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Multiyear Program Plan for 1998-2002

Office of Heavy Vehicle Technologies and Heavy Vehicle Industry Partners

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Foreword

This Multiyear Program Plan for the Office of Heavy Vehicle Technologies (OHVT) has been prepared based on the OHVT Technology Roadmap, DOE/OSTI-11690, October 1997. The multiyear plan was authored by members of DOE OHVT and national laboratories, and was reviewed by major industry stakeholders. This is the initial multiyear plan for OHVT, set in motion through an industry/government workshop held in April 1996 shortly after the OHVT was created.

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The review and comments by representatives of the **heavy vehicle manufacturers, engine manufacturers, heavy vehicle users, trade associations and other laboratories** were of utmost importance and are also recognized.

Dr. James J. Eberhardt
Director, Office of Heavy Vehicle Technologies

Table of Contents

Page

I. EXECUTIVE SUMMARY 1

II. INTRODUCTION 5

III. NATIONAL NEED - Efficiency, Environment, Competitiveness 9
- *A. FUEL USE TRENDS - Trucks Rival Automobiles in Fuel Use* 9
- *B. LIGHT TRUCK/VEHICLE MARKET TRENDS* 10
- *C. INTERNATIONAL COMPETITION (ECONOMICS)* 11
- *D. ENVIRONMENTAL SITUATION - Diesels Already Cleaner on Most Key Pollutants - More Work Needed on NOx and PM* 12
- *E. OHVT STRATEGY AND RESPONSE TO NATIONAL NEED - Diesels for Light Trucks, and More Efficient, Fuel Flexible Engines for Heavy Trucks* 13
- *F. LEGISLATIVE DRIVERS* 14

IV. PROGRAM BENEFITS 15
- A. *INCREASED ENERGY EFFICIENCY AND REDUCED OIL IMPORTS* . . 15
- *B. CLEANER AIR* 16
- *C. REDUCED GREENHOUSE GASES* 18
- *D. MAINTAIN AND IMPROVE OUR INTERNATIONAL COMPETITIVE POSITION* 18
- *E. OTHER BENEFITS REALIZED FROM MULTIPLE USE TECHNOLOGY ADVANCES* 19

V. TECHNICAL PLAN 21
- *A. GOAL 1. DIESEL ENGINE TECHNOLOGY FOR LIGHT TRUCKS AND SPORT UTILITY VEHICLES-35 PERCENT FUEL EFFICIENCY IMPROVEMENT* 23
  - 1. Status of Technology 23
  - 2. Technical Targets 24
  - 3. Barriers 25
  - 4. Technical Approach 27
- *B. GOAL 2. CLASS 7-8 10 MPG TRUCK @65 MPH, A 40 PERCENT IMPROVEMENT OVER COMMERCIAL TECHNOLOGY* 27
  - 1. Engine Requirements for 10 mpg Truck 28
    - a. Status of Technology 28
    - b. Technical Targets 31
    - c. Barriers 31
    - d. Technical Approach 32

Page

  - 2. Vehicle System Technology for 10 mpg Truck 33

a. Status of Technology 33
b. Technical Targets 34
c. Barriers 34
d. Technical Approach 35
C. GOAL 3. FUEL FLEXIBILITY FOR CLASS 3-8 TRUCKS 35
1. Class 3-8 Trucks 35
a. Status of Technology 36
b. Technical Targets and Barriers 36
c. Technical Approach 37
2. Fuel Flexibility for Class 1,2 Trucks 38
a. Status of Technology 38
b. Technical Targets and Barriers 38
c. Technical Approach 38
D. INCREASED EFFICIENCY AND REDUCED EMISSIONS IN CLASS 3-6 39
1. Background 39
2. Goal for Class 3-6 Trucks 40
3. Status of Technology 40
4. Approach 40
E. ENABLING TECHNOLOGIES 40
1. Combustion Technology 41
2. Exhaust Aftertreatment 41
3. Fuels 42
4. Materials 43
a. High Efficiency Engines 43
b. Emission Control 43
c. Fuel Flexible Engines 43
d. Other Applications 44
5. Natural Gas Storage 44
6. Environmental Issues of Heavy Vehicles 44

VI. IMPLEMENTATION PLAN 47
A. MANAGEMENT PLAN 47
1. Program Management 47
2. Performance Plans and Reporting 49
B. GOVERNMENT/INDUSTRY COORDINATION 49
C. INTRA- AND INTER-AGENCY COORDINATION 50
D. TECHNOLOGY TRANSFER 51

VII. RESOURCE PLAN/REQUIREMENTS 53

APPENDIX A 55

I. EXECUTIVE SUMMARY

The Office of Heavy Vehicle Technologies (OHVT) envisions the development of a fuel-flexible, energy efficient, near-zero emissions heavy-duty U.S. diesel engine technology devolving into all truck classes as a real and viable strategy for reducing energy requirements for commercial transport services and the rapidly growing multi-purpose vehicle market [pickups, vans, and sport utility vehicles (SUVs)].

Implementation of the OHVT program plan will have significant national benefits in energy savings, cleaner air, more jobs, and increased gross domestic product (GDP). Successful implementation will reduce the petroleum consumption of Class 1-8 trucks by 1.4 million barrels of oil per day by 2020 and over 1.8 million by 2030, amounting to a reduction in highway petroleum consumption of 13.2 percent and 18.6 percent respectively. All types of regulated emissions will be reduced: 20 percent drop in PM10 emissions (41,000 metric tonnes per year) by the year 2030, 17 percent reduction in CO_2 greenhouse gases (205 million tonnes per year), 7 percent reduction in NOx, 20 percent reduction in NMHC, and 30 percent reduction in CO. An increase of 15,000 jobs by 2020 is expected, and an increase of $24 billion in GDP.

The strategy of OHVT is to focus on the diesel engine. The diesel engine has numerous advantages: the highest efficiency of any engine today, 45 percent efficient versus 30 percent for production gasoline engines and can be made more efficient, 55 percent, possibly up to 63 percent; the engine of choice for heavy vehicles (trucks), and offers power, efficiency, durability, and reliability; extensive applications in rail, marine, and off-road vehicles; a production infrastructure in place; and can be ultra-low to near zero in emissions.

Participation and input from OHVT's customers were solicited early in the planning process through a series of customer-focused workshops to identify the critical R&D needs and define the R&D thrusts to meet those needs. In addition, the program managers have been conducting continuous consultation with industry, institutions of higher education, DOE national laboratories, and professional and technical societies in developing a comprehensive approach to deploying advanced heavy vehicle technologies into the transportation sector. Results from these customer outreach activities have been incorporated in the **Heavy Vehicle Technologies Roadmap (DOE/OSTI-11690, October 1997),** and specific R&D activities have been identified and are now outlined in this Multi-Year Plan.

The primary goals of the OHVT are as follows:

- Develop by 2002 the diesel engine enabling technologies to support large-scale industry dieselization of light trucks, achieving a 35 percent fuel efficiency improvement over equivalent gasoline-fueled trucks, and bettering applicable emissions standards,

- Develop by 2004 the enabling technology for a class 7-8 truck with a fuel efficiency of 10 mpg (at 65 mph) which will meet prevailing emission standards, using either diesel or a liquid alternative fuel,

- Develop by 2006 diesel engines with fuel flexibility and a thermal efficiency of 55 percent with liquid alternative fuels, and a thermal efficiency of 55 percent with dedicated gaseous fuels,
- By 2005, develop advanced powertrain technology for medium/heavy-duty trucks that achieve three times today's fuel economy (up to 30 mpg), and as a research goal, reduce criteria pollutant emissions to 30% below proposed regulated levels.

The OHVT Advanced Heavy Vehicle Technologies research and development (R&D) program has the following two-pronged approach:

(1) A partnership with the domestic transportation industry, energy supply industry, other federal agencies, and research and development organizations to develop high-efficiency engine technologies and alternative fuel utilization technologies for trucks and promote their acceptance. The technologies that were determined to have the greatest market applications and thus fuel savings are:

- Diesel for light trucks and sport utility vehicles
- Advanced diesel for class 3-8 trucks with enhanced fuel flexibility
- Improved near-term natural gas engine for buses and trucks
- Advanced natural gas engine with diesel-equivalent efficiency

(2) Continuing development of key enabling technologies to ensure market success:

- Exhaust Aftertreatment
- Materials
- Fuels
- Combustion
- Natural gas storage
- Environmental effects

These enabling technologies will be coordinated through a diesel cross-cut team that has linked diesel R&D in the OHVT and Partnership for a New Generation of Vehicles (PNGV).

Management of the Heavy Vehicle Technologies R&D Program is the responsibility of the Director of the OHVT, who reports to the Deputy Assistant Secretary for Transportation Technologies. Project selection is based on priorities as established by the Technical Roadmap and Steering committee and available budget. Planning and R&D implementation are closely coordinated with related activities within DOE and with other agencies that are sponsoring work in Heavy Vehicle Technologies. Research and development projects are placed through procurements and non-procurement mechanisms with industry, academia, independent researchers, and national laboratories.

The Heavy Vehicle Technologies Program supports the R&D of advanced technologies directly with engine and vehicle manufacturers and fuel developers and producers in order to insure the

technologies are transferred to appropriate customers who are ultimately responsible for commercializing the end products.

Wide dissemination of results from DOE-sponsored R&D is also accomplished through licensing of patented technologies, publications in technical and trade journals, presentations at technical society meetings, workshops, and contractor coordination meetings. Program review meetings provide a particularly effective means of exchanging information within the program. These forums allow direct interaction between the federal laboratories and industry researchers, facilitate the building of collaborative relationships, and promote technology transfer.

II. INTRODUCTION

How This Program Was Developed

The foundation of the Office of Heavy Vehicle Technologies Multiyear Plan is the Strategic Plan for the Department of Energy (DOE) Office of Transportation Technologies (OTT) published in August of 1996. The Strategic Plan addresses the energy, economic, and environmental challenges in meeting the future demand for transportation goods and services, in order to achieve its vision that "within the first decade of the twenty-first century, the United States will turn the corner in the growth of petroleum use for highway transportation." In particular, energy use by heavy vehicles (trucks and other commercial transport) is growing and at a faster rate than automobiles. Annual fuel use by trucks of all classes exceeded fuel use by passenger cars around 1995.

Hence, as an important component of OTT's strategy, the OHVT was created by the OTT organizational restructuring in March 1996. The mission of OHVT is to conduct, in collaboration with heavy vehicle industry partners and their suppliers, a customer-focused national program to research and develop technologies that will enable trucks and other heavy vehicles to fully exploit the energy efficiency and alternative fuel capabilities of the diesel engine while simultaneously reducing emissions.

At the initiation of the planning process, DOE's heavy vehicle industry customers, including truck and bus manufacturers, diesel engine manufacturers, fuel producers, suppliers to these industries, and the trucking industry were called together by OHVT in a workshop to elicit input in April 1996. As recommended by the participants in the workshop, a Technology Roadmap was developed as a first step in crafting a common vision for a government and industry R&D partnership. OHVT formed a team of DOE and national laboratories: Oak Ridge National Laboratory (ORNL), National Renewable Energy Laboratory (NREL), Sandia National Laboratory (SNL), and Argonne National Laboratory (ANL) planners to develop the roadmap. The approach to the roadmap was to:

- Formulate goals consistent with the OTT strategic plan,
- Assess the status of the technology,
- Identify technical targets,
- Identify barriers to achieving the technical targets,
- Develop an approach to overcoming the barriers, and
- Develop schedules and milestones.

The OHVT Technology Roadmap was reviewed by industry stakeholders, who provided comments at a second workshop held October 15, 1996, in conjunction with the Society of Automotive Engineers International Truck and Bus Meeting.

Seven additional targeted workshops were held with industry stakeholders to provide input to the program plan; including focus on:

- Alternative Fuels, November 21–22, 1996
- Natural Gas Engines, January 14–15, 1997
- Fuels and Engines Policies and Directions, April 1997
- Truck Aerodynamics, January 30–31, 1997
- Diesel Engine Emission reduction, July 1997

The present multiyear program plan, documented herein, follows as a natural progression and incorporates the technical input from the industry workshops and the technology roadmap.

Program Goals

The primary goals of the OHVT are as follows:

- Develop by 2002 the diesel engine enabling technologies to support large-scale industry dieselization of light trucks, achieving a 35 percent fuel efficiency* improvement over equivalent gasoline-fueled trucks, and bettering applicable emissions standards,
- Develop by 2004 the enabling technology for a class 7-8 truck with a fuel efficiency of 10 mpg (at 65 mph) which will meet prevailing emission standards, using either diesel or a liquid alternative fuel,
- Develop by 2006 diesel engines with fuel flexibility and a thermal efficiency of 55 percent with liquid alternative fuels, and a thermal efficiency of 55 percent with dedicated gaseous fuels, and
- By 2005, develop advanced powertrain technology for medium/heavy-duty trucks that achieve three times today's fuel economy (up to 30 mpg), and as a research goal, reduce criteria pollutant emissions to 30% below proposed regulated levels.

Program Strategy

The strategy of OHVT for meeting the vision of the Office of Transportation Technologies is to focus on the diesel engine. The diesel engine:

- Has the highest efficiency of any engine today, 45 percent efficient versus 30 percent for production gasoline engines,
- Can be made more efficient , 55 percent, possibly up to 63 percent,
- Is the engine of choice for heavy vehicles (trucks), and offers power, efficiency, durability, and reliability,
- Has extensive applications in rail, marine, and off-road vehicles,
- Has a production infrastructure in place, and
- Can be ultra-low to near zero in emissions.

*Which translates to 50 percent increase in miles per gallon due also to diesel fuel higher energy content per gallon.

Program Approach

The OHVT Advanced Heavy Vehicle Technologies R&D program has the following two-pronged approach:

(1) A partnership with the domestic transportation industry, energy supply industry, other federal agencies, and research and development organizations to develop high-efficiency engine technologies and alternative fuel utilization technologies for trucks and promote their acceptance,

(2) Continuing development of key enabling technologies to ensure market success:

- Exhaust Aftertreatment,
- Materials,
- Fuels,
- Combustion,
- Natural Gas Storage, and
- Environmental Effects.

