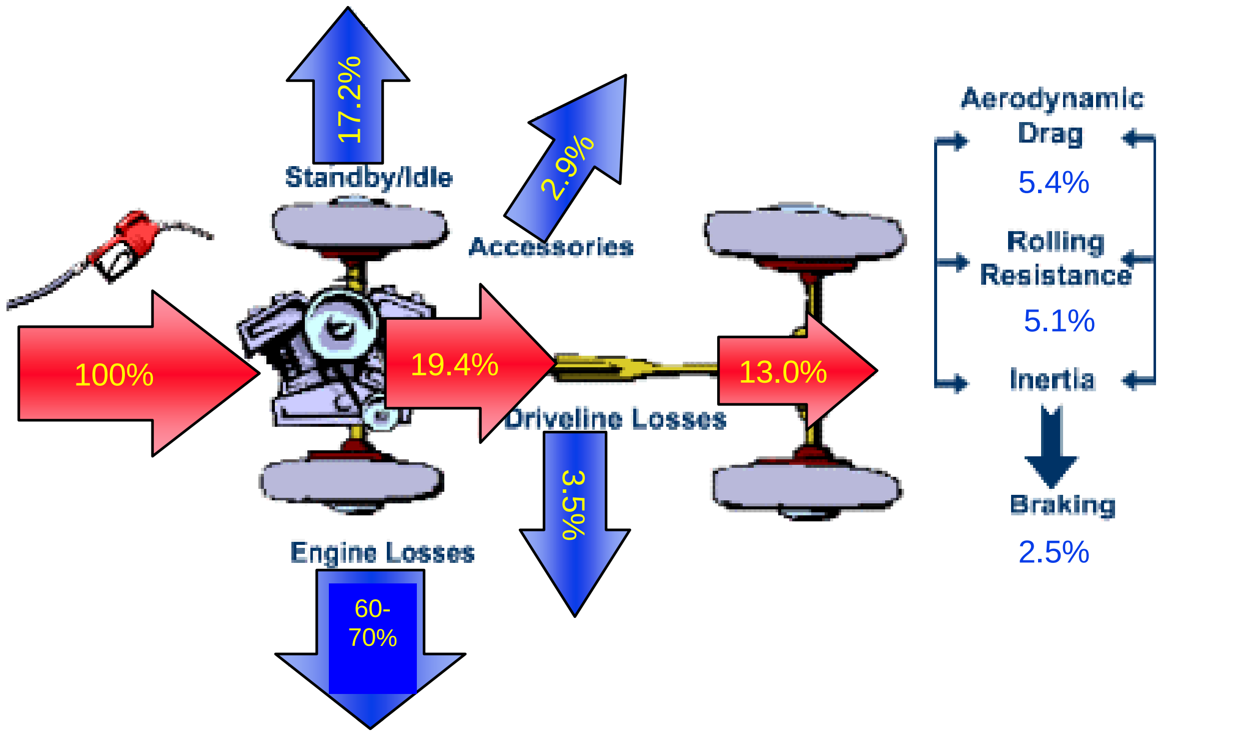
1.0 REDUCING EMISSIONS FROM ENERGY END USE AND INFRASTRUCTURE

1.1 TRANSPORTATION

1.1.1 LIGHT VEHICLES – HYBRID, FUEL CELL, AND ALTERNATIVE-FUEL VEHICLES

Technology Description



Conventional vehicle energy audit used as baseline for analysis of advanced design options.

Hybrid electric vehicles (HEVs) use a combination of electric and mechanical power. HEVs can reduce greenhouse gas emissions by nearly 50% over conventional vehicles.[1] An HEV with a compression ignition, direct-injection (CIDI) engine (and whose chassis incorporates lightweight materials) could improve peak energy efficiency by more than 100% compared to present-day gasoline engines. Advanced combustion engines alone could reduce fuel consumption by 50%. Fuel cell vehicles (FCVs) are one type of HEV, distinguished by the use of a fuel cell to electrochemically produce electricity from hydrogen and oxygen rather than using an internal-combustion engine. Although R&D to enable FCVs that run on gasoline or other fuels reformed "onboard" to produce hydrogen has been conducted, it appears that most of the world's automakers have decided to move directly to designs powered by hydrogen stored onboard. FCVs using onboard hydrogen produce only water as a tailpipe emission. The hydrogen source (nuclear, fossil fuel, renewables) must be factored into determinng the net energy and environmental benefit of FCVs. All hybrid vehicles could potentially benefit from batteries with greater energy capacity that can recharge from the electrical grid (i.e. plug-in hybrids). Plug-in hybrids could provide additional emissions reductions and efficiency improvements; but because most electricity is produced from fossil fuels, the contributions to reductions in carbon emissions needs to be evaluated. Alternative fuel vehicles (AFVs) are defined as those capable of running on one or more fuels such as ethanol, natural gas, propane, hydrogen, biodiesel, electricity, methanol, or blends. Some of these fuels may be useful as components in fuel blends that enable higher

[1] FCVT MYPP ES-2

combustion efficiencies and also displace petroleum. The fuels used and how they are produced will determine the degree of carbon-emissions reduction compared to conventional vehicles.

System Concepts

- HEVs that provide even limited power-assist during acceleration can dramatically reduce peak engine size, resulting in substantial fuel economy benefits.
- HEVs have led to the introduction of "idle-off" strategies using a combined alternator/starter. The engine automatically turns off when the engine is idling or decelerating. In such cases, stored energy is required to operate the ancillary loads, such as cabin climate control.
- HEVs with more electrical energy storage capacity and plug-in capability can run in "electric-only" mode for an expanded range (allowing even combustion-engine HEVs to act temporarily as zero-emissions vehicles), and they may also be able to contribute to electric grid stability and peak-shaving.
- FCVs can either store a liquid fuel onboard that uses a reformer or other chemical reaction to produce hydrogen (an approach now dropped by the U.S. Department of Energy and by U.S. automakers), or it can directly store hydrogen in gaseous or liquefied (cryogenic) form.
- Reducing the weight of vehicle by as much as 50% could improve vehicle energy efficiency by more than 30%, regardless of the type of power train (combustion, fuel cell, HEV).
- AFVs often require fuel tank modifications, emission-related systems, and appropriate fuel supply and infrastructure.

Representative Technologies

- Hybrid electric powertrains (advanced power electronics, electrical energy storage, and electric motors).
- Greater energy storage capacity for enabling plug-in HEV or all electric-vehicle applications.
- Fuel cell component technologies such as Polymer electrolyte membranes (PEM), catalysis, and bipolar plates.
- Advanced internal combustion engine such as CIDI, lean combustion (e.g. homogeneous charge compression ignition), gasoline direct-injection.
- Nonpetroleum-based fuels (including renewable fuels), improved petroleum-based fuels, and eventually, renewably produced hydrogen.
- Lightweighting materials technologies that can reduce vehicle weight.

