3.6 Natural Gas Vehicles

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Natural Gas Vehicles

3.6.1 Technology Summary

Overview

Natural gas (in both compressed and liquefied form) use in vehicles is a promising alternative fuel in terms of cost-competitiveness, domestic sources, vehicle performance, and potentially low emissions of criteria pollutants and greenhouse gases. Significant environmental and energy efficiency benefits are possible. Natural gas combustion results in no emissions of lead or visible particulates and almost no toxic emissions. There would also be major reductions in most other key pollutants (especially non-methane hydrocarbons) and greenhouse gases (provided that methane is adequately captured and controlled during extraction from wells). Use of natural gas in its gaseous or liquid form is extremely efficient, compared with use of petroleum-based transportation fuels, when the total life-cycle of the fuel is considered (extraction, processing, and final use in a vehicle).

A significant increase in natural gas use in vehicles will not be possible unless it is economically viable and attractive to consumers in terms of safety and fueling. Acceptance of natural gas vehicles depends on total costs that are competitive with traditional fuels. Total costs consist of both direct and indirect costs. Direct costs are associated with capital and operational costs and are more easily addressed by R&D, in contrast to indirect costs, which are harder to quantify. Indirect costs include hedonic costs (for example, inconveniences associated with fueling or lack of fueling sites), cost of environmental emissions, cost of energy security, and perceived or real future supply constraints.

As a first approximation of economic feasibility, operational costs of a natural gas vehicle must be low enough to offset the additional capital costs inherent in natural gas on-board-fuel-storage systems compared with those for gasoline or diesel fuel. (Currently, approximately one-half of the incremental capital cost of a natural gas vehicle is due to the cost of its on-board fuel storage.) Operational costs consist of cost of the fuel used by the vehicle (affected by vehicle configuration and engine efficiency), maintenance costs, and costs associated with vehicle replacement (durability). Fuel cost itself is important and includes the cost of fuel extraction, processing, distribution infrastructure, and taxes. Safety is reflected in direct insurance costs and indirect costs associated with personal injury and property damage. This plan addresses technologies that reduce direct costs and some indirect costs, such as ease or difficulty of fueling.

Critical R&D needs for natural gas vehicles, identified through discussions with industry stakeholders, universities, and national laboratories are as follows:

- Lower capital cost of natural gas vehicles.
- Improved vehicle efficiency (especially engine efficiency) and improved component durability and reliability (which affect operational costs).
- Improved safety and means to ensure integrity of vehicle fuel system.
- Improved fuel availability (fueling infrastructure).

Medium- and heavy-duty fleets that are centrally fueled are the logical niche for early market entry of natural gas in transportation. The advantages of clean-burning natural gas in air-quality nonattainment areas is seen as a key benefit. As natural gas infrastructure expands to supply fleet operations normally centrally-fueled, additional markets (like taxis and automobiles) can be accommodated as publicly accessible fueling stations are added to the distribution base. Tractor trailers (Class 8 trucks) offer a promising near-term application of LNG technology. Locomotives also provide an early market entry for LNG.

Department-Wide Program

The transportation sector of the United States faces major energy, environmental, and economic challenges. Petroleum is used to supply 97 percent of the transportation sector's energy needs, and transportation consumes approximately two-thirds of the Nation's oil demand. The number of vehicles and miles driven continue to increase. As a result, U.S. oil import demands continue to rise – oil imports are expected to rise from 8 million barrels per day (bpd) in 1995 to almost 10 million bpd in 2010. Worldwide oil reserves are becoming more concentrated in few countries, many of which are politically unstable and are opposed to U.S. interests. Emissions from transportation sources cause concern related to air quality and global warming potential. Also, there are concerns about U.S. ability to compete with imported cars and trucks which are perceived to be technologically superior to U.S. products.

DOE's Office of Transportation Technologies (OTT) and other Federal programs are working toward a "revolution" in transportation technologies which will enable significant reductions in petroleum use and move toward a cleaner, sustainable, geographically-distributed fuels base. DOE is coordinating transportation technology

Natural Gas Van at a Fuel Pump

activities involving the combined effort of industry, national laboratories, universities, and fuel suppliers.