Three of these enabling technologies, combustion, exhaust afterteatment, and fuels, will be coordinated through a **diesel cross-cut team that has linked diesel R&D in the OHVT and PNGV.**

III. NATIONAL NEED - Efficiency, Environment, and Competitiveness

Trucks, encompassing pickups, sport utility vehicles, and heavy trucks, have become the greatest fuel-consuming vehicles in the transportation sector. This growth is principally due to two factors: (1) the imperative of continuing to transport goods and provide services via heavy trucks, important for economic growth, and (2) the fact that light trucks have become the dominant choice for personal transportation. The growth in use of trucks is outpacing advancement and implementation of fuel efficient technology and alternative fuel use, thereby perpetuating the nation's reliance on imported oil and hindering air quality improvement. The DOE OHVT, in collaboration with the heavy vehicle industry, is supporting research and development of advanced technologies that will enable the United States to effectively address these issues and concerns.

A. FUEL USE TRENDS - Trucks Rival Automobiles in Fuel Use

The transportation sector will continue to be the single largest user of petroleum in the United States as the demand for transportation goods and services continues to grow into the next century. Truck highway energy use is growing and at a faster rate than that of automobiles. Trucks of all classes combined already use more energy than automobiles (Figure 1). For all heavy vehicles (i.e.,all trucks

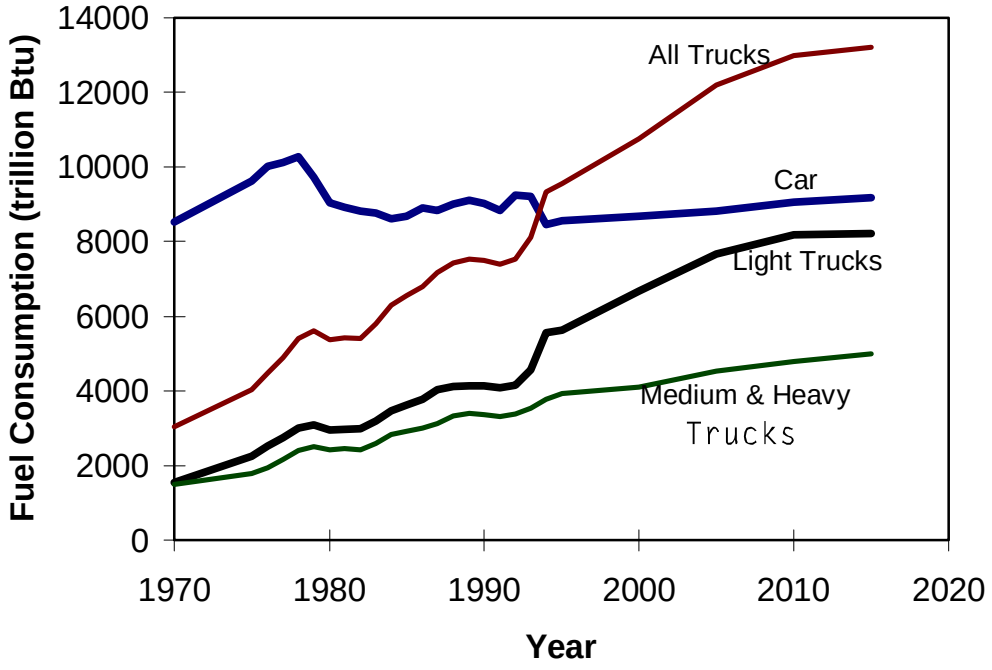

Figure 1. Heavy Vehicles Account for Increasing Highway Transportation Energy Use.

as well as rail, marine, and other off-highway vehicles) energy use by the year 2010 is projected to be as much as 12.5 quads if the current transportation energy use trend continues.

B. LIGHT TRUCK VEHICLE MARKET TRENDS

The increase in truck energy use is due partly to the growth in demand for multi-purpose vehicles (Class 1 and 2 trucks which include pickups, vans, and sport utility vehicles). Sales of multi-purpose vehicles (which predominately use less efficient gasoline engines) have increased dramatically in the past 13 years (see Figure 2) from approximately 3 million vehicles in 1983 to over 6.6 million in 1996 (from 25 percent to over 43 percent of the foreign and domestic sales in the United States). Consequently, the industry is shifting substantial manufacturing emphasis to light trucks.

Sales in the light truck segment is shifting toward the heavier Class 2 trucks, reducing the average fuel economy for this segment. As a result, the U.S. auto manufacturers are having difficulty meeting current light truck CAFÉ standards. Both GM and Chrysler failed to meet the 20.6 mpg standard for the 1995 model year.

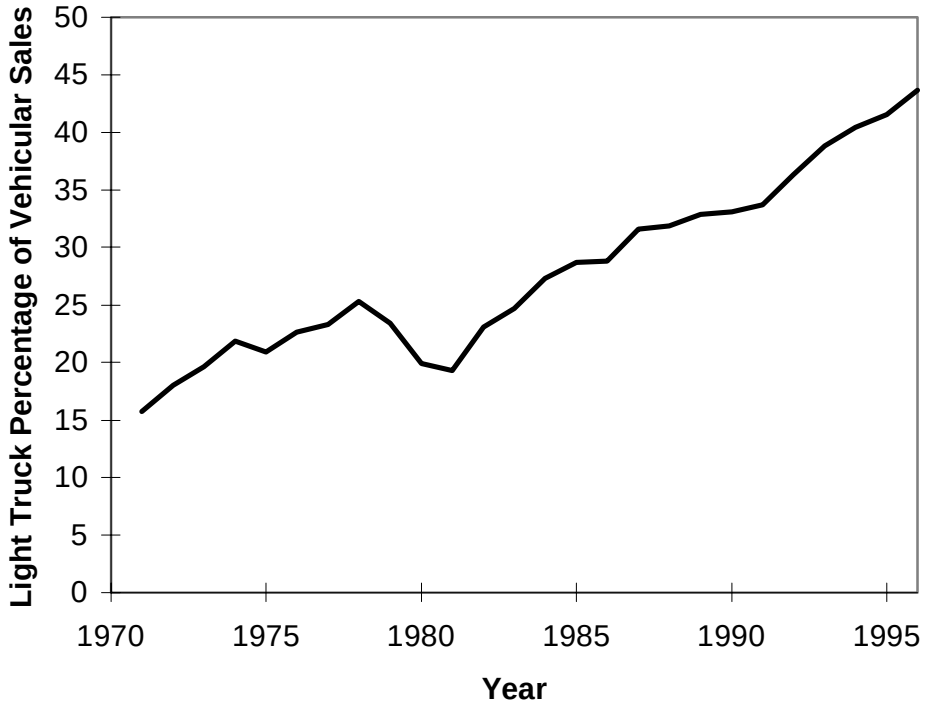

Figure 2. Trends in U.S. Light Truck and Automobile Sales (1970-1995). Light Truck Fraction of Total Vehicle Sales has Steadily Increased Since 1983.

C. INTERNATIONAL COMPETITION (ECONOMICS)

The transportation sector is a major contributor to the growing U.S. trade deficit. Imports of oil, vehicles and motor vehicle parts accounted for 71 percent of the $150 billion trade deficit in 1994. Trucks of all classes contributed $25.7 billion in net oil imports and $5.4 billion in net imports of Class 1–2 trucks (partially offset by $0.1 billion in net exports of Class 3–8 trucks and truck parts).

The health and continued growth of the U.S. economy are dependent on maintaining the energy security and profitability of the trucking industry, now and into the foreseeable future. Trucks are the mainstay for trade/commerce and economic growth. The GDP, and hence, economic activity is linked to freight transport (see Figure 3). Total highway freight transportation expenditures (local and intercity trucks) were over $348 billion, accounting for 79 percent of the Nation's freight bill and approximately 4.8 percent of the GDP (1995). Meeting energy demand for movement of goods is, therefore, critical to the economy.

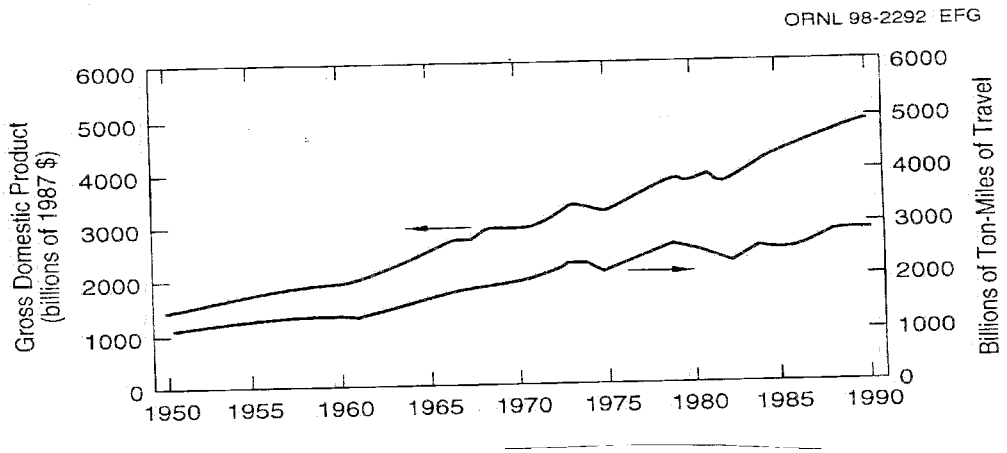

Figure 3. Economy is Linked to Efficient Heavy Vehicle Transportation

The heavy vehicle industry (which includes the trucking industry, truck manufacturers, engine manufacturers, fuel producers, and component suppliers) will need to maintain a dominant role in assuring that the U.S. economy remains healthy. In 1994, the U.S. heavy-duty truck manufacturing industry accounted for nearly $80 billion of the $307 billion motor vehicle shipments.

Over the past several years European companies have purchased many U.S. truck manufacturing companies (Freightliner by Mercedes, GM Heavy Truck by Volvo, Mack by Renault). In 1996, domestic truck manufacturers had less than a 50 percent share of the Class 8 truck market. U.S.

market share is expected to erode further with the recent sale of Ford's heavy truck division to German-owned Freightliner. The U.S. diesel engine manufacturers, in contrast, continue to dominate the North American market for diesel engines used in Class 8 trucks. United States diesel engine manufacturers hold an 87 percent market share in the $3.5 billion per year market.

United States auto manufacturers currently dominate the United States light truck market with a share of 86.4 percent in 1996. With mounting international pressure for the United States to reduce transportation greenhouse gas emissions, the domestic auto makers may lose this market share to foreign competition if the United States is driven towards dieselization of light trucks (which presents an opportunity to decrease CO_2 emissions by 35 percent just by replacing the less-efficient gasoline engines with diesel engines). Currently, European and Japanese manufacturers produce advanced diesel engines for light vehicles that will be able to successfully compete with gasoline engines in performance (yet still need considerable reduction in emissions).

A partnership between the United States diesel engine manufacturers (with their world-recognized expertise in advanced diesel engine technologies) and the United States car manufacturers presents an opportunity for domestic companies to retain the lead in the light truck market (if pressures indeed drive this market to dieselize). Only a small percentage of light trucks in the United States (4.0 percent in 1995) are sold with factory installed diesel engines, mostly supplied by the United States diesel engine manufacturers. These engines are certified for heavy-duty engine emissions standards and need further R&D to meet vehicle emissions standards for light-duty trucks (the current cut-off is at 8500 lbs GVW). In addition, this partnership will provide an opportunity for United States-developed, advanced diesel engine technology to compete successfully in the worldwide market for diesel-powered light trucks and autos, leap-frogging foreign competition and providing benefits much sooner.

D. ENVIRONMENTAL SITUATION - Diesels Already Cleaner on Most Key Pollutants - More Work Needed on NOx and PM

There is a growing national concern about air pollution and increasing levels of greenhouse gases from use of energy in general and recognition that a major contributor to this problem is exhaust emissions from transportation vehicles. The Clean Air Act and introduction of new technologies have reduced emissions per vehicle mile by more than 90 percent since the 1960s but, with an increase in vehicle miles traveled, transportation emissions still remain significant. Under the authority of the Clean Air Act Amendments of 1990, more stringent standards are expected such as the Environmental Protection Agency's (EPA's) Tier II and California's ultra-low emissions vehicle (ULEV) requirements. These standards present serious technical challenges to industry.

High efficiency diesel engines produce low greenhouse gas (CO_2) emissions when running on hydrocarbon fuels. Emissions of carbon monoxide (CO) and unburned hydrocarbons (HC) are also very low, approximately 1/10 of Federal standards. Also, diesel engines have the advantage of near-zero evaporative emissions, low cold-ambient emissions over gasoline engines, and lower upstream (fuel processing and infrastructure) emissions. Since EPA mandated a maximum of 0.05 percent sulfur in diesel fuel, which started in October 1993, SOx emissions have been greatly reduced.

Today's diesel engines, ideal for trucks due to their high efficiency and durability, face challenges in two emissions categories; NOx, and particulate matter (PM). Since 1980, diesel manufacturers have reduced both NOx and PM by over 90 percent, but to penetrate the key fuel-consuming applications, diesel NOx and PM must be reduced by another 70–80 percent. The U. S. diesel manufacturers have agreed to the principle of meeting future emissions standards, and there are indications in laboratory tests that advanced technologies may be able to meet more stringent emissions standards, but the question of cost-competitiveness and time remains.

E. OHVT STRATEGY AND RESPONSE TO NATIONAL NEED - Diesels for Light Trucks, and More Efficient, Fuel Flexible Engines for Heavy Trucks

The OHVT envisions the development of a fuel-flexible, energy efficient, near-zero emissions, heavy-duty United States diesel engine technology evolving into all truck classes as a real and viable strategy for reducing energy requirements for commercial transport services and the rapidly growing multi-purpose vehicle market (pickups, vans, and sport utility vehicles).

This engine-focused strategy has the following key components: (a) to utilize the expertise of the world-class United States Diesel engine manufacturers in developing highly efficient, ultra-low to near-zero emissions diesel engines that will be commercially competitive with gasoline engines in the multi-purpose Class 1 and 2 truck markets, achieving at least 35 percent fuel economy improvement over gasoline-fueled engines and (b) to improve the efficiency of Class 7 and 8 truck Diesel engines to 55 percent or more and improve the capability to utilize alternative fuels, while simultaneously reducing emissions to ultra-low or near-zero levels. Although research to improve natural gas-fueled engines will be supported in the near-term by adopting the diesel (compression ignition) cycle engine as the primary energy conversion system, a diversity-of-feedstocks strategy is possible, where alternative feedstocks such as natural gas, coal, and biomass are cost-effectively converted to fuels appropriate for the diesel engine and dispensed through the existing fueling infrastructure. (The lack of a fuel production and distribution infrastructure has been the most significant barrier to the use of alternative, nonpetroleum-based fuels for commercial transport services.) The OHVT approach, therefore, leads to efficiency improvements that reduce energy demand, as well as extensive displacement of petroleum by indigenous alternative fuel feedstocks to reduce dependence on imported oil. The technical challenges for diesels are formidable but achievable. The perception of diesels as smoky and unreliable may still exist in the light-duty sector and must be reversed for acceptance into that market.

