 95% of that for the gasoline engine, decreasing to 91% in 22 years.

The 0–30-mph acceleration times in seconds were taken as follows: small pickup, 4.1; large pickup, 4; small sport utility, 3.9; large sport utility, 4.2; and large van, 4.3. The

0–30 acceleration times are available through such magazines as *Open Road, Car & Driver,* and *Consumer Reports*. These times depend on the specific procedures used in conducting the tests. The ratios of 0–30-mph times to 0–60-mph times were observed to range from 0.3 to 0.4. A majority of the vehicles tested by the above-mentioned magazines have optional high-power engines and do not always represent the average vehicle of the class. The EPA publishes information relating to 0–60-mph times for cars and light trucks (Heavenrich and Hellman 1999). The 1999 values for the five vehicles are 12 for the small pickup, 10.3 for the large pickup, 11 for small sport utility, and 11.1 for the large sport utility and large van. The diesel acceleration times were the assumed to be slightly lower at 97.5% of the gasoline truck acceleration times in 2003, linearly decreasing to 95% by 2010.

The availability of refueling facilities represents perceived disutility for the less prevalent fuel. Currently, the diesel refueling stations represent 16% of the gasoline refueling stations (McNutt and Hadder 1999). We assumed the ratio to increase steadily to 40% (equivalent to four out of ten gasoline stations also having diesel refueling facilities) by 2015. The top speeds were assumed to be identical for both gasoline and diesel vehicles.

3.2.2 U.S. Markets

The model predicted varying levels of clean diesel market shares for the five truck types. The highest year 2025 share of 10.5% was predicted for both small and large sport utilities. The

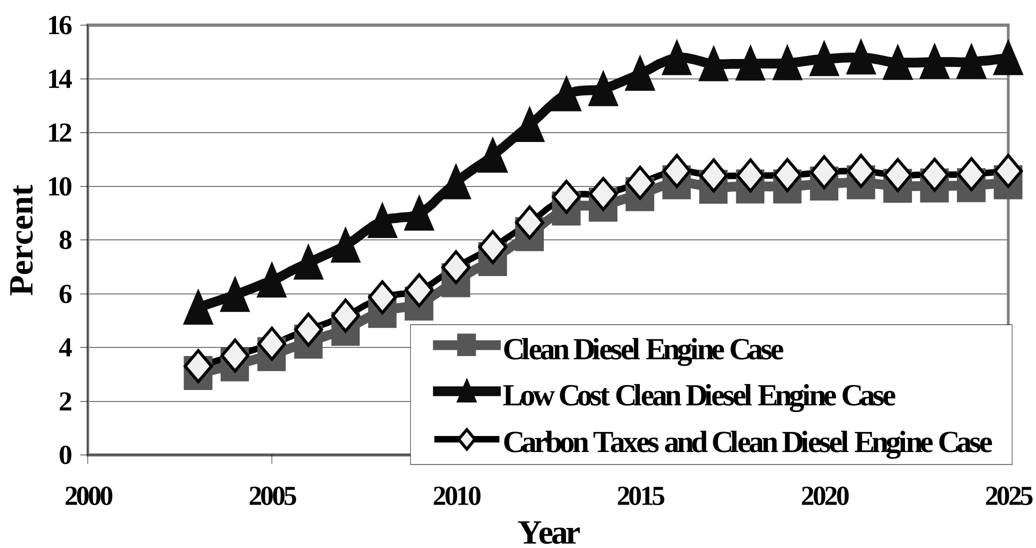

FIGURE 3.4 Market Share of New Light Trucks with Clean Diesel Engines under Alternative Cases (as percent of total light truck sales excluding small vans)

year 2025 shares for small and large pickups were projected as 9.8%, while the share for large vans was the smallest at 7.7%. Figure 3.4 shows the projected clean diesel market share under this case for the five truck types combined. The individual market shares were projected, the total market for each truck was estimated from the EIA data, and the year-by-year clean diesel shares for the five truck types combined were computed from these data. The small fluctuations in the figure are due to fluctuations in the EIA sales projections.

3.2.3 Exports

In addition to sales in the U.S. market, the new-technology vehicles could be exported. Exports of U.S. light-duty vehicles outside the Canada/Mexico sphere are very limited and are concentrated in only a few countries where U.S.-made vehicles are popular, mostly for historical reasons (308,000 trucks exported in 1996 [AAMA 1997]). Vehicle exports are limited in many parts of the world for many different reasons; some are restricted, or highly regulated, to favor local manufacturers or special types of vehicles. In general, the very special characteristics of U.S. vehicles (large, powerful, thirsty, expensive) has not made them suitable for wide export. For instance, U.S. manufacturers did not make right-hand-drive vehicles at all until just recently. Yet, almost one half of the countries in the world standardize on right-hand-drive vehicles. Among the biggest drawbacks of U.S.-made light-duty vehicles outside North America are their large engines and relatively poor fuel economy. The U.S. passenger cars, even small ones, usually start with an engine of about 2 liters (L) displacement and go up from there. Japanese- or European-made passenger cars start with much smaller engines (1.0 or 1.2 L) and then go up to about 2 L. Only large, “luxury” foreign-made vehicles use V6 engines of about 3-L displacement, which is the typical engine in U.S.-made cars. The large size of U.S. standard passenger cars, before the downsizing efforts of the late 1970s and early 1980s, also made them too expensive and less suitable for many foreign markets. The few export markets available to U.S.-made vehicles were taken over mostly by Japanese and European manufacturers, especially after the oil crisis. By the time U.S. manufacturers developed vehicles that could be competitive in some of these markets (in the late 1980s and early 1990s), it was too late to re-enter them without a costly effort. In addition, U.S. passenger car manufacturers have often preferred to attack foreign markets with products from their European and even Japanese subsidiaries, viewing those products as more suitable than U.S.-made vehicles. The net result is that exports of U.S.-made light-duty vehicles are limited to a few low-cost-fuel countries, or to places where a strong American influence has kept the product viable. These include a handful of Latin American countries and a very few Middle Eastern countries. Certain special U.S.-made vehicles that are not normally made by most foreign manufacturers, such as minivans, jeeps, and pickups, sell in tiny quantities in several of these foreign markets. In recent years, Chrysler (which has no historical base in Europe like that of Ford and GM) has actively marketed its vehicles in Europe and has succeeded in selling almost 100,000 units a year. However, Ford and GM, with their large local subsidiaries, export hardly any vehicles to Europe.

Our assumption under Case 2 was that this pattern of exports would not change drastically in the future. The availability of diesel-powered vehicles (something now limited to Japanese and European importers) would improve the competitiveness of U.S.-made vehicles, resulting in additional net sales; however, some of the diesel sales would come from cannibalization of gasoline sales. The authors assumed that because of the low level of potential exports of clean diesel engines, the U.S. companies would focus on domestic markets and would not be able to compete in Europe or Japan, which have their own advanced diesel light trucks. No exports of diesel light trucks to Europe and Japan are projected during the period 2003–2024 (Figure 3.5). Most U.S. export sales would come from countries in Central America and the Caribbean, Saudi Arabia and Israel in the Middle East, Australia and New Zealand in the Pacific rim, and a very few from other locations in Africa, Asia, and Latin America. In general, the increase in projected vehicle sales was kept extremely modest because the price of U.S.-made vehicles should only be marginally competitive. For these territories, the 2024 market penetration of light trucks with CD engines was assumed to approach 2,500 units to Australia, 1,000 to Africa, 3,200 to Asia, 16,800 to Latin America, and 8,400 to the Middle East (Figure 3.5). The total exports of light trucks with CD engines increase from 9,600 units in 2003, their introductory year, to 30,600 units in 2015 and 32,000 in 2024. In 2024, Latin America accounts for a 53% share of total exports, followed by 26% for the Middle East, 10% for Asia, 8% for Australia, and 3% for Africa. We further assumed that half the diesel light-truck exports would displace gasoline light-truck exports.

3.3 LOW-COST DOMESTIC CLEAN DIESEL ENGINE CASE (CASE 3)

Under the Low-Cost Clean Diesel Engine Case, we assumed that the additional cost of clean diesel engines would be lowered through further research and development efforts. This

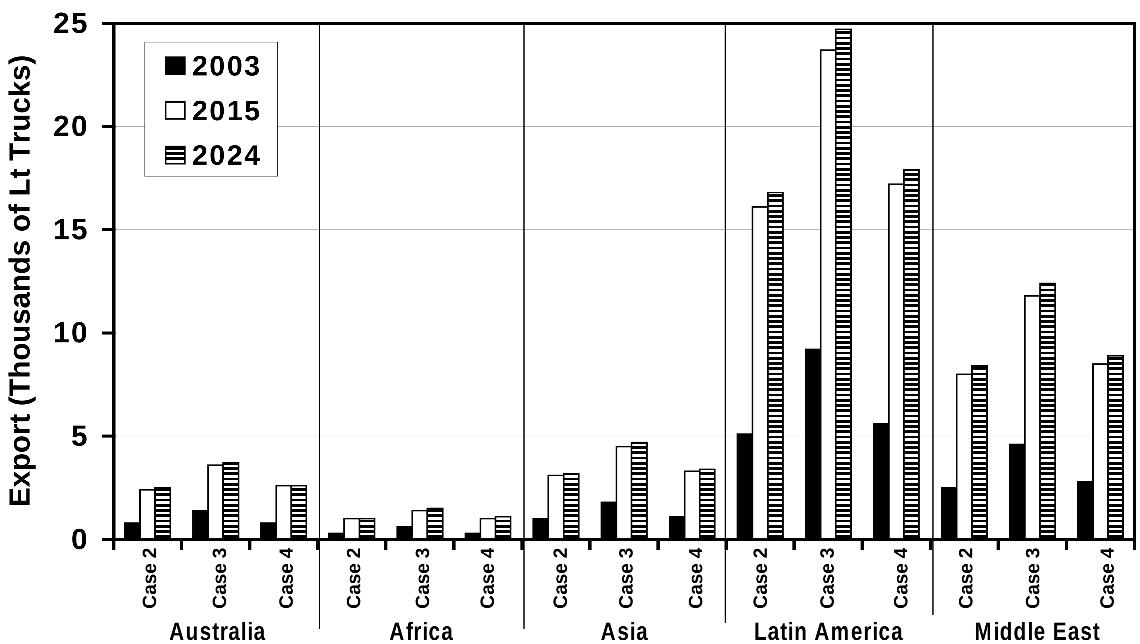

FIGURE 3.5 Assumed U.S. Exports of Light Trucks with Clean Diesel Engines under Cases 2, 3, and 4 (1,000 units)

would reduce the purchase price of clean diesel engines. The vehicle price variable within the market penetration projection model provided the highest contribution to the choice process.