Program Activity Summary

OTT's vehicle-related R&D is divided into two customer-focused offices: (1) Office of Heavy Vehicle Technologies (OHVT) and (2) Office of Advanced Automotive Technologies (OAAT). The overall goal of OHVT is to develop, by 2004, the enabling technologies needed to achieve fuel flexibility, ultra-low emissions, and 10 mpg efficiency in Class 7 and 8 trucks, while simultaneously devolving these technologies to Class 1 through 6 trucks, with Class 1 and 2 trucks achieving at least a 35 percent mpg improvement over current gasoline fueled trucks. The overall goal of OAAT is to research, develop, and validate technologies that will enable domestic market introduction of light vehicles which have (a) several times the fuel economy of current, comparable conventional vehicles, (b) fuel flexibility, (c) emissions that comply with statutory limits projected to be in place when the vehicles are available for the marketplace, and (d) other attributes, such as price, that render them competitive with conventional products.

FY 1996-1998 Crosscut Budget Summary ($ in Millions)

Program	FY 1996	FY 1997	FY 1998
OHVT Natural Gas	6.79	7.24	8.00
OAAT Natural Gas	0.65	1.52	2.65
Total	**7.44**	**8.76**	**10.65**

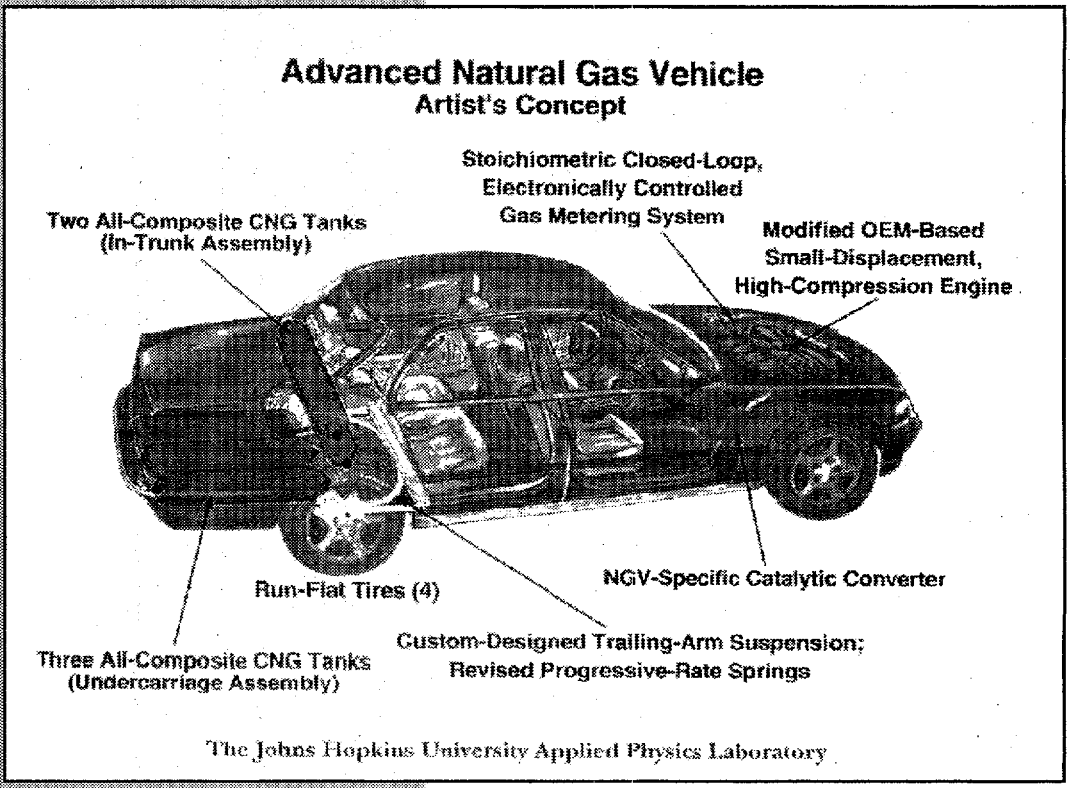
Program Schedule

The following program schedule outlines the major milestones within the natural gas R&D portion of OTT's technology portfolio.