The vehicle system R&D component of the program addresses lowering the parasitic power requirements of heavy trucks, thus leading to even greater energy savings.

F. LEGISLATIVE DRIVERS

P.L. 93-275, “Federal Energy Administration Act of 1974"
P.L. 93-577, “Federal Nonnuclear Energy Research and Development Act of 1974"
P.L. 94-163, “Energy Policy and Conservation Act” (EPCA) 1975
P.L. 95-91, “Department of Energy Organization Act” 1977
P.L. 95-238, Title III - “Automotive Propulsion Research and Development Act of 1978"
P.L. 96-512, “Methane Transportation Research, Development, and Demonstration Act of 1980"
P.L. 100-494, “Alternative Motor Fuels Act of 1988"
P.L. 102-486, “Energy Policy Act of 1992,”
Section 2023, “Alternative Fuel Vehicle Program,”
Section 2027, “Advanced Diesel Emissions Program,”

IV. PROGRAM BENEFITS

Although the three primary goals for the OHVT program all target fuel efficiency or alternative fuel use, the benefits to be realized extend well beyond that of significantly reduced oil consumption. Important benefits will also be realized through reduced CO_2 emissions, reduced emissions of criteria pollutants and other species of concern, and through the accompanying array of technological advances. Obvious direct economic benefits include those associated with importing less oil, and bolstering (through improved technologies) the US engine and truck industry. Less measurable or predictable benefits may be realized through transfer of technology gains to stationary and off-road diesel engines, and an array of other multiple use technology applications. An expanded discussion of expected benefits from the OHVT program follows.

A. INCREASED ENERGY EFFICIENCY AND REDUCED OIL IMPORTS

Successful implementation of the OHVT program plan is the key to "turning the corner" on highway fuel consumption. It will reduce the petroleum consumption of Class 1–8 trucks by 1.4 million barrels of oil per day (B/D) by 2020 and over 1.8 million B/D by 2030, amounting to a reduction of total highway petroleum consumption (including passenger cars) of 13.2 percent and 18.6 percent respectively. The estimated drop in total highway petroleum use as a result of a successful OHVT program is depicted in Figure 4. The results for efficiency gains alone shown by the projected petroleum use reductions due to efficiency gains alone are estimated to be 552,000 B/D by 2020; this increases to 770,000 B/D and 7.8 percent by 2030. Petroleum use reductions due to market penetration of non-petroleum fuels alone are estimated to be 807,000 B/D by 2020 which is 8.0 percent of total highway petroleum use, increasing to 1.06 million B/D and 10.8 percent by 2030. The base case is the latest Energy Information Administration (EIA) estimates (AEO 97) extrapolated (by ANL) out to 2030. This base case already includes a significant amount of alternate fuel use in passenger cars for the later years shown, which is why the base case oil consumption is predicted to drop slowly after 2015.

Additional energy benefits would accrue in the non-road (rail, pipeline, marine, and off-highway vehicle) sectors, because these use engine technology common to the highway markets. Currently, over 1.3 million B/D is consumed by the non-road sector, excluding air transportation (see AEO, Table B7). A 10 percent energy reduction in this market would result in an estimated petroleum reduction of over 147,000 B/D in 2020, and 160,000 B/D in 2030.

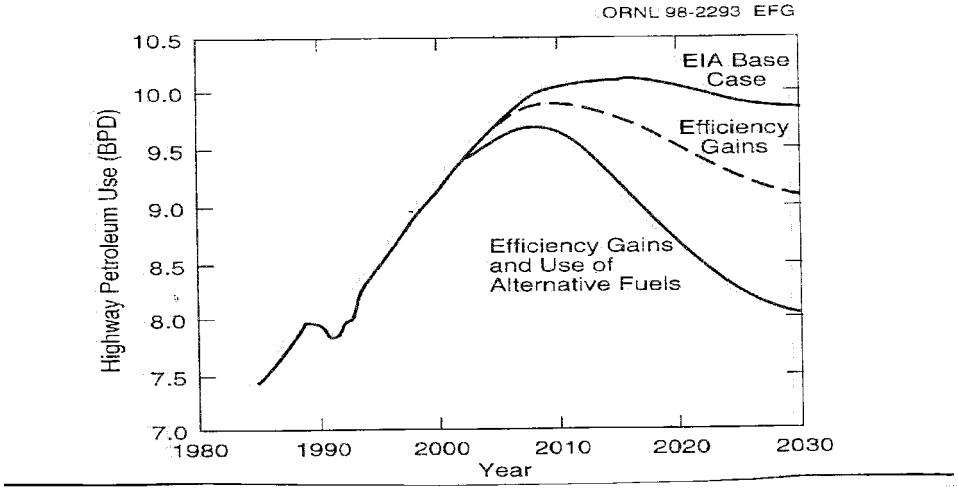

Figure 4. Highway petroleum use reductions as a result of OHVT supported technology improvements which result in efficiency gains and by non-petroleum fuel-capability.

B. CLEANER AIR

Successful implementation of the OHVT program plan will reduce all types of regulated emissions as depicted in Figure 5, which shows the estimated relative change in total fuel cycle emissions for all truck classes (1–8).

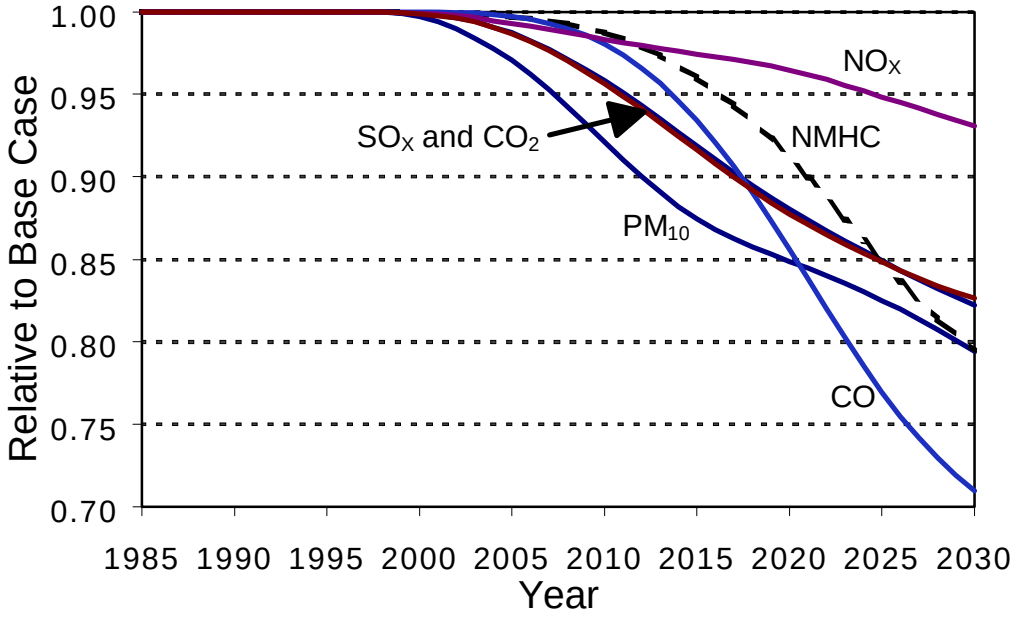

Figure 5. Total emission changes in class 3-8 trucks with a successful OHVT program.

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An expected increase in direct (tailpipe) PM10 emissions from class 1 and 2 trucks due to increased diesel use in these vehicles may appear problematic but would be off-set by a much greater drop in PM10 from the class 3-8 trucks. Any diesel PM is off-set further by less secondary PM from evaporative emissions from gasoline engines that are replaced. The combined results for all trucks would result in an estimated 20 percent drop in PM10 emissions (41,000 metric tonnes per year) by the year 2030 using conservative estimating methods. (The base case PM10 emission levels for class 3-8 trucks are likely to be underestimated because they are based largely on diesel engine certification results for class 3-8 trucks and do not consider the effects of engine aging, tampering and actual highway use - all of which are likely to increase particulate emission. A successful OHVT program would likely reduce PM10 by an amount significantly greater than 41,000 metric tonnes per year.)

In addition to a diesel engine powered vehicle producing less CO, HC and CO_2 than a comparable gasoline engine, the diesel powering of class 1-2 trucks will produce less of certain non-regulated emissions that are currently thought to be an environmental concern. In particular a diesel engine should produce less benzene, benzo(a)pyrene and 1,3 butadiene than an equivalent gasoline engine (Figure 6). Advances in diesel engines and aftertreatment should reduce the amount of aldehyde emissions, for which gasoline engines currently hold an advantage.

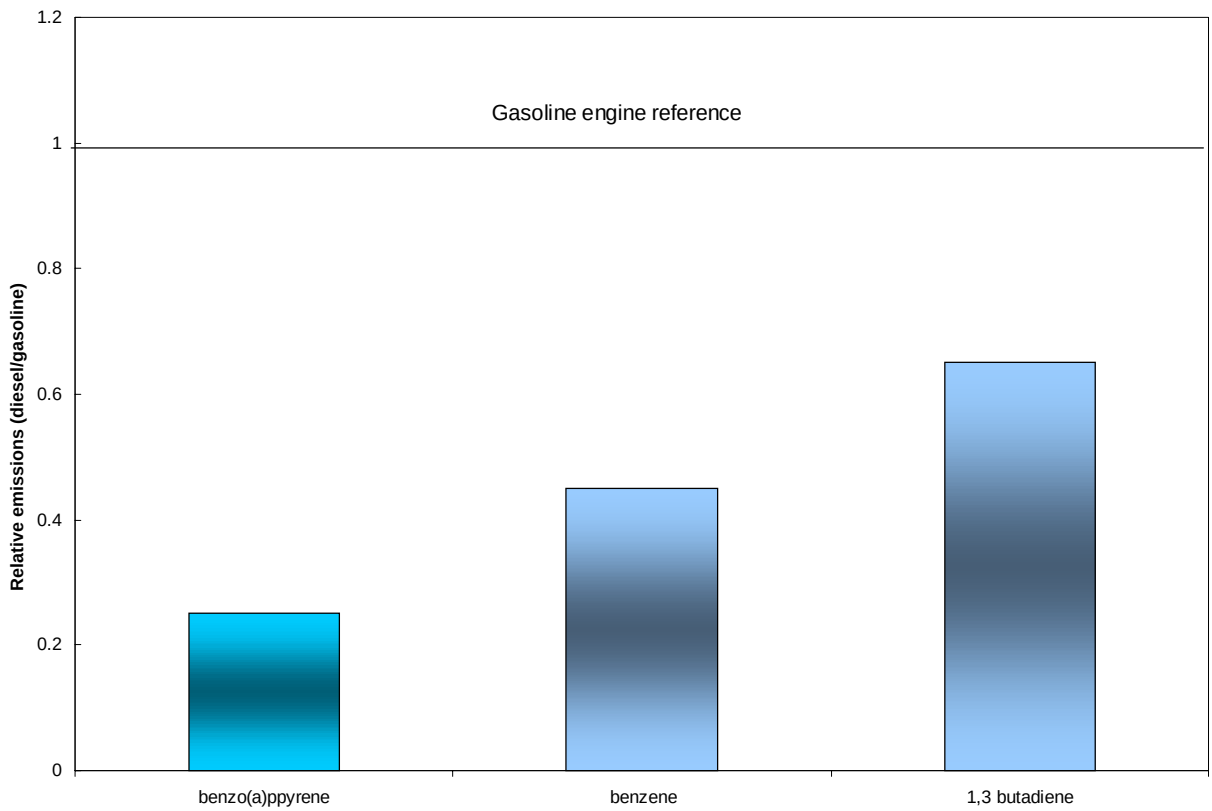


Figure 6. Diesel Engine Vehicles Produce Less of Certain Toxic Non-Regulated Emissions of Current Concern.

C. REDUCED GREENHOUSE GASES

An important benefit of a successful OHVT program will be reduced greenhouse gas emissions. As seen in Figure 5., CO_2 produced by class 1-8 trucks is projected to be reduced by over 12 *percent* by 2020 and by over 17 *percent* by 2030, in comparison to the base case. The amount of CO_2 released by all US trucks is estimated to be reduced by about 140 million tonnes/yr by 2020 and over 205 million tonnes/yr by 2030.

D. MAINTAIN AND IMPROVE OUR INTERNATIONAL COMPETITIVE POSITION

The obvious direct economic benefits of a successful OHVT program include those associated with importing less oil, and bolstering (through improved technologies) the United States heavy vehicle enterprise. A number of less obvious economic benefits are also expected.

If the estimated reduction in oil use is assumed to prevent an equivalent amount of oil imports, the avoided import oil cost is estimated to be $10.7 billion/yr in 2020 and $15.1 billion /yr in 2030 (based on 1.4 10^6 B/D at 21 $/B in 2020 and 1.8 10^6 B/D at 23 $/B in 2030; costs are in 1997 dollars). This would have a significant impact on the balance of trade. Preventing such oil imports also lessens pressure to move world oil prices upward, which will have an additional indirect benefit on imported oil costs.

The OHVT program reduces oil imports through both higher vehicle efficiencies and use of alternative fuels. It is very desirable that the alternate fuels will be produced domestically and the OHVT is working with the fuel-supply programs in DOE to ensure that. The direct effect of this will be to raise the national income and indirectly raise net employment. Based on previous work on the relationships among reduction in oil consumption, domestic jobs, and GDP by Argonne National Laboratory, we estimate an increase of about 15,000 jobs and an increase of $24 billion in GDP by 2020.

The technologies that will be developed with sponsorship by the OHVT program will benefit the preservation and expansion of truck and truck parts manufacturing sectors of the economy. The United States truck manufacturing sector produces and sells about $125 billion in new trucks (class 1–8) per year and also provides parts and services. The diesel engine industry alone employs about 640,000 persons, and the OHVT program fosters the preservation of these existing jobs.

The trucking industry will also benefit and shipping/transportation represents about $300 billion in business or about 5 percent of the United States GDP. It is obviously a very important portion of the economy. Advancing truck and engine technologies will help insure that the United States trucking industry can remain cost effective and operate without major disruptions at the same time environmental restrictions become more severe.

