Energy-Efficient Technologies

3. Transportation

3.1 Advanced Conventional Vehicle

3.2 Freight Vehicles

3.3 Hybrid, Electric, and Fuel Cell Vehicles

3.4 Alternative Fuel Vehicles

3.5 Air and High-speed Ground Transport

3.1 ADVANCED CONVENTIONAL VEHICLE

Technology Description

The advanced conventional vehicle applies near-term design and technology advances to a light-duty vehicle with a conventional drive train. Fuel economy gains are obtained from a combination of reductions in the vehicle's resistive forces (aerodynamic drag, rolling resistance, and inertial and weight drag) and increases in drive train efficiency (the efficiency with which the vehicle transforms fuel energy into power at the *wheels*). Benefits include non-drive train improvements to vehicles with unconventional drive trains. The technologies that this pathway addresses will have applications in the other four transportation pathways.

System Concepts

- Weight reduction: lightweight materials; redesign for equal structural integrity with less material.
- Drive train system efficiency improvement: reduced friction and pumping losses, higher thermodynamic efficiency, and so on.
- Reduced aerodynamic drag and rolling resistance: smoother body shape and design, better tires.

Representative Technologies

- Supercomputer structural design, direct injection diesel and stratified-charge gasoline engines, variable valve control (VVC), continuously variable transmissions (CVTs), aluminum and graphite composite materials, underbody panels.

Technology Status/Applications

- Current mid-size car ≈ 27–28 mpg (EPA).
- Best mid-size car = 49 mpg (EPA) VW Passat turbocharged diesel with manual transmission, without advanced materials, special tires, advanced aero.
- Cost-effectiveness is a major issue for many of the technologies, especially with low gasoline prices.

Current Research, Development, and Demonstration

RD&D Goals

- By 2001, develop and validate a vehicle systems concept that will achieve 45 mpg for a mid-size car without life-cycle cost or performance/reliability/safety/emissions (PRSE) penalty [DISC (direct-injection, stratified-charge) engine, 20% weight reduction, .006 rolling resistance coefficient (RRC) tires, .27 C_D, 5-speed automatic transmission]; equivalent light truck goal: 33 mpg.
- By 2005, develop and validate a vehicle systems concept that will achieve 52 mpg for a mid-size car without cost/PRSE penalty (DISC engine, 30% weight reduction, .005 RRC tires, .24 C_D, CVT) or 60 mpg [w/turbocharged direct injection (TDI) diesel with advanced particulate, NO_X controls]; equivalent light truck goal: 39/45 mpg.

RD&D Challenges

- Cost is an issue for all of the technologies with possible exceptions of C_D reduction, advanced tires.
- Cost, recycling, rapid production, repair are critical issues for carbon fiber structures; cost and repair are critical issues for aluminum.
- Control effectiveness, longevity are key challenges to lean NO_X catalysts, especially for diesels; also, GHG concerns highlight need to reduce N_2O emissions.
- Reducing particulate emissions from diesels, especially with proposed new EPA standards for fine particulates.
- Combustion control, longevity of high-pressure fuel injectors, cost are key challenges to DISC engine.
- Successful completion of these challenges will allow the application of these technologies to the full range of surface transportation vehicles, including advanced light-duty vehicles.

RD&D Activities

- All enabling technologies are being pursued worldwide by original equipment manufacturers and suppliers.
- American Iron and Steel Institute is pursuing lightweight steel; Alcoa and others are pursuing aluminum bodies.
- DOE recently has expanded research on advanced diesels to light-duty applications.
- DOE is spending about $13 million (FY 1997) on lightweight materials for light-duty vehicles: in order of funding, aluminum, polymer composites, cast steel and iron, and magnesium/titanium (material cost).

Recent Success

- Ford has developed a CVT compatible with larger, high-torque engines such as its Duratec V-6.

Commercialization and Deployment

- Most applicable technologies introduced in *some* commercial application in the United States or overseas: aluminum body/Audi A8; TDI diesel/VW Passat TDI; CVT/Civic HX; DISC engine/Toyota D4 (Japan); VVC/Honda VTEC.
- U.S. market penetration is modest for VVT, TDI diesel (rapid penetration in Europe), low-RRC tires, all-aluminum bodies, CVT; virtually universal for first-generation structural redesign with supercomputers and high-strength/lightweight steel.
- Critical challenges to deployment: lack of strong consumer interest in greater fuel economy (VVT is a case in point—despite Honda's technical success with it, most competing manufacturers have not adopted it because of high cost).

Potential Benefits and Costs

Carbon Reductions

- Potential carbon reductions include effects of non-drive train improvements on vehicles with unconventional drive trains (e.g., hybrids and electric vehicles).

2010	2020	2030
15–25 MtC	40–60 MtC	80–100 MtC

RD&D Expenditures

- FY 1998 DOE RD&D budget for this pathway is $31M.
- Annual DOE RD&D budget required for this pathway: 2000–2030, $75M/year.
- Advanced lightweight materials research will be needed well into the next century to develop enabling technologies to reduce the total material system life-cycle cost.