Program/Milestones		Year	
	2000	2004	2006
Office of Heavy Vehicle Technologies (OHVT)			
Engine	Advanced spark-ignited natural gas engine	Advanced natural gas engine, diesel-like thermal efficiency	
Storage	More comprehensive liquefied natural gas (LNG) tank standards		
Office of Advanced Automatic Technologies (OAAT)			
Vehicle system	5% improved fuel economy compressed natural gas (CNG) vehicle		10% improved fuel economy CNG vehicle
Joint OHVT/OAAT			
Storage	"Smart" CNG tanks	Improved CNG tank materials	Improved fuel system integrity
Fueling Infrastructure		Lower-cost fueling stations	

3.6.2 Project Descriptions

The Office of Heavy Vehicle Technologies (OHVT) and Office of Advanced Automotive Technologies (OAAT) carry out the natural gas vehicle-related R&D within the Office of Transportation Technologies (OTT). OHVT focuses on the development of fuel-efficient, fuel-flexible, environmentally acceptable, and economical heavy vehicles (Class 1-8 trucks, transit and school buses, off-highway vehicles, inland marine vessels, and locomotives). OAAT focuses on development of advanced automobiles. The following sections are divided into heavy vehicle R&D, administered by OHVT, and automotive R&D, administered by OAAT.



3.6.2.1 Heavy Vehicle R&D

Background

The transportation sector will continue to be the single largest user of petroleum in the U.S. as the demand for goods and services continues to grow into the next century. Currently, over 8 million barrels of oil are consumed each day by highway vehicles. Oil use is split evenly between automobiles and trucks (Class 1-8). Many Class 3-6 trucks are commercial vehicles that are centrally fueled; half by gasoline, and half by diesel fuel. Most Class 7-8 trucks run on diesel fuel. Because of concerns over fine particulate matter and nitrogen oxide emissions from diesel engines, natural gas has been cited as a potential alternative fuel having low particulate matter and nitrogen oxide emissions that can be used in modified heavy duty diesel engines.

Because natural gas burns cleanly, lower maintenance costs are projected for natural gas compared to diesel fuel. Drawbacks to using natural gas in heavy duty engines are lower efficiency than diesel fuel, and a lesser energy-density (as CNG) than diesel fuel, resulting in a lower range between fuelings. Another barrier is high first costs -- a heavy duty natural gas engine (including storage tank) costs about $15,000 more than a comparable diesel engine. While natural gas in liquefied form largely solves problems associated with range between fuelings (as it is more energy dense than CNG), problems associated with storage of cryogenic liquid must be addressed.

Major Goals

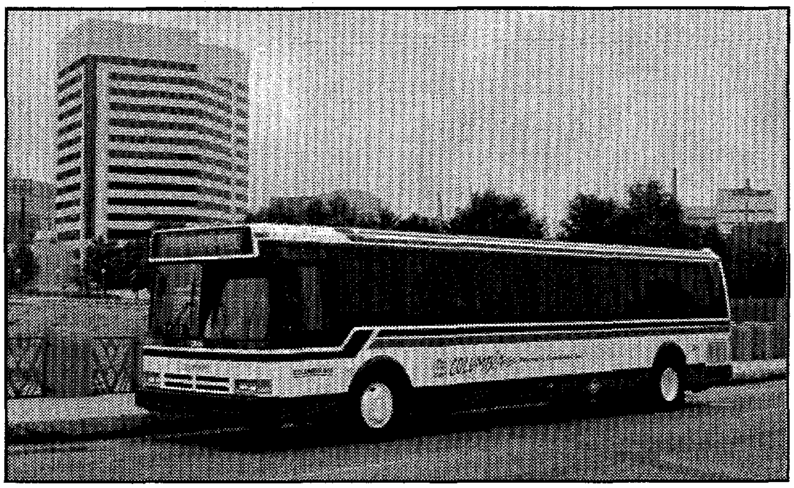
The goal of natural gas vehicle R&D for heavy vehicles (trucks, buses, off-highway vehicles, inland marine vessels, and railroad locomotives) is *to develop technologies that will enable the use of liquefied natural gas, compressed natural gas, and adsorbed natural gas (where applicable) in heavy vehicles with diesel-like thermal efficiency, ultra-low emissions, acceptable range, convenience of fueling, safety, and level of acceptance, including life-cycle costs similar to those of diesel-powered heavy vehicles.* Many Class 3-6 trucks are commercial vehicles that are centrally fueled, while many Class 7-8 trucks are tractor-trailers and refuse haulers. While the OHVT natural gas program is divided into two broad categories (Class 3-6 trucks and Class 7-8 trucks), other applications are served as well. Buses have engine systems common to trucks and are an integral part of the program. With modifications, many technologies developed for trucks could also be applied to inland marine vessels and locomotives. Therefore, natural gas inland marine engines and locomotives are also important elements of the program.