E. OTHER BENEFITS REALIZED FROM MULTIPLE USE TECHNOLOGY ADVANCES

A number of less quantifiable but potentially important benefits from the OHVT program will also be realized through the development of multiple-use technologies. Research and development will advance the state-of-the-art of materials, hydrocarbon chemical processing, combustion science, exhaust stream aftertreatment, vehicle technologies and aerodynamics, engine technologies, lubrication, and tribology. Some innovations from the OHVT program will certainly apply to stationary diesel engines, rail- and marine-engines, automobiles, gasoline engines, fuel and chemical production, and there will be other "spin-off" applications. Such technological advances will enhance both the efficiency of our economy, our global competitiveness, and quality of life.

V. TECHNICAL PLAN

This technical plan has been derived from the OHVT Technology Roadmap developed in 1996. The Technical Roadmap was reviewed by industry in October 1996 and was accepted with minimal revision. The Roadmap was developed through a process of:

- Setting goals,
- Assessing the Status of Technology,
- Setting Specific Technical Targets,
- Determining Barriers to Achieving Targets, and
- Formulating tasks to attack barriers.

It is appropriate to restate the **four major program goals** at this point:

- Develop by 2002 the diesel engine enabling technologies to support large-scale industry dieselization of light trucks, achieving a 35 percent fuel efficiency improvement over equivalent gasoline-fueled trucks, and bettering applicable emissions standards,
- Develop by 2004 the enabling technology for a class 7-8 truck with a fuel efficiency of 10 mpg (at 65 mph) which will meet prevailing emission standards, using either diesel or a liquid alternative fuel,
- Develop by 2006 diesel engines with fuel flexibility and a thermal efficiency of 55 percent with liquid alternative fuels, and a thermal efficiency of 55 percent with dedicated gaseous fuels, and
- By 2005, develop advanced powertrain technology for medium/heavy-duty trucks that achieve three times today's fuel economy (up to 30 mpg), and as a research goal, reduce criteria pollutant emissions to 30% below proposed regulated levels.

The technical approach has two major elements:

1. Focus R&D on selected engine technologies that have the market application potential to realize large fuel savings. The technologies that were determined to have the greatest market applications and thus fuel savings are:
   - Diesel for light trucks and sport utility vehicles,
   - Advanced diesel for class 3–8 trucks with enhanced fuel flexibility,
   - Improved near-term natural gas engine for buses and trucks, and
   - Advanced natural gas engine with diesel-equivalent efficiency.

2. Conduct R&D on key enabling and sustaining technologies to ensure market success of the engines. The key enabling technologies are as follows:
   - Combustion,
   - Exhaust Aftertreatment,
   - Materials,
   - Fuels,
   - Natural Gas Storage, and
   - Environmental Effects.

The key elements of the program, with milestones and schedules, are shown in Figure 7.

Figure 7. Key Activities and Schedule of OHVT Program.

A. GOAL 1. DIESEL ENGINE TECHNOLOGY FOR LIGHT TRUCKS AND SPORT UTILITY VEHICLES-35 Percent FUEL EFFICIENCY IMPROVEMENT

A program that seeks to introduce large numbers of advanced technology diesel engines in light-duty trucks in an industry which has been dominated by spark ignition, gasoline-fueled engines for many decades, represents a high-risk technical and economic challenge. To meet the challenge, a government-industry partnership (DOE, diesel engine manufacturers, and the automotive original equipment manufacturers) is applying joint resources to meet a specific goal that will provide benefits to the partners and to the nation.

1. Status of Technology

The light truck market is dominated by gasoline-fueled spark ignition (SI) engines. Today's SI engines are relatively low cost, exhibit acceptably low emissions, and have power and noise features highly acceptable to consumers. Their fuel economy is far short of what is readily achievable in diesel engines. Direct injection (DI) diesels,[**] of approximate size and power for light trucks, have efficiencies at peak power of 38–42 percent (See Table 1). Preliminary simulations show that diesels in this range could improve light truck fuel economy by the 35 percent (up to 50 percent "tank mileage")[***] selected as the program goal. Ironically then, engine efficiency is not the primary challenge in this overall fuel-saving strategy.

The two critical barriers to large scale utilization of high-efficiency diesels in light trucks are:

- Cost effectiveness, and
- Emissions certification

At present, there is no cost-effective diesel engine package of the appropriate power range. The cost of modern diesels is essentially double that of gasoline engines, and with low fuel prices in the United States the consumer has insufficient incentive to pay extra for high fuel economy technology. The minimum standard engine power in a full-size pickup is 108kW (145 hp), with optional engines capable of about 215kW (288 hp). The trend is toward higher powered engine offerings.

NOx and PM emissions of modern diesel engines, in spite of impressive improvements, are still two to three times higher than expected regulated levels for light trucks. The prevailing situation for diesel-powered light duty trucks are shown in Figure 8. The highly popular DI diesels now available in full-size pickups are certified as heavy-duty diesel engines instead of

[**]DI diesels are the most efficient configuration for this engine class.

[***]Increase in miles per gallon exceeds increase in fuel efficiency since diesel fuel has higher energy content per gallon than gasoline.

as passenger cars. Preliminary analysis suggests that these engines, packaged for a smaller vehicle, would exceed light-duty NOx standards by a factor of three. Hence, application of DI diesel technology in a smaller package appears to carry a substantial emissions barrier. One

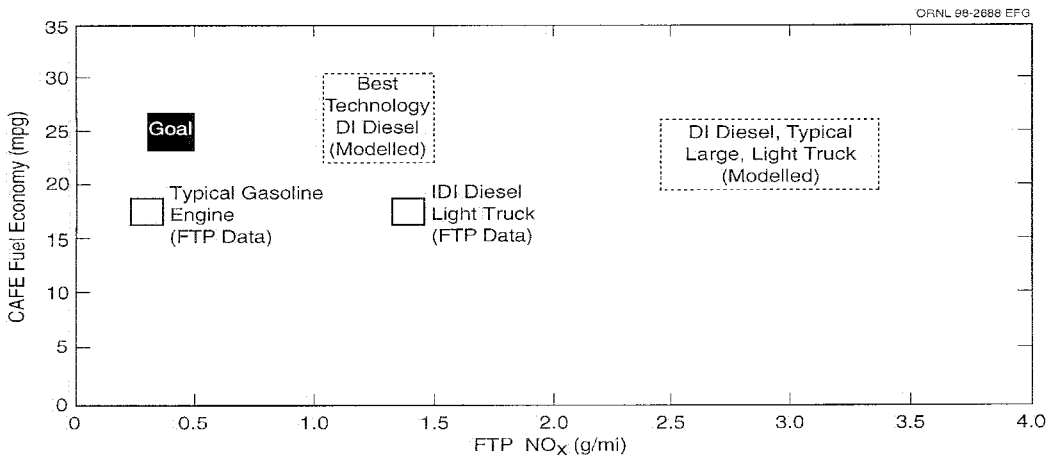


Figure 8. Major Gains in Light Truck Fuel Economy Achievable Once Diesel Emission Control is Resolved

indirect injection (IDI) diesel for pickups is certified per light-duty truck standards, but the IDI is a relatively inefficient design, and it still produces about five times more NOx than the SI engine offered in the same vehicle. There are only two DI diesel-powered light-duty vehicles certified in the United States today, and they only meet a less stringent NOx standard than comparable gasoline vehicles. Oxidation catalysts are now used on diesel-powered cars and light trucks to assist in PM control.

2. Technical Targets

Technical targets and barriers for a high-efficiency diesel that would be rapidly implemented in pickups and SUVs are summarized in Table 1. The principal efficiency target is to operate at over 40 percent efficiency through a wide range of loads and speeds. While diesel efficiency does not drop as markedly at light loads as in SI engines, the low-powered duty cycle of pickups and SUVs calls for more emphasis on light-load efficiency than for Class 7 & 8 trucks. In the light-duty vehicle federal test procedures (FTP) emissions/fuel economy driving cycle, a typical SUV will consume nearly 90 percent of its fuel with the engine operating at less than 30 hp. The cost target is an estimate, but clearly with today's fuel prices, the initial cost of the diesel must be reduced substantially.

Table 1. Key Efficiency-Related Characteristics of Engines of Approximate Size and Power for Class 1 & 2 Trucks

Engine Characteristic	Present Automotive Diesel	Present Automotive SI Engine	Present Heavy Duty Diesel	Target for this Program-Light Truck Diesel
Best Thermal Efficiency (percent)*	42.8	34	46.5	45
Power Specific Cost ($/kW)	40	20	50	20–30
Power Specific Weight (kg/kW)	2	1.1	3.6	2

*Note that diesel efficiency advantage is seven greater at off-peak conditions.

Concerns about the effects of particulates on human health, plus perceptions about "smoky" diesels suggest that aggressive emissions targets be established for a pickup/SUV engine.

Federal and California regulations for light-duty truck emissions were reviewed in depth. Electing a "clean diesel" philosophy, the following emissions targets have been selected.

NOx-	0.5 g/mile
NMHC-	0.07 g/mile
CO-	2.8 g/mile
Particulates-	0.04 g/mile

These are approximately the same as California ULEV for light-duty truck (LDT2), which would capture most of the SUVs and full-size pickups. Phase-in of this standard is to be completed by 2003. Even those these targets are the most aggressive that have been officially proposed, they are still derogated relative to expected standards for gasoline-fueled passenger cars. Federal standards for light-duty trucks are under review by EPA, but new rules have not been proposed beyond 1999. United States diesel manufacturers have agreed to adopt the same future emission standards as will be eventually proposed for gasoline-fueled light trucks.

3. Barriers

The principal barriers to be overcome for dieselizing Class 1 & 2 vehicles are emissions and the engine's cost, plus some nontechnical barriers such as market perceptions. Although pricing practice does not always reflect cost, the diesel option, for the few vehicles where it is available, costs at least $1000 more (in some cases much more) than the base gasoline engine. The fuel injection system for diesels, necessarily complex to achieve fine control of injection spray at high pressure, is one of the key cost drivers. The fuel injection system is critical to engine performance, efficiency, and emissions. Further adding to the cost is the air handling

system, including the turbocharger, aftercooler, and related hardware that diesels need in order to have competitive power density and responsiveness.

Achieving NOx and particulates emission regulations with engines of high efficiency and low cost is a significant barrier, particularly in the higher power range necessary for heavyweight trucks. This is illustrated in Figure 9. For in-cylinder controls, further development of exhaust gas recirculation (EGR) is necessary for heavy-duty diesels if they were to be "scaled down" for pickups. Cooled EGR has not been adequately developed for full commercialization. Fuel injection systems have seen recent advancements, but additional control of injection rate is believed needed.

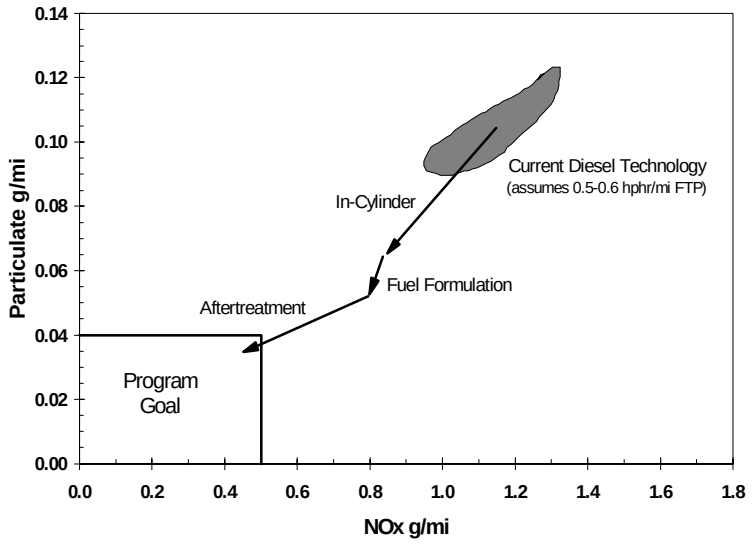


Figure 9. NOx and PM Standards Remain a Critical Technical Barrier for Class 1-2 Truck Applications, but Goals are Achievable.

Aspects of the fuel/air mixing process are still insufficiently understood and modeled to optimize engine design. Additionally, lean-burn NOx aftertreatment systems are not sufficiently developed for commercial application. Current oxidation catalysts eliminate only 30–40 percent of PM, which may be inadequate for future emission goals.

Other characteristics of the diesel engine may also inhibit its marketability. While the diesel has a recognized advantage over the gasoline engine in fuel efficiency, it is also perceived to have significant relative shortcomings in the areas of noise, vibration, and harshness (NVH), visible smoke emissions and odor, and low ambient temperature limitations. Some of these shortcomings are being ameliorated through improved design and component development.

4. Technical Approach

The light-truck diesel engine technical development approach includes three key elements:

a. System-driven development of critical technologies to ensure that advancements are successfully reduced to practice in the marketplace. These barrier-focused efforts include:

- Improve basic engine architecture for lower cost, less noise, and improved power density using advanced structural design and materials,
- Develop fuel injection components, controls, systems for improved control of fuel injection rate and timing based on improved understanding of phenomena,
- Improve air handling systems, including turbocharger systems, for reduced emissions, including during transients,
- Adapt and improve EGR for diesels in the required power range for SUVs, and
- Integrate and apply technology from enabling R&D, such as in exhaust aftertreatment, materials, combustion.

b. An industry and government partnership--cross-cut team--focused on enabling technologies principally addressing the emissions barrier for light truck and passenger car diesels. Key technologies are:

- Engine combustion,
- Exhaust aftertreatment, and
- Fuels formulation.

Further details are provided in "Enabling Technologies" in this plan.

The cross-cut team provides a focal point for diesel technology planning between the government-industry Partnership for a New Generation of Vehicles (PNGV) and the OHVT. The cross-cut team meetings provide a forum for reviewing data from numerous sources that benchmark the status of technology.

c. Materials enabling technology development in support of exhaust aftertreatment, and for technology improvements in engine efficiency, engine noise, and engine specific power.

B. GOAL 2. CLASS 7-8 10 MPG TRUCK, A 40 Percent IMPROVEMENT OVER COMMERCIAL TECHNOLOGY

The Program goal with respect to Class 7 & 8 trucks is to develop by 2004 the enabling technology for a truck with a fuel efficiency of 10 mpg (at 65 mph) which will meet prevailing emission standards, using either diesel or a liquid alternative fuel (fuel or fuels TBD). A separate task will focus on developing a highly efficient gaseous fuel engine.