Market

- From 300 MtC/year (2010) to 400 MtC/year (2030).

Nonenergy Benefits and Costs

- Reduce pollutant emissions, improve human health, and reduce the nation's dependence on imported oil.

Risk Factors

Technical Risk

1 2 3 4 5 6 7 8 9 10

Low — High

- For lightweight materials, crashworthiness and viable manufacturing techniques have not been demonstrated.
- Lean NO_X catalysts critical to the DISC engine and DI diesels require considerable further development.
- Control of fine particulates in DI diesels needs further improvement.

Commercial Risk

1 2 3 4 5 6 7 8 9 10

Low — High

- Large shift to diesel would require major refinery infrastructure investment and would impact fuel prices.

Ecological Risk

1 2 3 4 5 6 7 8 9 10

Low — High

- Recycling of polymer composites is not ensured.

Human Health Risk

1 2 3 4 5 6 7 8 9 10

Low — High

- There are ongoing concerns about diesel particulate and NO_X emissions.
- Crashworthiness of new materials is uncertain.
- Workplace risks may exist in production, recycling of new materials.

Economic Risk

1 2 3 4 5 6 7 8 9 10

Low — High

- Marketability is a ubiquitous risk because increased fuel efficiency is not a widely-sought-after vehicle attribute.
- New structural materials may expose vehicle manufacturers to greater liability risks because of lack of industry experience in design and manufacture and lack of real-world safety experience.

Regulatory Risk

1 2 3 4 5 6 7 8 9 10

Low — High

- Tighter NO_x standards could impact feasibility of DISC, TDI diesel technology; tighter particulate standards could affect diesels.

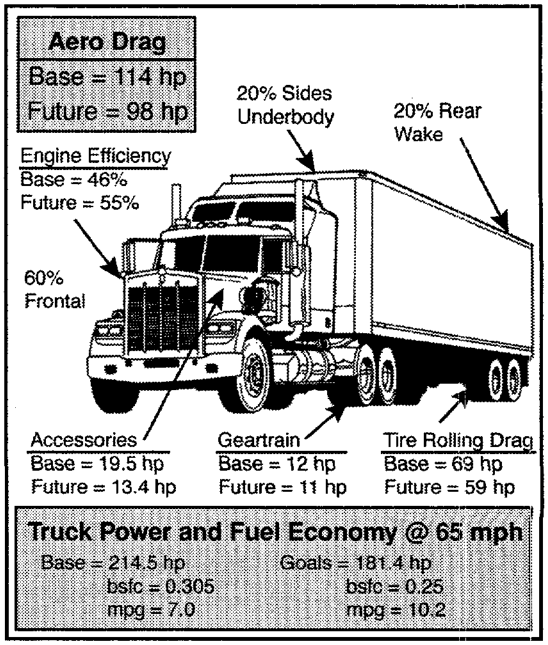
Key Federal Actions

- Some market transformation measures may be necessary if cost goals are not met—higher fuel taxes, new fuel economy standards, "feebates."
- Without strong market transformation, increased federal sponsorship of RD&D would be necessary for technology development because of lack of market stimulus, high market risk.

3.2 FREIGHT VEHICLES

Technology Description

Freight vehicles (class 7 and 8 trucks and rail) are essential to the economic vitality of the nation. Diesel engines are the dominant motive source for these vehicles. Vehicle efficiency can be increased by as much as 50% with a new generation of ultra-high-efficiency diesel engines that use advanced emissions control technology, coupled with improved aerodynamics and reduced rolling and parasite power losses. Successful development and commercialization of engines with 50% efficiency will significantly reduce transportation oil use, emissions (including CO_2), and related costs to the economy.



System Concepts

- Four-stroke, direct-injection diesel engines (with high peak cylinder pressures, thermal barrier coatings, high-pressure fuel injection systems, and turbocharging) are being developed.
- Lightweight materials, truck aerodynamics and advanced tires are being developed to improve overall fuel economy.
- Hybrid electric vehicles or regenerative braking may have application in local delivery vehicles.
- Laser glazing of rails, flywheels, diesels with oxygen-enriched air systems and fuels cells are being considered for locomotives.

Representative Technologies

- High-pressure, common-rail fuel injection, bottoming cycles, friction and wear reduction.
- Oxygen-enriched combustion air technology for locomotive diesel engines.
- Software technology to improve vehicle aerodynamics.

Technology Status/Applications

- Virtually all heavy-duty trucks and the entire fleet of locomotives are diesel powered, and there is an increasing trend to dieselize the medium-duty trucks as well. New advanced technologies for emission controls are required.
- Fuel cells are considered a long-term option. An active locomotive fuel cells program is being pursued by industry.
- Software tools are being developed to provide design guidance to reduce aerodynamic drag.