Project Objectives

The objectives for Class 3-6 trucks are as follows:

- By 2000, improve the full-load thermal efficiency of the typical spark-ignited natural gas engine from the existing 38-40 percent while meeting or exceeding emission standards for gasoline vehicles for that model year.
- By 2004, develop diesel-like thermal efficiency for a natural gas engine (about 45 percent thermal efficiency at full load) while meeting or exceeding

Natural Gas Powered Bus



emission standards for gasoline commercial heavy-duty trucks for that model year.

The objectives for Class 7-8 trucks are as follows:

- By 2000, assist industry and the appropriate agencies in developing appropriate safety standards for on-board LNG, including the issue of long-term on-board storage.
- By 2004, improve the full-load thermal efficiency of the natural gas engine from the current 38-48 percent while meeting or exceeding emission standards for heavy-duty trucks.

The objectives related to CNG are as follows:

- By 2000, develop "smart" CNG tanks that provide real-time sensing of important tank parameters, such as structural integrity, and are capable of responding appropriately to hazardous deterioration. R&D needs are in the area of sensor signal processing, system integration, and performance validation.
- By 2004, develop improved metallic and nonmetallic structural fuel tank materials that improve CNG containment.
- Develop tank standards of construction to improve the current fuel-system integrity standard from 15 years to 20 years by 2006.

The objective related to fueling infrastructure is as follows:

- By 2004, reduce the cost of fueling stations by 50 percent from 1996 levels.

Expected Benefits

Argonne National Laboratory estimated benefits of natural gas in the truck market. Assuming advanced CNG engines enter the market in 2004, peak market share for CNG in medium trucks (Class 3-6) is estimated to be 9 percent. Of centrally-fueled Class 3-6 trucks in EPACT Metropolitan Statistical Areas, the technology would capture a 33 percent peak market share. Petroleum displaced under this scenario would be 10,000 barrels of oil (equivalent) per day in 2010, and 50,000 barrels of oil (equivalent) per day in 2020. Particulate matter emissions would be reduced at the same time.

By avoiding imported oil, the balance of trade improves. Approximately one job is created for each 50 barrels per day of avoided oil imports, based on a study of advanced automotive parts by Argonne National Laboratory. Applying this factor to the heavy vehicle natural gas program, about 1,000 new jobs would be created by 2020.

Planned Products

Engines

- Improve basic understanding of design parameter effects (such as combustion chamber geometry, injection characteristics, and ignition characteristics) on performance and in-cylinder NO_x production.
- Develop improved metering components and control strategies for metering natural gas to optimize engine performance under a wider range of speeds and loads typical for heavy duty applications.
- Develop improved ignition systems (spark ignition, pilot ignition, and ignition-assists for direct injection).
- Develop "feed forward" sensors that enable engines to optimize performance for any fuel used.
- Develop reliable, lean misfire detection sensors and systems.
- Reduce throttling losses through the use of "skip-fire," Miller cycling, intake air heating, exhaust gas recirculation, and turbocharger waste-gate control.

- Develop improved control strategies and systems for advanced sensors and actuators.
- Develop improved nonfouling micro-pilot lube-oil injectors.
- Develop alternative fuels for pilot ignition engines (e.g., dimethyl ether).
- Develop a reliable, high-pressure fuel injector or common rail fuel system for direct injection of natural gas.
- Improve waste heat recovery.
- Develop novel enrichment techniques, such as on-board reforming, to produce a hydrogen-rich fuel for leaner operation.

Vehicle Fuel Systems – LNG

- Develop methods that would reduce or eliminate vapor releases.
- Develop a small, low-cost, high-pressure (3-4 kpsi) LNG pump for direct injection of natural gas.
- Develop "rapid pressure build" technology for *low-pressure* LNG (~100 psi) applications.

