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Field Operations Program—Overview of Advanced Technology Transportation

CY2000

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Field Operations Program—Overview of Advanced Technology Transportation, CY 2000

The transportation industry's private sector is adept at understanding and meeting the demands of its customers; the federal government has a role in encouraging the development of products that are in the long-term interest of the greater public good. It is up to the government to understand issues that affect public health, well-being, and security. This is reflected in the U.S. Department of Energy's (DOE) Office of Transportation Technologies' (OTT) mission—to promote the development and deployment of transportation technologies that reduce U.S. dependence on foreign oil, while helping to improve the nation's air quality and promoting U.S. competitiveness. For OTT's Field Operations Program (FOP), this means providing potential customers with unbiased information on transportation technologies that address these goals. The FOP is being implemented for DOE by the National Renewable Energy Laboratory (NREL) and the Idaho National Engineering and Environmental Laboratory (INEEL). Program managers from DOE, NREL, and INEEL must understand the transportation market well enough to focus their resources where they can have the greatest impact. Along these lines, program managers leverage program funds by partnering with other governmental and industry groups with similar goals.

In this document, we provide an overview of the transportation market in terms of energy use, vehicle sales, emissions, potential partners for the FOP, advanced technology vehicle availability, and other important factors. We do not draw conclusions from this information—that will be the function of a FOP strategy session to be held later in FY 2000. This paper provides the information necessary for the appropriate conclusions to be drawn during those sessions.

The information contained in this paper is based on several sources. A complete list of sources can be found in the appendix. Most of the statistics came from the following sources:

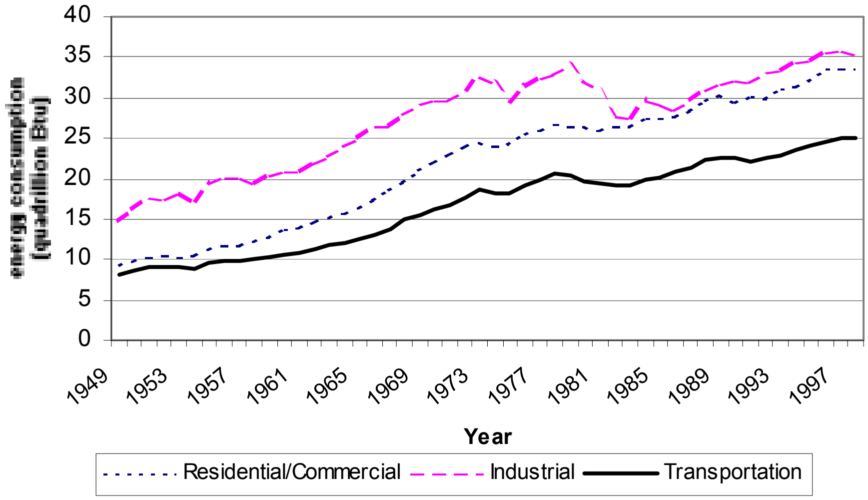
- The Energy Information Administration's (EIA) Annual Energy Review and Alternatives to Traditional Transportation Fuels.
- *Transportation Energy Data Book*, published for DOE by Oak Ridge National Laboratory.
- The U.S. Environmental Protection Agency's (EPA) National Air Pollution Emissions Trends Update 1970-1997.

These publications are usually produced annually. We used the most recent volumes available.

Transportation Energy Use

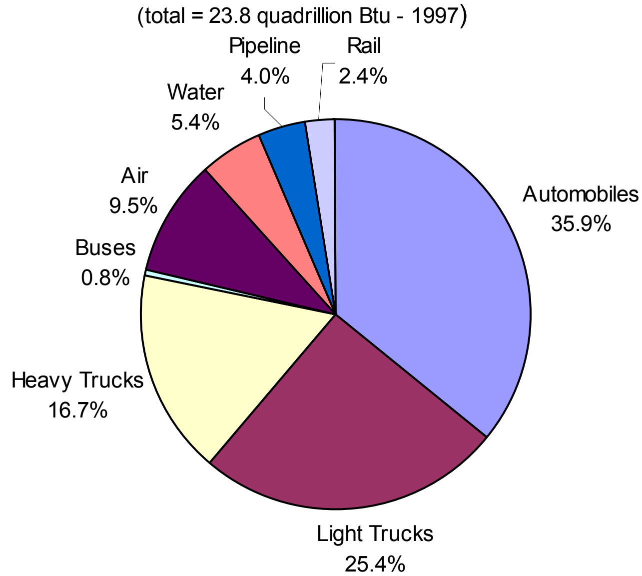
The transportation sector of the U.S. economy is a major consumer of energy. Figure 1 shows the total U.S. energy consumption from 1950 to 1999, categorized by transportation, residential, and industrial consumption. Transportation accounts for approximately 27% of the total energy consumption (94 quadrillion Btu/year) in the United States, including petroleum, coal, electricity, and natural gas (source: EIA's *Annual Energy Review*). Considering petroleum alone, transportation accounts for roughly 66% of the total yearly U.S. petroleum consumption (36.6 quadrillion Btu, or about 18.7 million barrels per day [source: *Transportation Energy Data Book* – 19th Edition, 1999]).

Figure 1. Energy Use by Sector
(EIA: Transportation Energy Data Book - Edition 19, 1999)



With transportation accounting for such a significant portion of U.S. energy consumption, it is important to understand which segments of transportation activity consume the most energy. Figure 2 shows that of total energy use for transportation (including highway and non-highway), automobiles and light trucks account for approximately 67%, heavy trucks account for 17%, and buses (including school, intercity, and transit) account for about 1%. Consumption of petroleum by automobiles and light-duty trucks exceeds that used by all other non-transportation consumers (industrial, residential/commercial buildings, and utilities). Heavy truck petroleum consumption is greater than that of buildings and utilities.

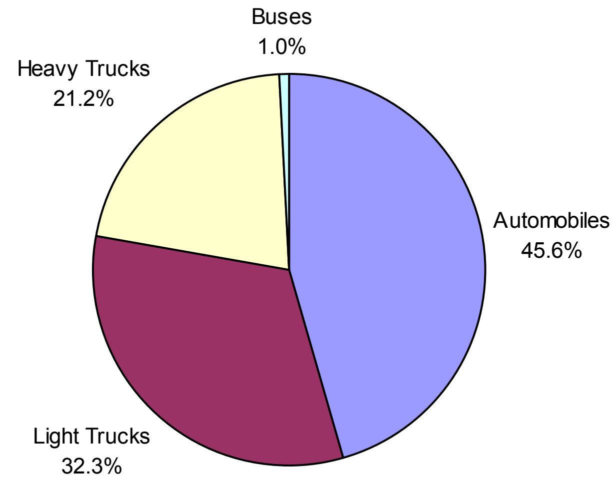
Figure 2. Transportation Energy Use by Mode
(total = 23.8 quadrillion Btu - 1997)



The FOP is primarily concerned with on-road or "highway" vehicles. Highway energy use (automobiles, trucks, and buses) accounts for about 79% of the transportation total. Figure 3 breaks down highway energy use. Automobiles and light trucks use about 78% of the highway energy use, heavy trucks use about 21%, and buses about 1%. It seems clear that from an energy-use perspective, highway transportation in general and cars and light trucks specifically provide the greatest potential for reducing petroleum usage. As an example, a 10% reduction in energy use from cars and light trucks (achieved by introducing an alternative fuel or improving fuel economy) would result in displacing nearly 750,000 barrels of petroleum per day. A similar percent reduction in petroleum energy use from heavy-duty trucks would displace around 200,000 barrels per day, and for buses petroleum consumption could be reduced by about 10,000 barrels per day. The Energy Policy Act of 1992 (EPAct) goals call for 30% displacement of imported petroleum by 2010.

Figure 3. Highway Energy Use by Mode

(total = 19.2 quadrillion Btu - 1997)



Vehicle Stock and Yearly Sales

The total number of highway motor vehicles (including automobiles, trucks, and buses) in use in the United States in 1997 was estimated to be between 205 million and 210 million. Figure 4 shows clearly that automobiles, and light (<10,000 pound) and medium trucks (between 10,001 and 26,000 pounds) dominate the total vehicle stock. Automobiles make up about 60% of the total, light trucks 35%, medium trucks 1%, heavy trucks 1%, and buses approximately 13%. The other important point to note on Figure 4 is that private individuals own about 90% of the total number of vehicles. Fleets own approximately 10%. Figure 5 shows the annual sales for 1997 and 1999 calendar years. As expected, Figure 5 shows that automobiles and light and medium trucks dominate the annual sales of vehicles. Automobiles made up approximately 53%, light trucks 44%, medium trucks less than 1%, and heavy trucks about 2% of the total annual vehicle sales in 1997. The recent rise in the light truck market is shown by the 1999 figures. Sales of light trucks were up to 46.6% of the market while automobiles dropped to 49.7%. Sales of heavy-duty trucks (3.6%) were up in 1999, showing record profits.

A market trend that has received considerable attention is the increase in market share of minivans, light trucks, and sport utility vehicles (SUVs). OTT's "Fact of the Week" (http://www.ott.doe.gov/facts) for December 6, 1999, stated: "The truck [light trucks, minivans and SUVs] share of the new light vehicle market has been growing since the early 1980s, with most of the growth attributable to SUVs and minivans. Collectively, light trucks accounted for 48% of light vehicle sales in model year 1999, with pickup trucks and vans at 22%, SUVs at 19%, and minivans at 8%." Data from this analysis (shown in Figure 6) dramatically illustrate the trend. Concern about the environmental implications of this trend has led the California Air Resources Board and EPA to tighten emissions regulations on this class of vehicles. Also, government and industry are currently considering whether to include SUVs under the Partnership for a New Generation of Vehicles (PNGV) program or to initiate a similar program for SUVs. Several automotive manufacturers have recently shown hybrid electric vehicle (HEV) SUVs and minivan concept vehicles.