Current Research, Development, and Demonstration

RD&D Goals

- By 2004, develop enabling technologies that will
— Lead to a fuel efficiency of 10 mpg (at 65 mph) for class 7 and 8 trucks.
— Reduce class 7 and 8 truck emissions to 2 g/hp-h of NO_x and 0.05 g/hp-h particulates.

RD&D Challenges

- The challenge is to improve efficiency (thus reducing CO_2) and meet emission regulations.
— Engine: high-pressure structural materials, in-cylinder processes and control, fuel effects.
— After-treatment: NO_x and particulate matter.
— Components: turbochargers, friction.
— Simulation of flows around vehicles.
— Emission control for a wide variety of gaseous and liquid fuels.

RD&D Activities

- DOE/OTT has a large heavy- and medium-duty diesel engine program for trucks.
- DOD/ARPA, California Energy Commission and the California Air Resources Board co-sponsor R&D projects with DOE.
- Federal Railroad Administration sponsors locomotive efficiency improvement projects.
- Analytical and modeling work are sponsored by DOE.

Recent Success

- New conceptual model of in-cylinder soot formation developed.
- Advanced multicylinder engine (expected efficiency of 52–53%) assembled at Caterpillar and being tested.

Commercialization and Deployment

- The diesel engine is the workhorse of all the heavy-duty transport modes that are responsible for most of the nation's intercity freight movement—the lifeblood of the economy. Because of low fuel consumption, high reliability, and long service life, it is widely acknowledged that the diesel engine will continue to dominate heavy-duty transport propulsion well into the next century.
- Strong coupling between efficiency and emissions controls is a significant barrier. Many engine design options currently available to manufacturers for emissions reduction involve a fuel economy penalty of 10 to 20%. In the absence of significant technology advancements, future emission regulations could affect the historical trend toward higher diesel engine efficiency.
- Stiff domestic and international competition from European and Japanese diesel engine manufacturers has reduced domestic market share. U.S. manufacturers have limited resources to identify, research, develop, and commercialize many of the promising advanced emission technologies.
- All new technologies have to meet high durability requirements.
- Fuel cells are at least 10 years from commercialization in any freight vehicle.

Potential Benefits and Costs

Carbon Reductions

In MtC/year

2010	2020	2030
7–10	15–30	25–35

RD&D Expenditures

- FY 1998 DOE RD&D budget for this pathway is $40M.
- Annual DOE RD&D budget required for this pathway: 2000–2030, $50M/year.

Market

- Approximately 100 MtC/year of carbon reduction.

Nonenergy Benefits and Costs

- These technologies would reduce the nation's dependence on imported oil. Success would improve the global position of domestic heavy-duty engine manufacturers and increase the competitiveness of domestic engine manufacturers in the automotive diesel engine market largely lost to foreign producers.

Risk Factors

Technical Risk

1 2 3 4 5 ⑥ 7 8 9 10

Low High

- Cost-effective after-treatment, regenerative braking, fuel cell technology are not practical commercial devices.

Commercial Risk

1 ② 3 4 5 6 7 8 9 10

Low High

- Diesel engines are ubiquitous in the freight industry.

Ecological Risk

1 ② 3 4 5 6 7 8 9 10

Low High

Human Health Risk

1 ② 3 4 5 6 7 8 9 10

Low High

- Fine particulate matter being evaluated as health risk. Other emissions are being controlled.

Economic Risk

1 2 ③ 4 5 6 7 8 9 10

Low High

- Diesel engines are already an integral part of the nation's infrastructure.

Regulatory Risk

1 2 3 ④ 5 6 7 8 9 10

Low High

- New focus on ultrafine particulates could lead to tightened particulate standards and control challenges to diesels.

Key Federal Actions

- Federal role is to ensure U.S. diesel engine manufacturers are competitive in the marketplace in the face of heavily subsidized foreign competition.
- Federal funds are needed for the continuing improvements in freight vehicle's fuel economy to mitigate the carbon dioxide emissions from the projected increase in freight vehicle traffic over the next ten to fifteen years. In addition, federal resources are required to ensure advanced aerodynamic software tools are available to manufacturers.