Vehicle Fuel Systems – CNG

- Develop a small on-board, cost-effective, high-pressure (3 kpsi) CNG compressor for direct injection technology.
- Develop lower-cost, lighter-weight CNG tanks.
- Develop cost-effective tank manufacturing techniques.
- Develop conformable CNG tanks and integrate them into vehicle structure.
- Develop improved adsorption techniques to increase on-board storage capacity for CNG.

Safety

- Assist industry and appropriate agencies in developing standards for handling, storing, and odorant "tagging" of LNG to ensure acceptance.
- Assist in development of a single, concise document that communicates LNG fundamentals, hazards, and safety measures to officials responsible for local siting of LNG fueling stations.

Fueling Infrastructure

- Continue to develop LNG corridors.
- Support city gate expansion to LNG development.
- Develop lower-cost LNG pumps and meters/dispensers.
- Develop small-scale, high-efficiency, lower-cost CNG compressors through the use of new materials and improved designs.
- Reduce costs by improving auxiliary components like oil separators, filters, dryers, sensors, and fuel dispensers.

Strategy (FY 97 Funding: $7.24 Million)

OHVT's R&D on natural gas trucks will initially have two thrusts: (1) LNG- and CNG-fueled heavy-duty Class 7-8 trucks that are centrally fueled, and (2) CNG-fueled Class 3-6 commercial vehicles (including buses). In addition to trucks, OHVT will develop natural gas-related technologies specific to railroad locomotives, off-highway vehicles, and inland marine vessels.

The strategy is to focus on developing technology and infrastructure to enable market entry of natural gas vehicles into those applications that are centrally fueled. The majority of centrally fueled vehicles are located in air-quality nonattainment areas, and clean-burning natural gas will have positive environmental consequences in these areas. It is envisioned that the commercialization of natural gas in vehicles will proceed from centrally-fueled urban buses (as CNG and LNG) to centrally-fueled Class 3-6 commercial trucks (as CNG), as well as to centrally-fueled Class 8 trucks (as LNG).

Finally, natural gas technologies will be developed for railroad locomotives (as LNG) and for off-highway vehicles and inland marine vessels (as either CNG or LNG). Activities will be closely coordinated with the natural gas program in OAAT where there is mutual interest, such as engine NO_x control and CNG fuel system, safety, and fueling infrastructure.

Recent Accomplishments

The following section summarizes recent accomplishments in two key areas of natural gas use in heavy vehicles.

Advanced Natural Gas Engine, Diesel-Like Thermal Efficiency—Development of a commercially viable, direct-injection (DI) natural gas engine in a four-stroke diesel cycle is seen as a key enabling technology to meeting the "stretch" goal of achieving diesel-like thermal efficiency in natural gas engines. Progress has been made over the past year in this area by Caterpillar on their model 3516 multi-cylinder engine (4.3 liters/cylinder, 16 cylinders). As of 1996, the engine has accumulated a total of 225 hours and has been to 1,500 rpm and 1,475 kW (95 percent of rated diesel power). Based on results, the key area needing improvement is the sealing of high-pressure natural gas inside the gas injector, and the glow plug ignition system. R&D in this area will begin in 1997. Also, comprehensive durability and emissions data will be obtained.

Advanced Spark-Ignited Natural Gas Engine—An ultra-safe, ultra-low emissions alternative fuel school bus, using a CNG-fueled, spark-ignite engine, was developed and is undergoing prototype testing by Southwest Research Institute. A key portion of this project is refinement of the natural gas engine. Lean operation of the engine was improved. The control system algorithms were improved for better steady-state and transient operation. In addition, various fuel metering devices, new methods for wastegate control, knock and misfire detection, and catalyst condition monitoring were investigated.

Program Funding

The following table summarizes DOE program funding required to implement the heavy vehicle plan. Industry cost-share is expected to be 50 percent.

Budget Estimate ($ in Millions)

R&D Category	FY 1998	FY 1999 Estimate
Engine R&D	**6.00**	**4.50**
Compression-Ignition Heavy-Duty Engines[a]	1.00	0.70
Spark-Ignition Heavy-Duty Engines[a]	5.00	3.40
Inland Marine LNG Engines	--	0.20
Locomotive LNG Engines	--	0.20
Vehicle Fuel System	**1.35**	**1.05**
CNG Storage	0.40	0.35
LNG Storage	0.75	0.60
Storage Systems Analysis	0.20	0.10
Safety/Systems Integration	**0.65**	**0.55**
Integrated Fuel Delivery/Storage	0.40	0.30
Advanced Sensors	0.25	0.15
In-Use Inspection Technology	--	0.10
Fueling Infrastructure	**--**	**0.20**
Small-Scale Fueling Station Development	--	0.10
Compressor Technology	--	0.10
Education and Training	--	--
Total	**8.00**	**6.30**

[a] Compression ignition and spark ignition refer to engine family from which the natural gas engine is derived, not necessarily the engine cycle.