Figure 4. Vehicle Stock (millions - 1997)
(EIA: Transportation Energy Data Book - Edition 19, 1999)

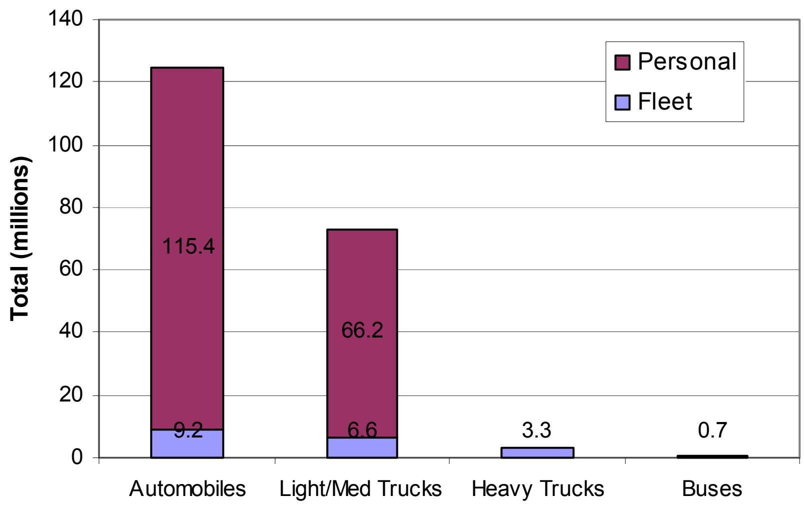
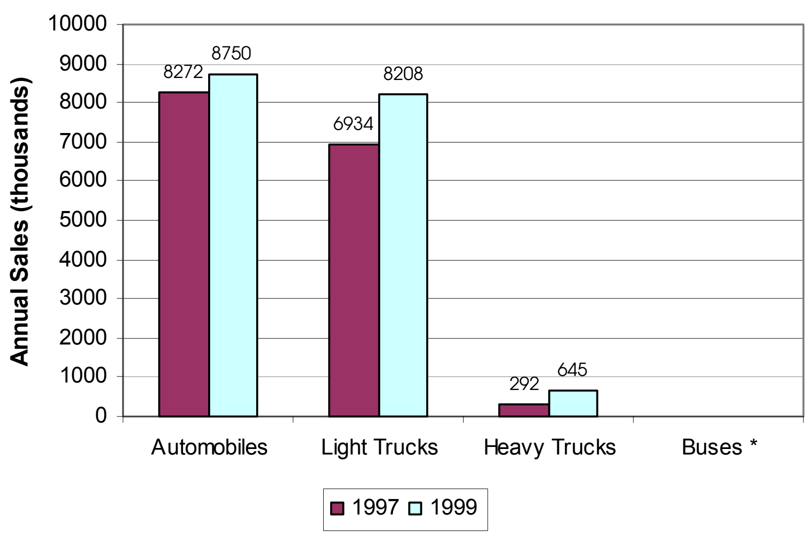
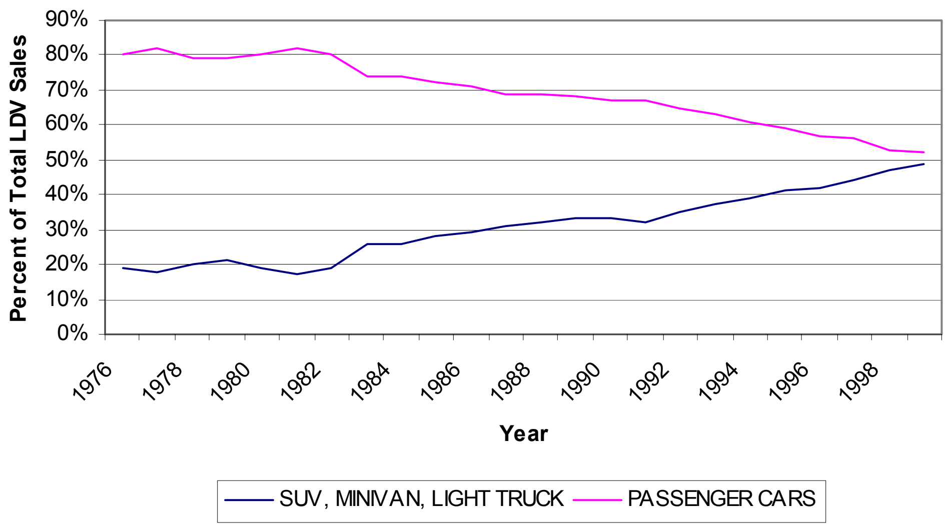


Figure 5. Vehicle Annual Sales



* Accurate sales figures for school, transit, and commercial buses are not readily available.

Figure 6. U. S. Light-Duty Vehicle Market Share



Energy Use per Passenger Mile

Of course, energy use and the number of vehicles are related—the more vehicles, the more energy used—but fuel efficiency and number of passengers per vehicle also play important roles. Figure 7 indicates how various transportation modes compare in terms of the energy used per vehicle mile traveled and the energy used per passenger mile (data were taken from the *Transportation Energy Data Book* – 19th Edition, 1999). Figure 7 indicates that although transit buses use 7 to 8 times more energy per vehicle mile than automobiles, the two modes use comparable amounts of energy per passenger mile. Intercity buses, on the other hand, use somewhat less per passenger mile. Based on the available data, the amount of energy used per passenger mile for an automobile is approximately 38% less than the energy used per vehicle. The energy used per passenger mile for a transit bus is 89% lower than the energy used per vehicle, and for intercity buses the energy used per passenger mile is 96% lower than the energy used per vehicle. The number of passengers per vehicle in a transit bus varies widely depending on the location of the service.

Emissions

As shown in Table 1, the transportation sector accounts for a large share of the national emissions of criteria pollutants. Highway vehicle emissions are somewhat less, but still make up a significant portion of the overall contribution.

Figure 7. Energy Intensities of Passenger Modes (1997)
(EIA: Transportation Energy Data Book - Edition 19, 1999)

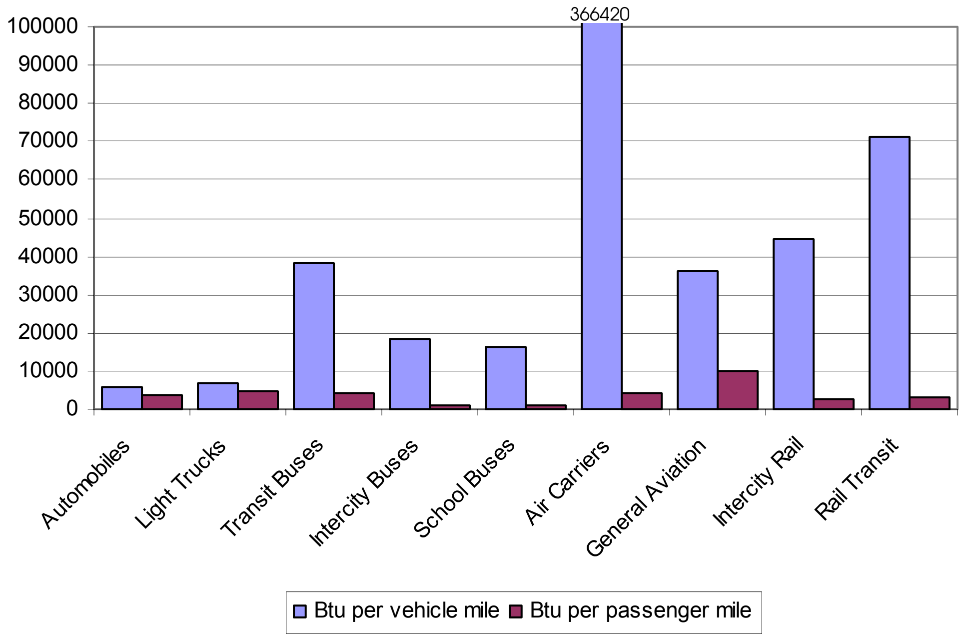
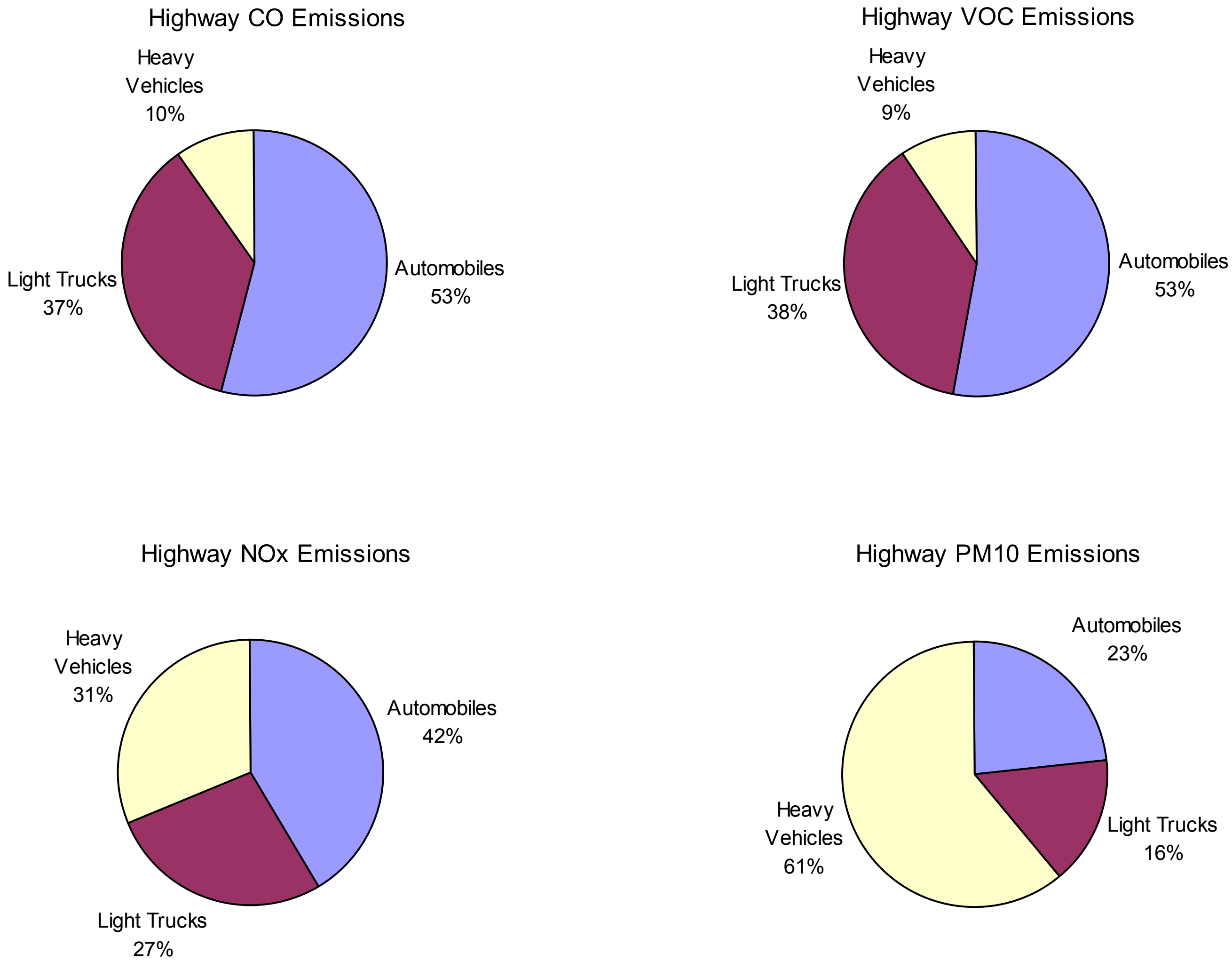


Table 1. Transportation Share of U.S. Emissions in 1997
(Source: National Air Pollutant Emissions Trends 1970-1997 - EPA)

Pollutant	Transport's Share of All Emissions	Highway's Share of All Emissions
CO	76.6%	57.5%
NO_x	49.2%	29.9%
VOC	40.7%	26.8%
PM10	2.2%	0.8%
PM2.5	7.4%	2.5%
SO_2	6.8%	1.6%
NH_3	7.5%	7.5%

Figure 8 shows that among highway vehicles, automobiles and light trucks account for most of the carbon monoxide (CO), volatile organic compound (VOC), and oxides of nitrogen (NO_x) emissions. Heavy vehicles are the source of most particulate matter (PM) emissions. Although the number of heavy vehicles (trucks and buses) on the road is less than 2% of the total number of vehicles, they account for more than 30% of the NO_x emissions and 60% of the PM emissions.