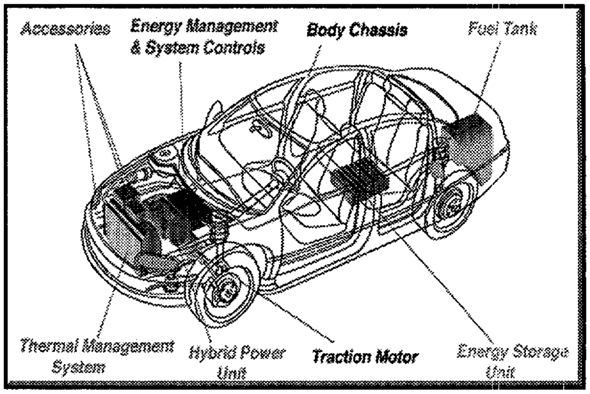
3.3 HYBRID, ELECTRIC, AND FUEL CELL VEHICLES

Technology Description

The current PNGV goal is to develop advanced vehicles that are up to three times more efficient than conventional vehicles and meet low emissions standards. Hybrid electric vehicles (HEVs) use a combination of electric propulsion and an auxiliary power unit. They can be designed in either series or parallel configuration. Electric vehicles (EVs) are powered by electric drive systems that receive energy from on-board energy storage devices. EVs emit zero regulated emissions from the tailpipe. With current and projected future average generation mix for 2015, EVs yield little or no carbon reduction. Fuel cell vehicles convert fuels to electricity directly. A vehicle powered by a hydrogen fuel cell may be twice as efficient and produce extremely low to zero tailpipe emissions. Fuel cells may initially run on gasoline or alcohol fuels reformed to produced hydrogen. The fuels used and how they are produced will determine whether carbon emissions are reduced by 50 to 100% over conventional vehicles.

System Concepts

- A series HEV drives the wheels using an electric motor while drawing energy from a battery pack, which is charged by a small on-board engine or another type of power unit. A parallel HEV uses both an electric motor and a power unit to drive the wheels.
- An EV uses a rechargeable battery pack, a motor controller, an electric drive motor, and a gear reducer to drive the vehicle.
- For fuel cells, hydrogen can be stored on the vehicle or can be made on-board using gasoline or alternative fuels.



Representative Technologies

- These technologies can use combinations of high-power energy storage devices (ultracapacitors, flywheels, batteries); small, high-efficiency integrated power units (gas turbines, direct-injection diesel engines, spark-ignited engines, Stirling engines, and fuel cells); and compact electric power systems (electric drive motors, electronic controllers).

Technology Status/Applications

- As part of a multiyear 50/50 cost-shared program with DOE, GM, Ford, and Chrysler have developed prototype HEVs that are being tested and analyzed. Simulation modeling techniques are being used to optimize components.
- In 1997, several versions of EVs became available for sale/lease in selected areas. However, these cars use batteries with limited range, which prevents widespread consumer acceptance, and there are still issues with the power mix.
- Fuel cells: Proton exchange membrane fuel cells are being demonstrated on vehicles and buses.

Current Research, Development, and Demonstration

RD&D Goals

- HEVs: DOE is striving to develop HEVs with triple the fuel efficiency of conventional vehicles and comparable performance, range, safety, and cost. By 2004, the goal is to have an 80 mpg vehicle that meets Tier II emissions standards.
- EVs: Industry and government are striving to develop advanced batteries with increased range and life-cycles. The long-term EV battery targets are power density of 460W/L, specific power of 300 W/kg, energy density of 230 Wh/L, specific energy of 150 Wh/kg, and a life of 10 years.
- Fuel cells: Stack systems with a power density of 500 W/kg, specific power of 500 W/L, efficiency of 68% at 25% peak power, durability of 5000 hours, a cold start-up time to maximum power of less than 30 seconds, and a cost of less than $50 kW must be developed.

RD&D Challenges

- HEVs: System integration and packaging, cost and durability of components, high-power battery packs, and compact high-efficiency engines.
- EVs: Cost, life, performance, weight, and range of EV battery packs. Reducing battery recharge time and optimizing battery thermal management are also important challenges.
- Fuel cells: Tolerance to CO poisoning and reductions in weight, volume, and cost. Lack of an adequate infrastructure system for new fuels (e.g., hydrogen, methanol) also is a problem.

RD&D Activities

- HEVs: DOE has related programs that conduct research on advanced gas turbines, engine materials, lightweight materials, advanced energy storage, and fuel cells. These programs are directly linked to DOE's PNGV/Hybrid Propulsion Systems Program.
- EVs: DOE has a High Power Energy Storage Program and Exploratory Technology Research Program. Other federal agencies (NASA, DOD) and private agencies have battery R&D programs of their own.
- Fuel Cells: DOE is working with industry and other federal agencies to develop fuel cells and fuel processing systems.

Recent Success

- GM, Ford, and Chrysler have numerous hybrid and electric vehicles in various stages of development. Technical feasibility of these concepts has matured, although cost and reliability barriers need continued attention.
- The nickel-metal hydride battery is approaching (in some cases attaining or exceeding) all performance goals, although cost remains an issue.
- Demonstration prototypes of fuel cell vehicles have been built and zero-emission fuel cell buses are in operation.