Figure 10 illustrates how the 10 mpg truck can be achieved. The program will achieve this goal by performing research and development required to improve engine efficiency and ensure

emissions compliance, with the ability to accommodate the range of fuels expected to be available. Further improvements in vehicle aerodynamics, rolling losses, and parasitic power losses will be necessary to achieve the stated goal, but the program largely will focus on the diesel engine.

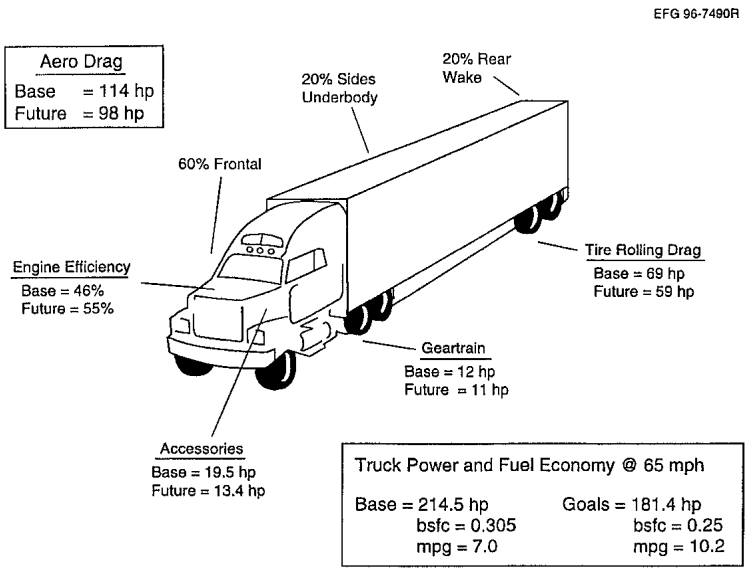


Figure 10. Technology Path to Improve Truck Fuel Economy

1. Engine Requirements for 10 mpg Truck

a. Status of Technology

Efficiency – Due to their high efficiency and reliability, diesel engines are the dominant power source for heavy-duty trucks and for city and intercity buses in the United States, and they are the preferred power source for commercial surface transportation worldwide. Compression ignition (diesel) engines are the most efficient energy conversion devices available, with very large units (e.g., land-based and marine engines) exceeding 50 percent thermal efficiency.[3]

Turbocharged diesels for highway trucks are now offered that exceed 46 percent efficiency (as compared to about 30 percent for production gasoline engines), an improvement of about 40 percent relative to diesel engines of the late 1970s. The diesel-engine industry believes that this number can be increased to 50-55 percent. Data from single-cylinder prototype engines indicate that heavy truck engines could be built today that achieve 52 percent thermal efficiency, although durability, emissions, and cost targets are not yet assured.

Emissions – Over the past twenty years engine manufacturers have made significant improvements by retarding fuel injection timing, increasing the injection pressure, and other design changes (see Figure 11). Also, lower fuel sulfur levels were mandated to reduce particulates. Modern diesels that meet the 1998 standards emit no visible smoke. In spite of these reductions, there continues to be concern about environmental and health effects of diesel engine emissions; in particular, the health effects of particulates. Current legislation mandates a reduction of NOx levels to 4 g/bhp-hr by 1998. The EPA and major engine manufacturers have issued a "Statement of Principles" that requires further reduction to 2.4 g/bhp-hr of NOx plus non-methane hydrocarbons (NMHC) or 2.5 g/bhp-hr of NOx plus NMHC with a maximum of 0.5 g/bhp-hr of NMHC by 2004. The Department of Energy Office of Health and Environmental Research and the OHVT have initiated a study of health issues associated with new engine technologies. Meeting the stringent emission standards set forth in the "Statement of Principles" while at the same time improving engine efficiency constitutes a major challenge for diesel engine manufacturers. To address these challenges one can consider the same three approaches as for light-truck diesels: (1) combustion technology and related in-cylinder processes, (2) cleaning the engine emissions to an acceptable level before exhausting to the environment (exhaust aftertreatment), and (3) developing fuel reformulations or additives.

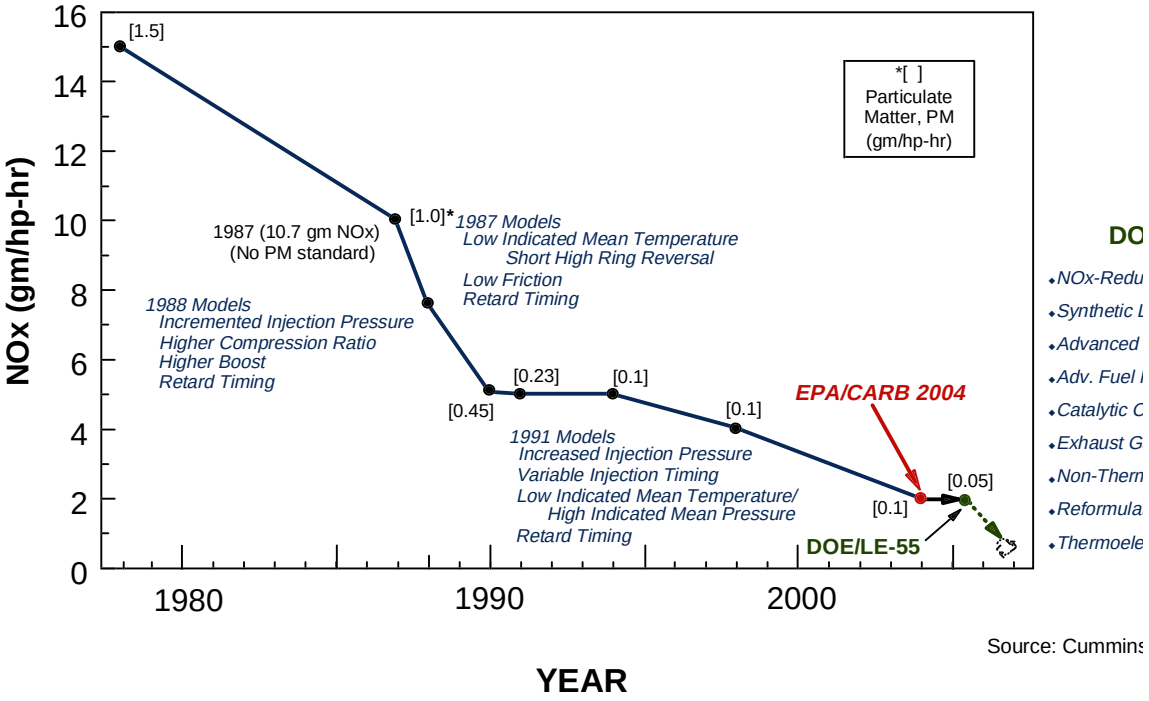


Figure 11. Evolution of Heavy Duty Diesel Cycle Engine Emissions Control

Engine-out emissions – In heavy-duty diesels for Class 7–8 trucks, essentially all significant reductions in emissions since 1974 have been made through combustion modifications (e.g., retarded injection timing, increased injection pressure and lower inlet air temperatures); however, further reductions are needed. Particulate emissions from diesel engines originate from lube oil as well as from fuel combustion. Although this effect is markedly less, it is nonetheless important if the new, more stringent regulations are to be met. Efforts continue to quantify the effect and means to minimize lube oil contribution to particulate emissions while maintaining adequate engine lubrication. Engine-out emissions today stand at the 1998 emissions regulations levels.

Fuel reformulations and additives – To reach the goal of lower emissions while maintaining efficiency, fuel quality standards must remain high. Fuel reformulations and additives can lead to lower exhaust emissions, better fuel economy, and improved cold start performance. The allowable sulfur content in diesel fuel was lowered several years ago to assist engine manufacturers in complying with the 1991–94 heavy vehicle emissions standards.

Exhaust aftertreatment - Various concepts are being pursued that could potentially impact both NOx and particulates but still require significant development before they could be considered ready for commercial use. Among Class 7–8 vehicles, only urban buses utilize exhaust aftertreatment, an oxidation catalyst, because the particulate standard for these engines is 50 percent lower than for highway trucks. Particulate trap field tests were conducted several years ago, and the technology was generally abandoned because of cost and maintenance issues.

Catalytic systems in today's automobiles operate with air/fuel ratios at or close to stoichiometric, in which both NOx reduction and CO and hydrocarbon oxidation can be accomplished in a single catalyst bed, i.e., sufficient reducing gases are present to reduce NOx and enough oxygen is available to oxidize the CO and hydrocarbons. Diesels, however, operate under lean conditions such that conventional catalysts are not effective. New NOx catalyst systems, some with plasma-assist, are the subject of intense R&D but are not yet at performance nor durability goals.

The status, targets, and barriers for engine technology required in a 10 MPG truck is summarized in Table 2.

Table 2. Engine Requirements for 10 mpg Heavy Truck.

Engine Parameter	Current Technology	Target	Barriers
Efficiency, percent	46	55	-Peak cylinder pressure limited by structural/materials technology and NOx emissions -Inadequate turbocharger efficiency -Exhaust heat recovery too expensive -Friction losses
NOx Emissions g/hp-h	4	2	-Inadequate understanding and control of in-cylinder NOx formation -Inadequate NOx aftertreatment technology -Incomplete exploitation of fuel technology for NOx control.
Particulate (PM) emissions g/hp-h	0.05	0.05	-Inherent increase of PM as NOx is reduced. -Inadequate in-cylinder control through fuel injection and mixing processes -PM aftertreatment systems inadequate for many applications -Fuel formulas for low PM not fully developed, nor cost effective

b. Technical Targets

Efficiency – A brake thermal efficiency of 55 percent for the engine has been set as an aggressive but achievable goal. Major diesel engine companies have considered and concurred with this target. For the most part, further advances in efficiency will be achieved with improvements in components and operating characteristics of engines similar in overall architecture to those now widely used. In addition to improvement to the reciprocator assembly, an effective exhaust recovery system is critical to meeting the 55 percent efficiency target. The contributions of the more detailed targets to the 55 percent goal are depicted in Figure 12.

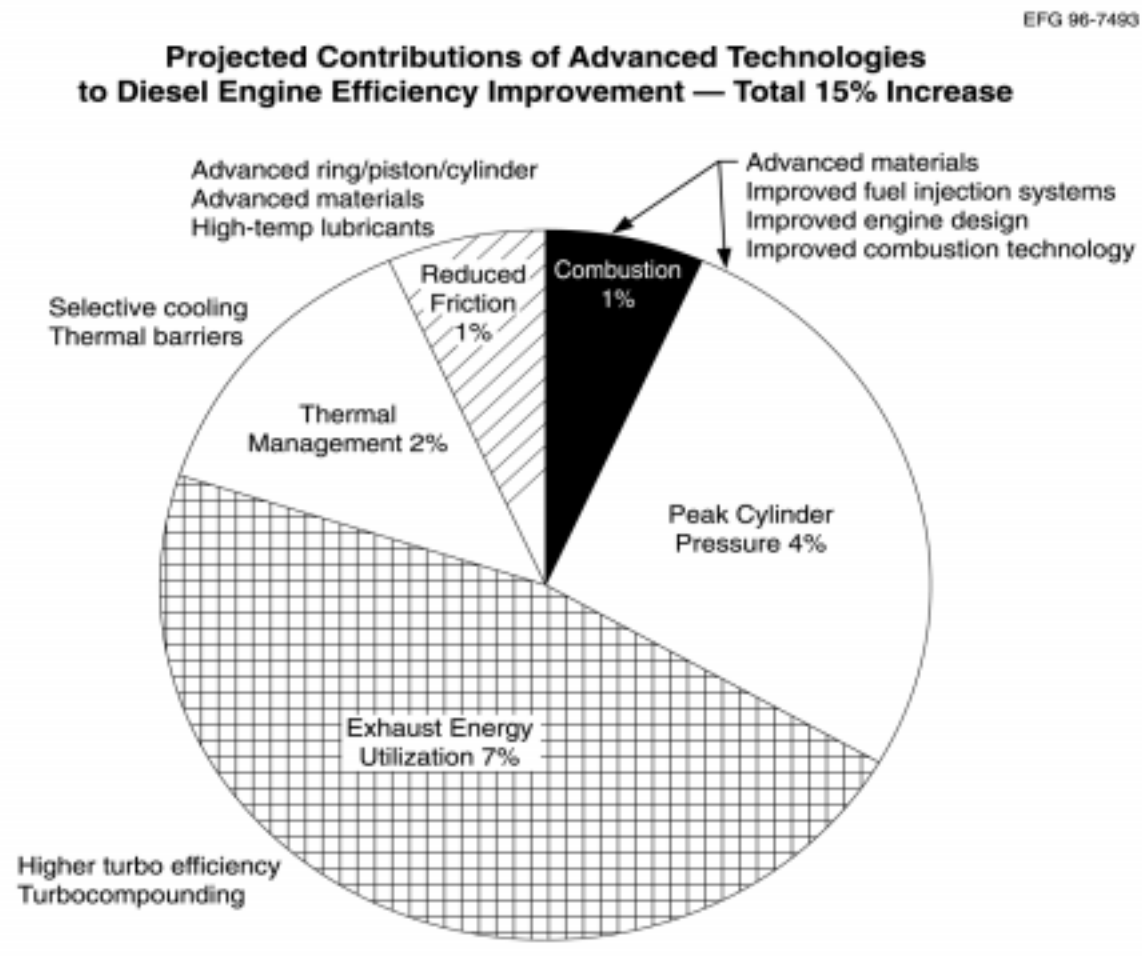
Emissions – Efficiency improvements as described in the previous section are pointless unless emissions compliance is achieved. Emission control (cost-effective) is indeed the greatest challenge for the high-efficiency diesel engine.

The emissions targets are: 0.05 g/bhp-hr of particulates and 2.4 g/bhp-hr of NOx plus NMHC or 2.5 g/bhp-hr of NOx plus NMHC with a maximum of 0.5 g/bhp-hr of NMHC or less by the year 2004, while achieving the efficiency goals stated above.

c. Barriers

The barriers that must be overcome to achieve the technical targets for the 55 percent efficient engine are summarized in Table 2.

Figure 12.