Figure 8. EPA Estimates of Highway Vehicle Emissions Distribution for CY 1997



Vehicle and Technology Trends

OTT's primary goals are to lower U.S. dependence on foreign oil imports and to reduce emissions of pollutants from vehicles. Partners within OTT represent important potential because of their relative budgets, familiarity with the technologies, strong industry contacts, and common goals. Following is a brief outline of some of the immediate focus areas in the Office of Heavy Vehicle Technologies (OHVT) and the Office of Advanced Automotive Technologies (OAAT).

The Office of Heavy Vehicle Technologies focuses on improving energy efficiency and reducing emissions from advanced diesel and natural gas engines, and on developing nonpetroleum fueled diesel engines. The most promising projects designed to meet these goals in the near term are developing clean-diesel technologies, next-generation natural gas engines, and HEVs. Clean-diesel technologies include advanced petroleum-based fuels, such as low-sulfur diesel and Fischer-Tropsch, and aftertreatment methods, such as exhaust gas recirculation and regenerative particulate traps. Although Fischer-Tropsch diesel produces lower exhaust emissions than conventional diesel, it is relatively expensive to produce and it is questionable whether it could be supplied in quantities sufficient to replace diesel in the marketplace in the near term. Because of this, use of Fischer-Tropsch will probably be limited to niche markets. OHVT goals will more likely be met in the near term with a combination of aftertreatment technology and use of low-sulfur fuel.

OTT has identified the development of next-generation natural gas vehicles as a strategic element in its program to reduce oil imports, vehicle pollutants and greenhouse gases. Through OHVT, OTT is initiating the effort to develop commercially viable medium- and heavy-duty natural gas vehicles to meet their goals. The two vehicle platforms identified for this effort are a Class 3-6 compressed natural gas (CNG) vehicle and a Class 7-8 liquefied natural gas (LNG) vehicle.

Heavy-duty HEVs are currently being demonstrated in several locations and show significant potential to meet OHVT goals. Most of the vehicles in demonstration programs are transit buses that are very close to commercial production.

The Office of Advanced Automotive Technologies focuses on future technology of personal transportation systems. The goal of this office is to research, develop, and validate technologies that will give automobiles three times their current fuel economy, allow them to meet Tier II emissions goals, and result in performance comparable to that of current vehicles. OAAT supports PNGV in these goals. These projects include hybrid vehicles using multiple energy or power sources, alternative fuel vehicles operating on nonpetroleum fuels, and electric vehicles (EVs) powered by advanced batteries or fuel cells. As with heavy-duty vehicles, near-term technology to meet OTT's goals involves hybrid electric powertrains. Although it shows great promise for reducing emissions, fuel cell technology will require extensive R&D as well as infrastructure development before it can be commercialized. Other areas of OAAT research for OAAT high-power energy storage devices, advanced automotive materials, fuels, and EV batteries.

To meet its goals, OAAT works closely with major automotive manufacturers and other industry partners. Important players include the three major U.S. auto manufacturers (DaimlerChrysler, Ford, and General Motors [GM]), Ballard, Lockheed-Martin, and H Power Corp.

Advanced Technology Vehicles

Global concern for the environment has been increasing throughout the last decade, and "green" technologies are being emphasized all over the world. Many companies are advertising efficient manufacturing processes, recycling efforts, and environmentally friendly products. With the vehicle industry cited as a major source of pollution, vehicle manufacturers are feeling pressure to produce cleaner cars and trucks.

All the major automotive manufacturers are working on some kind of environmentally friendly vehicle. HEVs are considered near-term technology; several hybrid vehicles are already in production, and will be available to consumers in 2000. Because most hybrid technology uses conventional fuels, such as gasoline and diesel, they are closer to market than more advanced technologies. Integrating these types of vehicles into fleets is easy because the fueling infrastructure is already in place. In some cases, an electric charging infrastructure may be needed, but many HEVs are "charge sustaining," meaning they do not have to be plugged in. The more advanced technologies being developed, such as fuel cells, may use fuels that have limited availability. Integrating these vehicles into society will take a concentrated and combined effort from vehicle manufacturers, fuel providers, and other industry partners.

This section is intended to give a "snapshot" of advanced automotive technologies being introduced into the market in the next 1 to 5 years. This information will help identify possible projects for partnerships and direct future activities for the FOP. Several methods were used to achieve this goal. The NREL Library staff conducted a literature search for information published within the last year on advanced technology vehicles. Staff in the Center for Transportation Technologies and Systems conducted an extensive Internet search, which included Web sites from automotive manufacturers, bus and truck manufacturers, automotive news, fuel industry, and state and federal governments. We obtained a database on HDV projects from WestStart-CALSTART that contained detailed information on past and ongoing projects all over the world. Weststart-CALSTART is a nonprofit organization made up of more than 200 companies and organizations that are dedicated to the creation of an advanced transportation technologies industry. To supplement this information, we interviewed several NREL employees about their work for OHVT and OAAT. Sources are listed in the appendix.

The following sections discuss the advanced technologies being developed, and give an indication of current trends. This summary focuses on technology and vehicles that are likely to be available in the U.S. market. Tables in the appendix give a detailed listing of these vehicles along with vehicles being developed in other parts of the world. A focus for all manufacturers is in reducing cost of production and individual components, so the end product is affordable to the average consumer.

Definitions of the terms used to describe the development stage of a given vehicle vary from manufacturer to manufacturer. For the purpose of this document, the following definitions apply:

- *Research* – In the early stages of development (drawings or models)
- *Concept* – An actual vehicle, usually operational, used by the manufacturer as a display or show vehicle
- *Prototype* – A working vehicle, very close to a production model
- *Demonstration* – Limited production of the vehicle being tested by the manufacturer in a real-world application
- *Production* – Available to the public.

Electric Technology

Light-Duty Vehicles

Pure EVs have been available for quite some time. Manufacturers, however, have restricted EV sales to certain areas of the country, and some models are available for lease only. These areas are mostly where the government has set zero emission vehicle (ZEV) mandates. (California laws mandate that 10% of vehicles sales by 2003 be ZEVs.) Although EVs represent the only currently available technology that yields no tailpipe emissions, the market for these clean vehicles has been small because of range issues and the high cost of battery technology. Future developments in this area will most likely center on advances in battery technology. The United States Advanced Battery Consortium (USABC) was formed in 1991 to address concerns about battery cost. USABC is focusing on: (1) lowering the cost of materials and using them more efficiently, (2) designing smaller and lighter batteries, and (3) overcoming issues with volume manufacturing. Table 2 shows current and near-term battery technologies that are being developed.

Table 2. Battery Technology

Battery Type	Energy (Wh/kg)	Cost ($/kWh)	availability
Lead Acid	35-40	150-200	production
Nickel Cadmium	45-55	300-500	production
Nickel Metal Hydride	60-70	300-700	production
Lithium Ion	100-150	150-220	research (1-4 yrs)
Lithium Polymer	100-150	150-220	research (1-4 yrs)

Table 3 lists the current light-duty EV models available in the United States. Many of the current technology EVs have been evaluated by the FOP at INEEL. The test methods for EVs have been established over the years since they were first introduced into the market. Future testing of pure EVs should focus on major breakthroughs in associated technologies, such as advanced batteries.

Table 3. Light-Duty Electric Vehicles Currently Available

Manufacturer	Model	Class	Battery Type	Estimated Range* (mi)
Chrysler	Epic	minivan	NiMH	80
Ford	Ranger	pickup	Pb Acid NiMH (CA only)	50 65-80
Chevrolet	S-10	pickup	Pb Acid NiMH (limited avail.)	45-50 65-80
GM	EV1	coupe	Pb Acid NiMH (limited avail.)	75 140+
Nissan	Altra	wagon	Li-Ion	90
Solectria	Force	sedan	Ni Cd Pb Acid NiMH	70 45 85
Toyota	RAV4	SUV	NiMH	95
Honda	EV Plus	wagon	NiMH	90

* based on data obtained from real-world driving conditions

Heavy-Duty Vehicles

Battery-powered electric buses have been in use since 1990. Some of the early demonstration projects on pure electric buses were not always successful, but others have led to usable products that are still in service. These demonstration and evaluation programs have led to modifications that allowed commercial products to meet the needs of many transit agencies. Electric buses, however, must be closely matched to an application that will not be adversely affected by the limitations of the current technology. Table 4 lists the heavy-duty EVs that are currently available in the United States.

Table 4. Heavy-Duty Electric Vehicles Currently Available

Manufacturer	Model	Class	Battery Type	Development Stage
Electric Vehicles International	EV22B	Transit bus	Lead-acid	production
Electric Vehicles International	EV22T	Trolley	Lead-acid/ NiCd	production
Electric Vehicles International	EV4000	Tram	Lead-acid	production
Electric Transit Inc.		Trolley		prototype being tested in SF, CA
Solectria	Citivan	Step van	sealed, Lead-acid	production

Hybrid Electric Technology

Light-Duty Vehicles

Most of the major automotive manufacturers are working on HEV technology. Most use gasoline for fuel, although Ford and GM have recently introduced diesel hybrid concept vehicles. Manufacturers are taking varied approaches in design, including parallel and series configurations. In a series hybrid, the power unit drives an alternator to generate electricity. This electricity is either stored in the batteries, or sent to the motor that powers the wheels. The series hybrid vehicle can operate in a zero emission mode until the batteries are drained to a certain level, when the engine will turn on and recharge them. A parallel hybrid is configured with two power paths: either the power unit or the electric propulsion system, or both, can power the wheels. More attention is currently focused on parallel hybrids for light-duty applications because they are more flexible in terms of battery, engine, and motor size. Because the output of engine and motor is combined, a parallel design can give similar performance as a conventional vehicle with smaller, lighter engines and components. Smaller components, especially batteries, means lower cost and higher fuel economy, but not necessarily lower emissions. Most light-duty hybrid vehicles at or near production are parallel configuration.

