ANL/ESD/TM-155

Assessing Economic Impacts of Clean Diesel Engines

Phase 1 Report: U.S.- or Foreign-Produced Clean Diesel Engines for Selected Light Trucks

ARGONNE NATIONAL LABORATORY

TRANSPORTATION TECHNOLOGY R&D CENTER

Center for Transportation Research
Argonne National Laboratory

Operated by The University of Chicago,
under Contract W-31-109-Eng-38, for the

United States Department of Energy

Argonne National Laboratory

Argonne National Laboratory, with facilities in the states of Illinois and Idaho, is owned by the United States Government, and operated by the University of Chicago under the provisions of a contract with the Department of Energy.

This technical memo is a product of Argonne's Energy Systems (ES) Division. For information on the division's scientific and engineering activities, contact:

Director, Energy Systems Division
Argonne National Laboratory
Argonne, Illinois 60439-4815
Telephone (630) 252-3724

Presented in this technical memo are preliminary results of ongoing work or work that is more limited in scope and depth than that described in formal reports issued by the ES Division.

Publishing support services were provided by Argonne's Information and Publishing Division (for more information, see IPD's home page: http://www.ipd.anl.gov/).

Disclaimer

Available electronically at http://www.doe.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

ANL/ESD/TM-155

Assessing Economic Impacts of Clean Diesel Engines

Phase 1 Report: U.S.- or Foreign-Produced Clean Diesel Engines for Selected Light Trucks

by A.P. Teotia, A.D. Vyas, R.M. Cuenca, and F. Stodolsky

Center for Transportation Research, Energy Systems Division,
Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439

May 1999

Work sponsored by U.S. Department of Energy,
Assistant Secretary for Energy Efficiency and Renewable Energy,
Office of Transportation Technologies, Office of Heavy Vehicle Technologies

CONTENTS

CONTENTS (Cont.)

FIGURES

TABLES

TABLES (Cont.)

NOTATION

Initialisms

AFV	alternative-fuel vehicle
ANL	Argonne National Laboratory
BOP	balance of payments
CAFE	Corporate Average Fuel Economy
CD	clean diesel
CPI	consumer price index
DRI	Standard & Poor's Data Resources, Inc.
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
FY	fiscal year
GDP	Gross Domestic Product
GM	General Motors Corp.
M2	Money Supply
NO_x	oxides of nitrogen
OHVT	Office of Heavy Vehicle Technologies
ORNL	Oak Ridge National Laboratory
SUV	sport utility vehicle

Units

Btu	British thermal unit
quad	10^{15} (one quadrillion) Btu

ACKNOWLEDGMENTS

This research task was sponsored by the U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Transportation Technologies, Office of Heavy Vehicle Technologies (OHVT). The authors thank Dr. James J. Eberhardt, Director of OHVT, for strong support and valuable guidance throughout the research phase. We are also very thankful to Joyce Yanchar of Standard & Poor's Data Resources, Inc. (DRI), for her assistance in generating the alternative simulations based on the DRI model of the U.S. economy.

Several people provided useful and prompt reviews.

Finally, the authors wish to thank Floyd Bennett for editing this report and Kerri Schroeder for providing word processing assistance in preparing it.

ASSESSING ECONOMIC IMPACTS OF U.S.- OR FOREIGN-PRODUCED CLEAN DIESEL ENGINES IN SELECTED LIGHT TRUCKS

A.P. Teotia, A.D. Vyas, R.M. Cuenca, and F. Stodolsky

ABSTRACT

Light trucks' share of the U.S. light vehicle market rose from 20% in 1980 to 41% in 1996. By 1996, annual energy consumption for light trucks was 6.0×10^{15} Btu (quadrillion Btu, or "quad"), compared with 7.9 quad for cars. Gasoline engines, used in almost 99% of light trucks, do not meet the Corporate Average Fuel Economy (CAFE) standards. These engines have poor fuel economy, many getting only 10-12 miles per gallon. Diesel engines, despite their much better fuel economy, had not been preferred by U.S. light truck manufacturers because of problems with high NO_x and particulate emissions. The U.S. Department of Energy, Office of Heavy Vehicle Technologies, has funded research projects at several leading engine makers to develop a new low-emission, high-efficiency advanced diesel engine, first for large trucks, then for light trucks. Recent advances in diesel engine technology may overcome the NO_x and particulate problems. Two plausible alternative clean diesel (CD) engine market penetration trajectories were developed, representing an optimistic case (High Case) and an industry response to meet the CAFE standards (CAFE Case). However, leadership in the technology to produce a successful small, advanced diesel engine for light trucks is an open issue between U.S. and foreign companies and could have major industry and national implications. Direct and indirect economic effects of the following CD scenarios were estimated by using the Standard & Poor's Data Resources, Inc., U.S. economy model: High Case with U.S. Dominance, High Case with Foreign Dominance, CAFE Case with U.S. Dominance, and CAFE Case with Foreign Dominance. The model results demonstrate that the economic activity under each of the four CD scenarios is higher than in the Base Case (business as usual). The economic activity is highest for the High Case with U.S. dominance, resulting in maximum gains in such key indicators as gross domestic product, total civilian employment, and federal government surplus. Specifically, the cumulative real gross domestic product surplus over the Base Case during the 2000-2022 period is about $\$56 \times 10^9$ (constant 1992 dollars) under this high U.S. dominance case. In contrast, the real gross domestic product gains under the high foreign dominance case would be only about half of the above gains with U.S. dominance.

1 INTRODUCTION

In the United States, light trucks (including sport utility vehicles and minivans) have grown increasingly popular in recent years. The introduction of minivans, and more recently the increased popularity of sport utility vehicles (SUVs), have primarily contributed to this trend. The sales of light trucks rose from 1.5×10^6 units in 1970 to 2.0×10^6 in 1980 (DRI 1983), 4.4×10^6 in 1990 (DRI 1993), and 5.1×10^6 in 1996 (EIA 1998a). Their share of the U.S. light vehicle market rose from 20% in 1980 to 41% in 1996. By 1996, annual energy consumption for light trucks had risen to 6.0×10^{15} Btu (6.0 quadrillion Btu, or "quad"), compared with 7.9 quad for cars, according to the U.S. Department of Energy (DOE)/Energy Information Administration (EIA); gasoline engines having low fuel economy accounted for almost 99% of all engines in these trucks (EIA 1998a). This use in light trucks accounted for 25% of petroleum consumption in the transportation sector (23.9 quad), and 17% of the total national petroleum consumption (36.0 quad) (EIA 1998b). These shares are expected to increase steadily over the next 15 years as the current stock of light vehicles on the road is gradually replaced by low-fuel-economy light trucks, such as sport utility vehicles. Besides their poor fuel economy, these gasoline engines do not meet the current light-truck Corporate Average Fuel Economy (CAFE) standards.

Over the years, the DOE Office of Heavy Vehicle Technologies (OHVT), under its Light Truck Clean Diesel (CD) Engine program, has sponsored extensive research on a number of technologies that have the potential to make these engines still more efficient and clean. The goal of the CD engine program is to meet all future emission standards, although they are uncertain at this time. 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 this time the emissions standards are undetermined for model year 2004 and beyond. The results of this DOE-sponsored CD-engine-related research, plus the results from many other studies throughout the world, have made it possible to develop a new generation of diesel engines that should 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, which have not yet reached the level of the CD engine discussed above, for light trucks. Mateja (1998) reported that Ford Motor Company had selected Navistar International Corp. to develop an advanced diesel engine for light trucks. The Cummins Engine Co. and Detroit Diesel Corp. have separately developed a small engine for light trucks (Cummins 1998). Also, General Motors Corp. and Isuzu Motors Ltd. are forming a joint venture (with combined capital of $320 million, constant 1998 dollars) to build a new generation of diesel engines for pickup trucks (White 1998).

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 CD engines for light trucks If U.S. industry attempts to introduce CD engines, it may decide either to manufacture or to import them. The impact of the import scenario is the closure of some gasoline engine plants. On the other hand, the decision to manufacture these engines would result in new plant facilities. The impacts are far-reaching and would affect several sectors of the economy.

The preliminary economic analysis presented here provides estimated impacts of U.S.- or foreign-based CD engines for selected light trucks, including sport utility vehicles, pickup trucks, and large vans. The authors assume that the technical hurdles in developing a small-size, low-emission, energy-efficient CD engine will be overcome. For this case study, two plausible alternative CD market penetration trajectories are developed and analyzed, assuming that the technology will come to be dominated either by the U.S. or by foreign companies.

This preliminary study provides estimates of direct and indirect economic effects under each of four economic scenarios, which were generated by solving the Standard & Poor's Data Resources, Inc. (DRI), U.S. economy model. 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 reductions resulting from the CD engine was not evaluated by this macro model, however, because it was not a focus of this study.

2 METHODOLOGY

The domestic economic impacts associated with energy-efficient CD engines could be significant because such an engine would replace the conventional gasoline engine in light trucks. The impacts can be put in two categories. First, any commercialization of CD engines in trucks will result in "direct impacts," such as capital expenditures on engine plants and fuel savings. Second, market penetration of the new CD engine could have significant "indirect impacts," such as reductions in crude oil imports and more jobs. The CD engine could be either developed domestically or imported; the U.S. economy would be affected differently by the two alternatives. In order to measure the direct and indirect impacts, a four-step approach was used, as described below.

2.1 ALTERNATIVE CLEAN DIESEL ENGINE CASES

The cases cover a range of levels of market penetration by the CD engine and whether its technology is dominated by domestic or foreign companies. Two alternative market penetration profiles have been developed. In the first profile, higher acceptance of CD engines was assumed on the basis of French experience with conventional diesel engines in light vehicles. In the second profile, CAFE standards are the primary incentive for launching CDs in light trucks. However, improved driveability and performance of CDs compared with that of traditional diesels could spur additional, consumer-driven demand. Therefore, our estimates of market penetration are conservative. For each of the market penetration trajectories (1 and 2), two alternative cases — based on who will dominate the new-technology engine market — were established.

Under the U.S. dominance cases (1U and 2U), domestic manufacturers would dominate the light-duty CD engine market. The United States is the leader in heavy-duty diesel engine manufacturing. U.S. diesel engine manufacturers have complied with stringent emissions regulations, and some of these manufacturers are participating in OHVT-sponsored research programs on the CD engine. In cases 1U and 2U, the expertise gained by diesel engine manufacturers in the area of heavy-duty engines would enable them to introduce the CD engine in light trucks first. Subsequently, the engine manufacturers would enter into commercial arrangements with domestic light-duty vehicle manufacturers for production of the new CD engines.

Under the foreign dominance (FD) cases (1F and 2F), the CD engines would be imported by U.S. manufacturers. U.S. vehicle manufacturers do not offer many types of diesel engines for light trucks. Usually, the smallest diesel engine for class 3 medium trucks (gross vehicle weight, 10,000-14,000 lb) is offered as an optional engine. European manufacturers offer a variety of light-duty diesel engines, and consumers in Europe have accepted them. The high cost of fuel is one of several reasons for the acceptance of these conventional diesel engines by consumers in Europe and other parts of the world. Because they are experienced producers of the lighter diesel engines, European vehicle manufacturers are more likely to adopt the CD engine immediately. In these FD cases, experienced European manufacturers would establish contracts to supply the new engines to U.S. vehicle manufacturers, thereby dominating the light-duty CD engine market.

2.2 MARKET PENETRATION

Alternative market-penetration trajectories for CD engines were developed as described below.

A new technology has attributes that define its usefulness to potential buyers. Argonne National Laboratory (ANL) has developed models that project 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 historical buying patterns. Because diesel use in light-duty vehicles in the United States is historically very low, these models would not be able to project the extent of market penetration by the new diesel technology, which differs substantially from conventional diesel technology.

Several alternative methods are available to evaluate a new technology not yet in market and to project its market penetration. These alternatives include stated preference surveys, Delphi surveys, or 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. The third alternative, using an analogy of historical market penetration elsewhere, is simple and requires limited resources. We selected this method for developing the alternative market penetration estimates.

The selected approach requires that a developed economy, with experience that would be applicable to the U.S. market, be identified. Western European economies are advanced and would provide such an analogy. The historical diesel market penetration data for selected European countries were collected. Mathematical models representing the underlying patterns were developed from these data. These models represent typical market penetration patterns for a new engine technology under different conditions. Such a market penetration pattern, developed from the French experience of diesel sales, was used for the high market penetration ("High") case.

The high market scenario represents new-vehicle sales shares resulting from conditions that are very favorable to the new technology. The market penetration pattern developed from the French experience would represent such a scenario. The maximum new-vehicle sales share for diesel technology neared 50% in the French experience. Such a high sales share by the new diesel technology is unlikely in the United States. In this country, both households and commercial establishments purchase light trucks. Each has different demands and would consequently view the new technology differently. Historical U.S. purchase patterns have been analyzed. Some 75% of the new light truck sales are to residential customers for personal use. The remaining 25% are sold to commercial customers who value diesel's cargo-carrying capacity and low operating cost. We established maximum sales shares for each of these two segments before applying the market-penetration pattern developed from the French experience. The procedure is described in the next chapter.