Technology Status/Applications

- Many major automotive manufacturers have developed or plan to develop HEVs and/or AFVs. More than 920,000 HEVs and AFVs were made available for sale in the United States in 2003.[2]
- HEVs are providing up to 40% gain in fuel economy as compared to equivalently equipped and sized nonhybrid vehicles.
- Diesel-powered passenger vehicles with up to 40% gain in fuel economy over comparable gasoline vehicles are gaining market acceptance.
- Polymer electrolyte membrane (PEM) fuel cells are being demonstrated on developmental vehicles and buses. Limited prototype plug-in HEVs are currently being demonstrated by automotive manufacturers and/or private industry.

Current Research, Development, and Demonstration

RD&D Goals (by 2010)

- To ensure reliable systems for future hybrid electric combustion or fuel cell powertrains, with costs comparable with conventional internal-combustion engine/automatic transmission systems, the goals are:
  - Electric-propulsion system with a 15-year life capable of delivering at least 55 kW for 18 seconds and 30 kW continuous at a system cost of $12/kW peak.
  - 60% peak energy-efficient, durable fuel cell power system that achieves a 650 W/kg power density and 650 W/L operating on hydrogen. Cost targets are $45/kW by 2010, $30/kW by 2015.
  - Electric drivetrain energy storage with 15-year life at 300 Wh with discharge power of 25 kW for 18 seconds at a cost of $20/kW.

[2] EIA form EIA-886, annual survey, table 14.

- To enable clean, energy-efficient vehicles (including HEVs) operating on clean, hydrocarbon-based fuels and powered by internal combustion powertrains, the goal is:
  - Internal combustion systems that cost $30/kW, have a peak brake engine efficiency of 45%, and meet or exceed emissions standards.
- To enable the transition to a hydrogen economy, ensure widespread availability of hydrogen fuels, and retain the functional characteristics of current vehicles, the goals are:
  - Demonstrate hydrogen refueling with developed commercial codes and standards and diverse renewable and nonrenewable energy sources. Targets: 70% energy efficiency well-to-pump; cost of energy from hydrogen equivalent to gasoline at market price, assumed to be $2-3 per gallon gasoline equivalent.[4]
  - Hydrogen storage systems demonstrating an available capacity of 6 wt% hydrogen, specific energy of 2,000 Wh/kg, and energy density of 1,100 Wh/L at a cost of $5/kWh.[5]
- Internal combustion systems operating on hydrogen that meet cost targets of $45/kW by 2010 and $30/kW in 2015, have a peak brake engine efficiency of 45%, and meet or exceed emissions standards.
- Develop light-duty engine and fuel technologies that utilize transitional alternative fuels and have as good or better performance than conventional engine technologies to meet future emissions standards.
- To reduce the weight of vehicles, the goal is to develop material and manufacturing technologies for high-volume production vehicles that enable and support the simultaneous attainment of:
  - 50% reduction in the weight of vehicle structure and subsystems,
  - affordability, and
  - increased use of recyclable/renewable materials.

Notes:
1. Cost references are based on CY 2001 dollar values. Where power (kW) targets are specified, those targets are to ensure that technology challenges that would occur in a range of light-duty vehicle types would have to be addressed.
2. Does not include vehicle traction electronics.
3. Includes fuel cell stack subsystem and auxiliaries; does not include fuel tank.
4. Targets are for hydrogen dispensed to a vehicle assuming a reforming, compressing, and dispensing system capable of dispensing 150 kg/day (assuming 60,000 SCF/day of natural gas is fed for reforming at the retail dispensing station) and servicing a fleet of 300 vehicles per day (assuming 0.5 kg used in each vehicle per day). Targets also are based on several thousand stations, and possibly demonstrated on several hundred stations. Technologies may also include chemical hydrides such as sodium borohydride.
5. Based on lower heating value of hydrogen; allows over a 300-mile range.

RD&D Challenges

- All advanced vehicles face the challenge of achieving competitive cost, reliability, and consumer acceptance.
- HEVs (especially plug-ins) and FCVs need affordable, durable, lighter, and more compact energy storage.
- Power electronics, required by all high-voltage systems, are expensive, need active cooling, and require significant space.
- All energy-efficient vehicles face a severe fuel economy penalty when ancillary loads are applied. Nonpropulsion related loads must be reduced.
- FCVs with hydrogen storage have no existing infrastructure for refueling. Onboard storage of hydrogen in quantities sufficient to meet range requirements is a major challenge.
- Low-cost, durable membranes and significant reductions in catalyst materials or inexpensive substitutes are needed for fuel cells.

RD&D Activities

- DOE, through the FreedomCAR and Fuel Partnership, is working with industry and other local, state, and Federal government agencies on vehicle-systems analysis, combustion technologies, materials R&D, fuels R&D, and technology introduction through fleet testing and evaluation.
- DOE's R&D through FreedomCAR that includes component and vehicle simulation, ancillary load reduction, component development and testing, energy storage, power electronics, electric motors, advanced engines, and lightweight materials.

Recent Progress
• Advances in energy storage systems – including hybrid storage consisting of batteries and ultracapacitors – show promise. The hybrid electric vehicles/electric vehicles battery market is expected to grow at an averge annual rate of more than 50% during the next five years to reach nearly $250 million in 2008. • The projected cost of advanced batteries (lithium ion) has been reduced from $3,000 (1998) to less than $1,000 (2004). • The projected cost of carbon fibers for lightweighting vehicles has been reduced from $12 per pound (1998) to a projected cost of less than $5 per pound (2004). • Reduced high-volume cost of automotive fuel cells from $275/kW (2002) to $200/kW (2005) using innovative processes for depositing platinum catalyst developed by national labs and fuel cell developers. • Reduced natural gas-based hydrogen production from $5 per gallon gasoline equivalent (gge) in 2003 to $3.60 per gge in 2005 using innovative reforming and purification technologies. • Selected new hydrogen projects (spanning basic sciences research to learning demonstrations) totaling more than $500 million ($750 million with private cost share) to overcome obstacles to a hydrogen economy. This represents more than one-third of the president's $1.2 billion commitment in research funding and will help bring hydrogen and fuel cell technology from the laboratory to the showroom. Selected through a merit-reviewed, competitive process, the projects address hydrogen production and delivery, storage, vehicle and infrastructure learning demonstrations, and fuel cells. An additional $87 million in fuel cell research is planned.
Commercialization and Deployment Activities
• HEVs: The biggest competition for gasoline HEVs are advanced combustion conventional vehicles. In Europe, high-efficiency diesel vehicles have demonstrated fuel economies similar to that of gasoline HEVs. Consumer acceptance and willingness to pay a little more for a more fuel-efficient, high-technology vehicle is key. HEVs use conventional fuels, with no refueling infrastructure challenges. Some HEVs have long ranges, appealing to consumers who dislike frequent refueling stops. • FCVs: Current developmental hydrogen-fueled fuel cell systems demonstrate efficiencies approaching 50% over a fairly wide range of operation, and produce zero criteria emissions. These vehicles have the potential to require less maintenance due to fewer moving parts and lower operating temperatures. However, cost, hydrogen storage, and infrastructure requirements are substantial barriers. DOE established a national "learning demonstration," which integrates automotive and energy companies in demonstrating hydrogen infrastructure and fuel cell vehicles. One purpose is to collect performance, durability, and cost data to refocus the research program. Another purpose is to use this data to measure progress at the system level. **Market Context** • The market for these technologies is all passenger vehicles (cars and light trucks). To be successful in the marketplace, these technologies need to be made less expensive and more attractive to new-vehicle buyers.