Two hybrid light-duty vehicles (LDVs) already in production will be available in the United States in 2000—the Honda Insight and the Toyota Prius. During the North American International Auto Show in January, Ford and GM introduced their latest hybrid electric concept cars, the Prodigy and Precept. DaimlerChrysler has introduced the Chrysler Citadel HEV concept car, as well as an HEV version of the Durango SUV. None of these manufacturers, however, has announced an estimate of when these vehicles might reach the market. Table 5 lists light-duty HEVs that may be available in the United States in the future. For more details on these and other HEVs, see the appendix.

Table 5. Light-Duty Hybrid Electric Vehicles

Manufacturer	Model	Body Style	Passengers	Power Type	Fuel	Development Stage	Projected Production Date
Toyota	Prius	sedan	4	parallel/series hybrid	gasoline	production	Spring 2000
Honda	Insight	coupe	2	integrated motor assist hybrid	gasoline	production	2000
GM	EV1	coupe	4	parallel hybrid	diesel	concept	not available
GM	EV1	coupe	4	series hybrid	gasoline	concept	not available
GM	Precept	sedan	5	parallel hybrid	diesel	concept	not available
Chevrolet/ Suzuki	Triax	SUV	5	hybrid	gasoline	concept	not available
Ford	Prodigy	sedan	5	low storage requirement hybrid	diesel (low sulfur)	concept	not available
Daimler Chrysler	ESX3	sedan	5	hybrid	diesel (zero sulfur)	concept	not available
Daimler Chrysler	Durango	SUV	5-8	hybrid	gasoline	concept	not available
Daimler Chrysler	Citadel	wagon	4	hybrid	gasoline	concept	not available
Toyota	HV-M4	miniva n	6	hybrid	gasoline	concept	not available
Mitsubishi	ESR	coupe		series hybrid	gasoline	concept	not available
Mitsubishi	HEV	wagon	4	hybrid	CNG	concept	not available

Heavy-Duty Vehicles

The trend for heavy-duty HEVs has been to take the easiest path to commercialization. In the HDV market, most hybrids are series designs fueled by diesel. Hybrid electric buses have been produced in limited quantities since the mid 1990s. HEV buses are being tested in many U.S. cities. There are several reasons that HEV technology is easily adapted into bus applications; for example, the size of a bus or trolley allows room for components and batteries, and fixed routes also make optimization of the drive system easier. Several heavy-duty hybrid trucks are also being tested. Table 6 summarizes the HDVs being demonstrated in projects around the United States (based on data collected for DOE/OHVT and NREL Heavy Hybrid Electric Vehicle Forum, Washington, DC, June 15, 1999).

Several of these projects stand out as important, and should be mentioned separately. The Metropolitan Transit Authority (MTA) in New York City is the largest transit agency in the United States, operating approximately 4,000 buses. Because NYC-MTA purchases more buses than any other transit agency, it has a large influence on the direction that technology will take for the industry. The agency has ordered 10 Orion IV HEV buses that will go into service in early 2000. NREL's FOP is participating in an evaluation being conducted by DOE/OHVT on these buses, five of which are already in service. The outcome of this hybrid bus project should have an effect on the future of HEV buses in the country. Since the project began, NYC-MTA has ordered 125 additional HEV buses from Orion.

In partnership with Advanced Vehicle Systems, Inc. (AVS), the Electric Transit Vehicle Institute in Chattanooga, Tennessee, has been promoting the design and production of electric buses since 1992. These buses have been placed in real-life applications through Chattanooga Area Regional Transportation Authority as well as other organizations all over the country. In addition to the electric bus projects, the partnership is testing CNG hybrid buses. The city of Tempe, Arizona, has 31 AVS CNG HEV buses on order, and Tampa, Florida, has ordered 10 AVS diesel hybrids.

United Parcel Service (UPS) is currently testing a fleet of HEV delivery trucks in three U.S. cities. The UPS hybrid project is the first medium-duty urban application of HEV technology. The truck uses a Navistar diesel engine with a Lockheed-Martin HybriDrive control system. Navistar is a leading manufacturer of heavy- and medium-duty trucks in the country. The outcome of this project could influence the industry.

Several issues must be addressed in order to begin extensive test and evaluation of the HEV LDVs and HDVs being introduced on the market. Test methods must be developed and standardized so that comparisons can be made. Considering the varied levels of hybridization, this could prove challenging. Each configuration needs to be understood to match it to various types of service. The recent trend to light-duty diesel hybrids brings up additional issues, such as aftertreatment methods to reduce PM and NO_x emissions from diesel fuel.

Fuel Cell Technology

Light-Duty Vehicles

Although manufacturers are working on HEVs for the near-term market, the most widely accepted solution for the future appears to be fuel cells. Most automotive manufacturers are currently working on some type of fuel cell vehicle (FCV). They run the gamut in size from minis to SUVs. The manufacturers have taken varied approaches to designing an FCV. Some are working alone on their ideas. Honda is developing its own fuel cell, and Nissan is designing a reformer. Partnerships, listed below, have also been formed to combine knowledge and skills to their best advantage.

- XCELLSIS Fuel Cell Engines – A joint venture between DaimlerChrysler, Ballard, and Ford to develop, manufacture, and commercialize fuel cell engines for buses, cars, and trucks.

- California Fuel Cell Partnership – A collaboration between auto manufacturers, oil companies, a fuel cell company, and state and federal governments. The goal is to demonstrate FCVs in real-world conditions, demonstrate the viability of infrastructure technology, explore the path to commercialization, and increase public awareness and enhance opinion about fuel cell technology.

- New Energy and Industrial Technology Development Organization (NEDO) – This Japanese partnership is sponsoring a 5-year research project with Nissan, Suzuki, and 11 universities to develop direct methanol FCVs.

Table 6. Heavy-Duty Hybrid Electric Vehicles

Manufacturer	Location	Development Start date	# of Vehicles	Hybrid Type	Vehicle Type	Fuel
AVS/Capstone	Chattanooga Area RTA	8/99 on order	7	Series	Bus	CNG
AVS/Allison/DARPA	Chattanooga Area RTA			Series	Shuttle bus	CNG
AVS/Arizona	Tempe AZ/Tampa, FL	on order	31/10	parallel	Shuttle bus	CNG/diesel
NASA Lewis	Cleveland RTA			Series	Bus	CNG
Orion IV Hybrid Bus	NYC MTA, NJ	9/98	10	Series	Bus	diesel
GM-Allison/NovaBUS Retrofit Kit	NYC	3/99	1	Series	Bus	diesel
Nova BUS RTS, DUETS Program	NYC MTA, Boston, MA	10/94	1	Series	Bus	CNG
Navistar MD Truck	UPS: NY, Atlanta, LA	6/98		Series	Truck	diesel
Flexible	Cleveland RTA			Series	Bus	natural gas
Eletricore/GM-Allison/Delphi	Indianapolis Airport & Chattanooga				Bus	
El Dorado	Oahu Transit			Parallel	Bus	propane
APS/Calstart	Contra Costa (AC) Transit	1/98	1	Series	Bus	propane
APS/Calstart	Vandenburg Air Force Base		3	Series	School bus	CNG
APS/Calstart	City of Lompoc		1	Series	Bus	CNG
APS/El Dorado EZ Rider 300				Series	Bus	various
APS Conversion - Genesis	CEC TETAP			Series	School bus	diesel
APS Conversion - Villager	Santa Barbara MTD			Series	Bus	diesel
APS Trolley	Santa Barbara MTD	10/94		Series	Trolley shuttle bus	diesel
Electric Vehicles Intl. (EVI) 22B				Series	Bus	CNG or LPG
GPX 4080				Series	Bus	gasoline
Solectria/New Flyer	Orange County (OCTA)	12/98	1	Series	Bus	diesel
TPI Composites/Solectria	Boston Logan Airport	2/99		Series	Bus	natural gas
AF/Navy Hybrid Program/TDM				Series	Van and shuttle bus	
AF/Navy Hybrid Program/ISE		5/99	3	Series	Tow tractor	
ISE Research/New Flyer	Omnitrans, San Bernadino, CA	4/00	5	Series	Bus	CNG
ISE Research/El Dorado RE-29-E	Los Angeles DOT	3/99	5	Series	Bus	propane
ISE Research/Calstart Kenworth T800	Crown Disposal, Los Angeles	12/98	2	Series	Line haul truck	CNG
ISE Research Military Tractor		5/99		Series	Military tractor	diesel
Gillig Phantom	Foothills Transit, Golden Gate Tr.	4/99	1	Series	Bus	
Hawaii Program (HEVDP)/Calstart					Bus	propane
Transportation Techniques (Transteq)	Denver RTD			Series	Mall shuttle bus	CNG
Electric Fuel Corp/NovaBUS	Clark County, NV				Bus	battery/ battery system
New Flyer DE40FL	Orange County, CA	9/98	2	Series	Bus	diesel
NovaBus	New York City	Spring 99	5	Series	Bus	diesel

Fuel cells are capable of running on a wide range of fuels through reforming. Methanol, gasoline, and natural gas are being considered for reforming, but only vehicles that operate on hydrogen can be ZEVs. A challenge in the development of FCVs will be determining the best fuel to result in efficient operation without compromising emissions. Several FCVs are already on the road. These are mostly custom-built, hydrogen-fueled proton exchange membrane (PEM) fuel cell buses that are being tested in transit applications.

The first production FCVs will most likely be fueled by hydrogen and placed in fleet applications. Because this technology is simpler than reformer models, it will be ready for demonstration earlier. Fleets will be targeted because of the lack of hydrogen fueling infrastructure. A fleet would be able to invest in a centralized fuel site for fueling its own vehicles. Fleets are also targeted because of government mandates and incentives. As reformer technology improves, FCVs powered by other fuels may emerge on the market. After fleet testing, limited lease programs should be available. These will likely be high profile individuals in a position to "get the word out" to the public. Within the next 10 years, there is expected to be limited production of FCVs available for personal purchase. To put the vehicles on the road, the first of these vehicles will probably be subsidized by the manufacturer. As demand grows, production costs will drop, and the OEM will eventually realize a profit on these vehicles. The California ZEV emissions mandate, which goes into effect in 2003, will put pressure on the manufacturers to finalize the technology.

Table 7 lists the light-duty FCVs being developed that will likely be available in the United States, as well as their development stage and estimated time to market introduction. The biggest issue to enable testing and evaluation of FCVs is fueling infrastructure. Test methods for the technology will also have to be developed and standardized.