Commercialization and Deployment

Commercialization

- HEVs: The Big 3 automakers are working with DOE to develop production-feasible HEV propulsion systems by 1998. Vehicle commercialization will begin when the market is ready and a business case can be made. Toyota will soon market a 65-mpg hybrid called Prius.
- EVs: Almost all major manufacturers began selling/leasing some version of an EV to public and/or private fleets in 1997. GM and Honda were the first two companies to lease EVs to private individuals. Consumer leasing figures have been less than anticipated. Additional improvements need to be made to increase the range and reduce cost so that more people will find these vehicles acceptable.
- Fuel cells: Almost all major auto manufacturers are pursuing fuel cell development. Manufacturability and cost are the most significant barriers to commercialization. Size and weight must also be substantially reduced to make them competitive with alternatives.

Deployment

- HEVs: An HEV's biggest competitor is an advanced conventional vehicle. Consumer acceptance and willingness to pay a little more for a more fuel efficient, high-technology vehicle is key. Depending on the fuel used in the HEVs, there will be minimal refueling infrastructure challenges that may affect widespread deployment.
- EVs: An EV's competition is an advanced conventional vehicle and an HEV. HEVs will have low GHG emissions and possibly low criteria emissions along with a range comparable to a conventional vehicle. Society will have to weigh the benefits of having a vehicle with limited range and no tailpipe emissions against the benefits of having an advanced vehicle with possibly lower emissions.
- Fuel cells: Fuel cell vehicles can combine the zero emissions of an EV and the range of conventional vehicles. Fuel cell vehicles have the potential to require less maintenance and have a more durable engine than conventional vehicles. Larger investments and longer lead times for the fuel cells to mature make this technology lag EVs and HEVs.

Potential Benefits and Costs

Carbon Reductions

- The combination of advanced vehicles will result in GHG emissions reductions of 10–15 MtC by 2010, 25–45 MtC by 2020, and 50–75 MtC by 2030.

RD&D Expenditures

- The federal government and its industry partners will need to continue to invest in EV, HEV, and fuel cell technologies to make the pathways successful. FY 1998 DOE RD&D budget for this pathway is $104M. Annual DOE RD&D budget required for this pathway: 2000–2010, $230M/year; 2010–2030, $250M/year. While the budgets for outyears are speculative, technology-driven opportunities for carbon reductions in this sector will continue to be large well into the next century.

Market

- From 300 MtC/year (2010) to 400 MtC/year (2030).

Nonenergy Benefits and Costs

- Besides reducing emissions, HEV, EV, and fuel cell technologies will improve human health and reduce dependence on imported petroleum.

Risk Factors

Technical Risk

1 2 3 4 5 ⑥ 7 8 9 10

Low — High

- Battery improvement, system integration processes, infrastructure availability, and component optimization, are issues.

Commercial Risk

1 2 3 4 5 ⑥ 7 8 9 10

Low — High

- A market needs to be developed. A battery with adequate range is critical. Cost, reliability, and performance are key for acceptability to buyers.

Ecological Risk

1 2 3 4 ⑤ 6 7 8 9 10

Low — High

- Ecological risks are low, but battery recycling must be addressed. The system in place recycles ~98% of lead acid batteries. Other recycling systems for various advanced batteries are scarce and must be perfected.

Human Health Risk

1 ② 3 4 5 6 7 8 9 10

Low — High

- Human health risks are almost nonexistent for these technologies.

Economic Risk

1 2 3 4 ⑤ 6 7 8 9 10

Low — High

- Significant capital investment will be required by the automobile manufacturers to introduce these technologies. Continued research will be required to make them cost-effective. It may take many years for any auto manufacturer to gain a return on its investment in these technologies.

Regulatory Risk

1 2 ③ 4 5 6 7 8 9 10

Low — High

- Regulations may be required to encourage and promote battery recycling.

Key Federal Actions

- Continuation of industry/government partnership to develop HEV, EV, and fuel cell technologies.
- Incentives for advanced vehicle purchases, including tax credits, preferential parking, and freeway lane access; reduced electricity rates for EV charging; and purchase discounts.
- Government mandates on vehicle production are a powerful incentive to commercialization although they risk damage to consumer acceptance if technologies are forced into the market prematurely.

3.4 ALTERNATIVE FUEL VEHICLES

Technology Description

Alternative fuels include compressed and liquefied natural gas, biomass ethanol, liquefied petroleum gas, biodiesel, and dimethyl ether. The real leverage in carbon reductions comes from the use of biomass-derived fuels—ethanol, biodiesel, and dimethyl ether. When biomass ethanol is used purely as a blending agent with gasoline (up to at least 10% by volume, and possibly higher), no changes in vehicle technology are needed.

System Concepts

- Alternative-fuel vehicles (AFVs) are similar to today's vehicles, except for certain fuel- and emission-related systems.
- Alcohol vehicles require corrosion-resistant fuel lines and fuel tanks, modified fuel injectors, and modified engine lubricants.
- Gaseous-fuel vehicle fuel system components include fuel regulators, air and fuel mixing apparatus, and modified fuel injectors. Fuel tank modifications are also required.