1.1.2 HEAVY VEHICLES

Technology Description

Freight vehicles (Class 7 and 8 trucks and rail) and commercial delivery vehicles (Class 2b through Class 6) are essential to the economic vitality of the nation. Diesel engines are the dominant motive source for these vehicles. Vehicle efficiency could be increased by as much as 50%, if all current research areas such as a new generation of ultra-high-efficiency diesel engines (using advanced emissions-control technology) and reduced aerodynamic drag, rolling resistance, and parasitic power losses are successful. Development and commercialization of trucks with higher efficiency will significantly reduce transportation oil use, emissions (including CO_2), and related costs to the economy. Increased use of lightweight materials will contribute to these goals. Hybrid propulsion systems have the potential to double the fuel economy of heavy-duty vehicles, such as buses or delivery vehicles, over urban driving cycles.

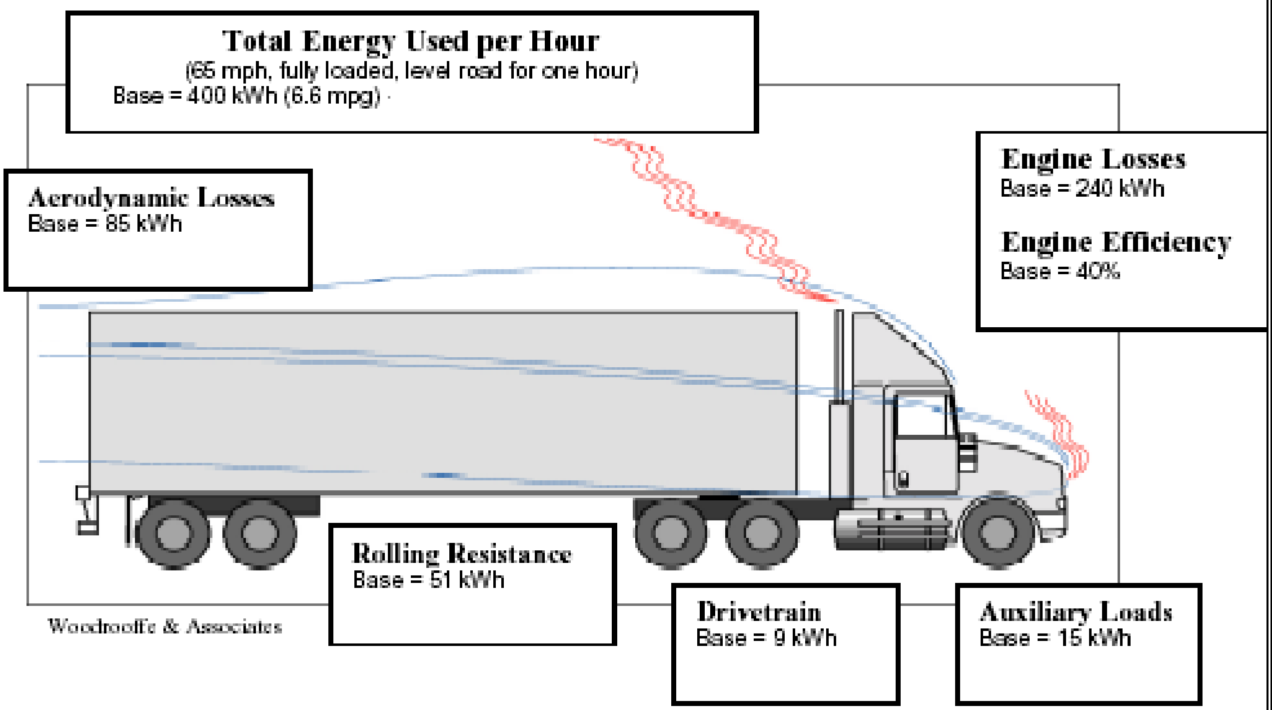


Fig. 4.1. Class 8 truck energy audit.

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 vehicles with regenerative braking may have application in local delivery vehicles and buses.
- Vehicle electrification can reduce parasitic losses from auxiliary loads and help reduce idling losses.

Representative Technologies

- High-pressure, common-rail fuel injection, bottoming cycles, and friction and wear reduction.
- Software technology to improve vehicle aerodynamics.
- Advanced power electronics, energy storage, hybrid powertrains, and lightweight materials technologies.

Technology Status/Applications

- Virtually all heavy-duty trucks and the entire fleet of locomotives are diesel powered, and there is an increasing trend to convert medium-duty trucks to diesel fuel as well. Advanced combustion concepts –

resulting in higher efficiency and lower emissions while maintaining power density – are needed. New advanced technologies for emission controls are required.

- Fuel cells are only considered a long-term option for heavy-duty trucks (except for truck auxiliary power units) due to hydrogen storage limitations. Fuel cell bus applications are seen as near term. A 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

- Engine systems including the integration of fuel, engine, and aftertreatment. Specific technology goals are:
  - Development and demonstration of a commercially viable, emissions-compliant engine system for Class 7-8 highway trucks that improves the engine system efficiency from the current 40% to 50%) by 2010 and demonstrate 55% efficiency in the laboratory by 2013.
- Parasitic losses account for 40% of the total fuel energy used to move a heavy vehicle down the road. These losses arise from aerodynamic resistance, rolling resistances, drivetrain, and auxiliary load losses. Specific 2012 technology goals are:
  - Develop and demonstrate advanced technology concepts that reduce the aerodynamic drag of a Class 8 tractor-trailer combination by 20% (from current 85 kWh to 68 kWh) in a practical, efficient, and commercially viable manner.
  - Develop and demonstrate commercially viable technologies that reduce auxiliary loads by 50% (from current 15 kWh to 7.5 kWh) for Class 8 tractor-trailers.
  - Develop and demonstrate commercially viable lightweight material and manufacturing processes that lead to a 5,000-pound reduction in Class 8 tractor-trailer combinations (a 15%-20% weight reduction)
  - Develop and demonstrate commercially viable technologies that increase heat-load rejected by thermal management systems by 20% without increasing radiator size.
- Class 7 and 8 trucks, alone, consume more than 825 million gallons of diesel fuel per year when idling. Technology goals are to reduce fuel use and emissions from idling heavy vehicles by greater than 65%. Specific technology goals are:
  - Develop and demonstrate a commercially viable fuel cell auxiliary power unit system in the 5-30kW range, capable of operating on diesel fuel at a delivered cost of $400/kW by 2012.