Table 7. Light-Duty Fuel Cell Vehicles

Manufacturer	Model	Body Style	Passengers	Fuel Cell Type	Fuel	Development Stage	Production Date
Honda	FCX-V1	SUV	4	PEM	hydrogen	concept	2003
Honda	FCX-V2	SUV	4	PEM	methanol	concept	2003
Toyota	FCEV RAV4	SUV	5		hydrogen	concept	2003
Toyota	FCEV RAV4	SUV	5		methanol	concept	2003
DaimlerChrysler	NECAR 4	sedan	5	PEM	hydrogen	prototype	2004
DaimlerChrysler	NECAR 5	sedan	5	PEM	methanol	prototype	2004
Ford	FC5	sedan	5	PEM	methanol	concept	2004
Jeep	Commander	SUV	5		gasoline	concept	not available
GM	EV1	coupe	4		methanol	prototype	not available
Ford	P2000	sedan	5		hydrogen	prototype	2004
Nissan	Altra based	sedan	5		methanol	research	2003-05

Heavy-Duty Vehicles

Fuel cell technology for HDVs has been concentrated on bus applications. Ballard Power Systems, XCELLSIS Fuel Cell Engines Inc. has been testing its fuel cell prototype bus in Chicago and Vancouver, British Columbia, since 1997. The demonstration in Chicago has recently ended, with positive results. During the two-year demonstration, the three fuel cell buses logged more than 5,000 hours in revenue service. The results from this project helped XCELLSIS design its new pre-commercial fuel cell engine that will enter revenue service in Palm Springs, California, in the summer of 2000. Ballard's chairman and chief executive officer announced in a recent press release that “A commercial fuel cell bus engine is now just two years away” (source: Ballard press release - 3/23/00). Table 8 lists ongoing fuel cell demonstration projects in the United States.

Table 8. Heavy-Duty Fuel Cell Vehicles

Manufacturer	Model	Body Style	Passengers	Fuel Cell Type	Fuel	Development Stage
XCELLSIS Fuel Cell Engines/New Flyer		bus	60	PEM	hydrogen	demonstration
Nova BUS/ Georgetown University	RTS/WFD	bus	40	PAFC	methanol	demonstration
DaimlerChrysler	Nebus	bus	60	PEM	hydrogen	prototype

Other Advanced Technologies

Many other associated technologies could further OTT’s goals. Here are a few:

- Advanced fuels for compression-ignition direct-injection engines such as low-sulfur diesel, dimethoxy methane, dimethyl ether, and Fischer-Tropsh
- New fuels/applications (biodiesel blends in the federal fleet, P-series fuels)
- Low-cost materials for CNG storage tanks
- Stirling engine for hybrid systems
- High-power energy storage devices
- Lightweight materials for vehicles and systems
- Gasoline direct injection engines
- Advanced dedicated CNG/LNG vehicles
- Dedicated hydrogen buses

Potential Partnerships

The FOP must work with industry and other stakeholders to test and promote advanced technology vehicles. This program is part of a larger effort being conducted in this area by other government offices, engine and vehicle manufacturers, fuel providers, vehicle customers, industry trade organizations, and R&D organizations. The program can maximize its limited resources by working with groups with similar goals. Program administrators should meet with these groups regularly, involve them in peer reviews of program plans and results, and find projects that leverage funding wherever possible.

The FOP could partner with a wide range of organizations and projects. This includes activities from within DOE’s OTT, other government organizations such as the Federal Transit Administration, industry trade groups such as the Electric Vehicle Association of America, automobile and component manufacturers, and private testing organizations.

The focus, direction, and funding of transportation programs and the marketplace for advanced technologies are continually changing and developing. Program representatives must maintain an awareness of the latest events so that program activities align with trends in technology and with the needs of our customers. The challenge will be to choose those projects that provide the greatest return in terms of impact on energy security and air quality, value to our customers, and leveraging of funds.

Appendix

The following tables are a compilation of information collected from various sources that include Internet sites of automotive manufacturers, news organizations, government, fuel providers, and industry. A list of these sites, and other sources follows the tables. Many of the technical details on pre-production vehicles are proprietary, and some manufacturers are more forthcoming than others. Blank spaces in the tables indicate the information is not readily available.

The tables are broken down by technology type and weight class (light- or heavy-duty). Vehicles that will potentially be available in the United States are listed first in each table, followed by others from various parts of the world.

Table A1 Light-Duty Electric Vehicles

Manufacturer	Model	Class	Passengers	Curb Wt.	Development Stage	Batteries			
						Make	Type	#	Capacity
Chevrolet	S-10	pickup	3	4300	production	GM Advanced Technology Vehicles	Pb Acid	27	312V
Chevrolet	EV1	coupe	2		production	Delco	Pb Acid	26	16.2
Chevrolet/Suzuki	Triax	SUV	5	1490kg	concept	USABC	NiMH		
Chrysler	Epic	minivan	6-8		production		NiMH	28	336V
Ford	Ranger	pickup	2		production		Pb Acid	39	23
Nissan	Altra	wagon	4	3749 lb	production	Nissan/Sony	Li-ion	12	345 V/set
Solectria	Force	sedan		2500 lb	production		Ni Cd/Pb acid/NiMH		
Toyota	RAV4	SUV	5	3440 lb	production		NiMH	24	27.36
Nissan	Cedric								
Nissan	Avenir								
Suzuki	EV Sport	SUV	2		prototype		NiMH		
Fiat	Seicento			1200kg	production				
Finland	Elcat	van		1180kg	production	Optima	Pb acid	18	72V total
Mazda	Demio	SUV					NiMH		
Mitsubishi	Libero EV	wagon			production (Japan)		NiCd		
Peugot	106	sedan			production		NiCd		
Peugot	Ion	mini		850kg	prototype?	Saft	NiCd		20kw
AC Propulsion	tzero	sports car				Optima	Pb acid	28	
Toyota	E-com	mini			prototype		NiMH	24	288v total
Citroen	Berlingo	utility/van			production				
Citroen	Saxo	sedan			production				
Diahatsu	Charade	sedan							

Table A1 Light-Duty Electric Vehicles (continued)

Manufacturer	Model	Motor			Range	Other Characteristics
		Type	#	kW		
Chevrolet	S-10	3-phase AC induction	1	85	40-55	regenerative braking
Chevrolet	EV1				55-95 or 75-130(NiMH)	regenerative braking
Chevrolet/Suzuki	Triax	GM Gen II	2	35 kW ea	165	regenerative braking AWD, inductive charging
Chrysler	Epic	AC induction	1		80-90	regenerative braking
Ford	Ranger	3 phase motor	1	90hp	50	regenerative braking
Nissan	Altra	Neodium permanent magnet syncronous AC motor		62	120	regenerative braking
Solectria	Force				50/85/105	regenerative braking
Toyota	RAV4	permanent magnet		50	125	regenerative braking
Nissan	Cedric					
Nissan	Avenir					
Suzuki	EV Sport	GM Gen III				Al body, batteries below floor, emergency backup engine (400 cc gasoline), RWD or FWD
Fiat	Seicento				90 km	
Finland	Elcat	DC series wound				
Mazda	Demio					
Mitsubishi	Libero EV				250 km	
Peugot	106				50km@50kph, 90km@90kph	7-8 hr charging time
Peugot	Ion	continuous current		20kw@1500rpm	110-150km	
AC Propulsion	tzero	AC propulsion	1	200hp		regenerative braking
Toyota	E-com	hp permanent magnet motor		19kW/25 hp	60 mi	regenerative braking
Citroen	Berlingo					
Citroen	Saxo					
Diahatsu	Charade					

Table A2 Light-Duty Hybrid Electric Vehicles

Manufacturer	Model	Class	Passengers	Technology Type	Curb Wt.	Development Stage	Target Introduction
Chevrolet/Suzuki	Triax	SUV	5	hybrid	1330 kg	concept	no plans
Chrysler	Citadel	wagon	4	parallel hybrid		concept	
DaimlerChrysler	Durango	SUV	5-8	hybrid		concept	
Dodge	Intrepid ESX2	sedan	5	parallel hybrid		concept	2003
Dodge	ESX3	sedan	5	parallel hybrid		concept	
Ford	P2000	sedan	5	LSR(low storage requirement) hybrid		prototype	
Ford	Prodigy	sedan	5	LSR(low storage requirement) hybrid		concept	2003
GM	EV1	coupe		parallel hybrid	3200 lb	prototype	2004
GM	Precept	sedan	5	hybrid		concept	
GM	EV1	coupe	4	series hybrid	2950 lb	concept	
Honda	Insight	coupe	2	hybrid		production	2000
Honda	Spocket	hybrid car/truck	2	hybrid		concept	
PEI Electronics	HMMWV	SUV		hybrid			
Toyota	Prius	sedan	4	parallel/series hybrid		production	1999
Toyota	HV-M4	minivan	6	hybrid		concept	no plans
Daihatsu	MOVE EV-HII		4	parallel/series hybrid			
Mercedes	S-class			parallel/series hybrid			
Mitsubishi	ESR (Ecological Science Research	coupe?		series hybrid		prototype	
Mitsubishi	HEV	wagon	4	hybrid			
Mitsubishi	SUW Advance	SUV	5	parallel/series hybrid			
Nissan	Tino	sedan	5	parallel/series hybrid		prototype	2000 (Japan)
Suzuki	Pu3 - commuter	mini	2	gasoline, electric, or parallel hybrid	600 kg	prototype	
US Electricar & Hyundai	FGV-II	sedan	4	parallel hybrid			
Volvo	S40/V40 based	wagon	5	power split hybrid		prototype	
Volvo	S40/V40 based	wagon	5	integrated starter generator hybrid		prototype	
Audi	Duo	wagon	5	parallel hybrid	3770 lb		
Australia	aXcess Australia	sedan		hybrid			
Citroen	Berlingo Dynavolt	truck/van	5	range extender series hybrid			
Fugi Heavy/Subaru	Elten Custom			hybrid		prototype	
Pininfarina/Unique Mobility	Ethos	roadster	2	hybrid		concept	
Pininfarina	METROCUBO	mini	5	hybrid		concept	
Renault	Kangoo	truck/van	5	range extender hybrid			

Table A2 Light-Duty Hybrid Electric Vehicles (continued)