The low market scenario represents a case in which vehicle manufacturers would benefit from the introduction of the new diesel technology light trucks. The technology would improve their corporate average fuel economy (CAFE). Consequently, the manufacturers would pay a smaller penalty for not meeting the CAFE requirements. The sales of new-technology vehicles would increase with increases in production capacity. Because CD engines are projected to cost more than the gasoline engine, manufacturers would pass the larger share of the avoided CAFE fines to the consumers to increase sales. Ultimately, a point would be reached where the benefits from additional sales of the new technology would be minimal. The market share for the new technology would stabilize at this point. An analysis of the current and projected CAFE shortfall provided the basis for this scenario. The procedure used in arriving at year-by-year market shares is described in the next chapter.

2.3 DIRECT ECONOMIC IMPACTS

For each level of penetration of the CD engine under each case, 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 assume that a CD engine would have a 55% higher fuel economy (miles per gallon), compared to a light truck gasoline engine.

For estimating additional consumer and business expenditures on light trucks with the CD engine under each case, ANL assumed that the total expenditures could be divided equally into these categories. For estimating additional capital expenditures on manufacturing plants for engines/light trucks under each of the cases (1U and 2U) with U.S. dominance, ANL assumed that because of competitive reasons, initially one CD engine plant with a capacity of 300×10^3 units would be introduced in 2000, 2002, and 2004 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 300×10^3 unit CD engine plant was assumed to be $\$500 \times 10^6$ (constant 1996 dollars).

For estimating reduced capital expenditures on engine/light trucks manufacturing plants under each of the cases (1F and 2F) with foreign dominance, we assumed that all required CD engines would be imported by U.S. manufacturers; as a result, construction of some new gasoline engine plants in the United States (with production capacity of 400×10^3 units) would be avoided. The construction cost of an avoided 400×10^3 unit gasoline engine plant was assumed to be $\$500 \times 10^6$ (constant 1996 dollars).

2.4 INDIRECT ECONOMIC IMPACTS

The indirect impacts of CD 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 CD engines are more energy-efficient than are conventional gasoline engines, market penetration by CD engines will result in substitution of capital for energy, 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 Cases 1U and 2U (U.S. dominance), variables were changed in the DRI model to accommodate increased levels of capital expenditures on engine/light-truck manufacturing plants, fuel savings, consumer and business expenditures on light trucks with CD engines, and exports of light trucks with CD engines. Details of these changes to the model are provided in the Appendix (Sec. A.1 for Case 1U, Sec. A.3 for Case 2U).

For Cases 1F and 2F (foreign dominance), variables were changed in the DRI model to accommodate reduced levels of capital expenditures on engine/light-truck manufacturing plants, with increased levels of fuel savings and consumer and business expenditures on light trucks with CD engines. Details of these changes to the model are also provided in the Appendix (Sec. A.2 for Case 1F, Sec. A.4 for Case 2F).

Macroeconomic projections were obtained by solving the DRI model for each of the above four cases (Sec. 5.1). The indirect economic impacts were measured by comparing these projections with the Standard and Poor's Data Resources, Inc., Base Case projections (DRI 1998). National impacts associated with commercialization of a CD 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 (Sec. 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. While the bigger, higher-power automotive diesel engines obtained a relatively large market in heavy and medium trucks almost immediately, for over-the-road transport and distribution, 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 kind, 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 in Europe, one in Japan, and none in the United States 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 most important issue forcing automotive diesel engine development in the world was the introduction of ever-tightening exhaust emissions regulations in the United States. These regulations were aimed primarily at 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 (electronic controls, very-high-pressure fuel injection, improved turbocharging and intercooling, etc.) that made modern diesel engines far cleaner, more economical, more powerful, lighter, more compact, etc., and thus, more competitive relative to other power plants. But these new developments were introduced first in heavy-duty diesel engines, specifically in the U.S. market, to satisfy the tough emissions regulations introduced in 1991 and 1994. In general, most light-duty diesel engines were not offered in the United States, and they remained relatively undeveloped until tougher European and Japanese exhaust emissions regulations started forcing a more rapid pace of development. Now that the volume of light-duty diesel production is relatively high, manufacturers can afford to make significant investments in research and development, and the state of development of this type of engine is catching up with and even surpassing that of heavier engines.

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 CD truck sales annually. In consultation with OHVT, the year 2000 was selected as the introductory year for the new technology. Two projections were developed, representing percent market shares by CD light duty trucks under the high and CAFE cases.

Future light-duty truck sales were derived from the DOE/EIA 1998 Annual Energy Outlook (EIA 1998b). 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. EIA projections extend through the year 2020; the growth rate during the last five years of the projections was used to extrapolate sales to 2022. Households own a majority of the minivans and sport utility vehicles 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 could be equipped with advanced diesel engines.

The fuel savings from the use of clean diesel technology would be substantial. The conventional gasoline engine's efficiency is in the range of 27-31%, while the current turbocharged diesel engine's efficiency is 44%. The most efficient gasoline engine, Honda's VTEC, is said to have an efficiency of 31.7%. On the basis of efficiency alone, then, 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). The most efficient current diesel engine would provide 55% more miles per gallon of fuel than the most efficient current gasoline engine. The advanced diesel technology is projected to increase engine efficiency to 50%, a 13.6% increase. The gasoline engine would also improve its efficiency with the possible introduction of direct injection engines. Assuming that future improvements would increase gasoline engine efficiency to 36%, we kept the fuel economy gain at 55%.

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

3.1 High Market Penetration Case

Under the high market penetration case, conditions would be favorable to clean diesel technology. Also, the consumer bias against diesel technology would be absent. The market penetration profile for this case was developed by using an analogy to the French experience with diesel technology in light-duty vehicles.

3.1.1 Assumptions

The market for new-vehicle sales by diesel technology in France increased from slightly over 1% in 1973 to nearly 45% in 1993, as shown in Figure 3.1. Several conditions contributed to this rapid rise. The overall prices of transportation fuels are high in France because of taxes. However, diesel fuel has been subject to lower taxes, making it cheaper than gasoline. Also,

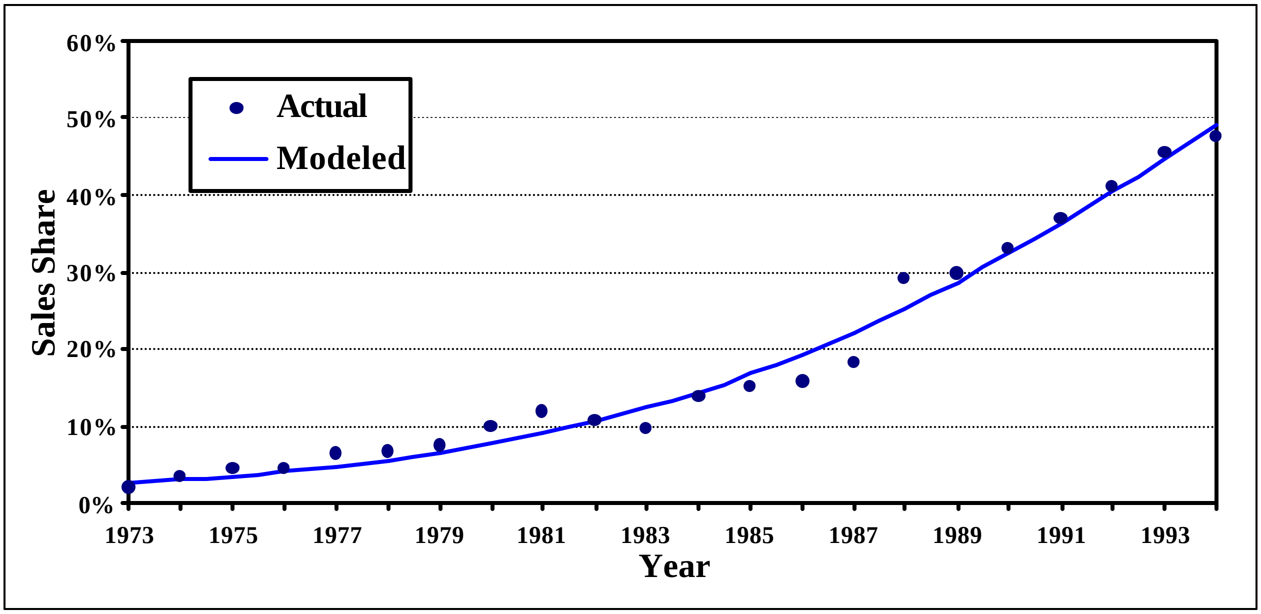

FIGURE 3.1 Sales Share of Light-Duty Diesel Vehicles in France

nearly all vehicle manufacturers have offered varying sizes of diesel engines. The winter temperatures in France are moderate, and consequently diesel's poor winter characteristics (i.e., engine starting and fuel clouding) do not cause concern among consumers.

Aside from the lower fuel consumption, the diesel engine has other advantages, too. It has lower maintenance and longer life. The gasoline engine has the advantage of better low-temperature characteristics and established refueling and maintenance infrastructure. Also, the current research on clean diesel would bring such characteristics as poor starting, smell, and noise, vibration, and harshness closer to those of the gasoline engine. OHVT also projects cost equality for mass-produced diesel engines. However, the diesel fuel's characteristic of clouding during low temperatures is likely to affect its market penetration in the northern parts of the United States. Nearly 43% of the U.S. population in 2010 would reside in the states having average January-February temperatures of 10ºF or less. The Energy Information Administration projects the cost of transportation fuels to remain low through 2020 (EIA 1998b). The cost of petroleum products would not rise at all over its 1996 level. The cost of diesel fuel would drop a little (0.2%), while the cost of gasoline would increase slightly (0.1%), during the 24-year period. Thus, even though CD technology would be competitive, it would not achieve market shares comparable with those shown in Figure 3.1.

Households purchase nearly 75% of the new light trucks. We assume this sector to have a maximum share of 25%, almost half of the highest level in France. The remaining 25% of the new light trucks are purchased by the commercial sector. The commercial sector would benefit from lower operating cost of the new technology and would not view its disadvantages of fuel clouding and sparse refueling and maintenance infrastructure as very restrictive. We assume that the commercial sector's purchases level out at 85%. The resulting combined maximum share for the technology would be 35%. As in the French experience, we assumed a 20-year period for the technology to reach the maximum share.

3.1.2 U.S. Markets

The new diesel technology engines would replace the existing gasoline technology engines. 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 in this analysis. 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, * and $ are coefficients that determine the shape of the market penetration curve, and : is the error term. The term * defines the midpoint in time for the symmetric market penetration curve represented by the above equation, while $ determines the rate at which the new technology would penetrate the market.

Initially, we estimated values of * and $ for the historical diesel vehicle sales in France. The nonlinear regression procedure in the SHAZAM econometric software (McGraw-Hill 1997) was used for this purpose. We then changed the value of $ to match the lower maximum market penetration by the new diesel technology. The resulting market penetration profile is shown in Figure 3.2.

3.1.3 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 of the Canada/Mexico sphere are very limited, being concentrated in just a few countries where U.S.-made vehicles are popular, mostly for historical reasons [308×10^3 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, etc. 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 of North America are

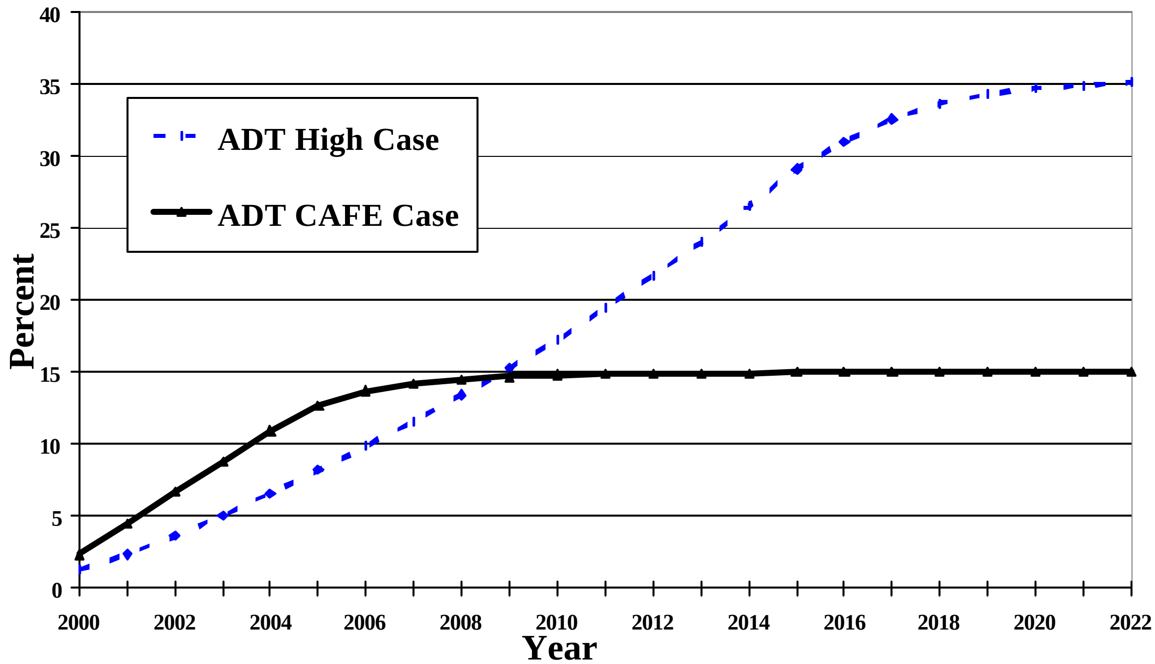

FIGURE 3.2 Market Share of New Light Trucks with CD Engines under High and CAFE Cases

their large engines and relatively poor fuel economy. 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 in 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, pickups, etc., sell in tiny quantities in several of these foreign markets. In recent years, Chrysler has actively marketed its vehicles in Europe and has succeeded in selling almost 100,000 units a year. However, Ford and General Motors (GM), with their large local subsidiaries, export hardly any vehicles to Europe.

