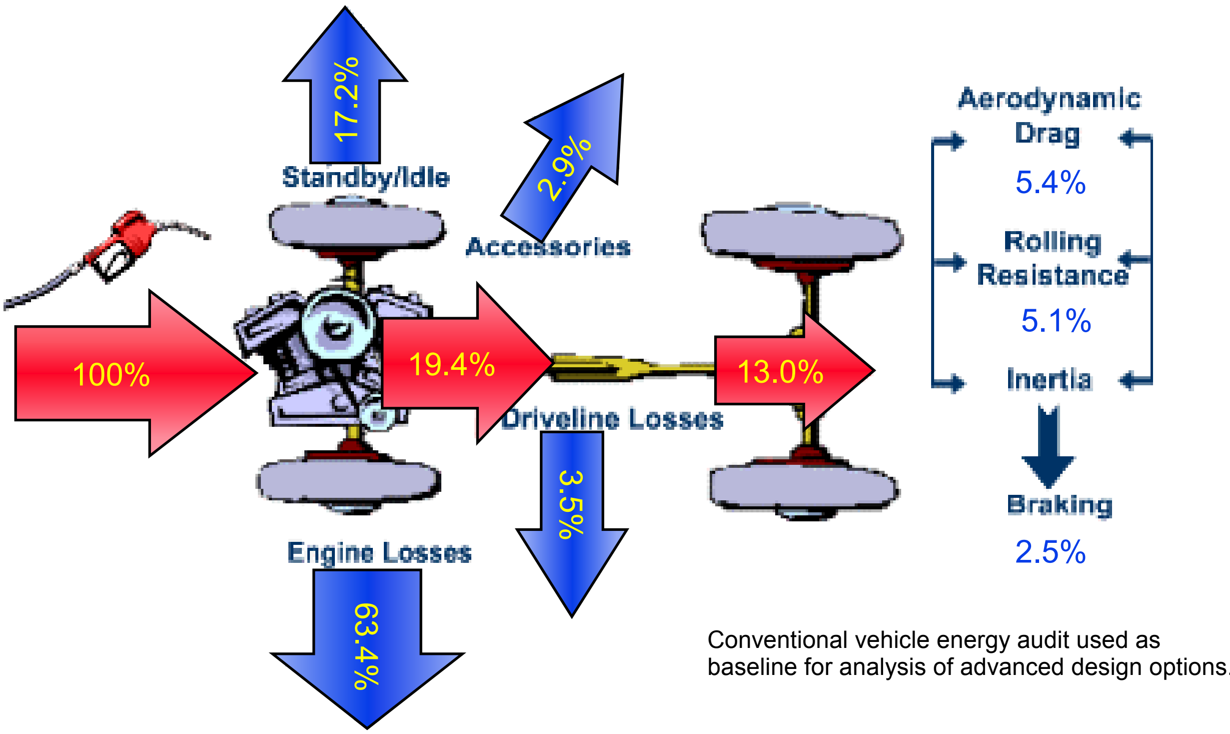
1.0 REDUCING EMISSIONS FROM ENERGY END USE AND INFRASTRUCTURE

1.1 TRANSPORTATION

1.1.1 LIGHT VEHICLES – HYBRIDS, ELECTRIC, AND FUEL CELL 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. An HEV with a compression ignition, direct-injection (CIDI) engine could offer low carbon emissions and peak energy efficiency more than 70% greater than available from present-day gasoline engines. Advanced combustion engines could reduce fuel consumption by 50%. Fuel cell vehicles (FCVs) directly convert fuels to electricity. Although FCVs may initially run on gasoline or other fuels reformed to produce hydrogen, in the long term they will be powered by hydrogen stored onboard. FCVs using onboard hydrogen produce only water as a tailpipe emission. 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 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 under low-load – such as decelerating or coasting. In such cases, stored energy is required to operate the ancillary loads, such as cabin climate control.
- FCVs can either store a liquid fuel onboard that uses a reformer or other chemical reaction to produce hydrogen, or it can directly store hydrogen in gaseous or liquefied (cryogenic) form.

Representative Technologies

- HEVs and FCVs will require energy storage systems, including some high-power storage that may include electrochemical batteries, ultracapacitors, or other forms of energy storage.
- HEVs also use an internal combustion engine such as CIDI, gasoline direct-injection, as well as efficient electric motors.