Manufacturer	Model	Hybrid Power Unit					Motor/Controller		
		Fuel	Type	Displ.	# Cyl.	Power	Type	#	kW
Chevrolet/Suzuki	Triax	gasoline	Suzuki turbo, DOHC, VVT	660cc	3			2	35
Chrysler	Citadel	gasoline		3.5L	6	253 hp	Siemens		
DaimlerChrysler	Durango	gasoline		3.9L	6		AC induction	1	
Dodge	Intrepid ESX2	diesel	Chrysler Turbo-diesel	1.8L	3	200hp	electric Zytek	2	155
Dodge	ESX3	diesel (0 sulfur)	Direct injection	1.5L	3		permanent magnet	1	15
Ford	P2000	Fischer-Tropsch	Ford DIATA(DI Al through bolt) CI	1.2L	4				
Ford	Prodigy	Fischer-Tropsch	Ford DIATA(DI Al through bolt) CI	1.2L	4	74hp@4100rpm	3 phase AC	1	
GM	EV1	diesel	Isuzu DOHC DI	1.3L	3	75 hp	DC brushless	1	
GM	Precept	diesel	Isuzu turbo DI	1.3L	3		Unique Mobility	1	15
GM	EV1	gasoline	GM/Williams Gas Turbine Power Unit			137 hp			
Honda	Insight	gasoline	Honda VTEC-E	1L	3				
Honda	Spocket	gasoline	Honda DOHC		4			2	
PEI Electronics	HMMWV	diesel					Unique Mobility permanent magnet	4	55
Toyota	Prius	gasoline	Toyota DOHC	1.5L	4	40 hp@940-2000rpm			
Toyota	HV-M4	gasoline	Toyota THS-C	2.4L				2	
Daihatsu	MOVE EV-HII			600cc		30kW@5000 rpm	PM syncronous		18
Mercedes	S-class	gasoline		3.3	6	132 kW			
Mitsubishi	ESR (Ecological Science Research	gasoline							
Mitsubishi	HEV	CNG		1.5L	4		AC inductor	2	60
Mitsubishi	SUW Advance	gasoline	GDI	1.5		77kW@5000 rpm	motor/generator		12
Nissan	Tino	gasoline	NEO DI	1.8	I4		PM syncronous	1	17
Suzuki	Pu3 - commuter	gasoline/electric							
US Electricar & Hyundai	FGV-II	gasoline		1.5	I4			1	10
Volvo	S40/V40 based	gasoline	Volvo	1.4L			Electric		55
Volvo	S40/V40 based								
Audi	Duo	diesel	Turbo DI	1.9	4 I	90 hp @4000 rpm	Siemens		
Australia	aXcess Australia	gasoline					Surge power unit (ultracapacitor)		
Citroen	Berlingo Dynavolt	LPG		500cc	2	8Kw @3400rpm			
Fugi Heavy/Subaru	Elten Custom	gasoline		660 cc	4			2	8.5
Pininfarina/Unique Mobility	Ethos								
Pininfarina	METROCUBO	gasoline	electric w/onboard generator	505cc	2	9.4bhp@2200rpm	Siemens		30
Renault	Kangoo								

Table A2 Light-Duty Hybrid Electric Vehicles (continued)

Manufacturer	Model	Storage System				Fuel Economy	Emissions Level	Other Characteristics
		Make	Type	#	Capacity			
Chevrolet/Suzuki	Triax		NiMH		350V	35	ULEV	AWD
Chrysler	Citadel					27/33		
DaimlerChrysler	Durango		Pb acid			18.6		
Dodge	Intrepid ESX2	Bolder Technologies	Pb Acid			70		100% Al body
Dodge	ESX3	Saft	Li ion		165V	72		Al engine, light weight materials
Ford	P2000		NiMH			60		
Ford	Prodigy		NiMH			70		Al body parts, low-rolling resistance tires
GM	EV1	Ovonic	NiMH	44		80	Tier 2/ZEV	Al parts, 4WD, ZEV mode range 40 mi, motor powers front wheels, engine powers rear wheels - combined hp=219
GM	Precept		NiMH or LiP					
GM	EV1	Ovonic	NiMH	44		60	ULEV/ZEV	either electric or hybrid mode
Honda	Insight		NiMH		144 Volt	61/70		Al Body, NOx adsorptive cat.
Honda	Spocket							
PEI Electronics	HMMWV	Electrosource	Pb acid			18		
Toyota	Prius		NiMH	40		68		
Toyota	HV-M4					x2		CVT, 4WD
Daihatsu	MOVE EV-HII		NiMH			87		FWD
Mercedes	S-class		NiMH		60kW			dual mass flywheel
Mitsubishi	ESR (Ecological Science Research						ZEV mode	solar cells on roof helps recharge batteries
Mitsubishi	HEV			30	336V		ZEV mode	low rolling resistance tires
Mitsubishi	SUW Advance		Li Ion		144v			FWD
Nissan	Tino		Li Ion					hyper CVT w/electromagnetic clutch
Suzuki	Pu3 - commuter					92		
US Electricar & Hyundai	FGV-II		NiMH					
Volvo	S40/V40 based				60kw	+ ~44%		
Volvo	S40/V40 based						LEV	
Audi	Duo		Pb Acid	22	264v	28		primary battery charge from grid
Australia	aXcess Australia		Pb acid			x2		
Citroen	Berlingo Dynavolt							
Fugi Heavy/Subaru	Elten Custom		NiMH			77.6		CVT
Pininfarina/Unique Mobility	Ethos							
Pininfarina	METROCUBO	Exide	Pb-Acid					
Renault	Kangoo		NiMH					

Table A3 Light-Duty Fuel Cell Vehicles

Manufacturer	Model	Type	Passengers	Development Stage	Target date	Engine/Motor				
						Fuel	Type	Displ.	# cyl	Power
DaimlerChrysler	NECAR 4	sedan	5	prototype	2004	hydrogen				
DaimlerChrysler	NECAR 5	sedan	5	concept		methanol				
Ford	FC5	sedan	5	concept	2004	methanol				
Ford	P2000	sedan	5	prototype		hydrogen	Zetec	2	4	
GM	EV1	coupe	4	prototype		methanol	AC induction motor			137hp
Honda	FCX-V1	sedan	4	concept	2003	hydrogen	Honda/Ballard			49kW
Honda	FCX-V2	sedan	4	prototype	2003	methanol	Honda/Ballard			49kW
Jeep	Commander	SUV	5	concept	2010	gasoline/other	DC			
Toyota	FCEV RAV4	SUV		concept	2003	hydrogen				
Toyota	FCEV RAV4	SUV		concept	2003	methanol	permanent magnet motor			
BMW	750hl	sedan				hyd./gasoline		5.4	12	
Daihatsu	MOVE FCV	microvan	4			methanol				
Mazda	Demio FCEV	wagon	4	prototype		methanol	AC syncronized motor			40kw
Mitsubishi	FCV	sedan		concept	2003-2005	methanol	PM motor			40kW
Mitsubishi/ Mitsubishi Heavy Industries				concept	2005					
Nissan	R'nessa	SUV		concept	2003/04					
Nissan	Altra based	wagon	5	concept	2003-2005	methanol				
GM/Opel	Zafira	minivan		concept		methanol				
VW/Volvo		mini				methanol				
Zevco	Taxi/van			production		hydrogen				

Table A3 Light-Duty Fuel Cell Vehicles (continued)

Manufacturer	Model	Batteries			Fuel Cell			Other Characteristics
		Make	Type	#	Type	#	kW	
DaimlerChrysler	NECAR 4					2	70	
DaimlerChrysler	NECAR 5				Mark 900		75	
Ford	FC5				Ballard			
Ford	P2000				Ford/Mobil			H2 storage in nanotubes
GM	EV1	Ovonic	NiMH	44				batteries charge in ~2 hr
Honda	FCX-V1				Ballard		60	long wheelbase, metal hydride tank for H2 storage
Honda	FCX-V2				Honda Polymer Electrolyte FC stack		60	
Jeep	Commander							2 EPIC motors to provide 4WD
Toyota	FCEV RAV4						25	
Toyota	FCEV RAV4						25	
BMW	750hl				PEM		5	dual fuel, RWD
Daihatsu	MOVE FCV		NiMH		polyelectrolyte		16	CVT
Mazda	Demio FCEV				Polymer electrolyte	4	20	ultracapacitor for extra 20 kw energy
Mitsubishi	FCV		Li ion		Mitsubishi group		40	
Mitsubishi/ Mitsubishi Heavy Industries								
Nissan	R'nessa							
Nissan	Altra based	Sony	Li ion		Ballard		10	
GM/Opel	Zafira							
VW/Volvo								
Zevco	Taxi/van				Alkaline			

Table A4 Heavy-Duty Hybrid Electric Vehicles and Projects

Project	Location	Tech. Type	Vehicle Type	Proj. Start Date	# vehicles	Length	# Pass.	Curb Wt.
AVS/Capstone	Chattanooga Area RTA	Series	Bus	8/99 on order	7	22	22 seated	15,000
AVS/Allison/DARPA	Chattanooga Area RTA	Series	Shuttle Bus					
NASA Lewis	Cleveland RTA	Series	Bus			40		26,054
Orion IV Hybrid Bus	NYC MTA, NJ	Series	Bus	Sep-98	10	40		30,800
GM-Allison/NovaBUS Retrofit Kit	NYC	Series	Bus			40		
Allison "EV DRIVE" drivetrain	None - drivetrain only	Parallel	For HD					
Nova BUS RTS, DUETS Program	NYC MTA, Boston	Series	Bus	Oct-94	1	40		
Navistar MD Truck	UPS: NY, Atlanta, LA	Series	Truck	Jun-98				27,000
Flexible	Cleveland RTA	Series	Bus			40		
Eletricore/GM-Allison/Delphi	Indianapolis Airport & Chattanooga		Bus				19	
El Dorado	Oahu Transit	Parallel	Bus			30	50 total	
APS/Calstart	Contra Costa (AC) Transit	Series	Bus	Jan-98	1	40	34 seated	
APS/Calstart	Vandenburg Air Force Base	Series	School bus		3	28, 40		
APS/Calstart	City of Lompoc	Series	Bus		1	40	43	20,400
APS/El Dorado EZ Rider 300		Series	Bus			29		29,260
APS Conversion - Genesis	CEC TETAP	Series	School bus				66	
APS Conversion - Villager	Santa Barbara MTD	Series	Bus			28		
APS Conversions (many)	see www.santabarbara.net	Series	Buses					
APS Trolley	Santa Barbara MTD	Series	Trolley shuttle bus	Oct-94				
Electric Vehicles Intl. (EVI) 22B		Series	Bus			22		
GPX 4080		Series	Bus			40	80	
Solectria/New Flyer	Orange County (OCTA)	Series	Bus	late 98	2	40	39	
TPI Composites/Solectria	Boston Logan Airport	Series	Bus	Feb-99		30	26	16,200
Unique Mobility/John Deere			Drive system only					
Unique Mobility			Bus					
AF/Navy Hybrid Program/TDM		Series	Van and Shuttle bus					
AF/Navy Hybrid Program/ISE		Series	Tow Tractor	May-99	3			
ISE Research/New Flyer	Omnitrans, San Bernadino, CA	Series	Bus	Mar-00	5	40		
ISE Research/El Dorado RE-29-E	Los Angeles DOT	Series	Bus	Mar-99	5	30		
ISE Research/Calstart Kenworth T800	Crown Disposal, Los Angeles	Series	Line Haul Truck	Dec-98	2			
ISE Research Military Tractor		Series	Military Tractor	May-99				
Gillig Phantom	Foothills Transit, Golden Gate Tr.	Series	Bus			40		
Hawaii Program (HEVDP)/Calstart			Bus			40		
Transportation Techniques	Denver RTD	Series	Mall Shuttle Bus	Oct-98	1	45	127	30,000
Electric Fuel Corp/NovaBUS	Clark County, Nevada		Bus			40	40 seated	
NovaBus	New York City	Series	Bus	Mid 99	5	40		
ISE Research			Bus			40		
NAVC	NYC	series	refuse truck	Sep-98	1			
ISE Research/Peterbilt	LA	parallel	truck (class 8)	Jun-99	1			
AVS/Arizona	Tempe AZ	parallel	Shuttle Bus	Feb-01	31	22		
AVS/Arizona	Tampa, FL	parallel	Shuttle Bus	Feb-01	10	22		
CTC/US Army	Johnstown, PA	series	HMMWV	Aug-98	1			
APS/Alturdyne	Oakland, CA		Bus	Aug-98	1	40		
Orion	San Francisco, CA MUNI		Bus	in devel	2			
GMC	San Francisco, CA MUNI		truck	in devel	2			
United Defense	San Jose, CA	series	defense vehicles	98	1		12	
AVS/Capstone	Tampa, FL	parallel	Bus	in devel	10	22		
CRETC (Cedar Rapids Electric Transit Consortium)	Cedar Rapids, IA		Bus	Sep-96	4	34		
Orion/Lockheed Martin	Boston, MA		Bus	May-99	2	40		
Volvo Trucks/US Army	Army's Tank-automotive & Armaments Command		truck (class 8)	Dec-00	1			