3.3.1 Assumptions

The ongoing research on reducing and/or eliminating the price premium for diesel engines was assumed to cut the diesel price premium by half. We assumed the price premium to be $10/kW, down from $20/kW under the above-described Case 2. The lower premium for clean diesel engines would increase their market shares. All attributes, other than diesel vehicle price, were kept unchanged from Case 2, and the model was applied to each truck type.

3.3.2 U.S. Markets

The model projected a substantial increase in the clean diesel market under this case. The projected shares were nearly 47% higher. The year 2025 shares were 12.6 for the small pickup, 14.3% for the large pickup, 15.3% for the small sport utility, 16.8% for the large sport utility, and 12.2% for the large van. Figure 3.4 shows the projected market shares under the Low-Cost Clean Diesel Engine Case.

3.3.3 Exports

Availability of the low-cost clean diesel engine under Case 3 results in higher levels of market penetration of domestic diesel engines than under Case 2. The authors assumed that rate of change in export levels of clean diesel vehicles would be proportionate to the rate of change in domestic sales of those vehicles. All other assumptions with regard to the methodology for projecting diesel vehicles were kept same as those under Case 2 (Section 3.2.3). Under this case, total exports of clean diesel light trucks increase from 17,500 units in 2003 (the introductory year) to 45,100 units in 2015 and 47,000 in 2024. By 2024, exports of clean diesel light trucks are projected to approach 3,700 units to Australia, 1,500 to Africa, 4,700 to Asia, 24,700 to Latin America, and 12,400 to the Middle East (Figure 3.5).

3.4 CARBON TAXES AND DOMESTIC CLEAN DIESEL ENGINE CASE (CASE 4)

Scientists and policy makers have debated the effect of anthropogenic greenhouse gas emissions on the earth’s climate for some time. During December 1997, more than 160 nations met at a convention in Kyoto, Japan, to negotiate binding limitations on greenhouse emissions by the industrialized nations. An outcome of the meeting was a proposal to limit greenhouse gas emissions by these industrialized nations to some extent relative to the 1990 levels by 2012. With an expanding economy and increased use of industrial products and motor vehicles, the United States is expected to emit greenhouse gases at levels much higher than in 1990, unless actions are taken to curb them. The EIA has evaluated the impacts of achieving varying levels of greenhouse gas emissions reductions on the U.S. economy and fuel prices (EIA 1998b). We selected one of the scenarios evaluated by EIA and analyzed its impact on the clean diesel market penetration.

3.4.1 Assumptions

The EIA evaluated seven alternative greenhouse gas emissions scenarios. These scenarios included greenhouse gas emissions 33% above 1990 levels, 24% above 1990 levels, 14% above 1990 levels, 9% above 1990 levels, stabilization at 1990 levels, 3% below 1990 levels, and 7% below 1990 levels. We selected 9% above 1990 levels as the most likely case. This scenario represents the middle of the seven scenarios evaluated and involves a moderate increase in energy prices through carbon taxes. We also assumed that reductions in greenhouse gases can be achieved through fuel taxes. Gasoline and diesel prices from EIA's evaluation were obtained (EIA 1998b), and increases in energy prices due to the greenhouse gas emissions reduction requirements were estimated by subtracting the baseline gasoline and diesel prices (EIA 1998a). The resulting increases were added to the prices used in our analysis. With the carbon tax, the gasoline price (per gallon) was increased from $1.17 to $1.31 in 2003 and from $1.28 to $1.52 in 2025. The diesel price (per gallon) was increased from $1.12 to $1.28 in 2003 and from $1.18 to $1.46 in 2025. Because of its higher carbon content, diesel fuel is taxed slightly more than gasoline. However, the differences in the carbon tax were much lower than fuel economy gains for diesels. The resulting increases in fuel cost per mile were higher for the conventional SI and SIDI. All other variables were kept unchanged.

3.4.2 U.S. Markets

The model projected relatively small increases in the clean diesel market shares. The percent increases in diesel fuel prices were slightly higher than increases in gasoline prices. However, higher diesel fuel economies caused relatively lower percent increases in per-mile fuel costs. The year 2025 market shares were 10.2% for the small pickup, 10.3% for the large pickup, 10.9% for the small sport utility, 11% for the large sport utility, and 7.7% for the large van. The composite year 2025 market share was 10.6% compared to 10.1% under Case 2. Figure 3.2 shows the projected market shares.

3.4.3 Exports

Availability of the clean diesel engine under Case 4 results in slightly higher levels of market penetration of the domestic diesel engine than under Case 2. The authors assumed that the rate of change in export levels of clean diesel vehicles would be proportionate to the rate of change in domestic sales of those vehicles. All other assumptions with regard to the methodology for projecting diesel vehicles were kept the same as those under Case 2 (Section 3.2.3). With the underlying case, total exports of clean diesel light trucks increase from 10,600 units in 2003, the introductory year, to 32,600 units in 2015 and 34,000 in 2024. By 2024, exports of clean diesel light trucks were projected to approach 2,600 units to Australia, 1,100 to Africa, 3,400 to Asia, 17,900 to Latin America, and 8,900 to the Middle East (Figure 3.5).

4 ENHANCED BASE CASE (WITH SIDI ENGINES) MACROECONOMIC SCENARIO

The Enhanced Base Case (Case 1) was generated by solving the macroeconomic model under the assumptions that SIDI gasoline engines replace conventional gasoline engines for all categories of light trucks. The other assumptions are identical to the Standard & Poor's DRI Base Case (25-Year Trend Projection: T250899), released in August 1999. A complete description of the underlying assumptions is available from DRI (1999). Selected highlights of the Enhanced Base Case are provided below.

4.1 ENHANCED BASE CASE ASSUMPTIONS: SELECTED HIGHLIGHTS

Adoption of energy-efficient SIDI gasoline engines in light trucks results in significant energy savings. Because the fuel economy of SIDI engines is assumed to be 15% higher than that of conventional gasoline engines, and the rate of market penetration is maximum (99% saturation rate by 2017) under this case, the direct annual energy savings approach 0.179 quad by 2024. (The details of these estimates are given in the Appendix, Section A.1.)

Under this scenario (Case 1), we assume that the SIDI engines are built in the United States only, substituting for gasoline engines in any penetrated domestic light-truck markets. As a result, cumulative plant investment is $2.60 billion (1992 constant dollars) higher than in the DRI Base Case by 2024. (The annual estimates are given in the Appendix, Section A.1.)

Incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of SIDI trucks sold in the United States. Following the approach described in Section 2.3, the incremental expenditures were apportioned between consumers (75%) and businesses (25%), both of whom perceive the SIDI engine to be better in quality. Because of increased demand for light trucks in the United States, annual consumer and business expenditures on them rise to $1.59 billion (1992 constant dollars) by 2024. (The details of these estimates are given in the Appendix, Section A.1.)

All other macroeconomic assumptions were same as under the DRI Base Case (1999) provided to ANL. Some of the key assumptions of interest are discussed below.

Under the DRI Base Case projection, the labor force growth is projected to slow down in the future because of a lower growth in female participation rate (now 80% of the male rate), a slowdown in growth of the adult population, and an increase in the share of the population reaching retirement age. These factors will result in an average annual labor force growth of 1.2% between 1999 and 2004, 0.8% between 2004 and 2014, and only 0.5% between 2014 and 2024. This slowdown in the growth of the labor force is expected to reduce the growth rate of the country's economic output, as measured by the potential GDP. The Federal Reserve Board will continue to guard against any significant increase in inflation.

The Base Case projection assumes that the refiner's acquisition price for crude oil would remain below $20 per barrel through the end of 2008. However, in an environment of steadily increasing worldwide demand for crude oil, the OPEC cartel is destined to regain some pricing power. Nominal oil prices rise steadily to $42 per barrel by 2024 (Table 4.1). However, the increase in real oil prices in constant 1992 dollars is expected to average only a modest 0.24% between 1997 and 2024. Real oil prices in 2024 would still be less than the peak prices in 1980.

TABLE 4.1 U.S. Economy Outlook in Enhanced Base Case

Selected Variable	1997	2003	2006	2009	2015	2024
Gross domestic product						
Real GDP ($\$10^6$ 1992 dollars)	7,191	8,640	9,279	9,865	11,175	13,031
Real GDP (% change/yr)	3.8	2.5	2.1	1.9	2.2	1.8
Price level indicator						
GDP price index (% change/yr)	2.0	1.9	2.2	2.1	2.6	4.6
Employment indicators						
Total civilian employment (10^6)	129.44	139.67	143.71	147.02	154.01	161.63
Civilian unemployment rate (%)	5.0	4.8	5.2	5.7	5.3	5.2
Financial indicators						
30-year treasury bond yield (%)	6.61	5.57	5.62	5.99	6.58	7.97
Federal budget surplus (FY, $\$10^9$)	-22.0	170.9	211.9	184.2	30.8	-447.8
Federal budget surplus (% of GDP)	-0.6	1.7	1.9	1.5	0.6	-1.3
Current account balance ($\$10^9$)	-161.3	-381.1	-406.4	-405.2	-525.3	-817.7
Transportation indicators						
Total light-vehicle sales (10^6 units)	15.1	15.7	16.4	16.3	17.4	18.1
Light-truck sales (10^6 units)	6.9	8.4	9.2	9.5	10.4	11.0
Energy indicators						
Total energy demand (10^{15} Btu)	90.6	101.7	105.8	107.7	112.2	115.7
Refiners' acq. price for crude oil: Composite ($/bbl)	19.16	17.35	18.10	20.10	26.78	42.39
Refiners' acq. price for crude oil: Foreign ($/bbl, 1992 dollars)	16.68	13.8	13.41	13.96	15.91	17.78
Imports of petroleum and products ($\$10^9$, 1992 dollars)	65.9	84.7	90.3	91.2	95.5	100.2

4.2 ENHANCED BASE-CASE PROJECTIONS: SELECTED HIGHLIGHTS

Table 4.1 provides projections of selected key macroeconomic indicators under the Enhanced Base Case at selected intervals between 1997 and 2024. The methodology for estimating potential output (GDP) in the DRI model was discussed in Section 2.4. Because SIDI engines are more energy-efficient than conventional gasoline engines, market penetration by clean diesel engines results in the substitution of capital for energy. The capital stock in 2024 is approximately $6.5 billion (1992 constant dollars) higher than in the Base Case. Because of the increase in capital stock in the economy and reduced levels of energy imports, the real potential GDP is $33.7 billion higher than in the Base Case cumulatively over the 2003-2024 period. This increase in potential output enables actual output in the economy to grow by about $34.7 billion over the Base Case levels cumulatively over the 2003–2024 period. The annual rate of inflation declines very modestly, in the range of 0.0 to -0.05%.