Technology Status/Applications

- GM, Ford, and DaimlerChrysler are developing HEVs. Toyota and Honda have sold more than 140,000

HEVs in Japan and the United States since 1997. Some automakers have announced target sales of HEVs of 500,000 in less than 10 years.

- Although several versions of EVs were available, the cost of manufacturer support coupled with limited demand and high battery pack cost has nearly eliminated EVs as an option for consumers.
- Polymer electrolyte membrane fuel cells are being demonstrated on developmental vehicles and buses.
- Sales of vehicles with CIDI engines have exceeded 35% of the new light-duty vehicle sales in Europe and sales are more than 50% in some countries. U.S. sales may be limited due to impending Tier 2 emissions regulations. J.D. Power believes that diesel sales could be 12% of the U.S. market by 2010.

Current Research, Development, and Demonstration

RD&D Goals (by 2010)

- To ensure reliable systems for future 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 (including hydrogen storage) that achieves a 325 W/kg power density and 220 W/L operating on hydrogen. Cost targets are $45/kW by 2010, $30/kW by 2015.
- To enable clean, energy-efficient vehicles operating on clean, hydrocarbon-based fuels – powered by either internal combustion powertrains or fuel cells – the goals are:
  - Internal combustion systems that cost $30/kW, have a peak brake engine efficiency of 45%, and meet or exceed emissions standards.
  - Fuel cell systems, including a fuel reformer, that have a peak brake engine efficiency of 45% and meet or exceed emissions standards with a cost target of $45/kW by 2010 and $30/kW in 2015.[2 3]
- To enable reliable HEVs that are durable and affordable, the goal is:
  - 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.
- 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:
  - Demonstrated hydrogen refueling with developed commercial codes and standards and diverse renewable and non-renewable energy sources. Targets: 70% energy efficiency well-to-pump; cost of energy from hydrogen equivalent to gasoline at market price, assumed to be $1.50 per gallon (2001 dollars).[4]
  - Hydrogen storage systems demonstrating an available capacity of 6 wt% hydrogen, specific energy of 2000 Wh/kg, and energy density of 1100 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.
- To improve the manufacturing base, the goal is:
  - 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, fuel-processor 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 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 have no existing infrastructure for refueling or repair.
- Onboard storage of hydrogen in quantities sufficient to meet range requirements is a challenge.
- Significant reductions in catalyst materials or inexpensive substitutes are needed for fuel cells.

RD&D Activities

- DOE, through the FreedomCAR 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 is working on light vehicles through FreedomCAR that includes component and vehicle simulation, ancillary load reduction, component testing, energy storage, advanced engines, and lightweight materials.

Recent Progress

- GM, Ford, and DaimlerChrysler have developed a variety of hybrid-electric vehicles. The technical feasibility of these concepts has matured, although cost remains an issue.
- Advances in energy storage systems – including hybrid storage consisting of batteries and ultracapacitors – show promise.
- Prototype FCVs are being tested.

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: FCVs have the zero emissions of an EV but not yet the range of conventional vehicles. Fuel cell 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.

Market Context

- The market for these technologies is all light 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 100% if all current research such as new generation of ultra-high-efficiency diesel engines (using advanced emissions-control technology), reduced aerodynamic drag, rolling resistance, and parasitic power losses is successful. Development and commercialization of engines 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.