Table A4 Heavy-Duty Hybrid Electric Vehicles and Projects (continued)

Project	APU				Generator		
	Fuel	Type	Disp.	Power	Make	Type	Power
AVS/Capstone	CNG	Capstone Turbine	n/a	32			
AVS/Allison/DARPA	CNG	Volkswagen/IPMCO	2				
NASA Lewis	CNG	5 cyl, in-line	2.3	90		3 phase, wound field	50
Orion IV Hybrid Bus	diesel	DDC S30	7.3	230	Lockheed		120
GM-Allison/NovaBUS Retrofit Kit	diesel						
Allison "EV DRIVE" drivetrain							
Nova BUS RTS, DUETS Program	CNG	DDC S30	7.3	230			
Navistar MD Truck	diesel	Navistar T444E	7.3				
Flexible	natural gas	turbine					
Eletricore/GM-Allison/Delphi							
El Dorado	propane	4-cylinder					
APS/Calstart	propane	Alturdyne rotary engine		66			40 (300 V)
APS/Calstart	CNG	Cummins 4B	3.9				
APS/Calstart	CNG	Cummins 4B	4.9	67			
APS/El Dorado EZ Rider 300	various						
APS Conversion - Genesis	diesel						
APS Conversion - Villager	diesel						
APS Conversions (many)							
APS Trolley	diesel						
Electric Vehicles Intl. (EVI) 22B	CNG or LPG						
GPX 4080	gasoline			134			
Solectria/New Flyer	diesel	DDC 642 or Cummins B				DC	120
TPI Composites/Solectria	natural gas			68			
Unique Mobility/John Deere	natural gas	Deere 6068	6.8	225			
Unique Mobility	CNG						
AF/Navy Hybrid Program/TDM		Detroit Diesel	2.5		Unique		75
AF/Navy Hybrid Program/ISE		Cummins B5.9	5.9		Fisher		80
ISE Research/New Flyer	CNG	Cummins B5.9G				continuous	120
ISE Research/El Dorado RE-29-E	propane	GM/Mogas conversion	5.7		Fisher	permanent magnet	80
ISE Research/Calstart Kenworth T800	CNG (LPG avail.)	GM conversion	4.3			continuous	75
ISE Research Military Tractor	diesel	Cummins B5.9					
Gillig Phantom	CNG (?)	Cummins 4B					
Hawaii Program (HEVDP)/Calstart	propane	rotary engine					
Transportation Techniques	CNG	Ford/IPMCO conversion	2.5				
Electric Fuel Corp/NovaBUS	battery/battery system	Zinc-air battery (320kWh)					
NovaBus	diesel	HybriDrive		160			
ISE Research	gasoline/LPG/CNG/diesel	GM (gas, diesel, LPG) or Cummins (CNG)	5.9			continuous	120
NAVC							
ISE Research/Peterbilt	CNG/LNG	GM Vortec V6			Fisher	permanent magnet	
AVS/Arizona	LNG	Capestone turbine					
AVS/Arizona	diesel						
CTC/US Army	diesel	VW			Unique	permanent magnet	
APS/Alturdyne	LPG	Alturdyne			Alturdyne	rotary	40
Orion	diesel						
GMC	diesel						
United Defense	diesel	Caterpillar CI V6		400			
AVS/Capstone	CNG/LNG	Capstone turbine					
CRETC (Cedar Rapids Electric Transit Consortium)	diesel	Northrop Grummand			Powertech	UL JANIK G60	
Orion/Lockheed Martin	diesel	DDC Series 30			DDC	Series 40 DCC	
Volvo Trucks/US Army	diesel	Volvo VNL64		460			

Table A4 Heavy-Duty Hybrid Electric Vehicle Vehicles and Projects (continued)

Project	Batteries				Generator			
	Make	Type	#	Capacity	#	Make	Type	Power
AVS/Capstone	Fulmen	Lead-acid		60	2	Soletria	AC	140
AVS/Allison/DARPA								
NASA Lewis		Ultracapacitors	30		1		3-phase induction	149
Orion IV Hybrid Bus	Electrosource VRLA	Lead-acid				Lockheed	AC induction	179
GM-Allison/NovaBUS Retrofit Kit								
Allison "EV DRIVE" drivetrain			2 pks					
Nova BUS RTS, DUETS Program						Lockheed	AC induction	
Navistar MD Truck		Sealed lead-acid	46			Lockheed	AC induction	
Flexible		"super-capacitor"						
Eletricore/GM-Allison/Delphi								
El Dorado		Lead-acid						
APS/Calstart	Saft	Nickel cadmium	58		2	Rexroth Indramat		134
APS/Calstart		Lead-acid				Indramat	AC	
APS/Calstart	Saft	Nickel cadmium				Rexroth/Indramat	AC induction	
APS/El Dorado EZ Rider 300								
APS Conversion - Genesis								
APS Conversion - Villager							AC	
APS Conversions (many)								
APS Trolley	Saft	Nickel cadmium			2	Nelco	DC	84
Electric Vehicles Intl. (EVI) 22B		Flooded lead-acid						
GPX 4080		Lead-acid					320 V	402
Solectria/New Flyer		Lead-acid	52	30		Solectria		240
TPI Composites/Solectria				30	2	Solectria		
Unique Mobility/John Deere						Unique Mobility		
Unique Mobility					2	Unique Mobility		
AF/Navy Hybrid Program/TDM	Optima	Lead-acid			2	Seimens	AC Induction	
AF/Navy Hybrid Program/ISE	Concorde	Lead-acid	48		1	Seimens		100
ISE Research/New Flyer		Sealed lead-acid (Li & NiMH avail.)	48			ThunderVolt	continuous AC induction	288
ISE Research/El Dorado RE-29-E		Sealed lead-acid	48		1	Siemens	AC induction	140
ISE Research/Calstart Kenworth T800		Sealed lead-acid (Li & NiMH avail.)					AC induction	400
ISE Research Military Tractor								
Gillig Phantom	Horizon	Sealed lead-acid				Siemens		
Hawaii Program (HEVDP)/Calstart		Nickle-cadmium				Kaman PA44		
Transportation Techniques		Lead-acid	28		2			400
Electric Fuel Corp/NovaBUS		Nickle-cadmium		21		General Electric		
NovaBus						Lockheed		
ISE Research		Sealed lead-acid (Li & NiMH avail.)	48			ThunderVolt	continuous AC induction	288
NAVC								
ISE Research/Peterbilt	GNB Champion	sealed lead-acid				UDLP		
AVS/Arizona	Chloride	lead-acid, gel				Solectria	AC	
AVS/Arizona								
CTC/US Army	Electrosourse	lead-acid			2	Unique Mobility		
APS/Alturdyne	Saft	NiCd			4			
Orion								
GMC								
United Defense	Electrosourse	lead-acid	88			United Defense	high-speed induction	
AVS/Capstone	Chloride	lead-acid, gel				Solectria	AC	
CRETC (Cedar Rapids Electric Transit Consortium)	GNB	lead-acid, gel	112			Northrop Grumman		
Orion/Lockheed Martin	Electrosourse	lead-acid, gel				DDC	Navistar 30	
Volvo Trucks/US Army		lead-acid			2		AC	

Table A5 Heavy-Duty Hybrid Electric Vehicles and Projects Outside the US

Project	Location	Tech. Type	Vehicle Type	Proj. Start Date	# vehicles	Length	# Pass.	Curb Wt.
Hino Bus		Parallel	Bus			38	55	
Mitsubishi MCAT (concept bus)		Series	Truck					
Mitsubishi Canter		Series	Truck					
Toyota Coaster		Series	Bus				14 seated	9,130
Hytrax		Series	Delivery Van					
Man M2000	Veenendaal, Netherland	Parallel	Truck					
Man L2000	Expedite Centrum Gronigen	Parallel	Truck					16,500
Volvo Environmental Concept Bus	Sweden	Series	Bus					
Volvo B10L	Gothenborg, Sweden	Series	Bus					
Volvo FL6	Gothenborg, Sweden	Series	Truck	Oct-97	2			
Asia Motor Company (Korea)								
Jupiter Project/DAB CITYBUS		Series	Bus				35 seated	27,412
Stockholm THOREB bus	Stockholm, Sweden	Series	Bus				33 seated	
Scania S15 Bus	Stockholm & Aalborg, Sweden	Series	Bus					
Scania S11 Bus	Luxenbourg, Sweden	Series	Bus					
Scania S11 Bus	Friedrichshafen, Sweden	Series	Bus					
Daimler-Benz AG - MB Truck		Parallel	Truck					
Mercedes-Benz O 405 NUH	Oberallgan, Germany	Series	Bus			39	45 seated	
Mercedes-Benz O 405 GNDE	Stuttgart, Germany	Series	Bus			59	49 Seated	
Daimler-Chrysler HyTruck	Germany	Parallel	Truck					
Iveco Altrobus	Genoa and Turin, Italy	Series	Bus			36	31 seated	28,930
Iveco Altrobus	Italy	Series	Bus			18	9 seated	9,240
Ponticelli Feres OREOS 55			Minibus			25	55	
Joint Tatical Electric Vehicle		Series	Military (Marine)			14	2	4,195
Hybrid EB	Bangkok, Thailand		Bus				40 seated	
VITO/Van Hool A308H	Leuven, Belgium	Series	Bus					
APS Conversion- Dina Camiones	Mexico			Jan-94				
Asia-Japan,Tokyo and/or Osaka		parallel	truck, transit bus					