Our assumption under the High Case with U.S. dominance (Case 1U) 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. Most U.S. export sales would come from countries in Europe, Central America and the Caribbean, Saudi Arabia and Israel in the Middle East, Japan, Australia, and New Zealand; a very few would come from many other locations in Africa, Asia, and Latin America. Probably many of these vehicles would include specialties that are not very popular with foreign manufacturers, including SUVs, pickup trucks, vans, etc. In general, the increase in vehicle sales projected was kept rather modest, because the price of U.S.-made vehicles is not expected to be particularly attractive, although it should be reasonably competitive. Specifically, by 2020, exports of light trucks with CD engines are projected to approach 7.4×10^3 units to Australia, 3.0×10^3 to Africa, 9.6×10^3 to Asia, 50.0×10^3 to Latin America, 25.0×10^3 to the Middle East, and 150.0×10^3 to Europe (Table 3.1). Total exports of the advanced diesel light truck should increase from 3×10^3 units in 2000, its introductory year, to 121×10^3 units in 2010 and 245×10^3 in 2020. In 2020, Europe accounts for a 62% share of the total exports, followed by 20% for Latin America, 10% for the Middle East, 4% for Asia, 3% for Australia, and 1% for Africa. With sales saturated, the total exports of advanced diesel light trucks stay at that level between 2020 and 2022. It is further assumed that half of the diesel light truck exports would displace gasoline light truck exports.

3.2 CAFE CASE

Under the CAFE case (2U), clean diesel technology would penetrate the market at a rate that provides the maximum advantage to light truck manufacturers. Domestic vehicle manufacturers sell nearly 84% of the new light trucks. All light truck manufacturers are subject to a fine of $55 per truck if their corporate average fuel economy falls short of the CAFE standard by one mile per gallon (mpg). In 1996, the corporate average fuel economy of all domestic manufacturers was 20.2 mpg, against the standard of 20.7 mpg. Domestic manufacturers sold 4.9 million trucks in that year. The market penetration profile for this case was developed to minimize the extent of CAFE shortfall by domestic manufacturers.

3.2.1 Assumptions

Historic truck sales and fuel economy were analyzed to arrive at the share of sales for domestic manufacturers (Davis 1997). Future light truck sales and fuel economy values were obtained from EIA's *Annual Energy Outlook* (EIA 1998b). We used these two sources to estimate future domestic light truck sales and their average fuel economy. The manufacturers are given CAFE credit for the sale of alternative-fuel vehicles (AFVs). A set of AFV credits was assumed for this analysis. In 1995, the credit would be 0.05 mpg, increasing to 0.3 mpg in 2010; after 2010, the AFV credit would remain at 0.3 mpg. We also assumed that the manufacturers would have used up their prior CAFE credits.

TABLE 3.1 Assumed U.S. Exports of Light Trucks with Clean Diesel Engines under Cases 1U and 2U (1,000 units)

	Light Truck Exports under High Case, U.S. Dominance, by Year			Light Truck Exports under CAFE Case, U.S. Dominance, by Year		
Selected Region	2000	2010	2020	2000	2010	2020
Australia	0.0	3.7	7.4	0.0	3.7	3.7
Africa	0.0	1.5	3.0	0.0	1.5	1.5
Asia	0.0	4.7	9.6	0.0	4.7	4.8
Latin America	2.0	24.7	50.0	1.0	24.7	25.0
Middle East	1.0	12.4	25.0	0.5	12.3	12.5
Europe	0.0	74.1	150.0	0.0	0.0	0.0
All regions	3.0	121.0	245.0	1.5	46.9	47.5

3.2.2 U.S. Markets

Both historical analysis and projected data indicated that the sales-weighted CAFE shortfall would be very high, requiring a share of over 10% by the CD engine in its introductory year. Domestic light truck sales are estimated at 4.7 million in that year. A first-year production level of nearly 0.5 million new-technology diesel engines would be impossible to achieve. With the need for rapid market penetration by the new technology, we assumed that special incentives would be offered to buyers to increase sales. Also, we estimated that a reduction of nearly $600 (constant 1998 dollars) in CAFE penalty per sale of each new-technology light truck would be feasible. These incentives would give the technology a push, producing much higher market penetration than would normally be expected. As a result, the new-technology market penetration would not follow the classic S-shaped curve; instead, it would be nearly linear initially, much higher than the rate achieved under the high market penetration scenario. The sales of new-technology trucks would stabilize once the CAFE requirements were met; the market share for the new technology at this point would be 15%. Figure 3.2 shows the market penetration profile under this scenario.

3.2.3 Exports

The historical perspective on exports of U.S. light-duty vehicles discussed in Sec. 3.1.3 also provides the basis of export projections under the CAFE case of U.S. dominance.

In addition to sales in the U.S. market, the new-technology vehicles could be exported in modest quantity. Under the CAFE scenario, the authors assumed that in meeting the CAFE standards, 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 2000-2022 (Table 3.1). 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 on 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 be marginally competitive. For these territories, the market penetration of light trucks with CD engines was assumed to approach only 50% of the corresponding market penetration under the High Case discussed in Sec. 3.1.3 (Table 3.1). Specifically, by 2020, exports of light trucks with CD engines are projected to approach 3.7×10^3 units to Australia, 1.5×10^3 to Africa, 4.8×10^3 to Asia, 25.0×10^3 to Latin America, and 12.5×10^3 to the Middle East (Table 3.1). The total exports of light trucks with CD engines increase from 1.5×10^3 units in 2000, their introductory year, to 46.9×10^3 units in 2010 and 47.5×10^3 in 2020. In 2020, 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 of the diesel light truck exports would displace gasoline light truck exports.

4 BASE CASE MACROECONOMIC SCENARIO

The Base Case is identical to the Standard & Poor's DRI 25-Year Trend Projection, released in February 1998, for which a complete description of the underlying assumptions is available from DRI (1998). Selected highlights, based on the information provided by DRI to ANL, are provided below.

4.1 BASE CASE ASSUMPTIONS: SELECTED HIGHLIGHTS

Under the DRI trend projection, the U.S. economy is not subjected to any major shocks over the next 25 years. Because of higher female participation rates and the maturing of the "baby-boom" generation, the labor force grew at an average rate of 1.9% between 1970 and 1997. However, the labor force growth is projected to slow down in future because of a lower female participation rate (now 80% of the male rate) 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 1997 and 2002, 0.9% between 2002 and 2012, and only 0.3% between 2012 and 2022.

The coming slowdown in the growth of the labor force over the projected years is expected to reduce the growth rate of the country's economic output, as measured by the potential GDP.

A relatively accommodative policy is assumed on the part of the Federal Reserve Board. Specifically, the money supply (M2) is allowed to increase at an average annual rate of about 4.8%, in line with the nominal GDP average growth rate.

The federal government's fiscal policy is assumed to be under pressure as the government deals with increasing transfer payments to retiring baby boomers, particularly after 2010.

The nominal average acquisition price of foreign crude oil is assumed to remain around $16 per barrel between now and 2000. However, in an environment of steadily increasing worldwide demand for crude oil, the OPEC cartel may be able to exert increasing influence after 2000. Nominal oil prices rise steadily to $54 per barrel by 2022 (Table 4.1). However, the increase in real oil prices in constant 1992 dollars is expected to average only a modest 1.3% between 1997 and 2022. The real oil prices in 2022 would still be less than the peak prices in 1980.

TABLE 4.1 U.S. Economy Outlook in the DRI Base Case

Selected Variable	1997	2002	2007	2012	2017	2022
Gross domestic product (GDP)						
Real GDP ($\$10^9$, 1992 dollars)	7,191	8,041	9,007	9,930	10,694	11,379
Real GDP (% change/yr)	3.8	2.6	2.2	1.7	1.5	1.1
Price level indicator						
GDP price index (% change/yr)	2.0	2.2	2.8	3.3	3.5	3.9
Employment indicators						
Total civilian employment (10^6)	129.44	136.47	144.27	149.62	152.32	154.200
Civilian unemployment rate (%)	5.0	5.6	5.5	5.5	5.6	5.5
Financial indicators						
Three-month treasury bill rates (%)	5.06	4.10	4.35	4.82	5.43	6.00
Thirty-year treasury bond yield (%)	6.61	5.24	5.44	5.92	6.60	7.33
Federal budget surplus (FY, $\$10^9$)	-22.0	19.5	45.1	-30.5	-235.4	-626.4
Federal budget surplus (% of GDP)	-0.6	0.2	0.4	-0.1	-1.1	-2.4
Current account balance ($\$10^9$)	-161.3	-197.3	-146.1	-149.7	-280.3	-623.5
Transportation indicators						
Total light-vehicle sales (10^6 units)	15.1	15.5	16.1	16.7	16.8	16.9
Light truck sales (10^6 units)	6.9	7.7	8.2	8.5	8.5	8.5
Energy indicators						
Total energy demand (10^{15} Btu)	90.6	101.6	109.9	115.9	120.6	123.9
Refiners' acq. price for crude oil: Composite ($/bbl)	19.16	17.89	23.10	30.50	40.84	54.99
Refiners' acq. price for crude oil: Foreign ($/bbl, 1992 dollars)	16.68	14.18	16.07	18.19	20.55	23.05
Imports of petroleum and products ($\$10^9$, 1992 dollars)	65.9	85.3	93.1	98.4	102.0	101.6

4.2 BASE-CASE PROJECTIONS: SELECTED HIGHLIGHTS

Table 4.1 shows projected values for selected key macroeconomic indicators under the DRI Base Case at five-year intervals between 1997 and 2022.

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. Table 4.1 shows annual percent changes in real GDP for selected years. 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 2012 and at 1.4% between 2012 and 2022. This corresponds to an average annual rate of 1.85% over the next 25 years.

The inflation in the economy has been modest over the last 10 years. For example, the consumer price index (CPI) rose at an average annual rate of 3.5% between 1983 and 1996. This pattern is continued under the trend projection, with the CPI expected to rise by only 3.4% annually between 1997 and 2022. The broader-based GDP price index is projected to rise by 3.0% per year over that period. Table 4.1 also shows annual percent changes in GDP Price Index for selected years.

The job market stays healthy, and unemployment rates do not exceed 5.5% through 2000 (Table 4.1). Over the long term, civilian employment gains are expected to track labor-force growth, as discussed in Sec. 4.1. Total employment increases at an average annual rate of 1.0% between now and 2002, 0.9% between 2002 and 2012, and 0.3% in the following 10 years; in terms of people, total employment rises from 129.4 million in 1997 to 154.2 million in 2022 (Table 4.1). The unemployment rate averages 5.5% over the projection period.

Interest rates are driven by the rate of inflation in the economy. Table 4.1 shows representative interest rates for both the short term (three-month Treasury bills) and the long term (30-year Treasury bonds). Long-term government bond yields are expected to decline from 6.6% in 1997 to 5.2% by 2007 as growth slows, then rise to 7.3% by 2022 as the federal deficit widens sharply and short-term rates rise (Table 4.1).

Mirroring short-term trends in the economy, the federal budget is projected to show a surplus by 2002. However, for reasons discussed in Sec. 4.1, the federal budget will come under great pressure from increasing entitlements for retirees, whose numbers swell after 2011. As a result, the budget surplus will disappear by 2012 (Table 4.1). Thereafter, the deficit will steadily rise, to 1.1% of the GDP by 2017 and 2.4% by 2022. For the entire projection period, an average deficit equivalent to 0.5% 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 outside, are expected to grow modestly, at an average annual rate of 0.84%, between 1997 and 2022.