Reflecting the expected demographic trends and their adverse impact on potential GDP discussed in Section 4.1, a slowdown in the rate of growth of the U.S. economy is projected. Compared to a 2.8% average annual growth rate between 1970 and 1996, the real GDP is projected to grow at only 2.2% between 1997 and 2024. The inflation in the economy has been modest over the last 10 years. This pattern is continued under the trend projection, with the broader-based GDP price index projected to rise by 2.6% per year over that period. The job market stays healthy, and unemployment rates do not exceed 5.0% through 2006 (Table 4.1). Total employment rises from 129.4 million in 1997 to 161.6 million in 2024 (Table 4.1). The unemployment rate averages 5.2% over the projection period.

Interest rates are driven by the rate of inflation in the economy. Table 4.1 shows long-term government bond yields are expected to remain in the range of 5.6–8.0 over the projection period. The federal budget surplus is projected to remain in surplus for the early part of the projection period. The federal budget will come under great pressure from increasing entitlements for retirees, whose numbers swell particularly after 2011. As a result, the budget surplus will disappear by 2018 . Thereafter, the deficit will steadily rise to 1.3% by 2024. For the entire projection period, an average surplus equivalent to 0.7% of GDP is projected.

Sales of all light vehicles, including light-duty trucks (expected to be of major interest to DOE), are strong throughout the projection period (Table 4.1). Sales of light trucks, whether manufactured in the United States or elsewhere, are expected to grow modestly, at an average annual rate of 1.74%, between 1997 and 2024.

As discussed in Section 4.1, even in 2022, the real price of imported oil remains well below its 1980 peak (about $57/bbl in 1992 dollars). As shown in Table 4.1, the total energy demand increases from 90.6 quad (10^{15} Btu) in 1997 to 115.7 quad in 2024. This implies a continuation of the 1980-2000 pattern of declining energy use per unit of GDP.

On the international front, the dollar's real exchange rate should decline by only about 6% between 1999 and 2024. The current account balance remains stable prior to 2012 but falls rapidly thereafter, in line with deterioration in the merchandise trade balance, which occurs because of several factors, including escalations in imported fuel oil prices (nominal price increases from about $20/barrel in 2009 to $42 in 2024). The current account balance of payments (BOP) deficit rises from a nominal $161 billion in 1997 to $817 billion in 2024.

5 ECONOMIC IMPACTS UNDER ALTERNATIVE CLEAN DIESEL CASES

Macroeconomic projections under each clean diesel case were obtained by solving the DRI model for the 2003–2024 period. Prior to solving the model, changes in the selected variables were made under each case (see Appendix). To conform to the DRI model, specific changes made to investment, consumer and business expenditures, and exports under each case are shown in this section, in constant 1992 dollars. Section 5.1 presents highlights of the macroeconomic scenarios generated from the model, and Section 5.2 discusses specific national economic impacts on certain key macroeconomic indicators, such as GDP. The estimated macroeconomic impacts measured in dollars also are shown in this section (in constant 1992 dollars).

5.1 CLEAN DIESEL MACROECONOMIC SCENARIOS

This section provides key assumptions and long-term projections for the three alternative macroeconomic scenarios generated from the DRI Model. Under each of these cases (Cases 2–4), the authors assumed that clean diesel engines would be produced domestically. Construction of new clean diesel plants to meet domestic and exports demand will result in additional investment. Incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of clean diesel trucks sold in the United States. Following the approach described in Section 2.3, the incremental expenditures were apportioned between consumers (75%) and businesses (25%), both of which perceive the clean diesel engine to be better in quality. The penetration of more energy efficient clean diesel engines than SIDI gasoline engines should result in direct energy savings. The additional plant investment, direct energy savings, and exports levels under each case are summarized in the following subsections (Sections 5.1.1–5.1.3).

While projecting macroeconomic impacts of the clean diesel engine, one of the key factors to be considered is the potential output (GDP) in the economy. Because clean diesel engines are more energy efficient than SIDI gasoline engines, market penetration by clean diesel engines results in substitution of capital for energy. The specific methodology for estimating potential output in the DRI model used in the underlying analysis has been discussed in Section 2.4. The estimated potential output under each case (Cases 2–4) is provided in the following subsections (Sections 5.1.1–5.1.3).

5.1.1 Scenario for Case 2: Domestic Clean Diesel Engines

Assumptions

Under this case, the clean diesel engines, which are costlier but more energy efficient than SIDI gasoline engines, approach a saturation level of 10% by 2016. The direct annual energy savings approach 0.085 quad by 2024 (see Appendix, Section A.2). The cumulative plant investment approaches $1.24 billion (1992 constant dollars) higher than in the Enhanced Base Case by 2024 (see Appendix, Section A.2). Because of increased demand for light trucks in the United States, annual consumer and business expenditures on these rise to $0.28 billion (1992 constant dollars) by 2024. In addition, because of U.S. dominance, annual export demand for light trucks increases to $0.39 billion (1992 constant dollars) by 2024 (see Section A.2).

Projections

Table 5.1 provides projections of selected key macroeconomic indicators under Case 2 at selected intervals between 1997 and 2024. Under this case, the capital stock in 2024 is approximately $2.3 billion (1992 constant dollars) higher than in the Enhanced Base Case. Because of the increase in capital stock in the economy and reduced levels of energy imports, the real potential GDP is $16.5 billion higher than in the Enhanced Base Case cumulatively over the 2003–2024 period. This increase in potential output enables actual output in the economy to grow by about $17.5 billion* over the Enhanced Base Case levels cumulatively over the 2003–2024 period. The annual rate of inflation declines modestly, in the range of 0 to 0.05%.

For various reasons, minor changes with respect to the Enhanced Base Case values are projected under this scenario for interest rates on short-term Treasury bills, yields on long-term Treasury bonds, sales of light trucks, and prices for crude oil (Table 5.1). Detailed impacts on some of the key macroeconomic indicators are discussed in Section 5.2.

5.1.2 Scenario for Case 3: Low-Cost Domestic Clean Diesel Engines

Assumptions

Under this case (Case 3), by assumption, the clean diesel engines have very competitive cost relative to the SIDI engines. The clean diesel engines, with same level of fuel economy as under Case 2, approach a saturation level of 15% by 2024. The direct annual energy savings approach 0.127 quad by 2024 (see Appendix, Section A.3). The cumulative plant investment approaches $1.17 billion (1992 constant dollars) higher than in the Enhanced Base Case by 2024 (see Appendix, Section A.3). With the cost of clean diesel engines mostly lower than SIDI

* This implies some "slack" in the economy at the beginning of the period that is reduced by 2024, making actual output a higher percent of potential output, so that actual growth in output exceeds growth in potential output.

TABLE 5.1 U.S. Economy Outlook in Case 2

Selected Variable	1997	2003	2006	2009	2015	2024
Gross domestic product						
Real GDP ($\$10^9$ 1992 dollars)	7,191	8,641	9,279	9,865	11,176	13,032
Real GDP (% change/yr)	3.8	2.5	2.1	1.9	2.2	1.8
Price level indicator						
GDP price index (% change/yr)	2.0	1.9	2.2	2.1	2.6	4.6
Employment indicators						
Total civilian employment (10^6)	129.44	139.67	143.71	147.02	154.01	161.63
Civilian unemployment rate (%)	5.0	4.8	5.2	5.7	5.3	5.2
Financial indicators						
30-year treasury bond yield (%)	6.61	5.58	5.63	5.99	6.58	7.96
Federal budget surplus (FY, $\$10^9$)	-22.0	171.2	212.1	184.4	31.3	-446.4
Federal budget surplus (% of GDP)	-0.6	1.7	1.9	1.5	0.6	-1.3
Current account balance ($\$10^9$)	-161.3	-381.1	-406.4	-404.9	-525.0	-816.8
Transportation indicators						
Total light-vehicle sales (10^6 units)	15.1	15.7	16.4	16.3	17.4	18.1
Light-truck sales (10^6 units)	6.9	8.4	9.2	9.5	10.4	11.0
Energy indicators						
Total energy demand (10^{15} Btu)	90.6	101.7	105.8	107.6	112.1	115.6
Refiners' acq. price for crude oil: Composite ($/bbl)	19.16	17.35	18.10	20.11	26.78	42.38
Refiners' acq. price for crude oil: Foreign ($/bbl, 1992 dollars)	16.68	13.80	13.41	13.96	15.91	17.78
Imports of petroleum and products ($\$10^9$, 1992 dollars)	65.9	84.8	90.3	91.2	95.4	100.0

engines, there is a net reduction in annual expenditures approaching $0.22 billion (1992 constant dollars) by 2024. In addition, because of U.S. dominance, annual export demand for light trucks increases to $0.53 billion (1992 constant dollars) by 2024 (see Appendix, Section A.3).