Adapted from: Don Krull, Energy Efficient Heavy Vehicles Technologies, "The Engine Manufacturers Perspective," DOE/SAE Workshop on Energy Efficient Heavy Vehicle Technologies for Reducing Fuel Costs: Leveraging DOE's R&D Capabilities, Romulus, Michigan, April 17–18, 1996.

d. Technical Approach

The engine technology development efforts for Class 7–8 trucks will build on the success of the "Low-Emission, 55 percent" (LE-55) program. Similar to the strategy for the light truck diesel, a set of system development efforts, plus ongoing R&D in enabling technologies will comprise the program. In addition, the Class 7–8 engine projects will be integrated with those on fuel-flexibility described in the next section of this plan.

Efficiency –

- Define one or more advanced engine designs as reference engines serving as a guide and test bed for enabling technology projects. Conduct, on a continuing basis, analysis and supporting validation tests to assess progress toward goals,
- Develop advanced combustion chamber components for high peak pressures and high brake mean effective pressures, utilizing, as needed, new architectures for components, new materials, thermal barriers, and novel cooling strategies. Integrate the achievements from enabling R&D on materials,
- Develop fuel injection and combustion technologies that will provide higher peak cylinder pressure for better efficiency, without causing higher NOx. Develop and integrate sensors, controls, diagnostics and enabling experimental tools. Emission aftertreatment may be the approach to allow raising peak cylinder pressure without increasing NOx,
- Develop improved turbocharger and air-handling systems including variable geometry technology, improved rotor aerodynamics, low-inertia materials and response-enhancing technologies that may emerge, and
- Continue analysis and evaluation of new exhaust heat recovery technologies as they emerge, including direct energy conversion.

Emissions – Meeting the technical targets for emissions will require the same three-pronged diesel engine emission control strategy described for light truck applications, i.e., understanding and optimizing in-cylinder combustion processes, optimizing fuel formulation, and developing exhaust aftertreatment technologies, such as improved catalysts. These needs are addressed through the enabling technology tasks shared with the light truck diesel effort as well as with the PNGV diesel R&D throughout the cross-cut team. Specific R&D tasks are described in "Enabling Technologies."

2. Vehicle System Technology for 10 mpg Truck

The realization of 10 mpg trucks will require not only improvements in engine efficiency, but also substantial reductions in the power required to propel the vehicle. This can be achieved by a combination of reduced aerodynamic drag, reduced rolling friction, and reduced parasitic losses.

a. Status of Technology

Our baseline is fully-loaded Class 8 trucks, at 65 mph, which achieve about 7.0 mpg. Truck power requirements are dominated by aerodynamic drag, comprising mainly the form drag, surface drag (skin friction), and internal drag (engine compartment and passenger ventilation). The combination of these gave large highway trucks a drag coefficient (C_d) of near 1.0 for designs of the mid-1970s. Truck cabs with rounded exteriors, plus a combination of air dams, gap seals, and other fairings can potentially reduce the C_d for the tractor-trailer rig to less than 0.50, though the most advanced commercially available vehicles have C_ds in the range of 0.55-0.60. Estimates of fuel economy improvements are 14-19 percent for combined aerodynamic treatments to the tractor and trailer.

Rolling resistance is the second highest factor in truck power requirements. Already there has been a major shift toward use of radial tires instead of bias ply tires, with a low-profile radial in widespread use. The newest generation tire is the "super single" that offers less rolling drag. It offers a small percent of fuel savings, but there is user resistance for a variety of reasons, including lack of redundancy in the event of a failure and perceptions that road damage is higher. The "super singles" are also taller than other radials, thus detracting from the freight volume of a closed van trailer. They are used primarily in the niche application of tanker trucks.

b. Technical Targets

The distribution of power requirement comparing a typical Class 8 truck to one with advanced technology is also shown in Figure 10. Clearly the greatest gains are achievable by attacking losses due to aerodynamic and rolling resistance. Mechanical losses in gears, bearings, and auxiliaries become more important as the major power drains are reduced. The technical targets established to achieve reduced truck power requirements for a 10 mpg truck are given in Table 3.

c. Barriers

The barriers to achieving the technical targets for reduced truck power requirements are given in Table 3.

Table 3. Summary of 10 mpg Truck Parameters, Technical Targets, and Barriers

Vehicle Parameter	Current Technology	Target	Barrier
Aerodynamic drag	C_d=0.55-0.60 with best practicable designs	C_d=0.47 (or 15 percent reduction in widely used packages)	Maintenance nuisance, cost of aero designs. Non-optimal underhood designs, large radiator.
Rolling (tire) friction losses	Low-profile radials	Reduce rolling resistance by 8 percent (assure use of super singles)	Road damage and stability (safety) concerns for super single tires; availability.
Mechanical losses	Transmission and axles account for up to 7 percent of power requirements	Reduce by 25 percent	Cost-effective alternative materials and designs.
Auxiliaries, parasitics	Shaft-driven auxiliaries account for up to 12 percent of truck power requirement	Reduce by 25 percent	Cost-effective alternative materials and designs

d. Technical Approach

- Update vehicle systems analysis to define fuel savings benefits of specific technical strategies such as aerodynamic designs, weight reduction, tire substitutions, and auxiliaries improvements,
- Evaluate and address through R&D the system impacts of aerodynamic improvements on brake adequacy and vehicle maintenance,
- Improve and apply modern computational fluid dynamics codes to tractor-trailer systems and identify new configurations to reduce this element of aerodynamic drag. Follow analysis with design and experimental verification,
- Conduct design and tests of lightweight vehicle structures which appear to be promising in the systems analysis, and
- Work with the Department of Transportation and the American Trucking Association to conduct further assessments of the issues surrounding use of fuel-saving tire technologies and similar situations where fuel saving appears to be hindered by regulation or perceptions.

C. GOAL 3. FUEL FLEXIBILITY FOR CLASS 3-8 TRUCKS

1. Class 3–8 Trucks

The concept of fuel flexibility refers to the development of engine technologies that allow the use of alternative fuels to displace petroleum derived diesel fuel. On an engine specific basis, fuel flexibility can do more to reduce the demand for petroleum diesel fuel than is possible from engine efficiency gains alone. A combination of fuel flexibility and high efficiency offers the greatest potential for petroleum diesel fuel displacement. In order to successfully achieve DOE-OTT's goal to reduce the nation's reliance on imported oil, it is important that alternative fuels produced from alternative feedstocks, such as natural gas and biomass, be utilized in Class 3–8 trucks. The Heavy Vehicle Technologies program strategy focuses on the diesel engine with a future direction to run these engines on liquid alternative fuels in a fuel-flexible mode, or on gaseous fuels in a dedicated mode. This program will extend the work of these manufacturers to the development of liquid fuel-flexible engines and optimized gaseous fuel engines.

The development of fuel-flexible engines will be primarily directed toward the use of new diesel fuel blends containing non-petroleum components such as oxygenates, biodiesel, or Fischer Tropsch liquids. The requirements for non-petroleum blend components will include fuel properties compatible with diesel engine use and the potential for low-emission performance to help achieve the goal of displacement of petroleum diesel fuel. Liquid replacement fuels, such as dimethyl ether (DME) or other ethers that cannot be blended directly with petroleum diesel will also be considered as a subset of the liquid fuel, fuel-flexible engine concept. The development of gaseous fuel engines is directed at optimizing the efficiency and emission performance of either compressed or liquefied natural gas as a replacement for petroleum diesel.

a. Status of Technology

Alternative fuels can be effective in displacing diesel fuel in Class 3 through 8 trucks; however, in most cases, they cannot be directly substituted without substantial engine modifications. With current technology, optimum efficiency and emissions are only achieved with engines that are optimized for each fuel. Each of the Class 7 and 8 engine manufacturers produce engines designed to operate on alternative fuels, but most alternative fuel heavy-duty engines offered today run on natural gas. The two approaches that are being used in production engines today are spark-ignited natural gas (SING) and dual-fuel pilot ignition natural gas (PING).

b. Technical Targets and Barriers

The primary targets are: incremental improvement of thermal efficiency for dedicated gaseous fuel engines (a short-term target); fuel flexibility and a thermal efficiency of 50 percent with liquid alternative fuels (a long-term target); and a thermal efficiency of 50 percent with dedicated gaseous fuel engines (a long-term target). These targets are for model year 2006 with government/industry "Statement of Principles" emissions levels. Tables 4 and 5, respectively, summarize specific targets and barriers for each engine parameter for the liquid fuel-flexible engine and the dedicated gaseous fuel engine.

Table 4. Summary of Technical Targets and Barriers for Classes 3–8 Liquid Fuel-Flexible Engine

Engine Parameter	Current Practice	Target	Barrier
Cost	No fuel-flexible engine available now	Depends upon fuel combination	Costs of extra electronics, upgraded materials (including fuel tanks, lines, etc.), and reliable fuel sensors. Acceptance of any cost penalty.
Efficiency	Maximum efficiency of 39 percent (for dedicated methanol engine)	50 percent by 2006	Same barriers as for a high efficiency diesel engine, plus optimum combustion chamber, compression ratio, injection rate, spray hole size and number, etc. for different fuels.
Emissions	Dedicated methanol engines certified to 1992 standards: NOx<5.0 g/bhp-hr HC<1.3 g/bhp-hr CO<15.5 g/bhp-hr PM<0.25 g/bhp-hr	NMHC+NOx =2.4 g/bhp-hr or NMHC+NOx =2.5 g/bhp-hr and NMHC cap of 0.5 g/bhp-hr	Difficulty in optimizing control strategies for multiple fuels. Fixed combustion chamber tends to compromise emissions due to fuel property differences.
Reliability	No fuel flexible engine now	Essentially same as diesel	Additional components and complexity required for multi-fuel capability tends to reduce reliability.

Table 5. Summary of Technical Targets and Barriers for Class 7 & 8 Dedicated Gaseous Fuel Engine

Engine Parameter	Current Practice	Target	Barrier
Cost	15 percent to 100 percent more than a diesel engine	Same as diesel engine	Low production volumes. Cost of fuel storage system. Added components and complexity.
Efficiency	Maximum of 37 percent with lean-burn SING (15 percent less efficient than diesel in the field). 4 percent less than diesel with PING.	50 percent by 2006	Same barriers as for a high-efficiency diesel engine, plus low-cetane rating of natural gas. Need for low-cost fuel sensors and storage system weight.
Emissions (already below target levels)	Dedicated lean-burn SING. NOx=1.4 g/bhp-hr NMHC=0.5g/bhp-hr CO=6.0 g/bhp-hr PM=0.03 g/bhp-hr	NMHC+NOx = 2.4 g/bhp-hr or NMHC+NOx = 2.5 g/bhp-hr and NMHC cap of 0.5 g/bhp-hr	Maintaining low emissions while increasing efficiency.
Reliability	Similar to diesel	Same as diesel	Spark plug life, fuel delivery system reliability, valve/valve seat wear

c. Technical Approach

Liquid fuel-flexible engine - There are no liquid fuel-flexible, heavy-duty engines available now. Ideal liquid fuels from alternative feedstocks include Fischer-Tropsch diesel, biodiesel (vegetable oil esters), polymeric ethers, or other blendstocks which could be used directly in diesel engines without major modifications. Other fuels derived from alternative feedstocks, including liquefied petroleum gas, methanol, dimethyl ether (DME), ethanol, diethyl ether (DEE), and others may also be investigated. Specific elements of the technical approach to overcoming the barriers outlined in Table 5 may include several methods for optimizing performance on a variety of fuels, such as variable valve timing, EGR, skip firing, improved thermodynamic cycles, lowering the lean limit, ignition enhancement techniques, and advanced sensor and control systems or other approaches shown worthy of pursuit. Research will be conducted on alternative fuels including low-cost additives, fuel-flexible tanks, and new approaches for ignition assistance. Reduced emissions will be developed through new EGR controls and low NOx technologies as well as methods for minimizing particulate emissions.

Gaseous fuel engine - Current gaseous fuel truck engines are significantly less efficient than comparable diesel engines. The program will focus on improving the efficiency of these engines. Research and development will be targeted at improving the efficiency of dedicated gaseous fuel engines while meeting emissions standards. Elements of the technical approach to overcoming the barriers outlined in Table 5 may include variable valve timing, variable

geometry turbocharge EGR, skip firing, alternative thermodynamic cycles, Miller cycle, extension of the lean limit, advanced control systems, direct injection, micro-pilot injection, or other approaches shown worthy of pursuit. Developments planned under the program include the following: fuel sensors or other technology to detect fuel quality variations; durable, wear- and corrosion-resistant intake valves, valve seats, and valve guides of advanced materials to increase durability of natural gas engines; safe, lightweight, low-cost cylinders, fuel tanks, fuel storage media; and durable, low-cost ignition systems.

2. Fuel Flexibility for Class 1–2 Trucks

The goal is to develop the technologies required for liquid fuel-flexible operation of the new advanced diesels being developed under OHVT's Class 1 and 2 diesel program. This is similar to the approach used for Class 3 through 8 trucks.

a. Status of Technology

There are several bi-fuel compressed natural gas/gasoline light trucks being offered by manufacturers and there are but few Class 1 or 2 trucks currently available that operate on liquid alternative fuels (either dedicated or fuel-flexible). None of the small truck alternative fuel offerings operate on the diesel cycle. Most alcohol flexible-fuel engine designs to date have been done on gasoline spark-ignited engines used in passenger cars. Much of the technology developed for heavier engines may be applicable to engines for Class 1 and 2 trucks. A brief status of alternative fuel technology in heavy engines is given in the section on Class 3–8 liquid fuel-flexible engines.

b. Technical Targets and Barriers

The primary targets are fuel flexibility and diesel-like thermal efficiency with liquid alternative fuels. Table 6 summarizes the specific targets and barriers for each engine parameter for the fuel-flexible engine. The primary barrier is probably a market barrier and not a technical one. At present, there is little or no market demand for a flexible-fuel Class 1 and 2 truck engine. The OHVT believes, however, that the development of one should be pursued as a national security "insurance" policy.

c. Technical Approach

This program, in partnership with industry, will support research to develop the enabling technologies. The program will address the barriers to developing a prototype liquid fuel-flexible truck. The approach for overcoming technical barriers for Class 1 and 2 trucks will be similar to that developed for Class 3–8 trucks.