As discussed in Sec. 4.1, in an environment of increasing total energy demand in the United States (Table 4.1), the nominal average acquisition price of foreign oil is projected to remain near $16 per barrel through 2000 and then to rise steadily, to $35/bbl by 2015 and $54/bbl by 2022. In real terms, the per-barrel price of foreign crude oil rises from $14.18 in 2002 to $23.05 in 2022 (constant 1992 dollars). Over the projection period, the average rate of increase in real crude oil prices is 1.3% annually. However, even in 2022, the real price of imported oil remains well below its 1980 peak. As shown in Table 4.1, the total energy demand increases from 90.6 quad (10^{15} Btu) in 1997 to 123.9 quad in 2022.

On the international front, the dollar's real exchange rate should decline marginally between 1997 and 2007. The current account balance remains stable prior to 2012 (see Table 4.1) but falls rapidly thereafter, in line with deterioration in merchandise trade balance, which occurs because of several factors, including sharp increases in imported fuel oil price (nominal prices increase from $30/barrel in 2012 to $55 in 2022). The current account balance of payments (BOP) deficit rises from a nominal $161 billion ($\$1.61 \times 10^{11}$) in 1997 to $624 billion in 2022.

5 ECONOMIC IMPACTS UNDER ALTERNATIVE CASES

Macroeconomic projections under each CD case were obtained by solving the DRI model for the 2000-2022 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, exports, and imports under each case were estimated; such changes are shown in this section, in constant 1992 dollars. Section 5.1 presents highlights of the macroeconomic scenarios generated from the model, and Sec. 5.2 discusses specific national economic impacts on certain key macroeconomic indicators, such as gross domestic product. The estimated macroeconomic impacts measured in dollars are shown in this section (in constant 1992 dollars).

5.1 CLEAN DIESEL MACROECONOMIC SCENARIOS

This section provides a summary of key assumptions and projections for each of the four macroeconomic scenarios generated from the DRI model.

5.1.1 Scenario for Case 1U: High Case, U.S. Dominance

Assumptions

Adoption of energy-efficient CD engines in light trucks results in significant energy savings. Because CD engines are more energy-efficient and their rate of market penetration is high (35% saturation rate) under this case, the direct annual energy savings approach 0.45 quad by 2022. (The details of these estimates are given in Section A.1 of the Appendix.)

Under this scenario (Case 1U), we assume that the CD engines are built in the United States only, substituting for gasoline engines in any penetrated domestic light truck markets, and that the availability of fuel-efficient CD engines results in increased sales of light trucks to foreign countries. As a result, cumulative plant investment is $\$2.04 \times 10^9$ (1992 constant dollars) higher than in the Base Case by 2022. (The annual estimates are given in Section A.1 of the Appendix.)

Incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of CD trucks sold in the U.S. The incremental expenditures were divided equally between consumers and businesses, both of whom perceive the CD 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 $\$1.19 \times 10^9$ (1992 constant dollars) by 2022. In addition, because of U.S. dominance, annual export demand for light trucks increases to $\$2.48 \times 10^9$ (1992 constant dollars) by 2022. (The details of these estimates are given in Section A.1 of the Appendix.)

Projections

Table 5.1 provides projections of selected key macroeconomic indicators under Case 1U (High Case, U.S. Dominance) at five-year intervals between 1997 and 2022.

TABLE 5.1 U.S. Economy Outlook in Case 1U

Selected Variable	1997	2002	2007	2012	2017	2022
Gross domestic product						
Real GDP ($\$10^9$ 1992 dollars)	7,191	8,044	9,009	9,933	10,696	11,381
Real GDP (% change/yr)	3.8	2.7	2.2	1.7	1.5	1.1
Price level indicator						
GDP price index (% change/yr)	2.0	2.2	2.9	3.3	3.5	4.0
Employment indicators						
Total civilian employment (10^6)	129.44	136.49	144.29	149.62	152.33	154.24
Civilian unemployment rate (%)	5.0	5.6	5.5	5.5	5.6	5.5
Financial indicators						
Three-month treasury bill rates (%)	5.06	4.09	4.35	4.83	5.45	6.03
Thirty-year treasury bond yield (%)	6.61	5.23	5.43	5.92	6.61	7.35
Federal budget surplus (FY, $\$10^9$)	-22.0	20.7	47.2	-27.4	-231.5	-622.8
Federal budget surplus (% of GDP)	-0.6	0.2	0.4	-0.1	-1.1	-2.3
Current account balance ($\$10^9$)	-161.3	-197.5	-145.6	-149.0	-279.2	-623.5
Transportation indicators						
Total light-vehicle sales (10^6 units)	15.1	15.5	16.1	16.7	16.8	17.0
Light truck sales (10^6 units)	6.9	7.7	8.2	8.5	8.5	8.5
Energy indicators						
Total energy demand (10^{15} Btu)	90.6	101.6	109.9	115.8	120.4	123.5
Refiners' acq. price for crude oil: Composite ($/bbl)	19.16	17.89	23.12	30.53	40.90	55.08
Refiners' acq. price for crude oil: Foreign ($/bbl, 1992 dollars)	16.68	14.18	16.07	18.18	20.54	23.03
Imports of petroleum and products ($\$10^9$, 1992 dollars)	65.9	85.4	93	98.1	101.4	100.7

The methodology for estimating potential output (GDP) in the DRI model was discussed in Sec. 2.4. Because CD engines are more energy-efficient than conventional gasoline engines, market penetration by CD engines results in substitution of capital for energy. The capital stock in 2022 is approximately $\$21 \times 10^9$ (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 $\$45.4 \times 10^9$ higher than in the Base Case during the 2000-2022 period. This increase in potential output enables actual output in the economy to grow by about $\$56 \times 10^9$ over the Base Case levels during the 2000-2022 period. The annual rate of inflation rises only modestly, in the range of 0.0 to 0.2%.

For various reasons, minor changes with respect to 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 Sec. 5.2.

5.1.2 Scenario for Case 1F: High Case, Foreign Dominance

Assumptions

Adoption of energy-efficient CD engines in light trucks results in significant energy savings. Because CD engines are more fuel-efficient and their rate of market penetration is high under this case, the energy savings approach 0.45 quad by 2022. (The details of these estimates are given in Section A.2 of the Appendix.)

Under this scenario (Case 1F), we assume that the CD engines built in any foreign country are substitutes for the gasoline engines in any penetrated domestic light truck markets. As a result, the U.S. engine manufacturers will avoid some expenditure on plants. On a cumulative basis, the plant investment is $\$1.74 \times 10^9$ (1992 constant dollars) lower than in the Base Case during the 2000-2022 period. (The annual estimates are given in Section A.2 of the Appendix.)

The incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of CD trucks sold in the United States. The incremental expenditures were divided equally between consumers and businesses, both of whom perceive the CD 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 $\$1.19 \times 10^9$ (1992 constant dollars) by 2022. In addition, because of foreign dominance, annual import demand for CD engines also increases, to $\$1.19 \times 10^9$ by 2022. (The details of these estimates are given in Section A.2 of the Appendix.)

Projections

Table 5.2 provides projections of selected key macroeconomic indicators for this scenario at five-year intervals between 1997 and 2022.

Because CD engines are more energy-efficient than conventional gasoline engines, market penetration by CD engines results in substitution of capital for energy. The capital stock in 2022 is approximately $\$16 \times 10^9$ (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 $\$28.9 \times 10^9$ higher than in the Base Case during the 2000-2022 period. This

TABLE 5.2 U.S. Economy Outlook in Case 1F

Selected Variable	1997	2002	2007	2012	2017	2022
Gross domestic product						
Real GDP ($\$10^9$ 1992 dollars)	7,191	8,042	9,009	9,931	10,693	11,381
Real GDP (% change/yr)	3.8	2.7	2.2	1.7	1.5	1.1
Price level indicator						
GDP price index (% change/yr)	2.0	2.2	2.9	3.3	3.5	3.9
Employment indicators						
Total civilian employment (10^6)	129.44	136.48	144.29	149.61	152.31	154.25
Civilian unemployment rate (%)	5.0	5.6	5.5	5.5	5.6	5.5
Financial indicators						
Three-month treasury bill rates (%)	5.06	4.09	4.35	4.83	5.45	6.03
Thirty-year treasury bond yield (%)	6.61	5.23	5.43	5.92	6.60	7.32
Federal budget surplus (FY, $\$10^9$)	-22.0	20.2	46.8	-28.8	-233.9	-623.4
Federal budget surplus (% of GDP)	-0.6	0.2	0.4	-0.1	-1.1	-2.3
Current account balance ($\$10^9$)	-161.3	-197.5	-146.4	-150.1	-281.2	-625.1
Transportation indicators						
Total light-vehicle sales (10^6 units)	15.1	15.5	16.1	16.7	16.8	17.0
Light truck sales (10^6 units)	6.9	7.7	8.2	8.5	8.4	8.5
Energy indicators						
Total energy demand (10^{15} Btu)	90.6	101.6	109.8	115.8	120.3	123.5
Refiners' acq. price for crude oil: composite ($/bbl)	19.16	17.89	23.11	30.52	40.87	55.02
Refiners' acq. price for crude oil: foreign ($/bbl, 1992 dollars)	16.68	14.18	16.08	18.18	20.54	23.04
Imports of petroleum and products ($\$10^9$, 1992 dollars)	65.9	85.3	93.0	98.1	101.4	100.6

increase in potential output enables actual output in the economy to grow by about $\$29.4 \times 10^9$ over the Base Case levels during the 2000-2022 period, with the annual rate of inflation rising only modestly, in the range of 0.0 to 0.1%.

For various reasons, minor changes with respect to 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 Sec. 5.2.

5.1.3 Scenario for Case 2U: CAFE Case, U.S. Dominance

Assumptions

Adoption of energy-efficient CD engines in light trucks results in significant energy savings. Because CD engines are more energy-efficient and their rate of market penetration is moderate (15% saturation rate) under Case 2U, the energy savings approach 0.26 quad by 2022. (The details of these estimates are given in Section A.3 of the Appendix.)

Under this scenario (Case 2U), we assume that the CD engines built in the U.S. only substitute for gasoline engines in any penetrated domestic light truck markets, whereas the availability of fuel-efficient CD engines results in increased sales of light trucks to foreign countries. As a result, cumulative plant investment is $\$1.03 \times 10^9$ (1992 constant dollars) higher than in the Base Case by 2022. (The annual estimates are given in Section A.3 of the Appendix.)

Incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of CD trucks sold in the United States. The expenditures were divided equally between consumers and businesses, both of whom perceive the CD 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 by $\$0.51 \times 10^9$ (1992 constant dollars) by 2022. In addition, because of U.S. dominance, annual export demand for light trucks increases to $\$0.48 \times 10^9$ by 2022. (The details of these estimates are given in Section A.3 of the Appendix.)

Projections

Table 5.3 provides projections of selected key macroeconomic indicators under this scenario at five-year intervals between 1997 and 2022.

TABLE 5.3 U.S. Economy Outlook in Case 2U

Selected Variable	1997	2002	2007	2012	2017	2022
Gross domestic product						
Real GDP ($\$10^9$ 1992 dollars)	7,191	8,044	9,009	9,930	10,696	11,382
Real GDP (% change/yr)	3.8	2.7	2.2	1.7	1.5	1.1
Price level indicator						
GDP price index (% change/yr)	2.0	2.2	2.9	3.3	3.5	3.9
Employment indicators						
Total civilian employment (10^6)	129.44	136.49	144.28	149.6	152.32	154.25
Civilian unemployment rate (%)	5.0	5.6	5.5	5.5	5.6	5.5
Financial indicators						
Three-month treasury bill rates (%)	5.06	4.09	4.35	4.81	5.42	6.00
Thirty-year treasury bond yield (%)	6.61	5.23	5.43	5.92	6.60	7.32
Federal budget surplus (FY, $\$10^9$)	-22.0	20.7	46.9	-29.3	-232.9	-622.6
Federal budget surplus (% of GDP)	-0.6	0.2	0.4	-0.1	-1.1	-2.3
Current account balance ($\$10^9$)	-161.3	-197.5	-145.8	-148.9	-279.9	-623.1
Transportation indicators						
Total light-vehicle sales (10^6 units)	15.1	15.5	16.1	16.7	16.8	17.0
Light truck sales (10^6 units)	6.9	7.7	8.2	8.5	8.5	8.5
Energy indicators						
Total energy demand (10^{15} Btu)	90.6	101.6	109.8	115.8	120.4	123.7
Refiners' acq. price for crude oil: composite ($/bbl)	19.16	17.89	23.12	30.53	40.87	55.04
Refiners' acq. price for crude oil: foreign ($/bbl, 1992 dollars)	16.68	14.18	16.07	18.18	20.54	23.04
Imports of petroleum and products ($\$10^9$, 1992 dollars)	65.9	85.3	93.0	98.1	101.6	101.1

Because CD engines are more energy-efficient than conventional gasoline engines, market penetration by CD engines results in the substitution of capital for energy. The capital stock in 2022 is approximately $\$18 \times 10^9$ (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 $\$35.5 \times 10^9$ higher than in the Base Case during the 2000-2022 period. This increase in potential output enables actual output in the economy to grow by about $\$39 \times 10^9$ over Base Case levels during the 2000-2022 period, with the annual rate of inflation rising only modestly (in the range of 0.0 to 0.1%).