Projections

Table 5.2 provides projections of selected key macroeconomic indicators under Case 3 at selected intervals between 1997 and 2024. Under this case, the capital stock in 2024 is approximately $2.6 billion (1992 constant dollars) higher than in the Enhanced Base Case. Because of the increase in capital stock in the economy and reduced levels of energy imports, the real potential GDP is $21.3 billion higher than in the Enhanced Base Case cumulatively over the

TABLE 5.2 U.S. Economy Outlook in Case 3

Selected Variable	1997	2003	2006	2009	2015	2024
Gross domestic product						
Real GDP ($\$10^9$ 1992 dollars)	7,191	8,641	9,280	9.866	11,176	13,032
Real GDP (% change/yr)	3.8	2.5	2.1	1.9	2.2	1.8
Price level indicator						
GDP price index (% change/yr)	2.0	1.9	2.2	2.1	2.6	4.6
Employment indicators						
Total civilian employment (10^9)	129.44	139.67	143.72	147.02	154.01	161.63
Civilian unemployment rate (%)	5.0	4.8	5.2	5.7	5.3	5.2
Financial indicators						
30-year treasury bond yield (%)	6.61	5.58	5.62	5.99	6.57	7.96
Federal budget surplus (FY, $\$10^9$)	-22.0	171.1	212.1	184.4	31.1	-446.6
Federal budget surplus (% of GDP)	-0.6	1.7	1.9	1.5	0.6	-1.3
Current account balance ($\$10^9$)	-161.3	-381.2	-406.6	-405.1	-525.1	-816.8
Transportation indicators						
Total light-vehicle sales (10^6 units)	15.1	15.7	16.4	16.3	17.4	18.1
Light-truck sales (10^6 units)	6.9	8.4	9.2	9.5	10.4	11.0
Energy indicators						
Total energy demand (10^{15} Btu)	90.6	101.7	105.8	107.6	112.1	115.5
Refiners' acq. price for crude oil: Composite ($/bbl)	19.16	17.35	18.10	20.10	26.78	42.37
Refiners' acq. price for crude oil: Foreign ($/bbl, 1992 dollars)	16.68	13.80	13.41	13.96	15.90	17.78
Imports of petroleum and products ($\$10^9$, 1992 dollars)	65.9	84.8	90.3	91.2	95.4	100.0

2003–2024 period. This increase in potential output enables actual output in the economy to grow by about $22.6 billion* over the Enhanced Base Case levels cumulatively over the 2003–2024 period. The annual rate of inflation declines modestly, in the range of 0.00 to 0.05%.

For various reasons, minor changes with respect to the Enhanced Base Case values are projected under this scenario for interest rates on short-term Treasury bills, yields on long-term Treasury bonds, sales of light trucks, and prices for crude oil (Table 5.2). Detailed impacts on some of the key macroeconomic indicators are discussed in Section 5.2.

* See footnote in Section 5.1.1.

5.1.3 Scenario for Case 4: Carbon Taxes and Domestic Clean Diesel Engines

Assumptions

Under this case (Case 4), by assumption, the clean diesel engines face a fuel price trajectory under the “9 Percent above 1990 Levels” case of carbon taxes (EIA 1998b). In that environment, clean diesel engines would approach a saturation level of 11% by 2024. The direct annual energy savings approach 0.127 quad by 2024 (see Appendix, Section A.3). The cumulative plant investment approaches $1.21 billion (1992 constant dollars) higher than in the Enhanced Base Case by 2024 (see Appendix, Section A.4). Because of increased demand for light trucks in the United States, annual consumer and business expenditures on them rise to $0.29 billion (1992 constant dollars) by 2024. In addition, because of U.S. dominance, annual export demand for light trucks increases to $0.41 billion (1992 constant dollars) by 2024 (see Appendix, Section A.4).

Projections

Table 5.3 provides projections of selected key macroeconomic indicators under Case 4 at selected intervals between 1997 and 2024. Under this case, the capital stock in 2024 is approximately $2.3 billion (1992 constant dollars) higher than in the Enhanced Base Case. Because of the increase in capital stock in the economy and reduced levels of energy imports, the real potential GDP is $17.3 billion higher than in the Enhanced Base Case cumulatively over the 2003–2024 period. This increase in potential output enables actual output in the economy to grow by about $18.5 billion[*] over the Enhanced Base Case levels cumulatively over the 2003–2024 period. The annual rate of inflation declines modestly, in the range of 0.00 to 0.05%.

For various reasons, minor changes with respect to the Enhanced Base Case values are projected under this scenario for interest rates on short-term Treasury bills, yields on long-term Treasury bonds, sales of light trucks, and prices for crude oil (Table 5.3). Detailed impacts on some of the key macroeconomic indicators are discussed in Section 5.2.

5.2 SPECIFIC MACROECONOMIC IMPACTS

Section 5.1 provided an overview of each of the three clean diesel macroeconomic scenarios (Cases 2, 3, and 4) generated from the DRI model. Additional details on specific

[*] See footnote in Section 5.1.1.

TABLE 5.3 U.S. Economy Outlook in Case 4

Selected Variable	1997	2003	2006	2009	2015	2024
Gross domestic product						
Real GDP ($\$10^9$ 1992 dollars)	7,191	8,641	9,279	9,866	11,176	13,032
Real GDP (% change/yr)	3.8	2.5	2.1	1.9	2.2	1.8
Price level indicator						
GDP price index (% change/yr)	2.0	1.9	2.2	2.1	2.6	4.6
Employment indicators						
Total civilian employment (10^6)	129.44	139.67	143.71	147.02	154.04	161.64
Civilian unemployment rate (%)	5.0	4.8	5.2	5.7	5.3	5.2
Financial indicators						
30-year treasury bond yield (%)	6.61	5.57	5.63	5.99	6.58	7.96
Federal budget surplus (FY, $\$10^9$)	-22.0	171.2	212.1	184.4	31.4	-446.3
Federal budget surplus (% of GDP)	-0.6	1.7	1.9	1.5	0.6	-1.3
Current account balance ($\$10^9$)	-161.3	-381.2	-406.2	-405.0	-525.0	-816.8
Transportation indicators						
Total light-vehicle sales (10^6 units)	15.1	15.7	16.4	16.3	17.4	18.1
Light-truck sales (10^6 units)	6.9	8.4	9.2	9.5	10.4	11.0
Energy indicators						
Total energy demand (10^{15} Btu)	90.6	101.7	105.8	107.6	112.1	115.6
Refiners' acq. price for crude oil: Composite ($/bbl)	19.16	17.35	18.1	20.11	26.78	42.38
Refiners' acq. price for crude oil: Foreign ($/bbl, 1992 dollars)	16.68	13.80	13.41	13.96	15.91	17.78
Imports of petroleum and products ($\$10^9$, 1992 dollars)	65.9	84.8	90.3	91.2	95.4	100.0

impacts of selected key macroeconomic indicators (such as real GDP) are provided in this section.

5.2.1 Real Gross Domestic Product

Figure 5.1 shows projected annual changes over Base Case real GDP under the alternative cases. For the reasons discussed in Sections 5.1.1–5.1.3, potential and actual output in the economy is stronger in all three clean diesel scenarios as compared to the Enhanced Base Case with SIDI engines. Similarly, potential output in the Enhanced Base Case is higher than in the Base Case.

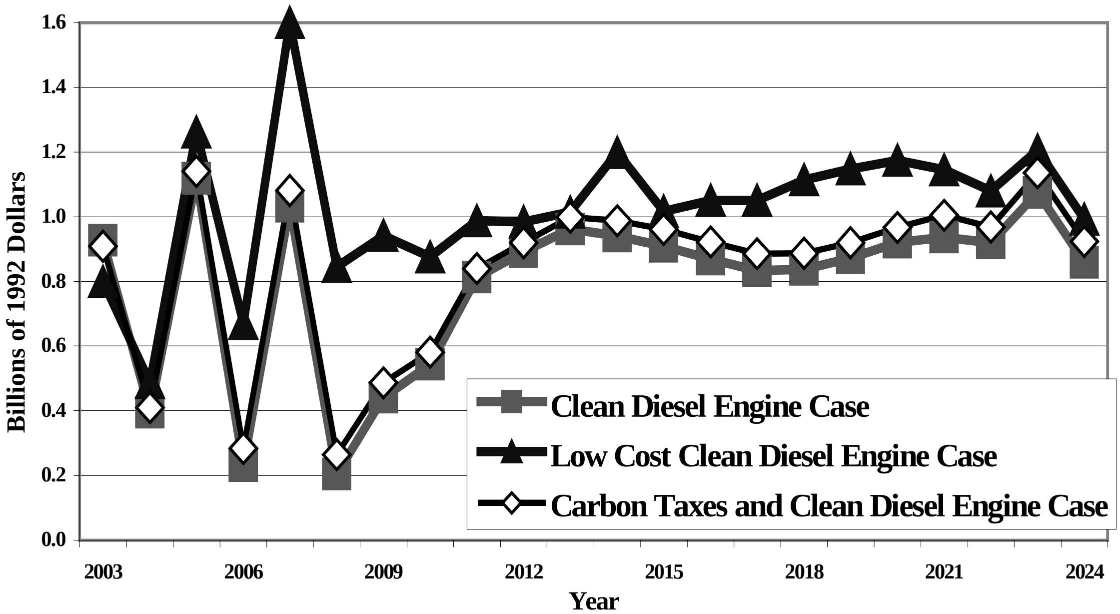

FIGURE 5.1 Real Gross Domestic Product: Change over the Enhanced Base Case

Domestic Clean Diesel Engine Case (Case 2): Without any special factors favorable to clean diesel engines, economic growth is lowest under this case among all the clean diesel engine scenarios. In this scenario, construction of an engine plant by one of the Big Three automobile manufacturers takes place in 2003, 2005, and 2007, thus boosting the investment, employment, and real GDP in those years. Assumed construction of one engine plant results in an investment in the range of about $0.3–0.4 billion (see Appendix, Table A.2). With rising light-truck sales and exports, the real GDP excess over the Enhanced Base Case increases by $0.93 billion in 2003, $1.11 billion in 2005, and $1.03 billion in 2007, but only in the range of $0.20–0.40 billion in other years between 2003 and 2008. Light-truck sales continue to rise, but very slowly, from $0.25 billion in 2008 to $0.28 billion in 2013, and exports grow from $0.20 billion in 2008 to $0.35 billion in 2013 (see Appendix, Table A.2). Thus, the real extra GDP steadily rises from $0.20 billion in 2008 to $0.96 billion in 2013, also helped very slightly by accelerating fuel savings from 0.01 quad (10^{15} Btu) in 2008 to 0.04 quad in 2013. The extra GDP then stabilizes in 2013. During the period of 2014–2022, as the stock of light trucks on the road continues to increase, the fuel savings rise to a modest level of 0.08 quad in 2022. Also, during this period light-truck sales rise by only an 0.8% average annual rate, and light-truck exports increase by only 1.0%. The extra GDP remains in the range of $0.83–0.94 billion between 2014 and 2022. In 2023, a clean diesel engine plant is assumed to be built to replace the plant built in 2003, which would have reached its 20 years of useful life. This investment primarily boosts the extra real GDP to $1.07 billion in 2023. In the following year, the extra GDP falls back to a trend oriented level of $0.86 billion. Overall, the increased economic growth is accomplished with lower fuel use, which reduces the rate of inflation (GDP deflator declining by a modest 0.00 to 0.05% during the projection period). The extra GDP peaks at $1.12 billion in 2005. On a cumulative basis, the real GDP is projected to total $17.53 billion above Base Case levels during the 2003–2024 period.

