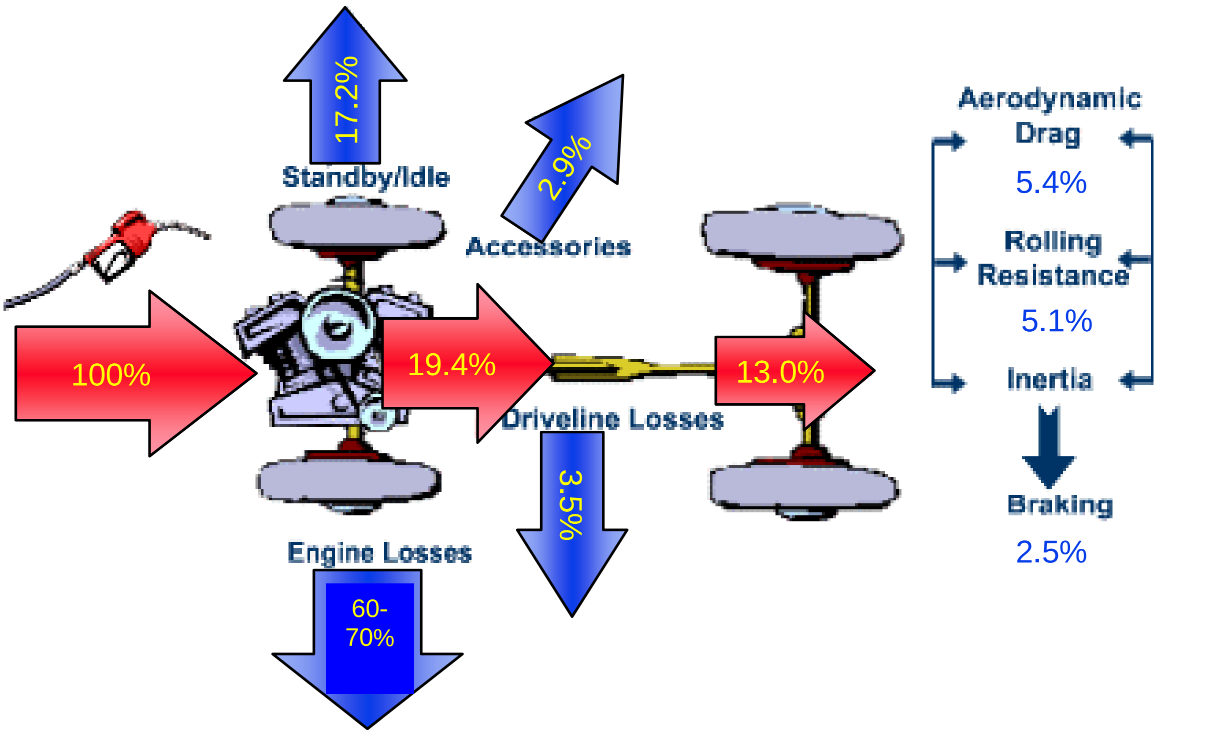
1.0 REDUCING EMISSIONS FROM ENERGY END USE AND INFRASTRUCTURE
1.1 TRANSPORTATION
1.1.1 LIGHT VEHICLES – HYBRID, FUEL CELL, AND ALTERNATIVE-FUEL VEHICLES

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.