For various reasons, minor changes with respect to 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 Sec. 5.2.

5.1.4 Scenario for Case 2F: CAFE Case, Foreign Dominance

Assumptions

Adoption of energy-efficient CD engines in light trucks results in significant energy savings. Because CD engines are more energy-efficient and their rate of market penetration is moderate (15% saturation rate) under Case 2F, the energy savings approach 0.26 quad by 2022. (The details of these estimates are given in Section A.4 of the Appendix.)

Under this scenario (Case 2F), we assume that the CD engines built in any foreign country are substitutes for gasoline engines in any penetrated domestic light truck markets. As a result, U.S. engine manufacturers will avoid some expenditure on plants. On a cumulative basis, the plant investment is $\$0.87 \times 10^9$ (1992 constant dollars) lower than in the Base Case during the 2000-2022 period. (The annual estimates are given in Section A.4 of the Appendix.)

Incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of CD trucks sold in the United States. The expenditures were divided equally between consumers and businesses, both of whom perceive the CD 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 by $\$0.51 \times 10^9$ (1992 constant dollars) by 2022. In addition, because of foreign dominance, annual import demand for CD engines also increases, to $\$0.51 \times 10^9$ by 2022. (The details of these estimates are given in Section A.4 of the Appendix.)

Projections

Table 5.4 provides projections of selected key macroeconomic indicators under this scenario at five-year intervals between 1997 and 2022.

Because CD engines are more energy-efficient than conventional gasoline engines, market penetration by CD engines results in the substitution of capital for energy. The capital stock in 2022 is approximately $\$16 \text{x} 10^9$ (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 $\$31.5 \times 10^9$ higher than in the Base Case during the 2000-2022 period. This increase in potential output enables actual output in the economy to grow by about $\$33.1 \times 10^9$ over the Base Case levels during the 2000-2022 period, with the annual rate of inflation rising only modestly (in the range of 0.0 to 0.1%).

TABLE 5.4 U.S. Economy Outlook in Case 2F

Selected Variable	1997	2002	2007	2012	2017	2022
Gross domestic product						
Real GDP ($$10^9$ 1992 dollars)	7,191	8,042	9,009	9,930	10,695	11,381
Real GDP (% change/yr)	3.8	2.7	2.2	1.7	1.5	1.1
Price level indicator						
GDP price index (% change/yr)	2.0	2.2	2.9	3.3	3.5	3.9
Employment indicators						
Total civilian employment (10^6)	129.44	136.48	144.29	149.6	152.31	154.24
Civilian unemployment rate (%)	5.0	5.6	5.5	5.5	5.6	5.5
Financial indicators						
Three-month treasury bill rates (%)	5.06	4.09	4.34	4.81	5.42	5.99
Thirty-year treasury bond yield (%)	6.61	5.23	5.43	5.92	6.60	7.32
Federal budget surplus (FY, $$10^9$)	-22.0	20.2	47.2	-29.2	-233.5	-623.6
Federal budget surplus (% of GDP)	-0.6	0.2	0.4	-0.1	-1.1	-2.3
Current account balance ($$10^9$)	-161.3	-197.6	-146.8	-149.8	-281	-624.2
Transportation indicators						
Total light-vehicle sales (10^6 units)	15.1	15.5	16.1	16.7	16.8	17.0
Light truck sales (10^6 units)	6.9	7.7	8.2	8.5	8.5	8.5
Energy indicators						
Total energy demand (10^{15} Btu)	90.6	101.6	109.8	115.8	120.4	123.6
Refiners' acq. price for crude oil: composite ($/bbl)	19.16	17.89	23.11	30.52	40.87	55.03
Refiners' acq. price for crude oil: foreign ($/bbl, 1992 dollars)	16.68	14.18	16.08	18.18	20.54	23.04
Imports of petroleum and products ($$10^9$, 1992 dollars)	65.9	85.3	93.0	98.1	101.6	101.0

For various reasons, minor changes with respect to 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 5.4). Detailed impacts on some of the key macroeconomic indicators are discussed in Sec. 5.2.

5.2 SPECIFIC MACROECONOMIC IMPACTS

Section 5.1 provided an overview of each of the four CD macroeconomic scenarios (Cases 1U, 1F, 2U, and 2F) generated from the DRI model. Additional details on specific 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 cumulative changes over Base Case real Gross Domestic Product under the alternative cases. For the reasons discussed in Secs. 5.1.1-5.1.4, potential and actual output in the economy is stronger in all four CD scenarios as compared to the Base Case.

Case 1U: Among all the CD engine scenarios, economic growth is highest under Case 1U (High Case, U.S. Dominance). In this scenario, construction of an engine plant by one of the Big Three automobile manufacturers takes place in 2000, 2002, and 2004, resulting in a net cumulative investment of about $\$0.99 \times 10^9$ during this period (see Appendix, Table A.1). With slowly rising light truck sales, exports, and fuel savings, the real GDP excess over Base Case values continuously increases, from $\$1.0 \times 10^9$ in 2000 to $\$3.5 \times 10^9$ in 2004. In the absence of a new engine plant until 2009, the extra GDP narrows to $\$2.0 \times 10^9$ by 2009. However, the extra GDP reverses its course and expands during the 2010-2015 period because of rising plant investment, plus the light truck sales, exports, and fuel savings shown in Table A.1. The extra GDP rises to $\$3.3 \times 10^9$ by 2015. The high economic growth before 2015 is slightly inflationary (GDP deflator rising to a modest 0.1% level by 2006 and 0.2% by 2013) and dampens the economy in the later periods. Even with rising light truck sales, exports, fuel savings, and plant investment (Table A.1), the extra GDP narrows to $\$1.7 \times 10^9$ by 2020. The extra GDP then stabilizes around $\$1.5 \times 10^9$ in later years. The extra GDP peaks at $\$3.5 \times 10^9$ in 2004. On a cumulative basis, the real GDP is projected to total $\$56 \times 10^9$ above the Base Case levels during the 2000-2022 period.

Case 1F: Among all the CD engine scenarios, economic growth is lowest under Case 1F (High Case, Foreign Dominance). The cost of imported engines and any reductions in engine plant investment under this scenario directly offset the real GDP. Light truck sales, imports, and fuel savings rise throughout the projected period, whereas plant investment declines in selected years (see Appendix, Table A.2). The real extra GDP over Base Case continuously increases,

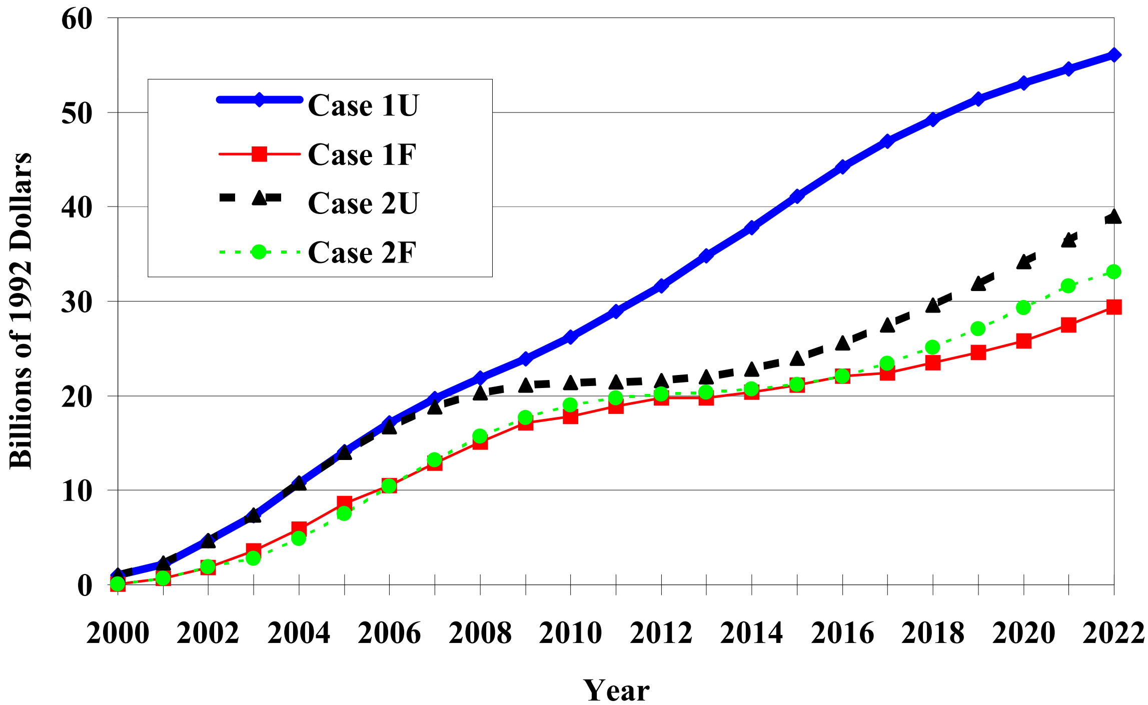

FIGURE 5.1 Real Gross Domestic Product: Cumulative Change over Base Case

from $\$0.1 \times 10^9$ in 2000 to $\$2.7 \times 10^9$ in 2005. In 2006, the real extra GDP drops to $\$1.9 \times 10^9$, primarily reflecting the reduction in investment of $\$0.44 \times 10^9$ for an avoided gasoline engine plant (Table A.2). The real extra GDP then bounces back to $\$2.4 \times 10^9$ in 2007 and only falls slightly, to $\$2.0 \times 10^9$ by 2009. Thereafter, in an environment made favorable by rising light truck sales and fuel savings, but unfavorable by rising imports, plant investment suffers by $\$0.44 \times 10^9$ in 2010 and again in 2013 (Table A.2), causing the real extra GDP to shrink to $\$0.0 \times 10^9$ in 2013. However, except in 2017, this extra GDP reverses its course and expands during the 2013-2022 period because of rising light truck sales, imports, and fuel savings (Table A.2). In 2017, the real GDP shrinks because of a reduction in investment of $\$0.44 \times 10^9$ for an avoided gasoline engine plant. The real extra GDP steadily expands, from $\$0.3 \times 10^9$ in 2017 to $\$1.9 \times 10^9$ in 2022. The excess peaks at $\$2.7 \times 10^9$ in 2004. On a cumulative basis, the real GDP is projected to total $\$29 \times 10^9$ above Base Case levels during the 2000-2022 period.

Case 2U: The economic growth under Case 2U (CAFE Case, U.S. Dominance) ranks second among the four CD engine scenarios. In this scenario, construction of an engine plant by one of the Big Three automobile manufacturers takes place in 2000, 2002, and 2004, resulting in a net cumulative investment of about $\$0.78 \times 10^9$ during this period (see Appendix, Table A.3). With rising light truck sales, exports, and fuel savings, the real GDP excess over Base Case values continuously increases, from $\$1.0 \times 10^9$ in 2000 to $\$3.4 \times 10^9$ in 2004. Light truck sales continue to rise but very slowly, from $\$0.39 \times 10^9$ in 2004 to $\$0.48 \times 10^9$ in 2011, and exports grow from $\$0.32 \times 10^9$ in 2004 to $\$0.45 \times 10^9$ in 2011 (Table A.3). This only requires an additional plant investment of $\$0.11 \times 10^9$ in 2008 (Table A.3). However, the real extra GDP steadily falls, to $\$0.1 \times 10^9$ by 2011, even while fuel savings accelerate from 0.03 quad (10^{15} Btu) in 2004 to 0.14 quad in 2011. The extra GDP then stabilizes in 2012. During the period of 2012-22, as the stock of light trucks on the road continues to increase, the fuel savings rise at an average annual rate of 5.3%, whereas light truck sales rise by only 0.4%, and light truck exports increase by only 0.5%. A large fraction of petroleum savings is imported, and a reduction in any imports directly boosts the GDP. The extra GDP steadily expands, from $\$0.4 \times 10^9$ in 2013 to $\$2.1 \times 10^9$ in 2018, followed by a moderation in growth to $\$2.5 \times 10^9$ in 2022. The high economic growth is slightly inflationary (GDP deflator rising to modest 0.1% level by 2006) and dampens the economy slightly in the later periods. The extra GDP peaks at $\$3.4 \times 10^9$ in 2004. On a cumulative basis, the real GDP is projected to total $\$39 \times 10^9$ above Base Case levels during the 2000-2022 period.