Schedule

The schedules are depicted in the following tables.

Technical Targets and Schedule: Class 3-6 Trucks			Year	
Parameter	Units	Current Natural Gas Practice	2000	2004
Engine Incremental Cost [a]	Dollars	1,000-5,000 [b]	400-2,000	150-750
Engine Efficiency at Full Load [c]		38% (SING) [d]	40% (SING)	45%
Emissions	g/bhp-h	1.4 NO_x 0.5 NMHC 2.0 CO [e] 0.03 PM	Meet or exceed EPA standards	Meet or exceed EPA standards
Engine Durability	Miles between overhauls	Better than gasoline or comparable with diesel	Better than gasoline or comparable with diesel	Better than gasoline or comparable with diesel

[a] Excludes cost of on-board fuel storage tanks. On-board fuel storage tank cost is a function of tank type, production volume, and number of tanks used per vehicle.

[b] Upper value based on estimate provided for Class 7-8 trucks by Caterpillar, Inc., Peoria, Illinois (April 1997). Lower value based on an incremental cost estimate for a CNG automobile engine relative to a conventional automobile engine.

[c] Based on lower heating value of fuel. Efficiency at half-load is approximately 90 percent of full-loadefficiency.

[d] Spark-ignited natural gas.

[e] Estimate provided by Cummins Engine Company, Indianapolis, Indiana (April 1997).

Technical Targets and Schedule: Class 7-8 Trucks			Year
Parameter	Units	Current Natural Gas Practice	2004
Engine Incremental Cost [a]	Dollars	5,000 [b]	1,000
Engine Efficiency at Full		38% (SING)	48%
Emissions	g/bhp-h	1.4 NO_x 0.5 NMHC 2.0 CO [c] 0.03 PM	Meet or exceed EPA standards
Engine Durability	Miles between overhauls	500K (comparable to diesel)	> 500K (comparable to diesel)

[a] Excludes cost of on-board fuel storage tank. Cost of on-board fuel storage tank is a function of tank type, production volume, and number of tanks used per vehicle. Cost targets for on-board fuel storage tanks are listed in the following table.

[b] Estimate provided by Caterpillar Inc., Peoria, Illinois (April 1997).

[c] Estimate provided by Cummins Engine Company, Indianapolis, Indiana.

Safety, Fuel System, and Fueling Infrastructure Goals and Schedule			Year		
Parameter	**Units**	**Current Practice**	**2000**	**2004**	**2006**
Safety, Overall	Relative to diesel	Insufficient data	Equal	Equal	Equal
	Relative to reformulated gasoline	Insufficient data	Equal or better	Equal or better	Equal or better
Vehicle Fuel Tank Monitoring (in use inspection)		Off-line	In-situ, smart tanks	In-situ, smart tanks	In-situ, smart tanks
Vehicle Fuel System Integrity	Years	15	17	19	20
Vehicle Fuel System Cost	Dollars/gallon gasoline equivalent	$100	$60	$45	$37
CNG Fueling Infrastructure Cost	Dollars relative to petroleum fuel	5X	5X	2.5X [a] (validated in 2003)	< 2.5X [b]
Fuel Quality	ASTM or equivalent standard		Meet agreed-upon standard	Meet standard & eliminate contamination	Meet standard & eliminate contamination

[a] Corresponds to a CNG compressor cost of less than $500/standard cubic feet per minute (scfm) of gas delivery, a dispenser cost of less than $15,000 (2-hose), and a dryer cost of less than $200/scfm treated.

[b] Corresponds to a CNG compressor cost of less than $300/scfm, a dispenser cost of less than $11,000 (2-hose), and a dryer cost of less than $150/scfm treated.