Table 6. Summary of Technical Targets and Barriers for Class 1 and 2 Liquid Fuel-Flexible Engine

Engine Parameter	Current Practice	Target	Barrier
Cost	No fuel-flexible engine available now	Depends upon fuel combination	Costs of extra electronics, upgraded materials (including fuel tanks, lines, etc.), reliable fuel sensors. Acceptance of any cost penalty.
Efficiency	Maximum efficiency of 39 percent (for dedicated methanol engine)	42 percent by 2006	Same barriers as for a high efficiency diesel engine, plus optimum combustion chamber, compression ratio, injection rate, spray hole size and number, etc. for different fuels.
Emissions	No fuel-flexible engine now	2006 emissions standards	Difficulty in optimizing control strategies for multiple fuels. Fixed combustion chamber tends to compromise emissions due to fuel property differences.
Reliability	No fuel-flexible engine now	Essentially same as diesel	Additional components and complexity required for multi-fuel capability tends to reduce reliability.

D. Increased Efficiency and Reduced Emissions in Class 3-6, Hybrid-Electric Technology

1. Background

Truck classes 3 (10,001 to 14,000 lbs. GVW) through 6 (19,000 to 26,000 lbs. GVW) represent 38 percent of trucking (by value) involving movement within states, primarily local deliveries of food, consumer staples, and manufactured goods between businesses and consumers. The largest concentration of these trucks and buses are found in private fleets. Private fleets include wholesalers or distributors, retailers and manufacturers. The second largest concentration is among construction, mining, and refuse collection companies. In these weight classes, the majority of construction vehicles are used by tradesmen (approximately 56%). (ref-Ö.). Class 3-6 trucks account for 6.3% of fuel used by all truck classes.

The relatively high societal cost of these vehicles in terms of energy use and urban emissions is overshadowed by their irreplaceable value in commerce. Gradual replacement with efficient, clean alternative vehicles will not only improve the outlook for energy use and environmental acceptability, but will also improve productivity in the commercial and transportation sectors. As an example of improved productivity, a major fleet manager and supporter of electric propulsion technology is planning new routes that take vehicles inside buildings, eliminating an intermediate loading point outside the facility for conventional vehicles.

DOE's participation in the Advanced Transportation Technology Consortium (ATTC) program will be included in this program element for class 3-6 trucks. Though launched originally through the Intermodal Surface Transportation Efficiency Act (ISTEA), ATTC has been funded for five

consecutive years by the Defense Advanced Research Projects Agency (DARPA) within the Department of Defense. The ATTC program, consisting of seven regional consortia, has been funded on a 50 percent cost-sharing basis for the development of electric and hybrid vehicle technologies. To ensure continued momentum of civilian projects, during 1998 the program will transfer from DARPA to a joint DOE, Office of Transportation Technologies, and Department of Transportation Research and Special Programs Administration, effort.

2. Goal for Class 3-6 Trucks

By 2004, develop and demonstrate commercially viable vehicles that achieve at least double the fuel economy of today's vehicles, and as a research goal, reduce criteria pollutant emissions to 30 percent below EPA standards.

3. Status of Technology

A significant fraction (approximately 65%) of medium and light-heavy trucks are still powered by gasoline spark-ignition engines that are intrinsically inefficient at low loads encountered in delivery service. The fleet fuel economy for class 3-6 ranges from about 7.2 to 9.2 miles per gallon.

4. Approach

Due to their operating service, class 3-6 trucks are prime candidates for diesel engines and hybrid-electric powertrains. A 2x fuel economy improvement appears to be quite feasible. Three program components are being planned and developed for goal achievement. A more complete plan will be included in the next update of the OHVT Multiyear Plan. First, a government-industry heavy-duty hybrid program will be implemented, fashioned similarly to the Class 1-2 light truck diesel program. The focus of this program will be the deployment of significant numbers of hybrid-electric trucks. Secondly, the ATTC will continue with advanced component and system developments which are linked to vehicle manufacturers and fleet managers, who in turn are responsible for successful marketplace application. Third, for Class 3-6 vehicles there will be enhanced focus on lightweight materials technology for reducing vehicle weight, believed to be a key step in fuel economy improvement in typical urban delivery vehicle operation. The OHVT Enabling Technologies R&D projects will support the development of critical natural gas storage, delivery, and engine systems technologies through the national laboratories and component suppliers. Additional aspects of the technical approach and implementation plan will be developed through the end of FY 1998.

E. ENABLING TECHNOLOGIES

Six enabling technologies have been identified that provide the foundation for the market application technologies. "Enabling" here implies that without some successes, the fuel saving technologies targeted in this program, such as the light truck diesel, may never be implemented. Research and development in the enabling technologies is carried out largely in cooperative programs between the DOE laboratories and industry, by universities, and by independent research institutions. The

selection of these R&D thrusts is based on their direct application to technical barriers described in previous pages.

1. Combustion Technology

Enabling technologies within Combustion Technology can be divided into three areas: (1) diesel combustion research; (2) model and submodel development; and (3) utilization of alternative fuels and fuel additives. In the first area, significant progress has been made, but additional information is required. For example, where and when NO forms in the cylinder of a diesel engine is not well understood, why some soot escapes the combustion process is not clear, and the role swirl plays in the combustion process still needs to be investigated. This information could lead to new strategies for reducing NOx (and breaking the soot/NOx tradeoff) without impacting efficiency. Finally, an understanding is needed on how intake temperature and pressure, engine speed, and fuel injection parameters affect scaling of the diesel combustion process.

Improvements in spray and soot submodels are still inadequate for accurately describing the diesel combustion process. Research is required to develop new techniques such as improved flamelet models that will better describe the combustion process within a flame zone yet be computationally efficient. Work is also required in developing or improving codes so that they can be run efficiently on parallel machines or in a distributed computing environment.

The investigation of alternative fuels and fuel additives will build on the information generated utilizing conventional fuels. Water is known to be an effective additive in reducing NO by reducing the in-cylinder combustion temperature. However, the most effective means of introducing water while maintaining efficiency is in need of research. Vegetable oil esters are considered to be potential blending agents with diesel fuel with the formation of NO as an issue at high blending levels. Chemical additives (e.g., oxygenates) could also play an important role in reducing emissions while maintaining efficiency. Alternative fuel and fuel additives offer potential improvements but a fundamental understanding of the combustion process is required before widespread use is considered.

2. Exhaust Aftertreatment

Exhaust aftertreatment is a critical part of the three pronged approach to diesel emission control. Based on projections for future engine-out emissions, aftertreatment systems will be required to reduce NOx by at least 50 percent for the light truck and SUV application. Particulate control through aftertreatment may be needed as well, at least through improved versions of oxidation catalysts that are already used on class 3–6 diesel trucks and urban buses. Without success in NOx and PM aftertreatment, the use of high efficiency diesels in growing market segments will not be feasible.

Work to date has identified catalysts and non-thermal plasma (NTP) as warranting continued development for NOx control. Recent research indicates that NTP systems must be used in conjunction with catalytic surfaces to be effective. The R&D process must include experiments to better define controlling mechanisms, and advanced microcharacterization of catalyst

materials, in order to streamline the Edisonian nature of catalyst synthesis. This will require development or improvements in analytical measurements for in-situ measurements on catalysts in simulated and real exhaust streams. In addition to catalyst synthesis, there must be research to define the optimum reductant (required in most NOx control technologies), how to produce the reductant on the vehicle, and how to introduce the reductant in the exhaust. Catalyst scale up processing, that is taking powder to full size, durable "bricks" remains a key challenge.

The NTP systems will require further development of power sources to minimize parasitic losses and to produce the most effective plasma for the NOx or PM control. Traps and filters for PM may still be required, so it is prudent to continue supporting R&D in filter materials and regeneration concepts and systems. Additional development of control systems and sensors is required to ensure a complete and functional system, including any legislative mandated diagnostics. A cost-effective sensor for NOx has been identified as a high priority requirement. Catalyst technology will benefit from work carried out through the DOE 2000 Materials Microcharacterization Collaboratory. Jointly sponsored by OHVT and DOE-ER, this effort brings together instrumentation and expertise from DOE labs, universities, and industry for real-time remote collaborative experiments.

3. Fuels

R&D in fuels will enable two key strategies:

- Using fuel formulation as an emission control strategy for diesel engines.
- Mitigating barriers to using alternative fuels.

Engineering fuel composition can provide significant contributions to (1) allowing use of lower cost fuel system materials, (2) controlling combustion processes, (3) enhancement of emissions reductions, and (4) optimization of vehicle systems. Fuels engineering therefore becomes a source of many cross-cutting technologies that enhance the overall performance of the vehicle. While specifics will be identified in other planning documents, the opportunities for applying fuels engineering as an important cross-cutting technical tool are briefly described below.

Fuel composition directly impacts the fuel combustion process and emissions. Additives or new fuel components can directly improve the combustion process itself, as well as influence the products or residue created in the cylinder. NOx and PM can, for example, be significantly impacted by diesel fuel aromaticity and by the addition of oxygenates by various methods. The direct effect of fuel ignition quality, whether set by fuel composition or additives, is not yet thoroughly understood. Appropriate selection and control of fuel composition will reduce the amount of pollutants that are fed into the aftertreatment system and can even influence its effectiveness.

With respect to alternative fuels, control of fuel composition to eliminate chemically active components or impurities will lessen the burden on material selection and improve durability of the integrated fuel systems. This usually results in lower cost materials while improving durability and reliability. Fuel additives may also be identified which reduce the chemical or mechanical activity between the fuel and the fuel system hardware. Finally, control of fuel

composition and physical state in the vehicle storage system can be a very important tool in reducing costs and improving performance in many of the vehicle systems.

4. Materials

Advanced materials offer the opportunity to improve the emissions, NVH, and performance of diesel engines. The design of advanced components for low-emission, high-efficiency diesel engines may push the performance envelope for materials of construction past the point of reliable operation. Higher mechanical and tribological stresses and higher temperatures of advanced designs limit the engine designer. However, advanced materials allow the design of components that may operate reliably at higher stresses and temperatures, thus enabling more efficient engine designs. Materials R&D encompasses not only the development and application of new materials, but also the critical work on characterization, from microstructure through physical properties.

The OHVT Technology Roadmap identified a number of critical materials issues for overcoming the barriers to low-emission, efficient, fuel-flexible diesel engines:

a. High Efficiency Engines

- Materials for advanced combustion chamber components for high peak pressures and high brake mean effective pressures
- Low inertia materials for turbochargers to improve efficiency and emissions
- Materials for improved insulation of exhaust system
- Improved coatings and other thermal barriers
- Materials for advanced fuel injection systems to improve combustion and reduce emissions
- Materials for advanced piston/ring/cylinder to reduce friction
- Low density materials to increase the engine power-specific weight to a level competitive with SI engines

b. Emission Control

- Improved materials for lubricant control to reduce particulate emissions
- Lean burn NOx catalysts
- Advanced materials for particulate traps
- High strength, non-galling, wear-resistant materials for high-pressure fuel injection systems to reduce particulate emissions

c. Fuel Flexible Engines

- Cost-effective materials which are compatible with diesel and alternate fuels
- Stable, corrosion resistant materials for glow plugs
- Durable wear and corrosion-resistant intake valves, valve seats, and valve guides to increase the durability of natural gas engines

d. Other Applications

- Cost effective alternate materials and designs to reduce mechanical losses in transmissions and axles
- Cost effective alternate materials and designs to reduce parasitic losses in shaft-driven auxiliaries

The Heavy Vehicle Propulsion System Materials Program will work with the diesel engine companies and suppliers to develop the enabling materials technology for low-emission, high efficiency diesel engines.

The High Temperature Materials Laboratory (HTML) will continue to support the heavy vehicle industry through the operation of its User Centers via the HTML User and Fellowship Programs. These programs make available the sophisticated equipment and skilled staff necessary to characterize advanced materials. The HTML has the capability to measure microstructure and microcomposition down to the atomic level, mechanical failure phenomena (creep, fast fracture, and fatigue), thermophysical properties, crystal structure, and residual stresses. These capabilities are important and relevant to the critical materials issues noted above.

5. Natural Gas Storage

To increase utilization of natural gas as a heavy vehicle fuel, problems have to be solved in the area of natural gas storage. This program plan supports the strategy of research and development of state-of-art natural gas components and systems that will meet the needs of the 50 percent thermal efficient future natural gas engine. One specific project need is the development of onboard high pressure fuel delivery systems because LNG tanks are currently designed for much lower holding pressures than required by direct natural gas fuel injectors. Other projects include: testing of conformable tanks, developing smark tank technologies, developing low pressure storage, studies on natural gas storage for heavy vehicle market penetration, and demonstrating the advantages of LNG/CNG refueling. Performance measures for this activity are developing safe, reliable, cost efficient components for heavy vehicle storage. Performance goals are as follows:

1. Forty percent more onboard storage than compressed gas cylinder by using conformable tanks.
2. Reducing life cycle cost by 25 percent for natural gas storage for heavy vehicles.
3. Increasing hold times, reliability and reducing boil-off for LNG storage.
4. Conserving 15 percent of the energy fuel value of natural gas through improving storage tank design, fuel delivery systems and fuel integration strategies.

6. Environmental Issues of Heavy Vehicles

As medical and environmental research continue to indicate that current levels of air pollution are damaging human health and the environment, National Ambient Air Quality Standards are becoming more stringent. Fortunately, better understanding of the relationships between

various emissions and air quality are helping to target those emissions sources that have the greatest impacts on pollution. Transportation fuel production, distribution, storage, and combustion have been shown to be major emissions sources affecting many pollutants of interest, and heavy vehicle use accounts for a large fraction of these emissions. Alternative fuels may have the capability to greatly reduce the air pollution contribution of transportation.

The objectives of this effort are to improve the understanding of the effects of diesel engine emissions on air quality and human health, and to examine potential air quality benefits and/or problems that would be caused by the widespread use of alternative transportation fuels in heavy vehicles. This will largely be accomplished by (1) participation and support for studies of diesel emissions and their health effects, (2) identification of major air quality problems affected by fuel-related sources, (3) examination of emissions from heavy vehicles running on diesel, biodiesel, CNG, LPG, methanol, ethanol, and other fuels of interest, and (4) the study of the transport and fate of the pollutants and/or their precursors.

Specific task areas are as follows:

- Analysis of Current Estimates of Heavy Vehicle Impacts on Air Quality.
- Analysis of Current Diesel and Alternative Fuel Emissions Measurements.
- Analysis of the Atmospheric Processes of Heavy Vehicle Emissions.
- Examination of Driving Cycle, Vehicle Class/Type, and Vehicle Activity Data.
- Collection of Diesel and Alternative Fuel Emissions Measurements.
- Modeling Air Quality Impacts from Heavy Vehicles.
- Strengthening the understanding of air quality health effects.