Case 2F: The economic growth under Case 2F (CAFE Case, Foreign Dominance) ranks third among the four CD engine scenarios. The cost of imported engines and reductions in engine plant investment under this scenario directly offset the real GDP. Light truck sales rise primarily between 2000 and 2006, but fuel savings rise throughout the projected period (see Appendix, Table A.4). Plant investment declines in 2003 and 2022 (Table A.4). With rising sales of light trucks with CD engines, the extra GDP over Base Case GDP continuously increases, from \$0.1 billion in 2000 to \$1.2 billion in 2002. In 2003, the extra GDP drops to \$0.9 billion, primarily reflecting a reduction in investment of \$0.44 billion for an avoided gasoline engine plant (Table A.2). The extra GDP then bounces back to \$2.1 billion in 2004 and grows to \$2.9 billion by 2006. Light truck sales change very little after 2007. The extra GDP steadily falls to \$0.2 billion by 2013, even while fuel savings accelerate from 0.06 quad in 2006 to 0.17 quad in 2013. During the period of 2014-2021, as the stock of light trucks on the road continues to increase, fuel savings rise at an average annual rate of 4.8%. A large fraction of the petroleum saved is imported, and a reduction in imports directly boosts the GDP. The extra GDP steadily expands, from \$0.3 billion in 2014 to \$2.3 billion in 2021. In 2022, the extra GDP drops to \$1.5 billion, primarily reflecting a reduction in investment of \$0.44 billion for an avoided gasoline engine plant (Table A.2). The extra GDP peaks at \$2.9 billion in 2006. On a cumulative basis, the real GDP is projected to total \$33 billion above Base Case levels during the 2000-2022 period.

5.2.2 U.S. Total Civilian Employment

Figure 5.2 shows projected cumulative 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 (Sec. 5.2.1).

Case 1U: Out of all the CD engine scenarios, the greatest number of jobs is created under Case 1U (High Case, U.S. Dominance). Compared to the Base Case, total employment steadily rises from 10×10^3 in 2000 to 40×10^3 in 2004, the peak year for both real GDP and

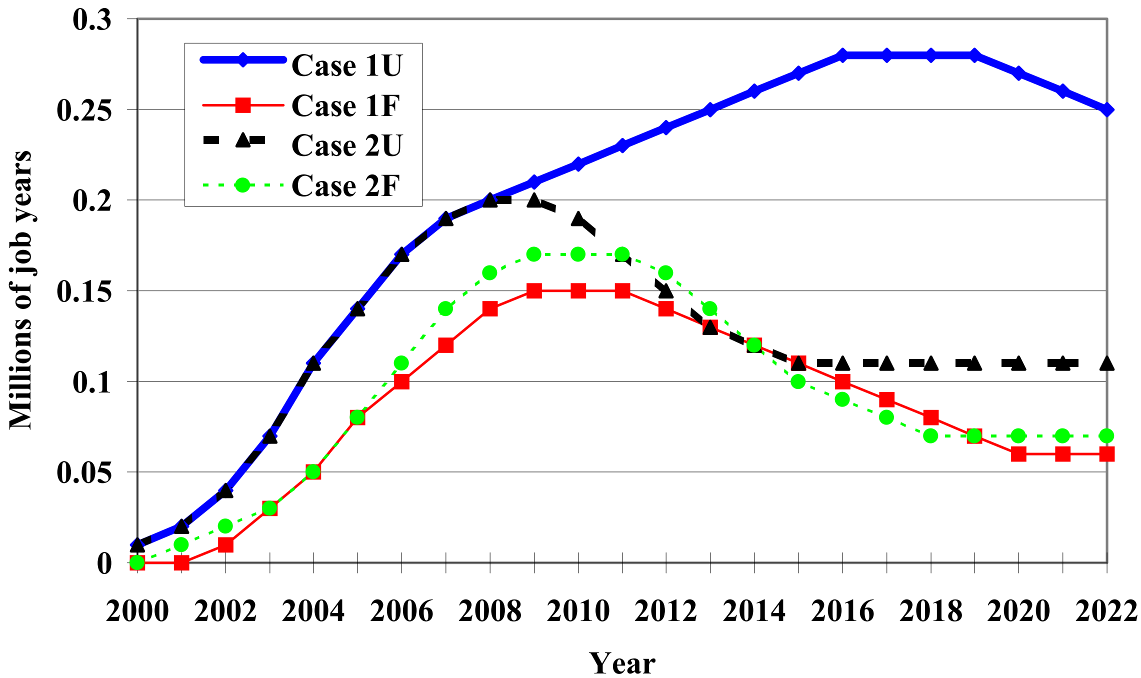

FIGURE 5.2 Total Civilian Employment Level: Cumulative Change over Base Case

total employment. The unemployment rate in the economy falls by 0.2% with respect to the Base Case in 2004. Many of the new jobs come from increased (labor-intensive) production of light trucks and their engines. As the real GDP narrows, the extra employment with respect to the Base Case also narrows, to 10×10^3 by 2008. The employment gap then remains in a narrow range of -10×10^3 to 10×10^3 over the remaining projection period. Additional gains in real GDP and total employment reach their troughs in 2022. On a cumulative basis, about 0.25×10^6 man-years of work are created in the economy over Base Case levels during the 2000-2022 period.

Case 1F: Among the CD engine scenarios, the least number of jobs is created under Case 1F (High Case, Foreign Dominance). Compared to the Base Case, total employment steadily rises from 0.0×10^3 in 2000 to 30.0×10^3 in 2005, the peak year for both real GDP and total employment. The unemployment rate in the economy falls by 0.1% with respect to the Base Case in 2005. As the extra GDP narrows (until 2013), the extra employment with respect to the Base Case also narrows, to -10×10^3 by 2013. With a rebound in real GDP in subsequent periods, except in 2017, the employment loss disappears by 2021. Additional gains in real GDP and total employment reach their troughs in 2013. On a cumulative basis, only about 0.06×10^6 man-years of work are created in the economy over Base Case levels during the 2000-2022 period.

Case 2U: Compared to the Base Case values, total employment steadily rises from 10×10^3 in 2000 to 40×10^3 in 2004, the peak year for both real GDP and total employment. The unemployment rate in the economy falls by 0.2% with respect to the Base Case in 2004. As the extra GDP shrinks (until 2011), the extra employment with respect to the Base Case becomes zero by 2009 and then falls to -20×10^3 by 2011. Additional gains in real GDP and total employment reach their troughs in 2011. With an upward trend in real GDP in place, the employment loss narrows to 10×10^3 by 2014 and reaches zero by 2016. On a cumulative basis, about 0.11×10^6 man-years of work are created over Base Case levels during the 2000-2022 period.

Case 2F: Job creation under Case 2F (CAFE Case, Foreign Dominance) ranks third among the four CD engine scenarios. The extra employment with respect to the Base Case steadily rises from 0×10^3 in 2000 to 30×10^3 in 2006, the peak year for both real GDP and total employment. The unemployment rate falls by 0.2% with respect to the Base Case in 2006. As the extra GDP narrows, the extra employment falls down to -20×10^3 by 2013. With steady growth in real GDP in subsequent periods until 2022, the employment loss disappears by 2019. On a cumulative basis, only about 0.07×10^6 man-years of work are created in the economy over Base Case levels during the 2000-2022 period.

5.2.3 Total Fuel Savings

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

Case 1U: Table A.1 (see Appendix) shows direct estimated fuel savings resulting from deployment of light trucks with CD engines between 2000 and 2022. As the stock of light trucks with CD engines increases, fuel savings in the economy as compared to the Base Case rise to 0.1 quad by 2010, 0.2 quad by 2014, 0.3 quad by 2019, and 0.4 quad by 2020. On a cumulative basis, the fuel savings are projected to approach 2.9 quad over Base Case levels during the 2000-2022 period.

Case 1F: Table A.2 shows direct estimated fuel savings resulting from deployment of light trucks with CD engines between 2000 and 2022. As the stock of light trucks with CD engines increases, fuel savings as compared to the Base Case rise to 0.1 quad by 2009, 0.2 quad by 2013, 0.3 quad by 2017, and 0.4 quad by 2019. On a cumulative basis, the fuel savings are projected to approach 3.4 quad over Base Case levels during the 2000-2022 period.

Case 2U: Table A.3 shows direct estimated fuel savings resulting from deployment of light trucks with CD engines between 2000 and 2022. As the stock of light trucks with CD

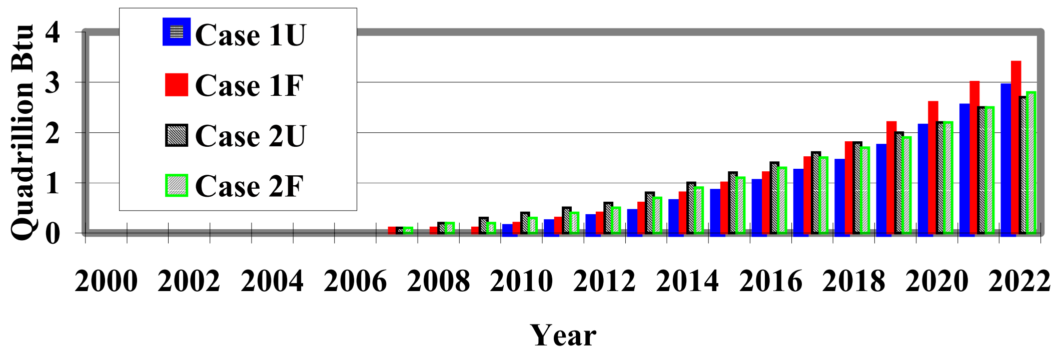

FIGURE 5.3 Cumulative Fuel Savings in the U.S. Economy over Base Case

engines increases, fuel savings as compared to the Base Case rise to 0.1 quad by 2007 and 0.2 quad by 2013. On a cumulative basis, the fuel savings are projected to approach 2.7 quad over Base Case levels during the 2000-2022 period.

Case 2F: Table A.4 shows direct estimated fuel savings resulting from deployment of light trucks with CD engines between 2000 and 2022. As the stock of light trucks with CD engines increases, fuel savings as compared to the Base Case rise to 0.1 quad by 2007, 0.2 quad by 2013, and 0.3 quad by 2020 and beyond. On a cumulative basis, the fuel savings are projected to approach 2.8 quad over Base Case levels during the 2000-2022 period.

5.2.4 Current Account Balance of Payments

Figure 5.4 shows projected cumulative changes over the 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. Exports/imports directly increase/reduce the GDP.

Case 1U: Out of all the CD engine scenarios, trade balance is most favorable under Case 1U (High Case, U.S. Dominance). Table A.1 (Appendix) shows estimated net export revenues from light trucks with CD engines between 2000 and 2022. With strong growth in the economy between 2000 and 2005, and not enough exports of light trucks, the trade is a drag on the economy. In subsequent periods, the trade adds to the economy. On a cumulative basis, the balance of payments improves by $\$6.6 \times 10^9$ over Base Case levels during the 2000-2022 period.

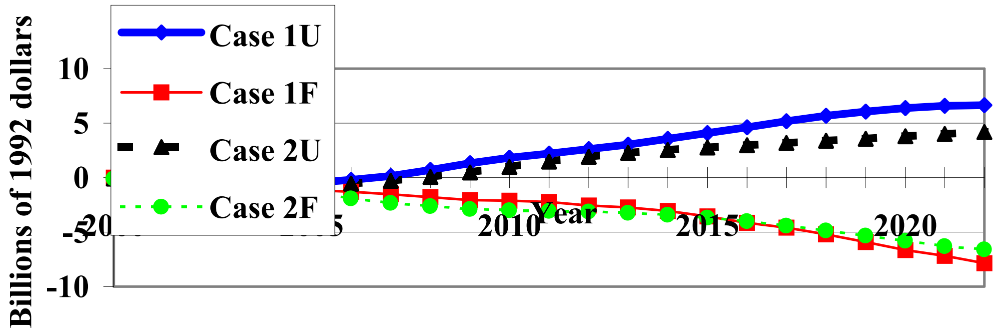

FIGURE 5.4 Balance of Payments: Cumulative Change over Base Case

Case 1F: Among the CD engine scenarios, trade balance is least favorable under Case 1F (High Case, Foreign Dominance). Table A.2 shows estimated net import revenues from light trucks with CD engines between 2000 and 2022. As imports of light trucks with CD engines rise, the trade remains a drag on the economy throughout the projection period. On a cumulative basis, the balance of payments deteriorates by $\$7.9 \times 10^9$ with respect to Base Case levels during the 2000-2022 period.

Case 2U: Among the CD engine scenarios, the Current Account BOP is second most favorable under Case 2U (CAFE Case, U.S. Dominance). Table A.3 shows estimated net export revenues from light trucks with CD engines between 2000 and 2022. With strong growth in the economy boosting imports, and not enough exports of light trucks to compensate, trade remains a drag on the economy between 2000 and 2007. In subsequent periods, trade adds to the growth of the economy. On a cumulative basis, the balance of payments improves by $\$4.2 \times 10^9$ over Base Case levels during the 2000-2022 period.