RD&D Challenges

- Technical challenges exist to improving engine efficiency, thus reducing CO_2 emissions, while meeting emission regulations
- Safety, durability, and reliability of new technology are being demanded by industry and required by other government agencies, all of which can add cost and weight.
- Meeting tighter emissions regulations can result in an additional load on the engine – such as additional backpressure – which can increase fuel consumption.

RD&D Activities

- DOE is working closely with industry in the 21st Century Truck Partnership.
- DOE programs and the Advanced Heavy-Duty Hybrid Propulsion System (AHHPS) industry teams are analyzing, developing, and validating a range of heavy hybrid vehicles, including Class 3-8 trucks and buses, to define system architecture, optimize control strategy, and quantify component requirements.
- Much heavy-vehicle testing is done at DOE's Renewable Fuels and Lubricants Laboratory, and EPA's National Vehicle Fuel Emissions Laboratory.
- Department of Defense Advanced Research Projects Agency, California Energy Commission, and the California Air Resources Board cosponsor R&D projects with DOE.
- DOE sponsors analytical and modeling work.

Recent Progress

- Under the AHHPS project, a validation truck and bus were developed, and tested (laboratory and field) successfully.

- An interim goal of 45% efficiency was achieved in heavy-duty multicylinder engines.
- Prototype engines operating in new combustion regimes have demonstrated, in the laboratory, 90% lower NOx and particulate matter – and with equal power density to that of conventional combustion engines.
- Demonstrated 51% reduction in aerodynamic drag for Class 8 trucks in wind tunnel tests.
- Electrification of underhood components – such as air compressors, water pumps, and oil pumps – was shown to reduce fuel consumption by up to 18%.

Commercialization and Deployment Activities

- 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 for many years.
- Prominent participants in the heavy vehicle industry, DOE and others, through cost-shared R&D activities, are employing strategies to introduce advanced heavy-vehicle technologies into the marketplace.
- With DOE assistance, Cummins Engine, John Deere Company, and Mack Trucks have introduced heavy-duty natural gas engines with high efficiency, power ratings, and torque that maintain very low emissions.
- All new technologies must meet high durability requirements.

Market Context

- 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. Effective partnership with national labs is essential for successful completion of advanced automotive research activities. The market encompasses all commercial highway vehicles with some benefit to off-highway vehicles from advanced combustion-engine improvements.

1.1.3 FUELS FOR ADVANCED COMBUSTION ENGINES

Technology Description

The Fuels for Advanced Combustion Engines activities are undertaken to enable advanced combustion regime engine technology, as well as identify practical, economic fuels and fuel-blending components with the potential to directly displace significant amounts of petroleum. A major focus of the fuels activities is to determine the impacts of fuel properties on the efficiency, performance, and emissions of advanced internal combustion engines. In the near term, these are expected – for the most part – to be direct-injection diesel engines and their associated emission-control systems.

A researcher uses a clean room to gather emissions data from future fuels.

System Concepts

- To enable current and emerging advanced combustion engines and emission control systems to be as efficient as possible while meeting future emission standards.
- To reduce reliance on petroleum-based fuels by supporting the introduction of fuels that displace petroleum.
- To reduce sulfur, particulate, and oxides of nitrogen emissions.

Representative Technologies—Fuels

- Low-sulfur diesel fuel that allows more efficient emissions control.
- Diesel fuel produced from expected heavier and sourer crude oil feedstocks.
- Diesel fuel produced from oil sands, shale oil, coal.
- Biodiesel produced from vegetable oils and waste fats.
- Fischer-Tropsch diesel produced from natural gas, biomass and coal.

Representative Technologies—Engines

- Direct-injection diesel engines equipped with emission controls such a diesel particulate filters (DPF), NOx Adsorber Catalysts (NAC), or Selective Catalytic Reduction (SCR) systems.
- Homogenous charge compression ignition (HCCI).
- Low-temperature combustion (LTC).

Technology Status/Applications

- Venezuelan and domestic heavy crude use in U.S. refineries is well established.
- Refining of synthetic crude derived from oil sands is growing in use in Canada, and expansion into U.S. petroleum pools is beginning.
- Fischer-Tropsch diesel fuels, synthesized from natural gas or coal (Coal-to-Liquids, CTL), have been studied in numerous engine tests to determine their impact on emissions and have been used as a blending material in California diesel fuels since 1993.
- Use of similar fuels derived from biomass – Biomass-to-Liquid (BTL) fuels – may increase in the future.
- Biodiesel (fatty acid methyl esters) produced from vegetable oils and waste fats has been used extensively as a blending component in Europe and its use in the United States is increasing.

Current Research, Development, and Demonstration

RD&D Goals

- By 2007, identify fuel formulations optimized for use in 2007-2010 technology diesel engines that incorporate use of nonpetroleum-based blending components with the potential to achieve at least a 5% replacement of petroleum fuels by 2015.
- By 2010, complete R&D to eliminate technical barriers to the achievement of the 5% petroleum

displacement goal for 2007-2010 engines, allowing these engines to meet key technical targets.

- By 2010, identify fuel formulations optimized for use in advanced combustion engines (2010-2020) providing high efficiency and very low emissions, and validate that at least 10% replacement of petroleum fuels could be achieved by 2025.

RD&D Challenges

To fully exploit the full potential of high-efficiency, clean advanced combustion regime engines, codevelopment of the engines and fuels is a necessity. Nearer term, understanding the compatibility of nonpetroleum-based fuels with 2007-2010 engines is critical for expanded use of these fuels. The technical barriers to achieving this are as follows:

- **Inadequate data and predictive tools for fuel property effects on combustion and engine optimization.** Existing data and models for engine efficiency, emissions, and performance – based on fuel properties and fuel-enabled engine designs or operating strategies – are inadequate. Also, the variability of refinery stream (blendstock) composition on the efficiency, performance, and emissions of engines appears to be significant but is poorly understood.
- **Inadequate data and predictive tools for fuel effects on emissions and emission-control system impacts.** The database on the extent to which petroleum fuel and nonpetroleum fuel components contribute to toxic emissions is inadequate and must be improved in order to optimize engine and aftertreatment systems from a fuel economy standpoint. The relationship between fuel properties and the formation of ultra-fine particles (i.e., particles of <0.1 nm in diameter) is not well established. Also inadequate are data on the effects of fuel properties (other than sulfur) on exhaust emission control systems; and widely accepted test procedures to measure these effects do not exist. Furthermore, suitable test equipment and universally recognized test procedures with which to generate this knowledge base are not available.
- **Long-term impact of fuel and lubricants on engines and emission-control systems.** The knowledge base is inadequate on the effect of fuel properties on the deterioration rates and durability of engine fuel system and emission-control system devices and components. The effects of lubricating oil on engine emissions and emission-control devices are not clearly understood, nor are the effects of nonpetroleum-based fuels on lubricating oil performance. Improved understanding is needed in developing approaches that mitigate any deleterious effects caused by fuel and lube oil components. Furthermore, new fuel formulations could require corresponding new lube oil formulations.