Table A5 Heavy-Duty Hybrid Electric Vehicles and Projects Outside the US (continued)

Project	APU				Generator		
	Fuel	Type	Disp.	Power	Make	Type	Power
Hino Bus	diesel	4 cycle	8				
Mitsubishi MCAT (concept bus)	CNG	4-cylinder	1.5	39			
Mitsubishi Canter	LPG, gasoline models	4-cylinder in-line	1.8	27		AC	30
Toyota Coaster	gasoline		1.3	27			
Hytrax		Peugeot XVD9TE	1.9				
Man M2000	diesel	MAN	4.58				
Man L2000	diesel						
Volvo Environmental Concept Bus	ethanol	Gas Turbine			Volvo		110
Volvo B10L	ethanol	Gas Turbine		134			
Volvo FL6	diesel	Volvo D6A210			ABB		
Asia Motor Company (Korea)	diesel						
Jupiter Project/DAB CITYBUS	gasoline	SAAB 2.3-16		74-87			
Stockholm THOREB bus		SAAB 2.3-17		74			
Scania S15 Bus			2				
Scania S11 Bus	gasoline and diesel versions	Volkswagon	2				
Scania S11 Bus							
Daimler-Benz AG - MB Truck	diesel			240			
Mercedes-Benz O 405 NUH	diesel	MB OM 477 hLA					
Mercedes-Benz O 405 GNDE	diesel	MB OM 477 hLA					
Daimler-Chrysler HyTruck							
Iveco Altrobus	CNG	diesel IDI NA	2.5			AC synchronous	
Iveco Altrobus	gasoline	otto cycle				AC	
Ponticelli Feres OREOS 55	propane	Renault VI					
Joint Tatical Electric Vehicle	diesel						
Hybrid EB							
VITO/Van Hool A308H	diesel	turbocharged					114
APS Conversion- Dina Camiones	diesel						
Asia-Japan,Tokyo and/or Osaka							

Table A5 Heavy-Duty Hybrid Electric Vehicle Vehicles and Projects Outside the US (continued)

Project	Batteries				Generator			
	Make	Type	#	Capacity	#	Make	Type	Power kW
Hino Bus	ER65H	lead-acid	25		1		Three-phase AC	22
Mitsubishi MCAT (concept bus)	Nissan-Sony	lithium-ion			3		AC induction	
Mitsubishi Canter		lead-acid	24	18.7	2		AC induction	100
Toyota Coaster		sealed lead-acid	24 (12v)		2		AC induction	70
Hytrax								
Man M2000		Nickel-Cadmium		64				30
Man L2000	Saft	Nickel-Cadmium	40 modules	24		Siemens	asynchronous 3 ph.	57
Volvo Environmental Concept Bus	Varta	Nickel-Metal Hydride		45				142
Volvo B10L		lead-acid		57			asynchronous	130
Volvo FL6		Nickel-Cadmium		43	2	ABB Hybrid Sys.	DC	
Asia Motor Company (Korea)								
Jupiter Project/DAB CITYBUS	Saft STH800	Nickel-Cadmium						
Stockholm THOREB bus	Saft STH801	Nickel-Cadmium	270 cells				asynchronous	52
Scania S15 Bus		Nickel-Cadmium						
Scania S11 Bus		Lead-acid						220
Scania S11 Bus	SEPA							
Daimler-Benz AG - MB Truck				38.4				
Mercedes-Benz O 405 NUH			4		2	ZF		75
Mercedes-Benz O 405 GNDE					4	ZF		50 (each?)
Daimler-Chrysler HyTruck								
Iveco Altrobus	Fiamm	lead-acid	300	60		Ansaldo	AC asynchronous	164
Iveco Altrobus	Fiamm	Lead-acid	96	19.2		310-22	DC	33
Ponticelli Feres OREOS 55	Saft	Nickel-Cadmium			1			90
Joint Tatical Electric Vehicle		lead-acid			2	GM	AC induction	102
Hybrid EB								
VITO/Van Hool A308H		lead-acid gel	48				AC	53
APS Conversion- Dina Camiones							AC	
Asia-Japan,Tokyo and/or Osaka								

Table A6 Heavy-Duty Fuel Cell Vehicles and Projects

Project	Location	Tech. Type	Vehicle Type	Proj. Start Date	# vehicles	Length	# Pass.	Curb Wt.
XCELLSIS Fuel Cell Engines/Newflyer/CTA	Chicago, IL, Vancouver, BC	fuel cell	Bus	Dec-97	6	40	60	
DOE/FTA/ Georgetown Univ.	Gainsville, FL	fuel cell	Bus	R&D testing 93	1	30	40	29,900
DOE/FTA/ Georgetown Univ.		fuel cell	Bus	Jan-00	1		40	
DOE/ Agusta-Richmond Co. Public Transit	Augusta, GA	H2	Bus	Apr-97	1	33		

Table A6 Heavy-Duty Fuel Cell Vehicles and Projects (continued)

Project	APU			Batteries			
	Fuel	Type	Power	Make	Type	#	Capacity
XCELLSIS Fuel Cell Engines/Newflyer/CTA	LH2	PEM fuel cell					
DOE/FTA/ Georgetown Univ.	methanol	Fugi Electric PAFC	100kW	Saft	flooded, NiCd	36	
DOE/FTA/ Georgetown Univ.	methanol	dbb FCE PEM					
DOE/ Agusta-Richmond Co. Public Transit	hydrogen	ICE		ElectroSource	lead-acid deep discharge	56	672

Table A6 Heavy-Duty Fuel Cell Vehicles and Projects (continued)

Project	Batteries			
	#	Make	Type	Power
XCELLSIS Fuel Cell Engines/Newflyer/CTA				
DOE/FTA/ Georgetown Univ.		GE	PM brushless DC	175kW
DOE/FTA/ Georgetown Univ.				
DOE/ Agusta-Richmond Co. Public Transit				

Table A7 Web Resources

Site	Address
News Sites/Magazines	
Automotive Intelligence News	http://www.autointell.com/news
Car and Driver	http://www.caranddriver.com
Detroit Free Press	http://www.freep.com
Electrifying Times	http://www.electrifyingtimes.com/
Environmental News Network	http://www.enn.com
EV World	http://www.evworld.com/
Metro Magazine Transit Center	http://www.transit-center.com
Ride and Drive e-zine	http://www.rideanddrive.com
Road and Track	http://www.roadandtrack.com
The Auto Channel News	http://www.theautochannel.com
Tech Mall Technology News	http://www.techmall.com/techdocs/1s981229-6.html
Light-Duty Vehicle Sites	
Audi news	http://www.audi.com/java/news/mapframe/datafram.html
BMW	http://www.bmw.com/bmwe/pulse/wasserstoff/index.shtml
DaimlerChrysler	http://www.fleet.chrysler.com/frameset.html
DaimlerChrysler News	http://www.us.media.daimlerchrysler.com/index_e.htm
Ford Motors	http://www.ford.com/default.asp?pageid=401
Ford News	http://www.ford.com/default.asp?pageid=106
GM	http://www.gmaltfuel.com/home.htm
GM News	http://www.generalmotors.com/news/index.htm
Honda news	http://www.hondacorporate.com/press_frame.html
Hyundai	http://www.hmc.co.kr/eng/vehicles/ve-subindex0101.htm
Mercedes-Benz	http://www.mercedes-benz.com/e/default.htm
Mitsubishi	http://www.mitsubishi-motors.co.jp/inter/technology/technology.html
Mitsubishi news	http://www.mitsubishi-motors.co.jp/inter/NEWS/Index/news_index.html
Nissan	http://www.nissan-na.com/1.0/1-2.html
Subaru news	http://www.fhi.co.jp/subaru/topa00.htm
Suzuki news	http://www.suzuki.co.jp/ovs4/auto/topics/findex.htm
Toyota	http://www.toyota.com/cgi-bin/top_frame@SK@0piN9sm14k1P@@.cgi?low_frame=vehicles%2fvehicles.tmpl&data_frame=%2fvehicles%2ffuture%2f
Volvo	http://www.car.volvo.se/index.asp?mainurl=/environment/Default.asp
Volvo news	http://www.car.volvo.se/press/default.asp

Table A7 Web Resources (continued)

Site	Address
Heavy-Duty Vehicle Sites	
Advanced Vehicle Systems	http://www.chattanooga.net/etvi/avs.html
ISE Corporation	http://www.isecorp.com
Navistar	http://www.navistar.com
New Flyer	http://www.newflyer.com
North American Bus Industries	http://www.transit-center.com/NABI/index.html
Nova Bus	http://www.novabuses.com
Unique Mobility	http://www.uqm.com
Volvo Trucks	http://www.volvotrucks.volvo.com
Lockheed-Martin Control Systems	http://www.lmcontrolsystems.com/News.htm
US Electricar	http://www.uselectricar.com
Fuel Cell Sites	
Ballard Power Systems	http://www.ballard.com
Fuel Cells 2000	http://www.fuelcells.org/
H Power Corporation	http://www.hpower.com/
Hydrogen and Fuel Cell Information	http://www.HyWeb.de/index-e.html
Hydrogen and Fuel Cell Letter	http://www.hfcletter.com/
International Fuel Cells	http://www.internationalfuelcells.com/
National Fuel Cell Research Center	http://www.nfcrc.uci.edu/
Miscellaneous Sites	
Advanced Vehicle Technologies Program	http://scitech.dot.gov/partech/nextsur/avp/avp.html#lagacy
California Fuel Cell Partnership	http://www.drivingthefuture.org
CALSTART	http://www.calstart.org
Electric Vehicle Transit Institute	http://www.etvi.org/
Northeast Sustainable Energy Association	http://www.nesea.org
USCar	http://www.uscar.org
Southern Coalition for Advanced Transportation (SCAT)	http://www.advtrans.org

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