Representative Technologies

- Flexible-fueled vehicles are available from the three major domestic automobile manufacturers.
- Several models of compressed natural gas and liquefied petroleum gas vehicles are offered by automakers.
- Heavy-duty alternative-fuel engines are offered as options to the commercial market for trucks and buses.

Technology Status/Applications

- Light-duty AFVs have shown superior in-service emissions performance and similar levels of fuel economy in federal fleet demonstrations. AFV purchase costs vary significantly depending on the fuel. Flexible-fueled vehicles have been purchased at prices below those of conventional cars, while compressed natural gas vehicles can cost $5K more than conventional vehicles.
- Heavy-duty AFVs have shown dramatic reductions in particulate emissions, with fuel economy near their diesel counterparts. Maintenance costs are higher but will decrease with experience. Alternative-fuel engines should be no more expensive, but high-pressure tanks will raise overall costs somewhat.

Current Research, Development, and Demonstration

RD&D Goals

- Develop light- and heavy-duty engine and fuel technologies to meet future emissions standards.
- Develop technologies that use alternative fuels in conventional vehicles with full range and performance characteristics by 2004.
- By 2011, develop automotive technologies that use non–petroleum-based fuels and achieve near-zero emissions while obtaining 100 mpg in lightweight vehicles.

RD&D Challenges

- AFVs must be developed to meet cost, performance, and future environmental and energy efficiency goals over the lifetimes of the vehicles. Specific areas of concern include cost, range, and refueling convenience; cold-start performance and engine efficiency of alcohol fuels; and fuel-injection and storage systems for dimethyl ether.

RD&D Activities

- The three U.S. automakers have significant ongoing R&D programs, and several vehicle models are available today.
- With DOE cofunding, heavy-duty engine manufacturers have major alternative-fuel engine R&D efforts.
- Component manufacturers, national laboratories and research institutions, universities, and state and local governments have sizable alternative-fuel R&D operations.
- The DOE AFVs funding levels for FY 1996 and FY 1997 were $29M and $26.3M.

Note: Fuel production and distribution research is discussed in Renewable Energy technology pathway 8.7, "Biomass Transportation Fuels" and hydrogen production and distributing is discussed in cross-cutting technology pathway 10.2, "Hydrogen."

Recent Success

- Work on the first-generation ultra-safe and ultra-low emission school bus powered by compressed natural gas has been completed and the bus is now commercially available. More than 100 have been sold in California, and work on the second generation is under way to improve engine efficiency and lower emissions even further.
- Honda has obtained ultralow emission vehicle certification for a compressed natural gas automobile.

Commercialization and Deployment

- Domestic automobile manufacturers have been producing AFVs since 1991. Today, 11 light-duty and 19 medium- and heavy-duty vehicle models are available, powered by a number of alternative fuels. The configurations used include flexible-fuel, dual-fuel, and dedicated. Prices for flexible-fuel vehicles have decreased to those of their conventional counterparts. AFV conversion companies are successfully filling any market voids left unoccupied by domestic automakers.
- DOE and GSA are working under an interagency agreement to manage the Federal Light Duty Alternative Fuel Vehicle Project.
- The federal fleet currently contains ~33,000 light-duty AFVs. Since its inception in 1991, the DOE-sponsored alternative-fuel, heavy-duty truck demonstration program has assisted in placing more than 300 heavy-duty data collection AFVs.
- The DOE Clean Cities Program actively enables deployment of AFVs through its locally-based government/industry partnership.
- AFVs are projected to number 400,000 light- and heavy-duty vehicles by the end of 1997 in the United States.

Potential Benefits and Costs

Carbon Reductions

2010	2020	2030
2–10 MtC	4–12 MtC	15–30 MtC

RD&D Expenditures

- FY 1998 DOE RD&D budget for this pathway if $18M.
- Annual DOE RD&D budget required for this pathway: 2000–2010, $50M; zero in the outyears.

Market

- The domestic market size for AFVs alone is between 300 MtC/year in 2010 and 400 MtC/year in 2030.

Nonenergy Benefits and Costs

- Deployment of alternative fuels may result in reductions in emissions of NO_x, CO, hydrocarbons, and fine particulates, yielding improvement in urban air quality.

Risk Factors

Technical Risk

1 ② 3 4 5 6 7 8 9 10

Low High

- Most of the alternative fuels RD&D is based on modifications to existing vehicle technology, and first-generation vehicles are already in commercial production.

Commercial Risk

1 2 3 4 ⑤ 6 7 8 9 10

Low High

- Commercial success depends not only on cost-effective technical solutions, but also on the creation of infrastructure to produce and supply the alternative fuels.

Ecological Risk

① 2 3 4 5 6 7 8 9 10

Low High

- Alternative fuels are environmentally superior choices to petroleum-based fuels. The stable of alternative fuels includes those that can substantially reduce emissions of toxics, ozone precursors, particulates, and GHGs.