Low-Cost Domestic Clean Diesel Engine Case (Case 3): With development of a low-cost clean diesel engine, economic growth is highest under this case among all the clean diesel engine scenarios. In this scenario, construction of an engine plant by one of the Big Three automobile manufacturers takes place in 2003, 2005, and 2007, thus boosting the investment, employment, and real GDP in those years. Assumed construction of one engine plant results in an investment in the range of about $0.1–0.4 billion (see Appendix, Table A.3). Because the price of a clean diesel engine is lower than the price of a SIDI engine, the light-truck expenditures under this case are lower than under the Enhanced Base Case (see Appendix, Table A.3), which very slightly reduces estimated economic growth. In the same period, rising light-truck exports help economic growth moderately. The real GDP excess over Enhanced Base Case values increases by $0.80 billion in 2003, $1.26 billion in 2005, and $1.60 billion in 2007, but only in the range of $0.49–0.85 billion in other years between 2003 and 2008. Light-truck sales expenditures continue to decline, but very slowly, from $0.04 billion in 2008 to $0.17 billion in 2013. However, exports grow from $0.31 billion in 2008 to $0.48 billion in 2013 (see Appendix, Table A.3). Thus, the real extra GDP rises from $0.84 billion in 2008 to $1.01 billion in 2013, also helped very slightly by accelerating fuel savings from 0.03 quad (10^{15} Btu) in 2008 to 0.06 quad in 2013. In 2014, a new clean diesel engine plant is constructed to meet the demand and results in boosting the extra GDP to $1.20 billion. During the period of 2014–2022, as the stock of light trucks on the road continues to increase, the fuel savings rise to a modest level of 0.12 quad in 2022. This enables the extra GDP to remain at a somewhat high level in the range of $1.01 to 1.19 billion between 2014 and 2022. In 2023, a clean diesel engine plant is assumed to be built to replace the plant built in 2003, which would have reached its 20 years of useful life. This investment primarily boosts the extra real GDP to $1.21 billion in 2023. In the following year, the extra GDP falls back to a trend oriented level of $0.99 billion. Overall, the increased economic growth is accomplished with lower fuel use, thus reducing the rate of inflation (GDP deflator declining by a modest 0–0.05% during the projection period). The extra GDP peaks at $1.60 billion in 2007. On a cumulative basis, the real GDP is projected to total $22.64 billion above Base Case levels during the 2003–2024 period.

Carbon Taxes and Domestic Clean Diesel Engine Case (Case 4): The assumed higher prices of diesel for clean diesel engines and gasoline for SIDI engines under this case very slightly boosts the economic growth as compared to the Enhanced Base Case. In this scenario, construction of an engine plant by one of the Big Three automobile manufacturers takes place in 2003, 2005, and 2007, thus boosting the investment, employment, and real GDP in those years. Assumed construction of one engine plant results in an investment in the range of about $0.3–0.4 billion (see Appendix, Table A.4). By also benefiting moderately with rising light-truck sales and exports, the real GDP excess over Enhanced Base Case values increases by $0.91 billion in 2003, $1.14 billion in 2005, and $1.08 billion in 2007, but only in the range of $0.30–0.40 billion in other years between 2003 and 2008. Light-truck sales continue to rise, but very slowly, from $0.27 billion in 2008 to $0.29 billion in 2013, and exports grow from $0.23 billion in 2008 to $0.37 billion in 2013 (see Appendix, Table A.4). Thus, the real extra GDP steadily rises from $0.26 billion in 2008 to $1.00 billion in 2013, also helped very slightly by accelerating fuel savings from 0.02 quad (10^{15} Btu) in 2008 to 0.04 quad in 2013. The extra GDP then stabilizes in 2013. During the period of 2014 to 2022, as the stock of light trucks on the road continues to increase, the fuel savings rise to a modest level of 0.08 quad in 2022. Also, during this period light-truck sales rise by only a 0.8% average annual rate, and light-truck exports increase by only 1.0%. The extra GDP remains in the range of $0.89–1.00 billion between 2014 and 2022. In 2023, a clean diesel engine plant is assumed to be built to replace the plant built in 2003, which would have reached its 20 years of useful life. This investment primarily boosts the extra real GDP to $1.13 billion in 2023. In the following year, the extra GDP falls back to a trend oriented level of $0.92 billion. Overall, the increased economic growth is accomplished with lower fuel use, thus reducing the rate of inflation (GDP deflator declining by a modest 0–0.05% during projection period). The extra GDP peaks at $1.14 billion in 2005. On a cumulative basis, the real GDP is projected to total $18.47 billion above Base Case levels during the 2003–2024 period, which is slightly more than Case 2. Note that diesel engine prices in this case are the same as those in Case 2 and not as optimistic as those in Case 3.

5.2.2 U.S. Total Civilian Employment

Figure 5.2 shows projected annual changes with respect to Base Case total civilian employment levels under the alternative cases. The trends in employment are expected to generally follow trends in the real GDP as discussed in Section 5.2.1.

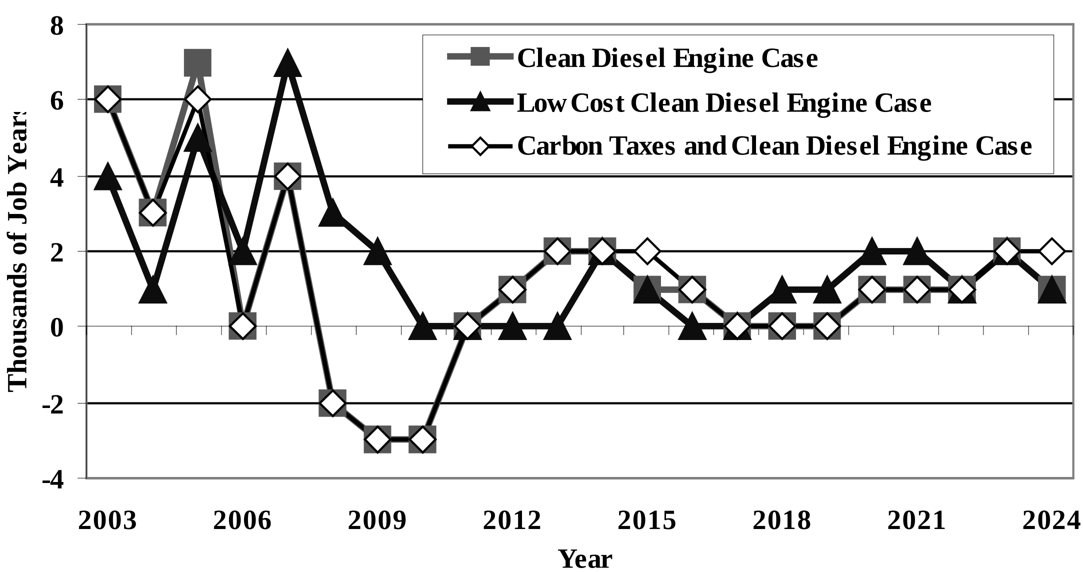

FIGURE 5.2 Total Civilian Employment Level: Change over the Enhanced Base Case

Domestic Clean Diesel Engine Case (Case 2): Among the clean diesel engine scenarios, the least number of jobs is created under this case. Compared to the Enhanced Base Case, total employment jumps by 6,000 job years in 2003, 7,000 in 2005, and 4,000 in 2007, the years of construction of a new clean diesel engine plant. The cumulative extra employment approaches 20,000 by 2007. The investment in new diesel engine technology also boosts the potential GDP (a function of capital, labor, energy, and R&D stock) in the 2003–2007 period. As a result, the economy does not need as much labor to produce goods and capital in the economy. When no additional investment in the engine plants is made in the following years, the total employment falls below the long-term equilibrium level by 2,000 jobs in 2008, 3,000 in 2009, and 3,000 in 2010. Over these three years, the employment declines and cumulative gains are reduced to 12,000 by 2010, the year it approaches long-term equilibrium. Then, matching the patterns of real extra GDP discussed in Section 5.2.1 (Case 2), the annual extra employment fluctuates between zero to 2,000 jobs between 2011 and 2024. On a cumulative basis, about 25,000 man-years of work are created in the economy over Enhanced Base Case levels during the 2003–2024 period.

Low-Cost Domestic Clean Diesel Engine Case (Case 3): Among the clean diesel engine scenarios, the greatest number of jobs is created under this case. Compared to the Enhanced Base Case, total employment jumps by 4,000 job years in 2003, 5,000 in 2005, and 7,000 in 2007, the years of construction of a new clean diesel engine plant. The investment in new diesel engine technology also boosts the potential GDP in the 2003–2007 period. As a result, the economy does not need as much labor to produce goods and capital in the economy. When no additional investment in the engine plants is made in the following years, the total employment falls to the long-term equilibrium level by 2010. The cumulative extra employment approaches 24,000 by 2010 and stabilizes over those levels for about four years. Then, matching the patterns of real extra GDP discussed in Section 5.2.1 (Case 3), the annual extra employment fluctuates between zero to 2,000 jobs between 2013 and 2024. On a cumulative basis, about 37,000 man-years of work are created in the economy over Enhanced Base Case levels during the 2003–2024 period.

Carbon Taxes and Domestic Clean Diesel Engine Case (Case 4): Compared to the Enhanced Base Case, total employment jumps by 6,000 job years in 2003, 6,000 in 2005, and 4,000 in 2007, the years of construction of a new clean diesel engine plant. The cumulative extra employment approaches 19,000 by 2007. The investment in new diesel engine technology also boosts the potential GDP during the 2003–2007 period. As a result, the economy does not need as much labor to produce goods and capital in the economy. When no additional investment in the diesel engine plants is made in the following years, the total employment falls below the long-term equilibrium level by 2,000 jobs in 2008, 3,000 in 2009, and 3,000 in 2010. Over these three years, declines in the extra employment reduce the cumulative gains to 11,000 by 2010, the year it approaches equilibrium. Then, matching the patterns of real extra GDP discussed in Section 5.2.1 (Case 4), the annual extra employment fluctuates between zero to 2,000 jobs between 2011 and 2024. On a cumulative basis, about 26,000 man-years of work are created in the economy over Enhanced Base Case levels during the 2003–2024 period.

5.2.3 Total Fuel Savings

Figure 5.3 shows projected annual energy savings in the economy with respect to the Enhanced Base Case under the alternative cases. These savings are estimated by measuring changes in the DRI model variable of demand for all fuels in all sectors (quadrillion Btu). In general, energy demand rises/falls with strength/weakness in the economy.