RD&D Activities

The fuels activities will test and evaluate a wide variety of fuels to develop a better understanding of the relationships between fuel properties, engine efficiency, system durability, and emissions. Exhaust emission-control devices are expected to be necessary to meet future emissions standards for diesel-powered vehicles. Fuels-compatibility testing will include such devices as they become available (through close collaboration with the Advanced Combustion Engine R&D activities).

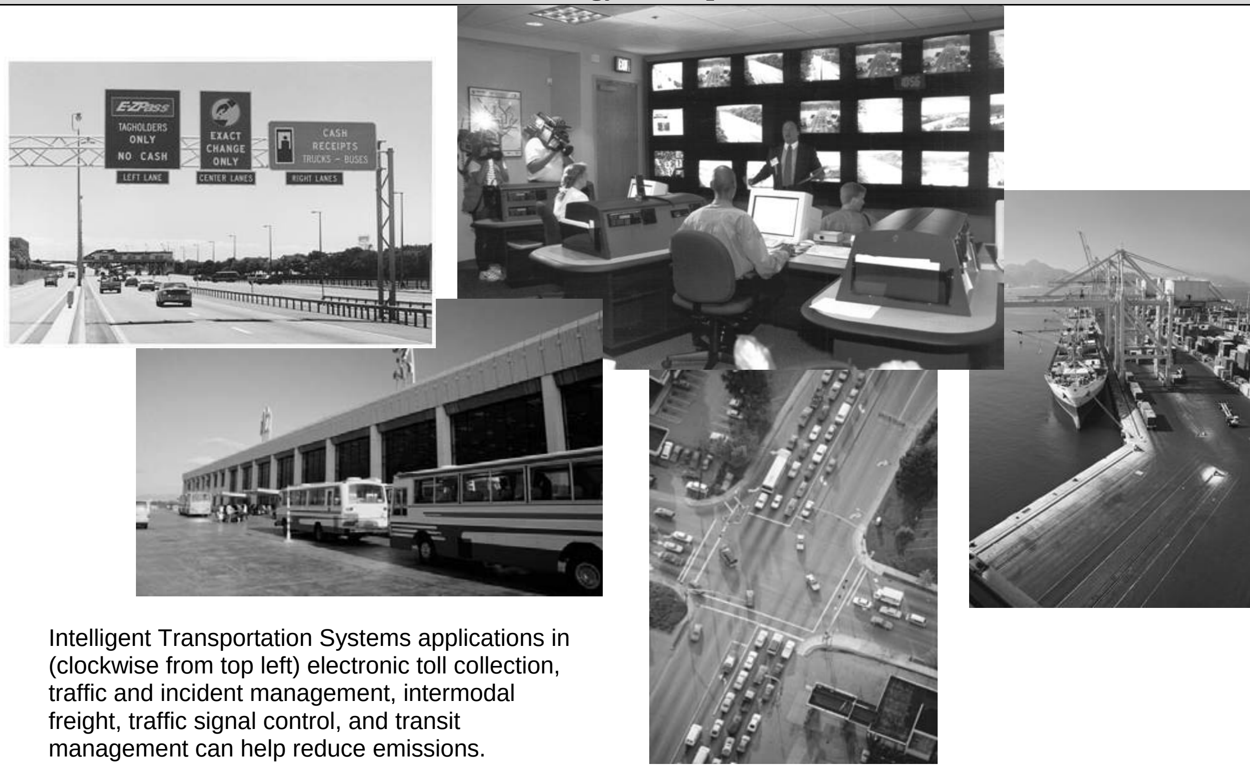
Key deliverables from these activities will be test data and test-databased analyses of the sensitivity of the performance and emissions of engines and emission-control devices to fuel and lubricant properties. As data accumulate in the database, it will become increasingly feasible to predict fuel formulations with favorable properties to reduce emissions of NOx and PM. In addition, some emission-control strategies rely on reductants derived from the fuel to operate effectively, a fact that will be taken into account as required reductant properties are identified by the Advanced Combustion Engine R&D activities. Technical tasks include:

- Evaluation of fuels and lubricants to enable high efficiency engine operation while meeting 2007-2010 emission standards.
- Evaluation of fuel properties effects on advanced combustion regimes and on engine regulated and unregulated emissions while operating in these regimes.
- Evaluation of petroleum displacement fuels and fuel-blending components.

Recent Progress
• A major focus of the fuels activities is to determine the impacts of fuel properties on the efficiency, performance, and emissions of advanced internal combustion engines. A recently completed major contribution to clean, efficiency transportation was a multiyear effort to determine the effects of fuel sulfur on diesel emissions controls that helped lead to and support EPA's rulemaking for low-sulfur diesel fuel. In the near term, advanced internal combustion engines are expected to be mostly direct-injection diesel engines and their associated emission-control systems. There exists little understanding of the compatibility of the engine-emission-control system with renewable fuels such as biodiesel or BTL. Additional information is also required on performance and durability with fuels derived from heavy-crude, oil sands, shale oil, and coal. • For the long term, focus is on fuels optimized for advanced combustion regimes, which include technologies that have the potential to provide diesel-like (or greater) efficiency with extremely low engine-out emissions. Combustion regime examples are homogeneous charge compression ignition (HCCI) and low-temperature combustion (LTC). • While anecdotal evidence points to variations in performance and emissions in near-term (e.g., prototype MY2007) engines related to fuel-property variations, it is almost certain that future, advanced combustion engine technologies will show a greater sensitivity to such variations. As such, codevelopment of fuels and engines will be essential to ensure availability of fuels optimized for operation in advanced combustion regime engines in the post-2010 time frame. This necessitates an improved fundamental knowledge about fuel properties and composition and their impact on combustion phenomena. If fuel specifications need tighter definition for engine operation in advanced combustion regimes, close coordination between the Advanced Combustion Engine and Fuels activities will be essential. • The expertise of the national laboratories is used for in-house research and development efforts, in "working group"-level interactions in government-industry consortia, and in technical management. In the near term, fuel issues associated with 2007-2010 engines and emissions-control systems are of concern. Near-term tasks support removing sulfur from the fuel at fueling stations or onboard the vehicle prior to combustion to provide a near-zero sulfur level, if necessary. An additional near-term focus is assessing the impact of renewable and nonpetroleum blending components such as biodiesel and BTL, and examining the impacts of fuels derived from heavy-crude. For the long term, the challenge is development of a fuel specification optimized for operation of advanced combustion regime engines up to full load and during transients. Other challenges include assessing the implications of the properties of newly developed fuels on engine performance and emissions, and identifying compatible lubricants for use with newly developed fuels.
Commercialization and Deployment Activities
• Guidance on the fuels testing and other tasks will come from industry, DOE, national laboratories, and others. Government/industry technical and supporting groups will make specific recommendations for tasks, data analyses, and overall direction. **Market Context** • **Infrastructure.** The lack of quality specifications, as well as distribution and fueling infrastructure is a major barrier for any nonpetroleum-based liquid fuel component that is not compatible with all current systems. This barrier must be addressed for non-fungible fuels to have a significant impact on reducing the transportation sector's dependence on petroleum-based fuels. • **Cost.** There are insufficient public data on refinery economics and processing strategies to enable comparison of options for advanced combustion engine fuels. Also inadequate are the databases on the health, safety, and regulatory issues associated with most nonpetroleum fuel components that might be used to replace petroleum-based fuels, and the knowledge base on the technical and economic impacts of nonpetroleum fuel components on the distribution, storage, and fueling.