Case 2F: Among the CD engine scenarios, trade balance is second least favorable under Case 2F (CAFE Case, Foreign Dominance). Table A.4 shows estimated net import revenues from light trucks with CD engines between 2000 and 2022. With rising imports of light trucks with CD engines, trade remains a drag on the economy throughout the projection period. On a cumulative basis, the balance of payments deteriorates by $\$6.6 \times 10^9$ with respect to the Base Case levels during the 2000-2022 period.

5.2.5 Federal Government Surplus

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

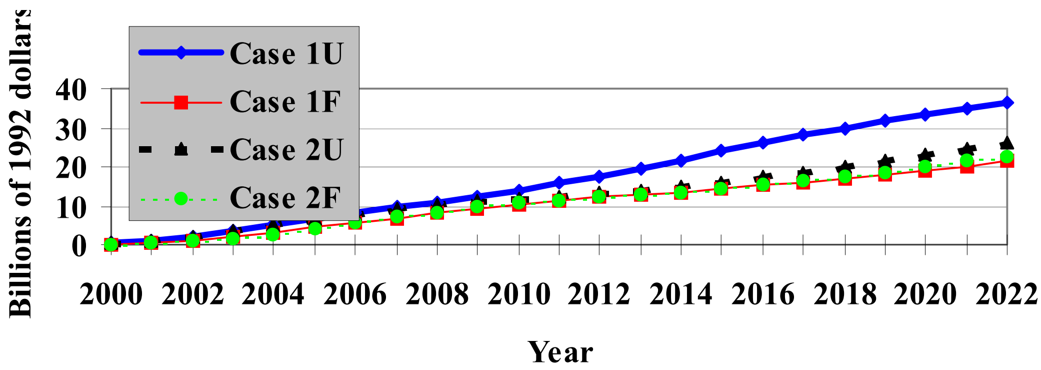

FIGURE 5.5 Federal Government Surplus: Cumulative Change over Base Case

Case 1U: Out of all the CD engine scenarios, the federal government surplus is most favorable under Case 1U (High Case, U.S. Dominance). As real GDP rises, the budget surplus compared to the Base Case jumps from $\$0.4 \times 10^9$ in 2000 to $\$1.6 \times 10^9$ in 2004, the peak year of GDP growth. In subsequent periods of rising real GDP, the surplus remains in the range of $\$1.4 \times 10^9$ to $\$2.2 \times 10^9$. On a cumulative basis, the federal budget improves by $\$36.4 \times 10^9$ over Base Case levels during the 2000-2022 period.

Case 1F: Among the CD engine scenarios, the federal government surplus is least favorable under Case 1F (High Case, Foreign Dominance). Compared to the Base Case, the surplus steadily rises from $\$0.1 \times 10^9$ in 2000 to $\$1.3 \times 10^9$ in 2005, the peak year for GDP growth. As the real extra GDP narrows, the surplus over the Base Case also narrows, to $\$0.6 \times 10^9$ by 2013. With a rebound in real GDP in subsequent periods, the surplus remains in the range of $\$0.7 \times 10^9$ to $\$1.3 \times 10^9$. On a cumulative basis, the federal budget improves by $\$21.5 \times 10^9$ over Base Case levels during the 2000-2022 period.

Case 2U: Among the CD engine scenarios, the Current Account BOP is second most favorable under Case 2U (CAFE Case, U.S. Dominance). As real GDP rises, the budget surplus compared to the Base Case jumps from $\$0.4 \times 10^9$ in 2000 to $\$1.6 \times 10^9$ in 2005, one year after the peak year of GDP growth. In subsequent periods of rising real GDP, the surplus remains in the range of $\$0.6 \times 10^9$ to $\$1.5 \times 10^9$. On a cumulative basis, the federal budget improves by $\$26.2 \times 10^9$ over Base Case levels during the 2000-2022 period.

Case 2F: Among the CD engine scenarios, budget surplus is third most favorable under Case 2F (CAFE Case, Foreign Dominance). As compared to the Base Case, the surplus steadily rises from $\$0.1 \times 10^9$ in 2000 to a peak of $\$1.5 \times 10^9$ in 2007, one year after the peak year for real GDP. As real extra GDP narrows, the surplus over the Base Case also narrows, to $\$0.7 \times 10^9$ by 2013. With a rebound in real GDP in subsequent periods, the surplus remains in a range of $\$0.7 \times 10^9$ to $\$1.4 \times 10^9$. On a cumulative basis, the federal budget improves by $\$22.5 \times 10^9$ over Base Case levels during the 2000-2022 period.

6 CONCLUSIONS

On the basis of results presented in Sections 5.2 and 5.3, 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. U.S. dominance of CD engine technology under the high market penetration case maximizes the economic benefits. In that case, the cumulative extra GDP over the Base Case could be as high as $56 billion during the 2000-2022 period. In addition, on a cumulative basis, about 250,000 man-years of work could be added to the total civilian employment base, and the federal government budget surplus could improve by about $36 billion. This case is to be considered as an upper boundary for the CD engine's market penetration, under the most favorable outlook for the U.S. automotive engine/truck industry in developing the clean engine.

In this study, the economic effects are estimated within the theoretical framework of a leading macroeconomic model, thus ensuring the reliability of the results. Another significance aspect of the research is to present and analyze a strategy that will reduce light trucks' CAFE shortfalls through adoption of the engine.

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

Some limitations of our research and the appropriate corrective actions are noted here. Several assumptions had to be made, so the results of this analysis must be viewed as preliminary. The methodology for estimating CD market penetration was based on historical French experience of diesel engines' market penetration in motor vehicles. If a more comprehensive CD market penetration model were to be developed, incorporating technical, economic, and market factors related to competing engines, the results of this study could be verified by using that model.

The results of this study should be of interest to government decision makers, such as DOE OHVT, in deciding on the extent of their support for developing this engine. In addition, the methodology and results of this research should be useful to other energy policymakers, researchers, and academicians.

7 REFERENCES

AAMA: See American Automobile Manufacturers Association.

American Automobile Manufacturers Association, 1997, *Motor Vehicle Facts & Figures: 1997*, Detroit, Mich., pp. 48-51.

Blackman, A.W., 1974, "The Market Dynamics of Technological Substitutions," *Technological Forecasting and Social Change* **6:**41-63.

Cummins, A., 1998, "Diesel Vehicles, in Greener Mode, May Stage Comeback," Wall Street Journal, New York, N.Y., April 9.

Davis, S.C., 1997, *Transportation Energy Data Book: Edition 17,* Oak Ridge National Laboratory Report ORNL-6819, Oak Ridge, Tenn.

DRI: See Standard and Poor's Data Resources, Inc.

Eckstein, O., 1981, *Core Inflation*, Prentice-Hall, Inc., N.J., pp. 97-99.

EIA: See U.S. Department of Energy/Energy Information Administration.

EPA: See U.S. Environmental Protection Agency.

Mansfield, E., 1961, "Technical Change and Rate of Imitation," *Econometrica* **29:**741-765.

Mateja, J., 1998, "V-6 Diesel a Tall Order for Navistar," Chicago Tribune, Sec. 3, p.4, Chicago, Ill., March 13.

McGraw-Hill, 1997, *SHAZAM Econometric Computer Program: User's Reference Manual, Version 8.0.*

Paul, R.A., 1979, *The Impact of Future Diesel Emissions on the Air Quality of Large Cities,* U.S. Environmental Protection Agency Report EPA-45075-79-005, Research Triangle Park, N.C.

Santini, D.J., 1989, "Interactions Among Transportation Fuel Substitution, Vehicle Quantity Growth, and National Economic Growth", *Transportation Research Part A*, Vol. 23, No. 3, pp. 183-207.

Standard & Poor's Data Resources, Inc., 1998, "Slowing Growth and Rising Deficits: The Trend Projection," *Review of the U.S. Economy: Long Range Focus Fall-Winter 1997-1998,* Lexington, Mass., Feb.

Standard and Poor's Data Resources, Inc., 1993, *Energy Review Spring-Summer 1993*, p. 75, Lexington, Mass.

Standard and Poor's Data Resources, Inc., 1983, *U.S. Long-Term Review-Winter 1982-83*, p. 11.11, Lexington, Mass.

Teotia, A.P.S., and Raju, P.S., 1986, "Forecasting the Market Penetration of New Technologies Using a Combination of Economic Cost and Diffusion Models," *Journal of Product Innovation and Management* **4:**225-237.

Tompkins, M., et al., 1998, "Determinants of Alternative Fuel Vehicle Choice in the Continental United States," presented to the Annual Meeting of the Transportation Research Board, Paper No. 980965,Washington, D.C.

U.S. Department of Energy/Energy Information Administration, 1998a, *Annual Energy Outlook 1998*, Worksheet generated from CN6005.PRJ.NEMS.FORTRAN.FTAB. D0722931, Tables 45, 48, 50, 114, Washington, D.C.

U.S. Department of Energy/Energy Information Administration, 1998b, *Annual Energy Outlook 1998*, Report DOE/EIA-0383 (98), Washington, D.C.

U.S. Environmental Protection Agency, Office of Air and Radiation, 1998, *Tier 2 Report to Congress*, Report EPA-420-R-98-008, Washington, D.C.

White, G., 1998, "GM, Isuzu Investing $320 Million to Build Advanced Diesel Engines for GM Pickups," Wall Street Journal, New York, N.Y., Sept. 11.

APPENDIX: CHANGES MADE IN THE DATA RESOURCES, INC., MODEL

As discussed in Section 2.4, the indirect economic impacts of CD engines were estimated by using the DRI model. Prior to solving the DRI model for the period 2000-2022, changes in the selected variables were made under each of the four CD engine 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 1U

We followed a three-step approach for estimating direct annual fuel savings resulting from substitution of gasoline engines by more efficient CD engines in selected categories of light trucks. First, for each year, the stock of CD engines was estimated by adding the number of new CD engines that penetrated in that year, and subtracting the number of engines scrapped in that year, to the previous year's stock value of CD 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 CD engines by multiplying the DOE/EIA projected fuel economy (EIA 1998, Table 50) for light trucks with gasoline engines by a factor of 1.55, as discussed in Section 3 (ANL assumed that a CD engine would have 55% higher fuel economy as compared to a light truck gasoline engine). On the basis of the estimated stock of light trucks with CD engines, average fuel economy for both gasoline and CD engines for a light truck, and average miles traveled by a light truck in a year, light trucks' annual fuel savings in the economy between 2000 and 2022 were estimated (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 CD engines.

The price of a CD engine is expected to exceed that of a gasoline engine. Under this scenario, we assumed that the incremental price of a light truck CD engine over a gasoline engine would be $870 (in constant 1992 dollars) higher in its year of introduction in 2000. The price gap then narrows to $654 by 2010, as CD engine producers are able to realize cost reductions resulting from economies of scale in production. The CD engine price gap then remains at $654 in the subsequent period. The incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of CD trucks sold in the United States; these expenditures were divided equally between 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.

In estimating the net export gains resulting from exports of light trucks with CD engines for each year, two steps were followed. First, the price of an exported light truck with a CD engine was estimated by adding the premium noted above to the DOE/EIA projected price of a

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

Year	Annual Expenditures on Plant ($\$10^6$, 1992 dollars)	Light Truck Consumer and Business Expenditures ($\$10^6$, 1992 dollars)	Light Truck Exports ($\$10^6$, 1992 dollars)	Light Truck Fuel Savings (10^{12} Btu)
2000	376	48	27	1.3
2001	17	86	148	3.7
2002	313	130	231	7.4
2003	13	180	324	12.6
2004	275	234	431	19.4
2005	15	288	536	28.1
2006	16	344	651	39.0
2007	15	396	763	51.6
2008	17	454	893	66.8
2009	126	506	1016	84.2
2010	18	560	1152	103.3
2011	130	634	1309	124.7
2012	20	712	1468	148.7
2013	130	794	1633	174.6
2014	23	880	1815	203.0
2015	132	966	1999	233.9
2016	126	1026	2139	265.0
2017	14	1086	2257	298.1
2018	10	1132	2342	330.3
2019	115	1162	2399	359.3
2020	4	1174	2437	395.4
2021	6	1186	2461	425.8
2022	127	1194	2477	455.1

new light gasoline truck (EIA 1998, Table 114). Second, the gain in value of additional exports of light trucks with CD engines was estimated by multiplying the exported units (Sec. 3.1.3) by the above estimated average price. We further assumed that 50% of exports of the advanced diesel light trucks would substitute for gasoline light trucks. The value of lost exports of gasoline light trucks was estimated by multiplying the lost export units by their average price. Table A.1 shows net gains in the value of exports of light trucks between 2000 and 2022. Exports of automotive vehicles and parts, a variable in the DRI model, was adjusted upward to reflect an increased export level of light trucks.