Domestic Clean Diesel Engine Case (Case 2): As shown in Table A.2, the direct clean diesel engine fuel savings under this case are estimated to be 2 trillion Btu (0.002 quad) in 2003, 4 in 2004, 6 in 2005, 9 in 2006, 12 in 2007, and 85 in 2024. However, these rising direct fuel savings are not sufficient to offset increased demand of all fuels in the economy, particularly initially in 2003, 2005, and 2007. These years show very high economic activity, primarily as a result of construction of a new engine plant (see Section 5.2.1: Case 2). As a result of overall higher energy consumption, the energy savings in the economy under this case as compared the Base Case is -8 trillion Btu in 2003, -7 in 2005, and zero in 2007. Thereafter, as the stock of light trucks with clean diesel engines increases, annual fuel savings in the economy as compared to the Enhanced Base Case steadily rise to 17 trillion Btu by 2010, 38 by 2015, 60 by 2019, and 80 by 2024. On a cumulative basis, the fuel savings are projected to approach 740 trillion Btu (0.74 quad) over Enhanced Base Case levels during the 2003–2024 period.

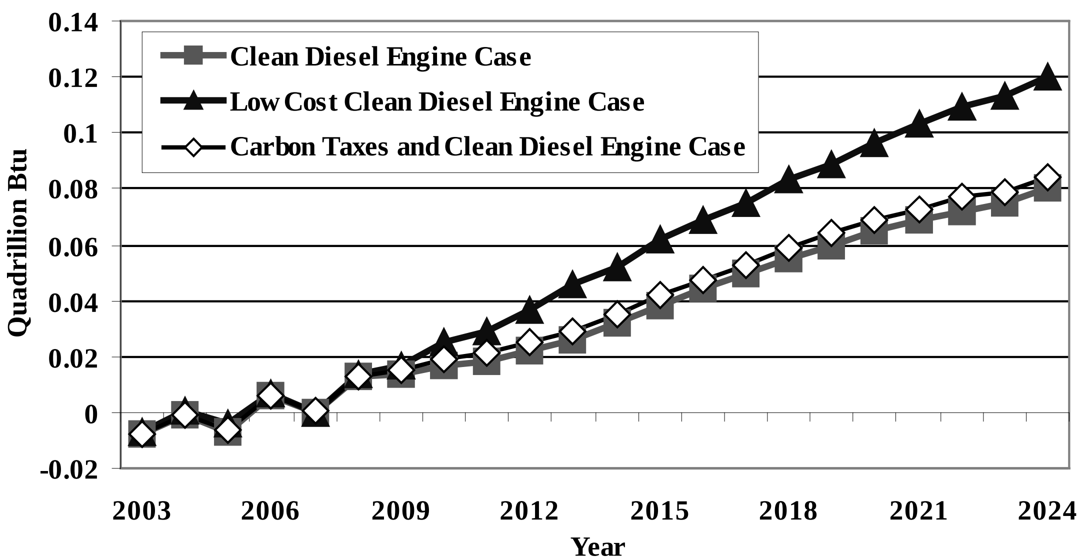

FIGURE 5.3 Fuel Savings in the U.S. Economy over the Enhanced Base Case

Low Cost Domestic Clean Diesel Engine Case (Case 3): As shown in Table A.3, the direct clean diesel engine fuel savings under this case are estimated to be 3 trillion Btu in 2003, 7 in 2004, 11 in 2005, 15 in 2006, 20 in 2007, and 127 in 2024. However, these rising direct fuel savings are not sufficient to offset increased demand of all fuels in the economy, particularly initially in 2003, 2005, and 2007. These years show very high economic activity, primarily as a result of construction of a new engine plant (see Section 5.2.1: Case 3). As a result of overall higher energy consumption, the energy savings in the economy under this case as compared the Base Case is –7 trillion Btu in 2003, -4 in 2005, and zero in 2007. Thereafter, as the stock of light trucks with clean diesel engines increases, annual fuel savings in the economy as compared to the Enhanced Base Case steadily rise to 25 trillion Btu by 2010, 62 by 2015, 89 by 2019, and 120 by 2024. On a cumulative basis, the fuel savings are projected to approach 1,136 trillion Btu (1.14 quad) over Enhanced Base Case levels during the 2003–2024 period and are greatest under this case as compared to other alternative clean diesel engine cases.

Carbon Taxes and Domestic Clean Diesel Engine Case (Case 4): As shown in Table A.4, the direct clean diesel engine fuel savings under this case are estimated to be 2 trillion Btu in 2003, 4 in 2004, 7 in 2005, 10 in 2006, 13 in 2007, and 89 in 2024. However, these rising direct fuel savings are not sufficient to offset increased demand of all fuels in the economy, particularly initially in 2003, 2005, and 2007. These years show very high economic activity, primarily as a result of construction of a new engine plant (see Section 5.2.1: Case 4). As a result of overall higher energy consumption, the energy savings in the economy under this case as compared the Base Case is -8 trillion Btu in 2003, -6 in 2005, and zero in 2007. Thereafter, as the stock of light trucks with clean diesel engines increases, annual fuel savings in the economy as compared to the Enhanced Base Case steadily rise to 19 trillion Btu by 2010, 42 by 2015, 64 by 2019, and 84 by 2024. On a cumulative basis, the fuel savings are projected to approach 796 trillion Btu (0.80 quad) over Enhanced Base Case levels during the 2003–2024 period.

5.2.4 Current Account Balance of Payments

Figure 5.4 shows projected annual changes over the Enhanced Base Case balance of payments (BOP) under the alternative cases. The current account BOP (including merchandise and services traded) is used as an indicator of the international trade balance. By definition, exports/imports directly increase/reduce the GDP on one-to-one basis.

Domestic Clean Diesel Engine Case (Case 2): As shown in Table A.2, the exports of light trucks with clean diesel engines under this case are estimated to be 118 million (1992) dollars in 2003, 130 in 2004, 144 in 2005, 162 in 2006, 180 in 2007, and 386 in 2016. Thereafter, exports of these diesel light trucks are assumed to stay at those saturated levels. The rising exports are not sufficient to offset increased imports of all goods and services in the economy, particularly initially in 2003, 2005 and 2007. These years show very high economic activity, primarily as a result of construction of a new engine plant (see Section 5.2.1: Case 2). As a result, the overall balance of payments under this case as compared the Base Case deteriorates by

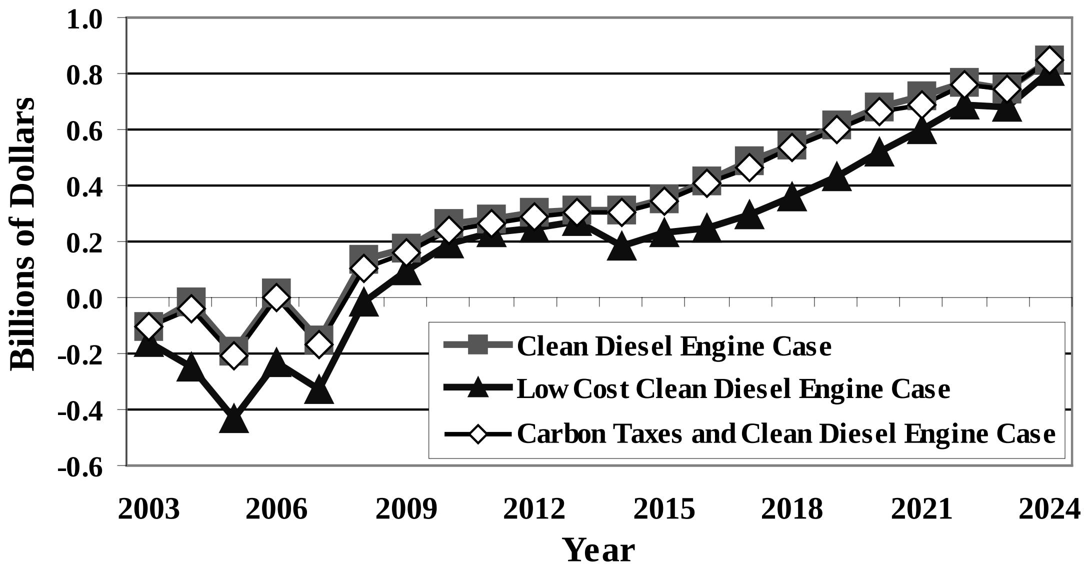

FIGURE 5.4 Balance of Payments: Change over the Enhanced Base Case

$103 million in 2003, 193 in 2005, and 149 in 2007. Thereafter, trade is favorably affected both by increased exports of these energy-efficient diesel light trucks and reduced energy imports. The extra balance of payments steadily increases from $133 million in 2008 to 851 in 2024. On a cumulative basis, the balance of payments improves by $7.5 billion over Enhanced Base Case levels during the 2003-2024 period.

Low-Cost Domestic Clean Diesel Engine Case (Case 3): As shown in Table A.3, the exports of light trucks with clean diesel engines under this case are estimated to be 194 million dollars in 2003, 211 in 2004, 230 in 2005, 254 in 2006, 277 in 2007, and 529 in 2016. Thereafter, exports of these diesel light trucks are assumed to stay near those saturated levels. The rising exports are not sufficient to offset increased imports of all goods and services in the economy, particularly initially in 2003, 2005 and 2007. These years show very high economic activity, primarily as a result of construction of a new engine plant (see Section 5.2.1: Case 3). As a result, the overall balance of payments under this case as compared the Base Case deteriorates by $163 million in 2003, 435 in 2005, and 332 in 2007. Thereafter, trade is favorably affected both by increased exports of these energy-efficient diesel light trucks and resulting reduced energy imports. This causes the extra balance of payments to bounce back to a very small loss in 2008, and then begin its rise from $94 million in 2009 to 268 in 2013. Again, primarily because of construction of a new diesel engine plant in 2014, the real GDP jumps in 2014, as discussed in Section 5.2.1. This boost in the real GDP is accompanied by increased levels of imports of goods and services, which cause the extra balance of payments to decline to $188 million in 2014. Subsequently, the extra balance of payments continues on its previous up trend and rises to $804 million in 2024. On a cumulative basis, the balance of payments improves by $4.6 billion over Enhanced Base Case levels during the 2003–2024 period.