Human Health Risk

1 2 ③ 4 5 6 7 8 9 10

Low High

- Alternative fuels are superior to petroleum-based fuels in terms of human health risks from their manufacture, distribution, and use. The agricultural production risk impact on human health is greater.

Economic Risk

1 2 3 ④ 5 6 7 8 9 10

Low High

- Investment in developing these vehicles is moderate, but the large-scale investment required for the infrastructure to deliver the fuels is still a concern.

Regulatory Risk

1 ② 3 4 5 6 7 8 9 10

Low High

- Alternative fuels for which vehicles are being developed are being used on a large scale. The vehicles themselves are being demonstrated, and in most cases the first generation is commercially available.

Key Federal Actions

- Vigorous implementation of current federal mandates (e.g., EPAct) could be pursued. Federal RD&D activities would contribute to development of vehicle technologies that can realize the inherent environmental and energy efficiency benefits offered by alternative fuels. Regulatory and/or tax reforms that reward alternative fuels for these benefits would increase demand for these vehicles. Vehicle cost reductions could also be pursued through continued RD&D. Finally, federal investment in fuel supply infrastructure would help alleviate fuel/vehicle, chicken-and-egg conundrum.

3.5 AIR AND HIGH-SPEED GROUND TRANSPORT

Technology Description

Carbon emissions from commercial jet aircraft can be cut through reduced drag, improved fuel combustion, and reduced idling. The National Research Council has set as a "reasonable goal" for new commercial aircraft a reduction in fuel burn per seat mile of 40% compared with current airplanes. Of the total 40%, 25% is expected from improved engine performance and 15% from aerodynamic and weight improvements. Electrified high-speed ground transportation modes (speeds > 150mph) can reduce carbon emissions by diverting trips from conventional fossil-fueled modes and by using more efficient suspension and propulsion system technologies. Since high-speed rail (HSR) and maglev systems derive their power from the utility grid, potential carbon reductions are directly linked to electric generating technology efficiencies and carbon emissions. Passengers are emphasized here, but technologies also apply to cargo.

System Concepts

- HSR (speeds of up to 200 mph) uses locomotive-drawn coaches supported by steel wheels on steel rails. Single-phase power is transformed from transmission-line voltages at substations, distributed along the right of way, and delivered to locomotives via catenary-pantograph systems, where it is converted by power conditioning equipment to voltages and frequencies needed by the propulsion motors. Regenerative braking systems can be used but generally require energy storage.
- Maglev is a new mode of high-speed (up to 300 mph or more) guided ground transportation that uses magnetic forces for non-contact support, guidance, propulsion and braking. Most of the power conditioning equipment and propulsion system is at wayside, making the vehicles much lighter and automatically controllable.
- Propulsion efficiency in aircraft can be increased by still higher turbo-fan bypass ratios, increased cycle pressure ratios, higher turbine inlet temperatures, improved turbine aerodynamics, and lighter engine parts. The most promising approach for reducing drag appears to be methods for increasing laminar flow next to the surface of aircraft, but turbulence control and reduction in induced drag also can help improve lift-to-drag ratios. A 1% reduction in empty aircraft weight can reduce fuel consumption by 0.25% to 0.50%. Maximum use of lightweight, high-strength materials could conceivably increase non-metallic content of aircraft to a maximum of about 80%, with an overall 30% reduction in weight.

Representative Technologies

- Existing HSR systems include the French TGV, German ICE, and Japanese Nozomi. All require electrified railways. Possible enhancements and alternatives include use of on-board energy storage devices and high-temperature superconducting components. Locomotive designs using advanced prime movers such as fuel cells and high-efficiency gas turbines could conceivably compete with electrified systems for speeds up to about 150mph, but market and emission benefits would be less.
- Foreign maglev technologies: the German Transrapid (conventional electromagnet, attractive-force system); the Japanese Linear Motor Express (superconducting magnet, repulsive-force system).
- Ultra-high bypass turbofans, increasing bypass ratios up to 10.
- Propfan technology with advanced, counter-rotating prop designs.
- Lightweight, high-strength structural and surface materials.
- Advanced computational fluid dynamics for engine and airframe design.
- Hybrid laminar flow control technology for drag reduction.

Technology Status/Applications

- HSR is a mature technology in several foreign countries, and it is not likely that the United States could compete. Hence, the benefits would derive from implementing that technology in the United States and diverting passengers and cargo from fossil-fueled modes.
- The German Transrapid was certified for application in 1991. Full-scale testing of the Japanese superconducting system on the Yamanashi Prefecture test line is scheduled to be completed in 1998.
- Foreign maglev technologies are expensive and have other characteristics that may limit their applicability in the United States.
- Foreign competition is driving new aircraft and engine designs by Boeing, NASA, GE, and Pratt & Whitney.
- Advanced aircraft technologies are under development by NASA, Boeing, and engine manufacturers.
- Propfan technology has been demonstrated but could benefit from cost reduction and noise and vibration improvements.
- Aspects of laminar flow control have been demonstrated in limited tests, but a practical system has not yet been developed.