In estimating additional capital expenditures on engine/light truck manufacturing plants, it was assumed that, for competitive reasons, one CD engine plant with a capacity of 300×10^3 units and a life of 20 years would be introduced initially in 2000, 2002, and 2004 by one of the domestic 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. To meet the total domestic and export demand for CD engines, producers of engines/light trucks are projected to build one new plant of the above size in 2009, 2011, 2013, 2015, 2016, 2019, and 2022. The construction cost of either a 300×10^3 unit CD engine plant or a 400×10^3 unit gasoline engine plant was assumed to be $\$435 \times 10^6$ (constant 1992 dollars). While estimating the incremental capital expenditures, a credit was given for the cost of any avoided gasoline plant. In addition, we also estimated any incremental capital expenditure on plants for manufacturing additional light trucks with a CD engine for exports. The investment on non-engine plants was estimated to be only a fraction of the investment on engine plants, because only a small fraction of CD engines produced were required for export. Table A.1 shows estimated values for incremental capital expenditures on manufacturing plants between 2000 and 2022. 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 CASE 1F

Argonne followed a three-step approach for estimating direct annual fuel savings resulting from substitution of gasoline engines by more efficient CD engines in selected categories of light trucks. First, for each year, the stock of CD engines was estimated by adding the number of new CD engines that penetrated the market in that year, and subtracting the number of engines scrapped in that year, to the previous year's stock value of CD engines. Survival rates for light trucks were as specified by ORNL (1996). Second, the fuel economy (mi/gal) of light trucks with CD engines was estimated by multiplying the DOE/EIA projected fuel economy (EIA 1998, Table 50) of light trucks with gasoline engines by a factor of 1.55, discussed in Section 3 (ANL assumed that a CD engine would have 55% higher fuel economy than a light truck gasoline engine). On the basis of the estimated stock of light trucks with CD engines, average fuel economy for both gasoline and CD engines for light trucks, and average miles traveled by a light truck in a year, we estimated light trucks' annual fuel savings in the economy between 2000 and 2022 (Table A.2). 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 CD engines:

The price of a CD engine is expected to exceed that of a gasoline engine. Under this scenario, the incremental price of a light truck CD engine over a gasoline engine was assumed to be $870 (in constant 1992 dollars) higher in its year of introduction in 2000. The price gap then narrows to $654 by 2010, as CD engine producers realize cost reductions resulting from economies of scale in production. The CD engine price gap remains at $654 in the subsequent period. Incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of CD trucks sold in the United States. These expenditures were divided equally between consumers and businesses. Real consumer and business expenditures on

TABLE A.2 Assumed Annual Changes in Capital Expenditures on Plant, Light-Truck Expenditures, Imports, and Fuel Savings for Case 1F

Year	Annual Expenditures on Plant ($$10^6$, 1992 dollars)	Light Truck Consumer and Business Expenditures ($$10^6$, 1992 dollars)	Light Truck Exports ($$10^6$, 1992 dollars)	Light Truck Fuel Savings (10^{12} Btu)
2000	0	48	48	1.3
2001	0	86	86	3.7
2002	0	130	130	7.4
2003	0	180	180	12.6
2004	0	234	234	19.4
2005	0	288	288	28.1
2006	-436	344	344	39.0
2007	0	396	396	51.6
2008	0	454	454	66.8
2009	0	506	506	84.2
2010	-436	560	560	103.3
2011	0	634	634	124.7
2012	0	712	712	148.7
2013	-436	794	794	174.6
2014	0	880	880	203.0
2015	0	966	966	233.9
2016	0	1026	1026	265.0
2017	-436	1086	1086	298.1
2018	0	1132	1132	330.3
2019	0	1162	1162	359.3
2020	0	1174	1174	395.4
2021	0	1186	1186	425.8
2022	0	1194	1194	455.1

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.

Net import gains resulting from imports of CD engines were assumed to be equal to the above estimated incremental consumer and business expenditures on light trucks. Table A.2 shows net gains in the value of imports of light trucks between 2000 and 2022. Imports of automotive vehicles and parts, a variable in the DRI model, was adjusted upward to reflect an increased level of imports for CD engines.

In estimating reduced capital expenditures on engine/light truck manufacturing plants, it was assumed that all required CD engines would be imported by U.S. manufacturers; as a result, construction of new gasoline engine plants with production capacity of 400×10^3 units in the

400×10^3 unit gasoline-engine plant was assumed to be $\$435 \times 10^6$ (constant 1992 dollars). Table A.2 shows estimated values of reduced capital expenditures on manufacturing plants between 2000 and 2022. The plant investment in the DRI model was adjusted downward to reflect reduced levels of capital expenditures on engine/truck plant investment.

A.3 CHANGES MADE TO DRI MODEL FOR CASE 2U

We followed a three-step approach in estimating direct annual fuel savings resulting from substitution of gasoline engines by more efficient CD engines in selected categories of light trucks. First, for each year, the stock of CD engines was estimated by adding the number of new CD 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 CD engines. Survival rates for light trucks were as specified by ORNL (1996). Second, the fuel economy (miles per gallon) of light trucks with CD engines was estimated by multiplying the DOE/EIA projected fuel economy (EIA 1998, Table 50) of light trucks with gasoline engines by a factor of 1.55, discussed in Section 3 (it was assumed that a CD engine would have 55% higher fuel economy than a light truck gasoline engine). On the basis of the estimated stock of light trucks with CD engines, average fuel economy for both gasoline and CD engines for a light truck, and average miles traveled by a light truck in a year, we estimated light trucks' annual fuel savings in the economy between 2000 and 2022 (Table A.3). 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 CD engines.

The price of a CD engine is expected to exceed that of a gasoline engine. Under this scenario, the incremental price gap between a light truck CD engine and a gasoline engine was assumed to be $870 (in constant 1992 dollars) in 2000. The price gap narrows to $654 by 2010, as CD engine producers realize cost reductions resulting from economies of scale, and it remains at this level in the subsequent period. Incremental expenditures on light trucks, estimated by multiplying the incremental price by the number of CD trucks sold in the United States, were divided equally between 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.

To estimate net export gains from diesel light trucks, two steps were followed. First, the average price of an exported light truck with a CD engine was estimated by adding the premium stated above to the DOE/EIA projected price of a new light gasoline truck (EIA 1998, Table 114). Second, we estimated the gain in value of additional exports of diesel light trucks 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

TABLE A.3 Assumed Annual Changes in Capital Expenditures on Plant, Light-Truck Expenditures, Exports, and Fuel Savings for Case 2U

Year	Annual Expenditures on Plant ($\$10^6$, 1992 dollars)	Light Truck Consumer and Business Expenditures ($\$10^6$, 1992 dollars)	Light Truck Exports ($\$10^6$, 1992 dollars)	Light Truck Fuel Savings (10^{12} Btu)
2000	327	88	14	2.4
2001	17	166	131	7.0
2002	212	244	196	13.9
2003	9	316	258	23.0
2004	214	386	323	34.3
2005	7	448	378	47.9
2006	4	478	408	62.9
2007	2	486	424	78.3
2008	110	490	436	94.5
2009	1	488	443	111.0
2010	0	480	447	126.7
2011	0	484	452	142.0
2012	0	490	456	157.0
2013	0	492	459	171.1
2014	0	494	461	184.5
2015	0	498	466	197.5
2016	0	496	468	208.8
2017	0	500	470	220.1
2018	0	504	472	229.8
2019	0	508	474	236.9
2020	0	506	476	248.5
2021	2	508	478	256.5
2022	126	512	480	264.0

lost export units by the gasoline truck's average price. Table A.3 shows net gains in the value of exports of light trucks between 2000 and 2022. Exports of automotive vehicles and parts, available in the DRI model, was adjusted upward to reflect the increased export level for light trucks.

To estimate additional capital expenditures, we assumed that one CD engine plant with an annual capacity of 300,000 units and a life of 20 years would be introduced initially in 2000, 2002, and 2004 by one of the domestic automobile/truck manufacturers for competitive reasons. Subsequently, new engine capacity was assumed to be added whenever plant utilization exceeded the 80% level. To meet the total demand for CD engines, engine/truck producers are projected to build one new plant of the size described above in 2008 and 2022. The construction cost of either a 300,000-unit/yr CD engine plant or a 400,000-unit/yr gasoline engine plant was assumed to be $435 million. In estimating the incremental capital expenditures, a credit was given for the cost of avoided gasoline plants. In addition, we also estimated incremental capital expenditures on plants for manufacturing additional diesel light trucks for export. The investment on non-engine plants was estimated to be only a fraction of investment on engine plants, because only a small fraction of CD engines were required for exports. Table A.3 shows estimated values for incremental capital expenditures on manufacturing plants between 2000 and 2022. The plant investment in the DRI model was adjusted upward to reflect an increased level of capital expenditures on engine/vehicle plant investment.

A.4 CHANGES MADE TO DRI MODEL FOR CASE 2F

Argonne followed a three-step approach in estimating direct annual fuel savings resulting from substitution of gasoline engines by more efficient CD engines in selected categories of light trucks. First, for each year, the stock of CD engines was estimated by adding the number of new CD engines that penetrated the market in that year, and subtracting the number of engines scrapped in that year, to the previous year's stock value of CD engines. Survival rates for light trucks were as specified by ORNL (1996). Second, we estimated the fuel economy (miles per gallon) of light trucks with CD engines by multiplying the DOE/EIA projected fuel economy (EIA 1998, Table 50) of light trucks with gasoline engines by a factor of 1.55, discussed in Section 3 (it was assumed that a CD engine would have a 55% higher fuel economy than a light truck gasoline engine). On the basis of the estimated stock of light trucks with CD engines, average fuel economy for both gasoline and CD engines for a light truck, and average miles traveled by a light truck in a year, light trucks' annual fuel savings in the economy between 2000 and 2022 were estimated (Table A.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 CD engines.

The price of a CD engine is expected to exceed that of a gasoline engine. Under this scenario, the incremental price of a light truck CD engine over a gasoline engine was assumed to be $870 (in constant 1992 dollars) higher in its year of introduction in 2000. The price gap then narrows to $654 by 2010, as CD engine producers realize cost reductions resulting from economies of scale in production. The CD engine price gap remains at $654 in the subsequent period. Incremental expenditures on light trucks were estimated by multiplying the incremental price by the number of CD trucks sold in the United States. The incremental expenditures were divided equally between 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.

Net import gains resulting from imports of CD engines were assumed to be equal to the incremental consumer and business expenditures on light trucks estimated above. Table A.4 shows net gains in the value of imports of light trucks between 2000 and 2022. Imports of automotive vehicles and parts, a variable in the DRI model, was adjusted upward to reflect the increased level of imports of CD engines.

To estimate reduced capital expenditures on engine/light truck manufacturing plants, we assumed that all required CD engines would be imported by U.S. manufacturers; as a result, domestic construction in 2003 and 2022 of a new gasoline engine plant with production capacity of 400,000 unit/yr would be avoided. The avoided construction cost of a 400,000-unit/yr gasoline engine plant was assumed to be $435 million. Table A.4 shows estimated values of reduced capital expenditures on manufacturing plants between 2000 and 2022. The plant investment in the DRI model was adjusted downward to reflect reduced levels of capital expenditures on engine/truck plant investment.

TABLE A.4 Assumed Annual Changes in Capital Expenditures on Plant, Light-Truck Expenditures, Imports, and Fuel Savings for Case 2F

Year	Annual Expenditures on Plant ($\$10^6$, 1992 dollars)	Light Truck Consumer and Business Expenditures ($\$10^6$, 1992 dollars)	Light Truck Exports ($\$10^6$, 1992 dollars)	Light Truck Fuel Savings (10^{12} Btu)
2000	0	88	88	2.4
2001	0	166	166	7.0
2002	0	244	244	13.9
2003	-436	316	316	23.0
2004	0	386	386	34.3
2005	0	448	448	47.9
2006	0	478	478	62.9
2007	0	486	486	78.3
2008	0	490	490	94.5
2009	0	488	488	111.0
2010	0	480	480	126.7
2011	0	484	484	142.0
2012	0	490	490	157.0
2013	0	492	492	171.1
2014	0	494	494	184.5
2015	0	498	498	197.5
2016	0	496	496	208.8
2017	0	500	500	220.1
2018	0	504	504	229.8
2019	0	508	508	236.9
2020	0	506	506	248.5
2021	0	508	508	256.5
2022	-436	512	512	264.0

A.5 REFERENCES CITED IN APPENDIX

EIA 1998: *Annual Energy Outlook 1998,* 1998 Worksheet generated from CN 6005.PRJ.NEMS.FORTRAN.FTAB.D0722931, Tables 45, 48, 50, and 114, U.S. Department of Energy, Energy Information Administration, Washington, D.C.

ORNL 1996: *Transportation Energy Data Book: Edition 16,* 1996, Oak Ridge National Laboratory Report ORNL-6898, Oak Ridge, Tenn., pp. 3-9, July.