Carbon Taxes and Domestic Clean Diesel Engine Case (Case 4): As shown in Table A.4, the exports of light trucks with clean diesel engines under this case are estimated to be 130 million dollars in 2003, 145 in 2004, 163 in 2005, 183 in 2006, 203 in 2007, and 410 in 2016. Thereafter, exports of these diesel light trucks are assumed to stay near those saturated levels. The rising exports are not sufficient to offset increased imports of all goods and services in the economy, particularly initially in 2003, 2005, and 2007. These years show very high economic activity, primarily as a result of construction of a new engine plant (see Section 5.2.1: Case 4). As a result, the overall balance of payments under this case as compared the Base Case deteriorates by $107 million in 2003, 206 in 2005, and 168 in 2007. Thereafter, trade is favorably affected both by increased exports of these energy-efficient diesel light trucks and resulting reduced energy imports. The balance of payments almost steadily increases from $107 million in 2008 to 848 in 2024. On a cumulative basis, the balance of payments improves by $7.2 billion over Enhanced Base Case levels during the 2003–2024 period.

5.2.5 Federal Government Surplus

Figure 5.5 shows projected annual changes over the Enhanced Base Case federal government surplus under the alternative clean diesel engine cases. The strong/weak economy increases/decreases the government surplus, mainly because of collection of higher/lower tax revenues.

Domestic Clean Diesel Engine Case (Case 2): As discussed in Section 5.2.1, construction of one clean diesel engine plant in 2003, 2005, and 2007 boosts the real GDP and the resulting government tax revenues in those years. The tax revenues fall to more normal levels between these years. The budget surplus compared to the Enhanced Base Case jumps to $0.3 billion in 2003 and $0.5 billion in both 2005 and 2007. The extra surplus then stabilizes at a level of 0.2 billion during the period 2009–2010. In subsequent periods of rising real GDP, the surplus approaches to $0.5 billion by 2015 and 1.0 billion by 2022. On a cumulative basis, the federal budget improves by $11.9 billion over Base Case levels during the 2003–2024 period.

Low-Cost Domestic Clean Diesel Engine Case (Case 3): As discussed in Section 5.2.1, construction of one clean diesel engine plant in 2003, 2005, and 2007 boosts the real GDP and the resulting government tax revenues in those years. The tax revenues fall to more normal levels between these years. The budget surplus compared to the Enhanced Base Case jumps to $0.1 billion in 2003, $0.4 billion in 2005, and $0.5 billion in 2007. The extra surplus then stabilizes at a level of $0–0.2 billion during the period 2008–2010. In subsequent periods of rising real GDP, the surplus approaches to $0.5 billion by 2019 and 1.0 billion by 2023. On a cumulative basis, the federal budget improves by $8.0 billion over Base Case levels during the 2003–2024 period.

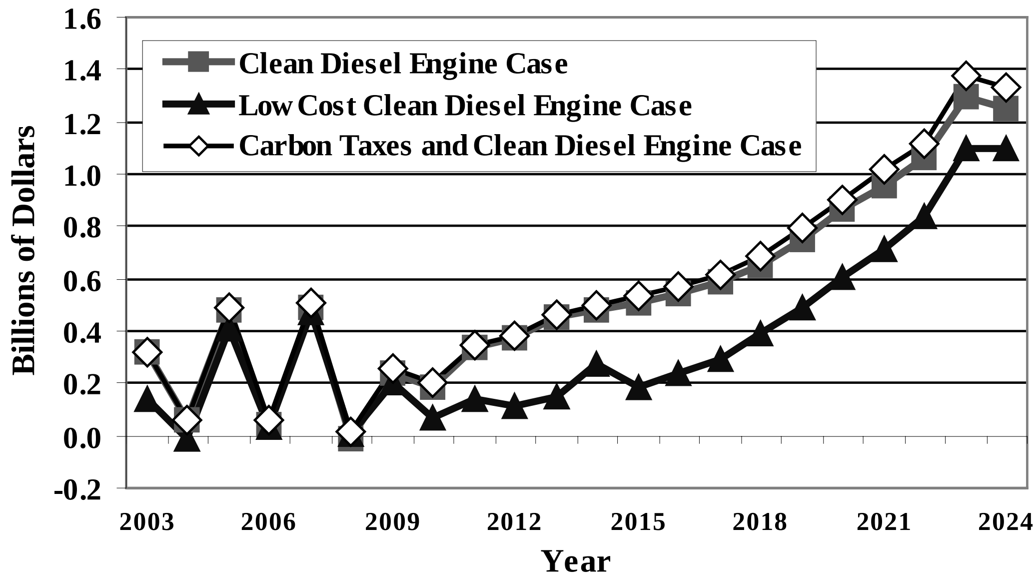

FIGURE 5.5 Federal Government Surplus: Change over the Enhanced Base Case

Carbon Taxes and Domestic Clean Diesel Engine Case (Case 4): As discussed in Section 5.2.1, construction of one clean diesel engine plant in 2003, 2005, and 2007 boosts the real GDP and the resulting government tax revenues in those years. The tax revenues fall to more normal levels between these years. The budget surplus compared to the Enhanced Base Case jumps to $0.3 billion in 2003 and $0.5 billion in both 2005 and 2007. The extra surplus then stabilizes at a level of 0.2 billion during the period 2009–2010. In subsequent periods of generally rising real GDP, the surplus approaches to $0.5 billion by 2014 and 1.0 billion by 2021. On a cumulative basis, the federal budget improves by $12.6 billion over Base Case levels during the 2003–2024 period.

6 CONCLUSIONS

We conclude that development and commercialization of the clean diesel engine for light trucks can result in significant direct economic benefits (lower oil consumption) and indirect economic benefits (higher GDP) to the nation, even assuming competition from the advanced SIDI engines. Furthermore, U.S. production of clean diesel engines under the low-cost scenario (Case 3) mostly maximizes the economic benefits. In that case, the cumulative extra GDP over the Base Case could be as high as $22.6 billion (1992 dollars) over a period of 21 years after its introduction. The annual extra GDP peaks at $1.6 billion in 2007, primarily aided by the assumed construction of a clean diesel engine plant in each of the years 2003, 2005, and 2007. In addition, on a cumulative basis, about 37,000 man-years of work could be added to the total civilian employment base in the 2003–2023 period. During this period, the greatest number of jobs of any year (7,000) would occur in 2007. The cumulative federal government budget surplus could also improve by about $8 billion during the projection period. The annual extra budget surplus would approach $1.1 billion by 2005. This case is to be considered as an upper bound for domestic market penetration by clean diesel engines, and exports of light trucks equipped with clean diesel engines, under the most favorable outlook for development of the clean diesel engine by the U.S. automotive engine/truck industry. Under this case, the net exports of light trucks with clean diesel engines approach a level of about $0.5 billion by the end of the projection period, an important factor in estimating the favorable economic effects discussed above.

We also conclude that commercialization of the clean diesel engine is slightly more favorable to the economy in an assumed environment that faces moderate carbon taxes on selected fuels. Cumulatively, in that case (Case 4), the real GDP is projected to be $18.5 billion higher than under the Base Case (with SIDI engines commercialization) levels during the 2003–2024 period.

Finally, we conclude that, of Cases 2 to 4, the least favorable case for the clean diesel engine is the business-as-usual case (Case 2). However, even that case is beneficial to the economy as, on a cumulative basis, the real GDP is projected to total $17.5 billion above the Base Case levels during the 2003–2024 period.

The results of this study are complementary to those of the Phase 1 study, under which the clean diesel engines were assumed to compete against the less-efficient conventional gasoline engines under the four scenarios involving domestic or foreign production of clean diesel engines. Under the most favorable scenario in that earlier study, a cumulative real GDP surplus over the Base Case for the 22-year period after the introduction of clean diesel engines was estimated to be about $56 billion (1992 dollars). That scenario entailed domestic production of clean diesel engines with a higher-level trajectory of projected market penetration of selected light trucks.

The very favorable results presented in this Phase 2 report, as well as those in the Phase 1 report, tend to support DOE OHVT's continuing interest in the development of low-emission, highly fuel-efficient clean diesel engines for light trucks.

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APPENDIX:

CHANGES MADE IN THE DATA RESOURCES, INC., MODEL

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CHANGES MADE IN THE DATA RESOURCES, INC., MODEL

As discussed in Section 2.4, the indirect economic impacts of clean diesel engines were estimated by using the DRI model. Prior to solving the DRI model for the period 2003–2024, changes in the selected variables were made under each of the four cases discussed in Section 2.1. The following sections discuss these changes for each of the cases.

A.1 CHANGES MADE TO DRI MODEL FOR CASE 1

We followed a three-step approach for estimating direct annual fuel savings resulting from substitution of conventional gasoline engines by more efficient SIDI gasoline engines in selected categories of light trucks. First, for each year, the stock of SIDI engines was estimated by adding the number of new SIDI engines that penetrated in that year, and subtracting the number of engines scrapped in that year, to the previous year's stock value of SIDI engines. Survival rates used for light trucks were as specified in an Oak Ridge National Laboratory report (ORNL 1996). Second, we estimated the fuel economy (miles per gallon) of light-trucks with SIDI engines by multiplying the DOE/EIA projected fuel economy (EIA 1999, Table 50) for light trucks with gasoline engines by a factor of 1.15, as discussed in Section 3 (we assumed that a SIDI engine would have 15% higher fuel economy as compared to a light-truck gasoline engine). On the basis of the estimated stock of light trucks with SIDI engines, average fuel economy for both conventional and SIDI gasoline engines for a light truck, and average miles traveled by a light truck in a year, we estimated the light-truck annual fuel savings in the economy between 2003 and 2024 (Table A.1). The four energy demand variables in the DRI Base Case — final demand for gasoline ($), total gasoline demand (gallons), end-use demand for petroleum (Btu), and total demand for fuels (Btu) — were adjusted downward to reflect energy savings from SIDI engines.

The price of a SIDI engine is expected to exceed that of a conventional gasoline engine. Under this scenario, we assumed that the incremental price of a light-truck SIDI engine over a conventional gasoline engine would be $279 (in constant 1992 dollars) higher in its year of introduction in 2003. The price gap then narrows to $232 by 2013, as SIDI engine producers are able to realize cost reductions resulting from economies of scale in production. The SIDI engine price gap then remains at $232 in the subsequent period. The incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of SIDI trucks sold in the United States; these expenditures were estimated separately for consumers and businesses. Real consumer and business expenditures on light trucks were adjusted upward in the DRI model. In addition, the negative effect of higher prices on unit truck sales was offset to keep the same level of unit truck sales as under the DRI Base Case.