1.1.4 INTELLIGENT TRANSPORTATION SYSTEMS INFRASTRUCTURE

Technology Description



Intelligent Transportation Systems applications in (clockwise from top left) electronic toll collection, traffic and incident management, intermodal freight, traffic signal control, and transit management can help reduce emissions.

Faced with annually increasing demand for travel and transport of goods, the transportation system is reaching the limits of its existing capacity. Intelligent Transportation Systems (ITS) can help ease this strain, and reduce the emissions created and fuel wasted in associated congestion and delays, through the application of modern information technology and communications. Several ITS applications and services offer the potential for reducing fuel use and related carbon emissions associated with travel and freight transportation.

System Concepts

- Intelligent transportation systems (ITS) apply well-established technologies in communications, control, electronics, and computer hardware and software to improve surface transportation system performance.
- ITS are intended to reduce congestion, enhance safety, mitigate the environmental impacts of transportation systems, enhance energy performance, and improve productivity.

Representative Technologies

- Adaptive traffic signal-control systems and freeway management systems smooth the flow of traffic, and reduce stops and delay, which lead to reductions in fuel use and emissions.
- By clearing incidents faster and more efficiently, incident management systems have demonstrated large reductions in energy use associated with the travel delays surrounding the incident.
- ITS applications for intermodal freight include freight and asset tracking, as well as enhancements to freight terminal and international border crossing processes. These enhancements can help create a seamless connection between modes of travel for goods shipments as well as reduce delays and associated emissions at terminals and inspection stations.
- Traveler information/navigation systems help travelers avoid major delays and avoid wasted fuel as a result of navigation errors.
- Electronic screening of commercial vehicles saves fuel and reduces emissions associated with stopping at inspection stations.
- Electronic toll collection – saves fuel consumption and emissions at tollbooths by minimizing delays, queuing, and idling time.

Technology Status/Applications

- Deployment of ITS is underway across the United States. A survey covering 78 of the largest U.S. cities finds that the most widespread deployments are electronic toll collection (ETC) (73% of toll lanes in surveyed cities are ETC capable), emergency management (75% of emergency vehicles are under computer-aided dispatch), and electronic fare payment (EFP) area (52% of fixed route buses accept EFP). Other areas of significant deployment include incident management and signal control systems.
- The Commercial Vehicle Information Systems and Networks (CVISN) is the collection of information systems and communications networks that support commercial vehicle operations in the United States. CVISN is expected to improve commercial vehicle safety, while enhancing productivity, reducing delays and associated emissions. Eight states have been fully funded to achieve Level 1 deployment (i.e., electronic credential administration, safety information exchange, and roadside electronic screening) by September 2003. Of these eight, four states have demonstrated Level 1 capabilities. Forty-nine states have completed a CVISN Business Plan, and 34 states have completed a CVISN Top-Level Design and CVISN Program Plan.

Current Research, Development, and Demonstration

RD&D Goals

- Develop improved analysis capabilities that properly assess the impact of ITS strategies.
- Develop strategies that will improve travel efficiency resulting in lower delays, thereby reducing emissions.

RD&D Challenges

- Develop the next-generation mobile emissions models that assess how reductions in stop-and-go traffic, resulting from effective ITS traffic management, reduce emissions – including those of greenhouse gases. Current models primarily consider vehicle miles traveled, whether that travel occurs at cruising speed (where current vehicles are extremely low-emitters) or under stop-and-go conditions (where vehicular emissions are significantly higher, except for hybrid electrics). Thus, they have the potential of incorrectly penalizing effective strategies.

RD&D Activities

- The Traffic Analysis and Tools Program is developing tools and models for evaluating various ITS strategies and courses of action.
- The Next Generation Simulation Model (NGSIM) program is developing a repository of improved and well-documented algorithms for use by traffic-simulation models.
- The Department of Transportation (DOT) is carrying out evaluations of Field Operational Tests of technologies to reduce commercial vehicle queues and wait times at weigh stations.
- The Electronic Toll Collection/Electronic Screening Interoperability Pilot deployment is being evaluated to determine the impact of using interoperable transponders for toll collection and electronic screening of heavy vehicles. The evaluation hypotheses being tested include the following: “With reduced delays and idle time, fuel consumption and emissions will be reduced.”
- EPA is developing the Multiscale Motor Vehicle and Equipment Estimation System (MOVES) mobile source emissions model. This model will provide improved characterization of vehicle emissions from high-emitting and heavy-duty vehicles.
- The Signal Timing Program is being carried out by FHWA to encourage localities to time or retime their traffic signals and optimize their signal systems. This will result in reduced stops and delays, thereby decreasing vehicular emissions.
- The Incident Management Program is developing strategies and providing guidance on clearing traffic incidents sooner. The resulting decrease in vehicle queues and delays result in reduced emissions.
- The Freeway Management Program is developing operational strategies, technologies, and policies for improved efficiency of freeway facilities. Included in the program is research on strategies for sharing HOV lanes with low-emission, energy-efficient vehicles when extra capacity is available; detecting and verifying incidents; and providing en route information to travelers. Reduced delay and travel time, both of

which result in reduced emissions and fuel conservation, are the relevant MOEs.

- The ITS Traffic Management Program carries out long-term and applied research toward smoothing traffic flow through management and control technologies. This enhances environmental goals by reducing stopping and starting of traffic, thereby reducing emissions.

Recent Progress

- Developed ITS Deployment Analysis System (IDAS) to determine impacts, benefits, and costs of ITS deployments.
- Completed evaluation of a Field Operational Test to reduce vehicle queues and idling times at land border crossings, including an estimate of the avoided health-related costs resulting from reduced emissions. For the Washington State/British Columbia border along the I-5 corridor alone, the avoided costs were calculated as $1.6M to $2.5M over a 10-year period, depending on the deployment scenario. These reductions are primarily from time savings at the border but include reduced idling at weigh stations.
- There has been a significant increase in the number of Traffic Management Centers (TMCs) implemented nationwide, which are essential for implementing and coordinating traffic-management strategies such as incident management and freeway management. For example, the 2002 Freeway Management Deployment Tracking Survey indicates that 83 agencies had a TMC, of which 41 provide environmental monitoring.
- Increased bus ridership at Acadia National Park, resulting from implementation of ITS technologies, resulted in an estimated reduction of 1.17 tons of emissions in 2002, the first year that ITS was operational.
- ITS deployment tracking in 75 large metropolitan areas indicates that 27 now have high levels of integrated ITS deployment and 30 have medium deployment levels.
- The Comprehensive Mobile Emission Model (CMEM) was developed under the National Cooperative Highway Research Program (NCHRP Project 25-11) to accurately reflect light-duty vehicular emissions, such as those from automobiles.