3.6.2.2 Automotive R&D

Background

There are over 150 million automobiles operating on U.S. highways. An overwhelming percentage of these vehicles operate on gasoline--about 4.5 million barrels of oil per day (as gasoline) are consumed by automobiles. While fuel efficiency and emissions per automobile have improved over the past two decades, the increased number of automobiles and vehicle-miles-traveled (VMT) has caused increased petroleum consumption and overall emissions from personal transportation use. Direct use of natural gas in passenger cars (as CNG) could significantly reduce reliance on imported petroleum, and reduce emissions of criteria pollutants and greenhouse gases. However, barriers to acceptance of CNG include short driving range between refuelings, high cost (especially the cost of fuel tanks), high methane emissions under certain conditions, and lack of fueling infrastructure.

Major Goals

The goal of natural gas vehicle R&D within OAAT is *to develop technologies that will enable dedicated compressed natural gas automobiles to be similar to gasoline automobiles in cost, range, fueling convenience, safety, and level of acceptance.*

Project Objectives

The objectives related to engine technology and vehicle costs are as follows:

- By 2000, validate technologies that improve fuel economy by 5 percent (miles per gallon equivalent), increase range to 300 miles, and reduce incremental vehicle purchase cost to $3,000, compared to equivalent gasoline-fueled automobiles, without reducing vehicle performance.
- By 2006, validate technologies that improve fuel economy by 10 percent (miles per gallon equivalent) and reduce incremental vehicle purchase cost to $1,500, compared to equivalent gasoline-fueled automobiles, without reducing vehicle performance.

The objectives related to CNG are as follows:

- By 2000, develop "smart" CNG tanks that provide real-time sensing of important tank parameters, such as structural integrity, and are capable of responding appropriately to hazardous deterioration. R&D needs are in the area of sensor signal processing, system integration, and performance validation.
- By 2004, develop improved metallic and nonmetallic structural fuel tank materials that improve CNG containment.
- Develop tank standards of construction to improve the current fuel-system integrity standard from 15 years to 20 years by 2006.

The objective related to fueling infrastructure is as follows:

- By 2004, reduce the cost of fueling stations by 50 percent from 1996 levels.

Expected Benefits

If CNG automobiles achieve a 2 percent share of the fleet by 2010, petroleum consumption will be reduced by about 80,000 barrels of oil (equivalent) per day. For a 5 percent share of the fleet by 2020, petroleum consumption would be reduced by about 250,000 barrels of oil (equivalent) per day. Assuming approximately one job is created for each 50 barrels per day of avoided oil imports (based on an Argonne National Laboratory study of advanced automotive parts), about 5,000 new jobs would be created by 2020 as a result of a successful CNG automobile market.

Planned Products

Engines

- Develop combustion chambers that support "mixed-mode"[1] operation.
- Develop medium pressure (~500 psi) injectors with high reaction speed.
- Develop improved ignition systems.
- Develop catalysts capable of supporting the alternately stoichiometric and lean-combustion modes of "mixed-mode."
- Develop "feed forward" sensors that enable engines to optimize performance for any fuel used.
- Develop reliable, lean misfire detection sensors and systems.
- Reduce throttling losses through the use of "skip-fire," Miller cycling, intake air heating, and exhaust gas recirculation.
- Develop improved control strategies and systems.
- Develop a bi-fuel catalyst.
- Improve waste heat recovery.
- Develop novel enrichment techniques, such as on-board reforming, to produce a hydrogen-rich fuel for leaner operation.

Vehicle Fuel Systems–CNG

- Develop lower-cost, lighter-weight CNG tanks.
- Develop cost-effective tank manufacturing techniques.
- Develop conformable CNG tanks and integrate them into vehicle structure.
- Develop improved adsorption techniques to increase on-board storage capacity for CNG.

Fueling Infrastructure

- Develop small-scale, high-efficiency, lower-cost CNG compressors through use of new materials and improved design.
- Reduce costs by improving auxiliary components like oil separators, filters, dryers, sensors, and fuel dispensers.

Strategy (FY 97 Funding: $1.52 Million)

Natural gas vehicle R&D within OAAT will focus on on-board fuel storage, efficiency improvements, and fueling infrastructure. Activities will be closely coordinated with the natural gas program in OHVT where there is mutual interest, such as safety-related technologies, CNG fuel system development, and fueling infrastructure development. In addition, R&D will be coordinated with the Partnership for a New Generation of Vehicles (PNGV).