TABLE A.1 Assumed Annual Changes in Capital Expenditures on Plant and Light-Truck Expenditures and Fuel Savings for Case 1

Year	Annual Expenditures on Plant ($\$10^6$, 1992 dollars)	Light-Truck Consumer Expenditures ($\$10^6$, 1992 dollars)	Light-Truck Business Expenditures ($\$10^6$, 1992 dollars)	Light-Truck Fuel Savings (10^{12} Btu)
2003	93	19	6	0
2004	0	36	12	1
2005	93	67	22	1
2006	0	122	41	3
2007	279	213	71	5
2008	279	352	117	9
2009	372	535	178	14
2010	372	737	246	22
2011	372	899	300	32
2012	279	1,012	337	44
2013	93	1,071	357	56
2014	0	1,132	377	68
2015	93	1,174	391	81
2016	93	1,185	395	93
2017	93	1,194	398	106
2018	0	1,196	399	118
2019	0	1,202	401	129
2020	0	1,199	400	141
2021	0	1,195	398	152
2022	0	1,193	398	161
2023	93	1,193	398	171
2024	0	1,197	399	179

In estimating additional capital expenditures on engine/light-truck manufacturing plants, it was assumed that, for competitive reasons, one SIDI with a capacity of 320,000 units and a life of 20 years would be introduced initially in 2003, 2005, and 2007 by one of the domestic automobile/truck manufacturers. New engine capacity was assumed to be added by these and/or other producers whenever plant utilization exceeded an 80% level. To meet the total domestic demand for SIDI engines, producers of engines/light trucks are projected to build 28 new plants of the above size between 2003 and 2024. The construction cost of either a 320,000-unit SIDI engine plant or a 400,000-unit gasoline engine plant was assumed to be $435 million (constant 1992 dollars). While estimating the incremental capital expenditures, a credit was given for the cost of any avoided gasoline plant. Table A.1 shows estimated values for incremental capital expenditures on manufacturing plants between 2003 and 2024. The plant investment in the DRI model was adjusted upward to reflect an increased level of capital expenditures on engine/vehicle plant investment.

A.2 CHANGES MADE TO DRI MODEL FOR CASES 2, 3 AND 4

For each of the three clean diesel cases (Cases 2–4), we followed a three-step approach in estimating direct annual fuel savings resulting from substitution of gasoline engines by more efficient clean diesel engines in selected categories of light trucks. First, for each year, the stock of clean diesel engines was estimated by adding the number of new clean diesel engines that penetrated the market in that year, and subtracting the number of engines scrapped in that year, to the previous year stock value of clean diesel engines. Survival rates for light trucks were as specified by ORNL (1996). Second, the fuel economy (miles per gallon) of light trucks with clean diesel engines was estimated by multiplying the DOE/EIA projected fuel economy (EIA 1999, Table 50) of light trucks with gasoline engines by a factor of 1.55, as discussed in Chapter 3. It was assumed that a clean diesel engine would have 55% higher fuel economy than a light-truck gasoline engine. Based on the estimated stock of light diesel trucks, average fuel economy of SIDI gasoline and clean diesel engines for a light truck, and average miles traveled by a light truck in a year, we estimated direct annual fuel savings resulting from penetration of clean diesel trucks in the economy. These fuel savings between 2003 and 2024 are shown in Table A.2 for Case 2, Table A.3 for Case 3, and Table A.4 for Case 4. The four energy demand variables in the DRI Base Case — final demand for gasoline ($), total gasoline demand (gallons), end-use demand for petroleum (Btu), and total demand for fuels (Btu) — were adjusted downward to reflect energy savings from clean diesel engines.

The price of a clean diesel engine is expected to exceed that of a gasoline engine. Under this scenario, the premium of a light-truck clean diesel engine over a gasoline engine was assumed to be $17.06/kW (in constant 1992 dollars) in 2003. The premium narrows to $15.81 by 2013, as clean diesel engine producers realize cost reductions resulting from economies of scale, and it remains at this level in the subsequent period. Assuming installation of a 90-kW engine on a small pickup, a 140-kW engine on a large pickup and small SUV, and a 180-kW engine on a large SUV and large van, incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of clean diesel trucks sold in the United States. These expenditures were estimated separately for consumers and businesses. Real consumer and business expenditures on light trucks were adjusted upward in the DRI model. In addition, the negative effect of higher prices on unit truck sales was offset to keep the same level of unit truck sales as under the Base Case.

TABLE A.2 Assumed Annual Changes in Capital Expenditures on Plant and Light-Truck Expenditures, Exports, and Fuel Savings for Case 2

Year	Annual Expenditures on Plant ($\$10^6$, 1992 dollars)	Light-Truck Consumer Expenditures ($\$10^6$, 1992 dollars)	Light-Truck Business Expenditures ($\$10^6$, 1992 dollars)	Light-Truck Exports ($\$10^6$, 1992 dollars)	Light-Truck Fuel Savings (10^{12} Btu)
2003	279	127	42	118	2
2004	2	137	46	130	4
2005	419	149	50	144	6
2006	2	162	54	162	9
2007	402	173	58	180	12
2008	1	187	62	205	15
2009	4	183	61	215	18
2010	3	196	65	248	22
2011	4	199	66	277	26
2012	4	204	68	311	31
2013	1	208	69	347	36
2014	2	208	69	353	41
2015	2	217	72	369	46
2016	-1	223	74	386	51
2017	0	218	73	380	57
2018	0	217	72	381	61
2019	0	216	72	382	66
2020	0	217	72	387	71
2021	-1	216	72	389	75
2022	0	211	70	384	78
2023	116	211	70	385	82
2024	0	211	70	386	85

TABLE A.3 Assumed Annual Changes in Capital Expenditures on Plant and Light-Truck Expenditures, Exports, and Fuel Savings for Case 3

Year	Annual Expenditures on Plant ($\$10^6$, 1992 dollars)	Light-Truck Consumer Expenditures ($\$10^6$, 1992 dollars)	Light-Truck Business Expenditures ($\$10^6$, 1992 dollars)	Light-Truck Exports ($\$10^6$, 1992 dollars)	Light-Truck Fuel Savings (10^{12} Btu)
2003	129	-3	-1	194	3
2004	2	-4	-1	211	7
2005	397	-7	-2	230	11
2006	3	-11	-4	254	15
2007	376	-19	-6	277	20
2008	1	-31	-10	310	26
2009	5	-45	-15	320	31
2010	4	-67	-22	361	37
2011	5	-88	-29	397	43
2012	5	-108	-36	437	50
2013	1	-125	-42	479	58
2014	119	-134	-45	486	65
2015	3	-146	-49	507	73
2016	-1	-154	-51	529	80
2017	0	-154	-51	522	87
2018	0	-156	-52	523	94
2019	1	-159	-53	524	100
2020	0	-161	-54	531	107
2021	-1	-162	-54	534	113
2022	0	-161	-54	527	118
2023	116	-163	-54	529	123
2024	1	-165	-55	531	127

TABLE A.4 Assumed Annual Changes in Capital Expenditures on Plant and Light-Truck Expenditures, Exports, and Fuel Savings for Case 4

Year	Annual Expenditures on Plant ($\$10^6$, 1992 dollars)	Light-Truck Consumer Expenditures ($\$10^6$, 1992 dollars)	Light-Truck Business Expenditures ($\$10^6$, 1992 dollars)	Light-Truck Exports ($\$10^6$, 1992 dollars)	Light-Truck Fuel Savings (10^{12} Btu)
2003	263	138	46	130	2
2004	2	151	50	145	4
2005	410	166	55	163	7
2006	2	180	60	183	10
2007	396	192	64	203	13
2008	1	206	69	230	16
2009	4	200	67	239	20
2010	3	211	70	272	24
2011	4	212	71	300	29
2012	4	215	72	335	34
2013	1	219	73	371	39
2014	2	218	73	376	44
2015	2	227	76	392	50
2016	-1	233	78	410	55
2017	0	227	76	404	60
2018	0	226	75	405	65
2019	1	226	75	405	70
2020	0	227	76	411	75
2021	-1	225	75	413	79
2022	0	221	74	408	83
2023	116	220	73	409	86
2024	1	220	73	410	89

To estimate net export gains from each type (small pickup, large pickup, small SUV, and large SUV and large van) of diesel light trucks, two steps were followed. First, the average price of an exported light truck with a clean diesel engine was estimated by adding the premium stated above to the DOE/EIA projected price of a new gasoline light truck (EIA 1999, Table 114). Second, we estimated the gain in value of additional exports of each type of diesel light truck by multiplying the exported units (Section 3.1.3) by the above estimated price. We further assumed that 50% of exports of advanced diesel light trucks would result from substitution for gasoline light trucks. The value of lost exports of gasoline light trucks was estimated by multiplying the lost export units by the gasoline truck's average price. Net gains in the value of exports of light trucks between 2003 and 2024 are shown in Table A.2 for Case 2, Table A.3 for Case 3, and Table A.4 for Case 4. Exports of automotive vehicles and parts, available in the DRI model, were adjusted upward to reflect the increased export level for light trucks.

To estimate additional capital expenditures, we assumed that one clean diesel engine plant with an annual capacity of 300,000 units and a life of 20 years would be introduced initially in 2003, 2005, and 2007 by one of the domestic automobile/truck manufacturers for competitive reasons. Subsequently, new engine capacity was to be added whenever plant utilization exceeded the 80% level. However, except for a replacement plant in 2023, no new plant was needed between 2003 and 2024 to meet the total domestic and export demand for clean diesel engines under Cases 2 or 4. But under Case 3, producers of engines/light trucks were projected to build one new plant of the above size in 2014 and 2023. The construction cost of either a 300,000-unit/yr clean diesel engine plant or a 320,000-unit/yr SIDI gasoline-engine plant was assumed to be $435 million (constant 1992 dollars). In estimating the incremental capital expenditures, a credit was given for the cost of avoided SIDI gasoline plants. In addition, we also estimated incremental capital expenditures on plants for manufacturing additional diesel light trucks for export. The investment on nonengine plants was estimated to be only a fraction of the investment on engine plants, because only a small fraction of clean diesel engines were required for exports. The estimated incremental capital expenditures on manufacturing plants between 2003 and 2024 are shown in Table A.2 for Case 2, Table A.3 for Case 3, and Table A.4 for Case 4. The plant investment in the DRI model was adjusted upward to reflect an increased level of capital expenditures on engine/vehicle plant investment.

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