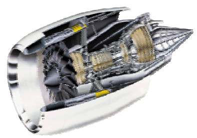
Commercialization and Deployment Activities

- An example of the many commercialization activities underway in ITS is the Center for Commercialization of ITS Technologies recently established in California. Having begun operations on February 7, 2002, the center is a unique partnership among the State DOT, the University of California, and the industry to facilitate and accelerate the deployment and commercialization of ITS Technologies.
- Deployment of electronic toll collection (ETC) systems continues to expand. In a 2002 survey, 73% of toll lanes in 78 of America's largest cities were equipped with ETC.

1.1.5 AVIATION

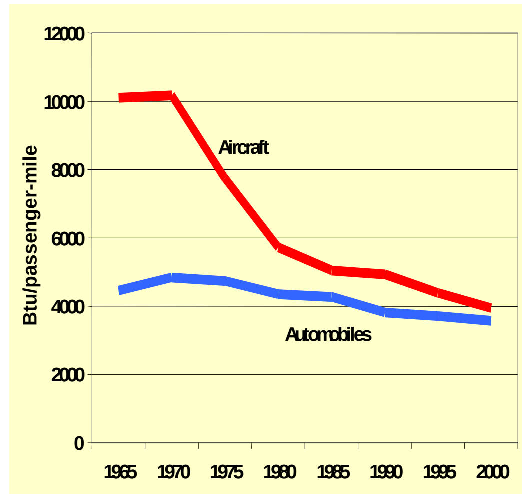
Technology Description

GE90 High Bypass Turbofan



Boeing 777

Today's airplanes are 300 times more energy efficient than early jets.

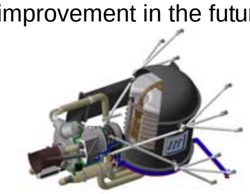


The energy intensity of aircraft and automobiles has improved substantially during the past several decades. Automobile energy intensity has fallen by almost one-fifth, while aircraft energy intensity has fallen by three-fifths during the same period.

LNG Buses at LAX

New technologies reduce ground emissions

…. and revolutionary new concepts offer opportunity for continued improvement in the future.



Humans benefit from the ability to move people and products all over the globe – quickly and safely. Aviation contributes to our quality of life – allowing us to visit friends and relatives, to travel, to experience new places, to shrink the borders of the world. The statistics are impressive. In 1903, Earth's population was 1.6 billion. Today, more than 1.6 billion people use the world's airlines. The Air Transport industry provides 28 million direct, indirect, and induced jobs worldwide. And aircraft carry about 40% of the value of all world trade, providing the "just in time" deliveries critical to productivity improvements. Aircraft use conventional hydrocarbon fuels, and contribute about 10% of greenhouse gas emissions from the transportation sector. Also, emissions from aircraft engines are unique in the aspect that they are deposited directly throughout the upper atmosphere. Subsonic aircrafts emit gases and particles directly into the lower stratosphere and upper troposphere, while emissions from supersonic aircrafts are deposited at higher altitudes. These aircraft emissions perturb the atmosphere by changing the background levels of trace gases and particles, and by forming contrails.

The Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) – together with industry, academia, and other Federal agencies – are pursuing strategies to improve aviation fuel efficiency and reduce its impact on global climate.

System Concepts

- Optimized Operations – more efficient operations to reduce fuel burn.
- Optimize Propulsion – advanced turbine engine technologies to reduce fuel burn.
- Reduce airframe weight and drag – airframe technologies that reduce fuel consumption.
- Alternative vehicles – ground support equipment, airframe concepts, propulsion systems, and fuels that dramatically reduce or completely eliminate emissions from civil aircraft.

Representative Technologies

- Alternate fuel Ground Support Equipment (GSE) and airport ground access vehicles (e.g., electricity, natural gas, propane, fuel cells) reduce ground-based aviation greenhouse emissions.
- Advanced propulsion concepts greatly reduce greenhouse gas and other harmful emissions.
- New materials and design practices continue to reduce aircraft empty weight, enhancing fuel efficiency.
- Information technology and management science advances enable more efficient air traffic management and ground operation procedures.

Technology Status/Applications

- New engine and airframe technologies in today's jets have led to a 70%-80% improvement in fuel burn per seat mile since the early 1960s.
- Airports and airlines are adopting low-emissions technologies available for ground-support equipment and airport access vehicles – substantial progress in replacing gasoline and diesel-powered airport ground vehicles with new vehicles running on cleaner alternative fuels, primarily electricity and compressed natural gas (CNG).
- Enhanced operational procedures offer opportunities for near-term greenhouse gas emissions reductions.
- Continued advances require continued breakthroughs in more efficient engine and airframe technologies; and aircraft technology development and capital turnover follow relatively long cycles, which limits the pace of fundamental changes in design.
- Airborne fuel cells and other alternative-fueled air vehicles have the potential for significant emissions reductions, but are far-term (25 years or more) options.

Current Research, Development, and Demonstration

RD&D Goals

- FAA goal – improve aviation fuel efficiency per revenue plane-mile by 1% per year through 2008, as measured by a three-year moving average, beginning with the three-year average of 2000-2002.
- NASA technology goals – new technologies with the potential to reduce CO_2 emissions of future aircraft by 25% within 10 years and by 50% within 25 years (using 1997 subsonic aircraft technology as the baseline).

RD&D Challenges

- Developing new technology that reduces emissions while still being affordable.
- Ensuring new concepts do not result in additional system weight, which increases fuel burn substantially.
- Very high premium for safe operation, which constrains the use of unproven new technologies and strategies relative to other transportation modes.

RD&D Activities

- NASA is pursuing research activities on efficient engine technologies, advanced aerodynamic shapes and structures, autonomous robust avionics, and low-emissions alternative power, which could lead to significant emissions reductions.

• FAA has a roadmap for continuing to mitigate the environmental impacts of aviation. This includes research to improve its understanding of the role of aviation emissions on the environment and optimize overall environmental impact mitigation strategies. • Department of Energy research on alternative-fuel ground vehicles can lead to reduced emissions from airport ground-support equipment and access vehicles.
Recent Progress
• FAA's Inherently Low-Emission Airport Vehicle (ILEAV) Pilot Program seeks to evaluate airport use of alternative-fuel vehicles and infrastructure to determine their reliability, performance, and cost-effectiveness in the airport environment. Under this pilot program, there are 125 project vehicles in operation and at least 150 more vehicles planned for service. • NASA's primary engine research program, the Ultra-Efficient Engine Technology Program (UEET), has made significant progress toward demonstrating its goals of 15% fuel burn (equivalent to CO_2) reduction and 70% NO_x reduction relative to 1996 standards. • FAA has developed a unique capability to estimate aircraft emissions ranging from a single flight to regional and worldwide scales. The System for assessing Aviation's Global Emissions (SAGE) will be able to develop aviation emission inventories, both for baseline conditions and forecasted technology, operational, and market-based measures and improvements. • Airlines have launched new initiatives to reduce fuel burn by limiting the use of auxiliary power units by using ground power whenever possible. • FAA has established a new Center of Excellence for Noise and Emissions Mitigation, which will identify solutions for existing and anticipated aircraft emissions-related challenges.
Commercialization and Deployment Activities
• Aircraft are dependent on liquid fossil fuels, and potential modifications to fuel type and composition for environmental benefits are limited. • FAA's Low-Emission Airport Vehicle (ILEAV) Pilot Program is assisting in deploying low-emissions technology to airport operations. • Fuel costs are a significant portion of operating costs for an airline; hence airlines have great incentives to reduce fuel burn. • Better meteorological information, yield-management tools, and the hub and spoke system – combined with the growth of low-cost, point-to-point carriers, and a significant increase in the number and reach of regional airlines – is improving the efficiency of the entire aviation network.