VI. IMPLEMENTATION PLAN

A. MANAGEMENT PLAN

1. Program Management

Management of the Heavy Vehicle Technologies R&D Program is the responsibility of the Director of the OHVT, who reports to the Deputy Assistant Secretary for Transportation Technologies. The OHVT Director is responsible for implementing agency policy, establishing program goals and objectives, formulating and modifying the program plan, justifying and allocating resources, coordinating the various program elements, establishing priorities among program activities, evaluating progress, coordinating with other government and private sector organizations, and reporting to senior DOE management.

The authority for day-to-day operation of the program activities is assigned to the Team Leaders of three major elements within the program, namely, (a) Heavy Vehicle Engine Technologies R&D, (b) Heavy Vehicle Systems Technologies R&D, and (c) Fuels and Lubrication Technologies R&D). Team Leaders at DOE headquarters lead budget requests, evaluation and control of program activities, and assessment of new research initiative opportunities.

Figure 13 shows the DOE/OHVT organizational structure.

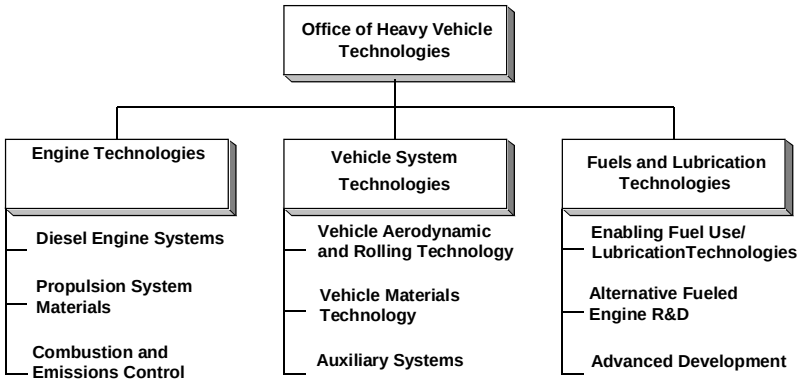


Figure 13. Heavy Vehicle Technologies Program Management

Project selection is based on priorities as established by the Technical Roadmap and Steering Committee and available budget. Research and development projects are placed through procurements and non-procurement mechanisms identified in Figure 14, with industry,

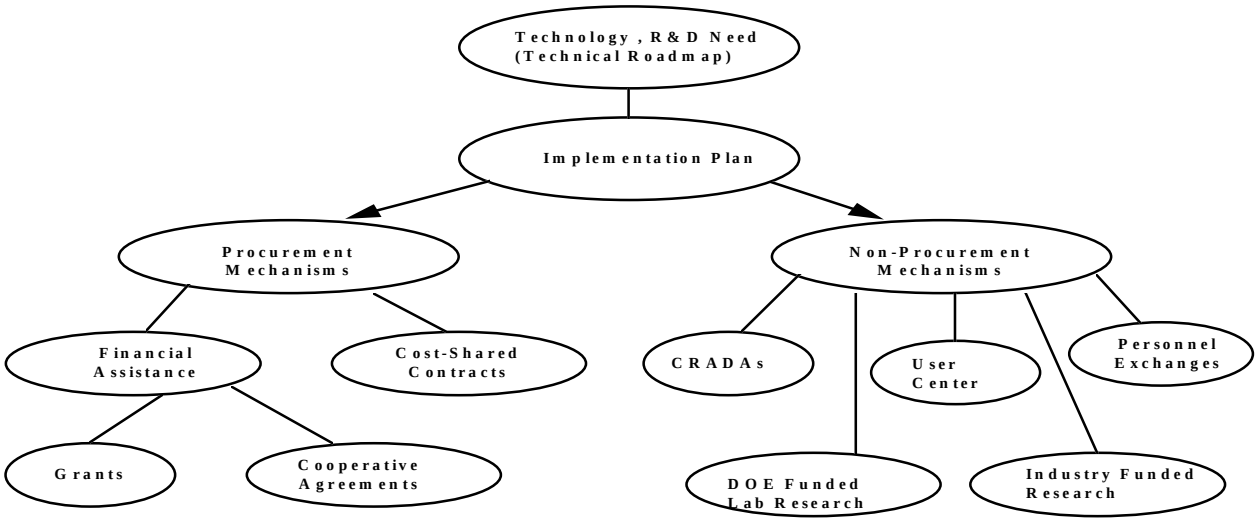


Figure 14. Project Implementation Paths in OHVT.

academia, independent researchers, and national laboratories. Quarterly review meetings are held by the DOE Program Office to coordinate program activities. Regular visits are made to program customer sites to review program progress, discuss the state of heavy vehicle technology, and elicit industry input on program direction and recommendations of technical areas that should be considered for inclusion within the program.

Several DOE field offices are utilized in support of R&D activities. Specific functions performed by the field offices include contract negotiations, contract and government administration, and program financial monitoring and control.

In addition to their participation in specific barrier-focused R&D projects, the DOE laboratories also assist DOE/HQ in program planning, technical assessments, strategic analysis, and technology benchmarking. Research and development projects are occasionally procured through the labs when there is a particular advantage, and in those situations the labs carry out the technical project management.

Regular reporting is critical to effective management control. Researchers and subcontractors are responsible for preparing regular progress reports for DOE, some of which are transmitted through the DOE laboratories.

In addition to written reports, program review meetings are held. Representatives from the lead laboratories report on their activities and review the results of research. The reviews are conducted to ensure that research results are of the highest quality and to maintain communication among the research centers. In addition, the annual Customers' Coordination Meeting provides a forum for program planning, coordination, and review of Federal legislative requirements.

2. Performance Plans and Reporting

The Government Performance and Results Act of 1993 requires that government agencies have quantifiable goals and plans to facilitate program management. The act requires a Strategic Plan by September 30, 1997. Each agency is required to prepare a Performance Plan for each program activity set forth in the budget. The Performance Plan is to establish goals and to express the goals in quantifiable, measurable form, describe the resources required to meet the goals, provide a basis for comparing actual program results with the established performance goals, and describe the means to be used to verify and validate the measured values. Lastly, beginning no later than March 31, 2000, each government agency is required to prepare annual Program Performance Reports for the previous fiscal year.

The OHVT is in compliance with the Government Performance and Results Act and will continue to comply. The Department of Energy published a Strategic Plan in April 1994, and is revising the plan in consultation with the Congress. The OTT published a strategic plan in August 1996. These Strategic Plans include mission statements, strategic issues, general goals and objectives, and major milestones. The OHVT prepares an annual Program Execution Plan (PEP) for each program within the office. The PEP includes detailed, measurable milestones, hardware and document deliverables, and resource plans as required by the act. At the conclusion of fiscal year 1999, and each year thereafter, OHVT will prepare an annual Program Performance Report comparing performance in the past fiscal year to the performance plans.

B. GOVERNMENT/INDUSTRY COORDINATION

Participation and input from OHVT's customers (Figure 15) have been solicited early in the planning process through a series of customer-focus workshops to identify the critical R&D needs and define the R&D thrusts to meet those needs. In addition, program managers have been conducting continuous consultation with industry, institutions of higher education, DOE national laboratories, and professional and technical societies in developing a comprehensive approach to deploying advanced heavy vehicle technologies in the transportation sector. Results from these customer outreach activities have been incorporated in the **Heavy Vehicle Technologies Roadmap** and specific R&D activities have been identified and are now outlined in this Multi-Year Program Plan.

Customer participation in the research and development will be key to the successful implementation of the program plan described in this document. The technical program focus is on the critical technologies where there is a strong consensus for industry and government collaboration and for which industry will have a prime role. Teaming arrangements are encouraged for broader participation of the industrial technical community and to ensure that activities are focused on potential commercial applications. Industry contractors are expected to cost-share 20 to 50 percent of direct R&D expenses, with each additional indirect cost-sharing. The program also encourages participants to pool their resources and work with

Heavy Vehicle Technologies R&D Customers

- Diesel Engine Manufacturers
- Heavy Vehicle Manufacturers
- United States Automakers (truck divisions)
- Component Manufacturers
- Alternative Fuel Developers/Producers
- Materials Suppliers
- Catalyst manufacturers
- Universities
- Truck users (e.g., fleet operators)

Figure 15. Heavy Vehicle Technologies Customers

each other and with the Government in pre-competitive technology areas. The ***OHVT Executive Steering Committee*** has been established to guide OHVT research and development activities. The Committee provides essential input and industrial perspective on the technologies pursued to ensure that DOE program funds are directed to the most important problems and issues critical to the heavy vehicle industry.

C. INTRA- AND INTER-AGENCY COORDINATION

The Heavy Vehicle Technologies R&D Program closely coordinates planning and R&D implementation with other related activities within DOE and other agencies. In addition to DOE, a number of Federal and state agencies are sponsoring or planning work in Heavy Vehicle Technologies with substantial cost-sharing from industry.

Examples of coordinated efforts in diesel technology development include:
OHVT efforts in Diesel engine technologies development are coordinated through the following: a) ***DOE2000*** pilot ER/EE collaboratory projects on Diesel Combustion and Materials Micro-characterization (of lean-burn NOx catalysts, coordinated and integrated through the DOE2000 infrastructure to enable concurrent research on Diesel emissions control; and b) ***Cross-cutting Diesel Engine Technologies Development Team***, chaired by DOE and with representation from the Partnership for a New Generation of Vehicles/Compression-Ignition Direct-Injection (PNGV/CIDI) Tech Team, Diesel Technologies Development Team, Department of Defense/Tank-Auto Command (DOD/TACOM), and the EPA. Heavy Vehicles Materials Technology research is coordinated through the Energy Materials Coordinating Committee (EmaCC).

The OHVT participates in collaborative R&D and coordination in fuels strategies with the International Energy Agency Alternative Fuels Committee.

D. TECHNOLOGY TRANSFER

The Heavy Vehicle Technologies Program strategy is to support the research and development of advanced technologies directly with the engine and vehicle manufacturers, and the fuel developers/producers who are ultimately responsible for commercializing the end products. This ensures transfer of the technology to the appropriate customers and the benefits from Federally-sponsored research is utilized in a timely manner. Industry participates through Government cost-shared R&D contracts and cooperative agreements and Cooperative Research and Development Agreements (CRADAs) with DOE laboratories. These cooperative programs provide direct feedback from industry on the usefulness of the research results to their critical needs. Also, with the technical agenda performed jointly by industry, national laboratories, and universities, collaboration provides considerable opportunity for interdisciplinary review of technology needs, definition of problems requiring solutions, and ready transfer of research results to the technology users.

Wide dissemination of results from DOE-supported R&D is also accomplished through licensing of patented technologies, publications in technical and trade journals, presentations at technical society meetings, workshops, and contractor coordination meetings. Program review meetings provide a particularly effective means of exchanging information within the program. These forums allow direct interaction between the federal laboratory and industry researchers, facilitate the building of collaborative relationships, and promote technology transfer.

VII. RESOURCE PLAN/REQUIREMENTS

The resource requirements to carry out the first five years of this plan were developed with consideration of the substantial technical challenges, yet large benefits. In addition, the budget requirements factor in the cost share, 50 percent, for the parts of the program that directly involve industry.

Leveraging of federal resources has been achieved by joining or coordinating with related activities such as:

-CIDI crosscutting effort with PNGV
-DOE 2000 effort with DOE/ER (DOE/ER FY 97 contribution was $2.7 million)
-Advanced propulsion development in DOD
-Fuels development in DOE/FE

The total DOE/EE OHVT funding requirements are outlined in Table 7. These resources will support, at an appropriate level, the barrier-driven R&D needed to realize the fuel-saving technologies described in this plan.

Table 7 . Resource Plan for OHVT
($k)

Budget Sector and Key Activities	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
I. Advanced Heavy Vehicle Technologies								
A. Heavy Vehicle Systems R&D	7,100	12,900	33,200	45,500	49,000	55,000	43,500	45,000
1. High Efficiency Engine R&D (light truck diesel technology, combustion and emission reduction enabling R&D)	7,100	11,200	22,000	24,500	25,000	27,000	6,000	6,500
2. Vehicle Systems Technologies (enabling R&D electric/hybrid commercial truck)	--	1,700	10,000	19,000	22,000	22,500	35,000	36,000
3. Vehicle Systems Technologies (enabling R&D for 10 mpg heavy truck)	--	--	1,000	2,000	2,000	2,500	2,500	2,500
B. Heavy Vehicle Alternative Fuels R&D (engine R&D for natural gas, enabling technology R&D for fuel flexibility)	12,400	12,700	11,000	15,000	17,000	17,000	18,500	18,000
II. Transportation Materials Technologies								
A. Heavy Vehicle Materials Technology	7,800	8,050	7,300	14,200	16,300	18,300	19,300	19,900
1. Heavy Vehicle Propulsion System Materials	5,000	4,950	6,300	8,500	9,500	10, 500	11,200	11,800
2. High Strength Weight Reduction Materials	2,800	3,100	1,000	5,700	6,800	6,800	8,100	8,100
B. High Temperature Materials Laboratory	4,700	5,200	5,500	6,200	6,500	6,700	6,700	6,900
TOTAL	**32,000**	**38,850**	**57,000**	**80,900**	**88,800**	**97,000**	**88,000**	**89,000**

APPENDIX A

List of Acronyms

C_d	Drag Coefficient
CIDI	Compression Ignition Direct Injection
DEE	Diethyl Ether
DI	Direct Injection
DME	Dimethyl Ether
DOE	Department of Energy
EGR	Exhaust Gas Recirculation
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FTP	Federal Test Procedures
GDP	Gross Domestic Product
GVWR	Gross Vehicle Weight Rating
HTML	High Temperature Materials Laboratory
IDI	Indirect Injection
LDT	Light Duty Truck
NMHC	Non-Methane Hydrocarbons
NREL	National Renewable Energy Laboratory
NTP	Non-Thermal Plasma
NVH	Noise, Vibration, and Harshness
OHVT	Office of Heavy Vehicle Technologies
ORNL	Oak Ridge National Laboratory
OTT	Office of Transportation Technologies
PEP	Program Execution Plan
PING	Pilot Ignition Natural Gas
PNGV	Partnership for a New Generation of Vehicles
R&D	Research & Development
SI	Spark Ignition
SING	Spark Ignited Natural Gas
SNL	Sandia National Laboratory
SUV	Sport Utility Vehicle
ULEV	Ultra Low Emission Vehicle