Current Research, Development, and Demonstration

RD&D Goals

- For speeds of 90 to 150 mph, the DOT/FRA Accelerail Program focuses on passenger rail technologies that can use existing railroad rights of way (mainly owned by the freight railroads).
- Implement electrified HSR systems where commercially viable.
- Develop and test concept of innovative domestic maglev system designs within the next 2 years; refine designs and performance testing within the following 2 years; design and initiate demonstration projects in the following 2 years.
- Develop room-temperature maglev (LLNL contract with NASA to develop its Inductrack System).
- Achieve 40% overall efficiency improvement in new aircraft by 2025, 25% propulsion efficiency improvement, and 15% efficiency gain from drag and weight reduction.

RD&D Challenges

- Meet or exceed performance of foreign maglev systems at reduced construction costs. Develop manufacturing techniques and lightweight, strong, inexpensive materials for vehicle and guideway components.
- Develop suspension and propulsion system components that will meet the higher performance and lower cost requirements.
- Develop efficient, reliable superconducting magnet designs.
- Reduce NO_x emissions while increasing turbine cycle temperatures and pressures for thermodynamic efficiency.
- Develop a low-cost, low-maintenance, low-noise and -vibration propfan so that airlines will demand their installation on new aircraft.
- Develop a hybrid laminar flow control system that is practical and maintainable under real world operating conditions (e.g., dust, insects).
- Lower the cost and improve the manufacturability of high-strength, lightweight, non-metallic materials for engines and airframes.

Current Research, Development, and Demonstration (continued)

RD&D Activities
- Design and test maglev system components.
- Develop supporting technologies such as high-temperature superconductors, composite materials, power electronics, zero- or low-carbon-emitting electric power generating technologies.
- Design transportation systems together with incentives that incorporate maglev and HSR systems cost-effectively and that divert as many trips as possible from privately owned vehicles and short-haul aircraft.

Recent Success

- New HSR technology has increased the top speed for commercial operation to 200 mph in France. Development of German and Japanese maglev and HSR has been highly successful. Four innovative maglev system designs were developed under the auspices of the NMI.
- High bypass turbo-fan on Boeing 777, advanced propfan able to achieve Mach 0.7, numerous advances in laminar flow control, and adoption of drag reduction via riblets and winglets on several commercial aircraft.

Commercialization and Deployment

- Construction on the first commercial route of the Transrapid system (Hamburg to Berlin) is scheduled to begin in 1998. The Japanese will reach a decision on commercialization by the year 2000. Deployment of existing maglev technology in the United States could begin with small pilot projects to introduce the technology and demonstrate its benefits and ability to attract financing.

Potential Benefits and Costs

Carbon Reductions

2010	2020	2030
7–12 MtC	15–30 MtC	25–50 MtC

RD&D Expenditures
- Current NASA RD&D budget for energy-efficient aircraft is $175M/year.
- Annual federal RD&D budget required for this pathway: 2000–2030, $300M/year.

Market
- From 85 MtC/year (2010) to 150 MtC/year (2030).

Nonenergy Benefits and Costs
- Maglev and to a lesser extent HSR: reduction of urban air pollution, highway and airport congestion, freeing of airport slots for more efficient long-haul and international flights, increased mobility, increased energy security.

Risk Factors

Technical Risk

1 ② 3 4 5 6 7 8 9 10

Low — High

- Japanese and German maglev is near the application stage. Some risk is involved in developing domestic maglev options until testing and demonstration is completed.

Commercial Risk

1 2 3 4 ⑤ 6 7 8 9 10

Low — High

- Commercial risk can be mitigated by developing two or three well-designed pilot projects with the support of partnerships involving federal, state, and private financing. Short-haul airlines could be significantly impacted in HSR and maglev corridors.

Ecological Risk

1 ② 3 4 5 6 7 8 9 10

Low — High

- Electrified HSR and maglev systems are relatively environmentally friendly compared with conventional trains and aircraft. Elevating tracks reduces ecological risk further.

Human Health Risk

① 2 3 4 5 6 7 8 9 10

Low — High

- There are no local emissions and magnetic field exposure does not pose a human health risk.

Economic Risk

1 2 3 ④ 5 6 7 8 9 10

Low — High

- Ridership base for high speed rail is uncertain.

Regulatory Risk

1 ② 3 4 5 6 7 8 9 10

Low — High

Key Federal Actions

- Establish an RD&D program for next-generation maglev technology in the United States. Identify and fund supporting technologies. Use the existing MOU with DOT.
- Establish a program to demonstrate existing technology through two or three revenue-earning pilot projects, each of about 40 miles.
- Provide leadership for the formation of public/private partnerships to finance and operate such projects. Incorporate programs into NEXTEA legislation. Request and support legislative actions to appropriate funding for programs.