1.1.6 TRANSIT BUSES – URBAN-DUTY CYCLE, HEAVY VEHICLES

Technology Description

Current transit buses use large-displacement, slow-speed, four-stroke diesel engines as the prime propulsion system. Due to their high efficiency and reliability, diesel engines are the dominant power source for heavy-duty transit buses in the United States, and they are the preferred power source for commercial surface transportation worldwide. In a transit bus, the engine is coupled to a four- or five-speed automatic transmission, which drives through a differential within the solid rear axle that mounts dual rear tires, resulting in a direct (or nearly direct) relationship between wheel speed and engine speed. The engine also directly drives all major vehicle auxiliary systems, through belt, hydraulic, or gear drives or combinations thereof.

Conventional transit bus designs waste substantial energy through braking resulting in poor propulsion system efficiency. The current state of practice simply discards this braking energy as heat during deceleration; none of it is recovered. Past attempts have been made at energy recovery through hydraulic or pneumatic systems. The inherent inefficiency, size, weight, and added complexity of these systems precluded them from production consideration.

The urban duty cycle of transit buses (constant stop and start cycles with as many as 14 cycles every 10 minutes in the case of the CBD-14 driving cycle) means the engine, transmission, and auxiliary systems are most frequently operated in a transient mode. Transient operation in this type of drive system is a condition detrimental to the goals of high efficiency and low emissions.

System Concepts

- Hybrid electric propulsion systems using diesel engines in both parallel and series configuration.
- Lightweight materials including composite body structures and components.
- Clean fuel formulation including bio-gas, synthetic diesel, ultra-low sulfur petroleum diesel.
- Fuel cell systems as standalone propulsion systems and in hybrid configuration.

Representative Technologies

- Compressed natural gas spark-ignited engines.
- Diesel hybrid electric systems with current energy storage technologies.
- Exhaust after-treatment technology for both NO_x and particulates.

Technology Status/Applications

- Diesel buses are still the dominant technology; 20% of all new bus purchases are for natural gas buses.
- Clean fuel formulations continue to be evaluated including bio-diesel, synthetic diesel, and bio-gas.
- Diesel hybrid buses (both parallel and series hybrid) with current energy storage technologies are entering commercial infancy.
- Hydrogen fuel cell buses continue to be demonstrated.

Current Research, Development, and Demonstration

RD&D Goals

- Meet or exceed proposed EPA emissions standard for heavy-duty bus engines of 0.01 g/bhp-hr particulates and 0.20 g/bhp-hr of NO_x plus 0.14 g/bhp-hr of non-methane hydrocarbons (NMHC) by 2007. By 2015, have zero-emission or near zero-emission transit bus commercially available.
  - Advance hybrid electric drive systems in combination with fuel formulation and after-treatment.
  - Continue RD&D for advance energy storage options to enhance commercial viability of hybrid electric and ultimately fuel cell buses.
- Gross load passenger capacity increased from 53-88 to 100 passengers and seated passenger capacity increased from 43 to 50 on a two-axle bus. Transit buses with a maximum single-axle load no greater than 20,000 pounds at the gross vehicle weight with a full passenger capacity of 90-100 people by 2006.
  - Accelerate RD&D of composite body structure bus and bus components.
  - Accelerate broader deployment of composite body structure buses.
- By 2010, transit buses with 10-mpg (128,400 btu/gal equivalent) fuel efficiency at seated load weight on the CBD-14 driving cycle.
  - Advance hybrid electric drive systems with advanced energy storage technology.
  - Advance lightweight bus structures.
- Mean miles between failure (individual components) increased by 50%. Mean time to repair failure (individual components) reduced by 50%.
- By 2015, commercially viable fuel cell transit buses meeting all prevailing standard transit bus operating and maintenance requirements at less than twice the cost of a comparable transit vehicle. Incremental capital cost no greater than 50% compared to standard bus five years after commercial introduction.
  - Continued RD&D for fuel cell propulsion systems specifically designed for heavy-duty transit buses.
  - Continued RD&D for light-duty fuel cell hybrid fuel cell systems for buses.

RD&D Challenges

- Tradeoff between improving vehicle fuel efficiency and vehicle-exhaust emissions.
- Need to consider vehicle systems approach to vehicle fuel efficiency and emissions as opposed to current engine approach.
- Transit bus market volume too low to be technology driver. However, transit bus fleets are ideal platforms for the introduction of new technologies.
- Compact, lightweight, robust, reliable, and durable energy storage technology for hybrid electric and fuel cell buses.
- Cost, reliability, durability, and performance of hydrogen fuel cells need significant improvements for commercialization to be viable.

RD&D Activities

- DOT through FTA continues to be in the forefront of the RD&D of fuel cell buses and is developing a hydrogen and fuel cell bus initiative with key stakeholders.
- DOT through FTA is working in collaboration with DOE, EPA, DOD along with state, regional, and local government agencies (CEC, CARB, SCAQMD, NYSERDA) in the RD&D of advanced bus technologies.

Recent Progress

- Demonstrated 30-foot fuel cell hybrid bus with an automotive fuel cell system that achieved 11 miles per gasoline equivalent fuel efficiency.

Commercialization and Deployment Activities
• New York City Transit has ordered 325 series hybrid electric transit buses that are being delivered. • Long Beach Transit has ordered 27 gasoline hybrid electric transit buses with added-on orders from other agencies potentially totaling 100. • Demonstrations of parallel hybrid electric transit buses are underway and planned in Philadelphia, Seattle, Orange County, Minneapolis, and Austin. • Demonstrations of seven Generation I fuel cell buses with the California Fuel Cell Partnership at AC Transit, Santa Clara VTA, and SunLine Transit. • U.S. Heavy-Duty Fuel Cell Working Group established in 2002 with specific focus on buses. An International Fuel Cell Bus Workshop in Long Beach will facilitate the formation of an International Fuel Cell Bus Working Group. **Market Context** • Electric drive vehicle technology encompassing hybrid electric and fuel cell technologies are global in nature and highly competitive with major European and Asian companies actively pursuing RD&D.