Recent Accomplishments

The following is an example of recent accomplishments in natural gas use in automobiles.

Advanced Natural Gas Vehicle—In 1996, OTT unveiled an innovative concept for natural gas vehicles offering a range nearly double that of prior models and within 15 percent of comparable gasoline models, and a reclamation of most of the trunk space lost to the CNG tank in current retrofit designs. The vehicle was designed by a team of research organizations, component suppliers, and a vehicle manufacturer. The team assembled a high-compression, small-displacement replacement engine that increased fuel efficiency, which, in turn, increased vehicle range. The rear suspension was redesigned so that fuel tanks could be installed with minimal intrusion into vehicle cargo space. The other technology improvement was incorporation of "run flat" tire technology which does away with the

[1]The term called "mixed-mode" refers to an engine combustion process whereby the engine alternates between stoichiometrics operations and lean burn operations, depending on engine speed and load.

traditional spare tire, effectively increasing cargo space. This proof-of-concept vehicle has demonstrated its ability to meet both stringent Ultra Low Emission Vehicle (ULEV) emission standards and consumer demands for performance and convenience. Future work will focus on development of an integrated storage system (ISS) which replaces the "strapped together tanks" approach to natural gas storage, and an improved fuel injection system.

Schedule

The technical targets and schedules are depicted in the following tables:

Program Funding

The following table summarizes DOE program funding required to implement the automotive plan. Industry cost-share is expected to be 50 percent.

Budget Estimate ($ in Millions)

R&D Category	FY 1998	FY 1999 Estimate
Engine R&D	**0.45**	**0.50**
Mixed-Mode Operation	--	0.25
Efficiency Improvements	0.25	0.25
Advanced High-Efficiency Components	0.20	--
Vehicle Fuel Storage System	**1.80**	**1.00**
Lower-Cost Materials	0.20	0.50
Cost-Effective Tank Manufacturing	0.20	0.50
First Generation Integrated Vehicle Storage	0.60	--
Advanced CNG	0.80	--
Fueling Infrastructure	**0.40**	**0.50**
Compressor	0.275	0.25
Auxiliary Equipment	0.125	0.25
Total	**2.65**	**2.00**

SCHEDULE

The technical targets and schedules are depicted in the following tables.

Natural Gas Automobiles			Year		
Parameter	**Units**	**Current Practice**	**2000**	**2004**	**2006**
Vehicle Incremental Cost [a]	Dollars	4,000	3,000	2,000	1,500
Vehicle Fuel Efficiency [b]	MPGE [c]	Equal to gasoline	+ 5%	+ 8%	+ 10%
Range	Miles	150	300	380	380
Emissions	CA/Federal standard	ULEV/ILEV	ULEV/ILEV	ULEV/ILEV	ULEV/ILEV

[a] Includes incremental cost of engine and fuel system, including tanks, and assumes high-volume production.

[b] Assumes natural gas automobile has same interior space and cargo volume as a conventional vehicle.

[c] Miles per gallon, gasoline equivalent.

Safety, Fuel System, and Fueling Infrastructure Goals and Schedule			Year		
Parameter	**Units**	**Current Practice**	**2000**	**2004**	**2006**
Safety, overall	Relative to reformulated gasoline	Insufficient data	Equal or better	Equal or better	Equal or better
Vehicle fuel tank monitoring (in use inspection)		Off-line	In-situ, smart tanks	In-situ, smart tanks	In-situ, smart tanks
Vehicle fuel system integrity	Years	15	17	19	20
Vehicle fuel system cost	Dollars/gallon gasoline equivalent	100	60	45	37
CNG fueling infrastructure Cost	Dollars relative to petroleum fuel	5X	5X	2.5X [a] (validated in 2003)	< 2.5X [b]
Fuel quality	ASTM or equivalent standard		Meet agreed-upon standard	Meet standard & eliminate contamination	Meet standard & eliminate contamination

[a] Corresponds to a CNG compressor cost of less than $500/standard cubic feet per minute (scfm), of gas delivery a dispenser cost of less than $15,000 (2-hose), and a dryer cost of less than $200/scfm treated.

[b] Corresponds to a CNG compressor cost of less than $300/scfm, a dispenser cost of less than $11,000 (2-hose), and a dryer cost of less than $150/scfm treated.