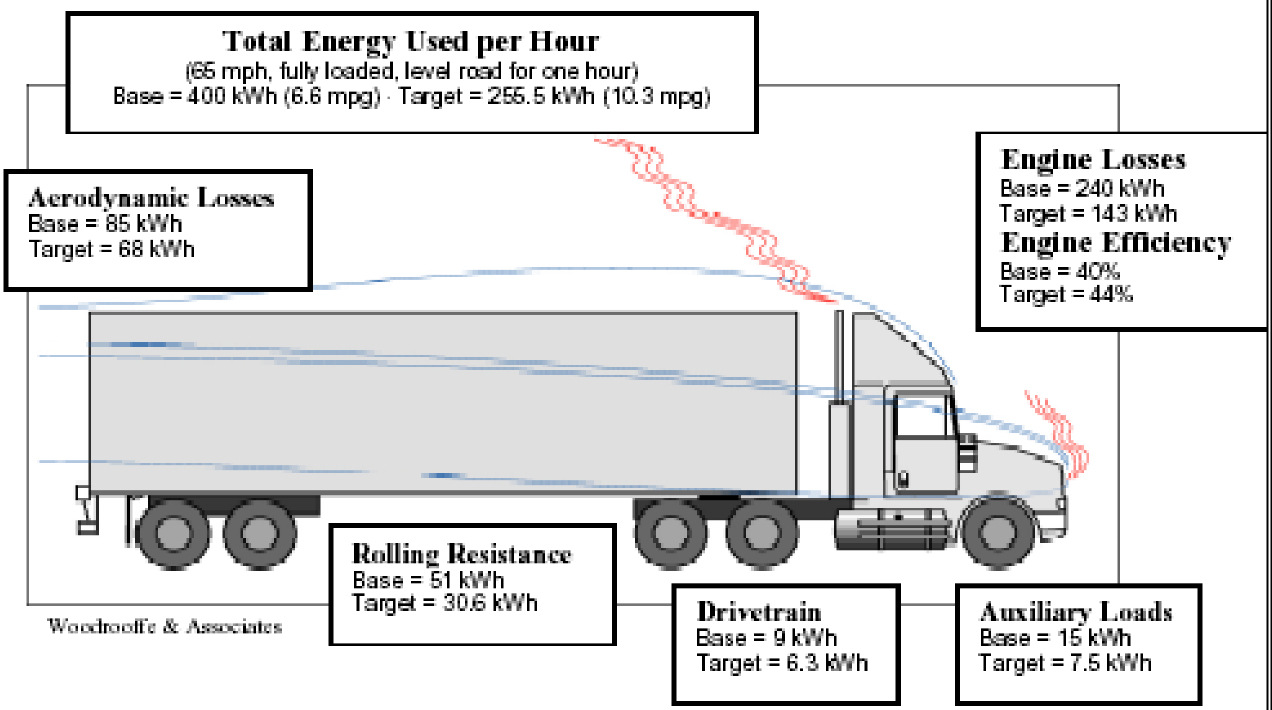


Fig. 4.1. Class 8 truck energy audit.

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.
- 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.

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 considered a long-term option. 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 system efficiency by 20% (from current 42% to 50%) by 2010 and demonstrate 55% efficiency in the laboratory by 2012.
  - Identification of a commercially viable, domestically produced non-petroleum diesel-blending agent that would enable a 5% displacement of diesel fuel by 2012.
- 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 a 10% reduction (from current 51 kWh to 46 kWh) in tire-rolling resistance values vs. existing best-in-class standards without compromising cost or performance.
  - 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:
  - Development and demonstration of a commercially viable 5 kW, $200/kW, diesel-fueled, internal-combustion engine auxiliary power units by 2007 (0.2 gallons of diesel fuel per hour; 200 lbs. weight; maximum 0.5 cubic-meter size; meeting prevailing emission standards; cooling and fuel systems integrated into vehicle platform, less than 65 dB noise inside cab; noise, vibration, and harshness as good or better than the prime mover engine).
  - 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.
- Advanced technology often involves more durable materials, additional components, or additional manufacturing processes, 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.
- The Environmental Protection Agency's National Vehicle Fuel Emissions Laboratory plans to add advanced heavy diesel cycle engines and innovative hybrid drive-train systems for urban delivery trucks to its Advanced Automotive Technology Program.
- 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
• New conceptual model of in-cylinder soot formation has been developed. • Advanced multicylinder engine demonstrated more than 90% reduction in NO_x and particulate matter. • 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. • The strong coupling between efficiency and emissions controls is a significant barrier. Many of the engine design options currently available to manufacturers for emissions reductions involve a fuel economy penalty of 10%-20%. In the absence of significant technology advancements, future emission regulations could detrimentally affect the historical trend toward higher diesel-engine efficiency. • 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.

1.1.3 ALTERNATIVE-FUELED VEHICLES

Technology Description

A school bus in New Jersey runs on biodiesel (right). United Parcel Service maintains a natural gas compressor station and CNG fueling island at several facilities in Connecticut (left).

Alternative fuels that will be important during the transition to hydrogen include electricity, ethanol, biodiesel, liquefied petroleum gas, and compressed natural gas. These fuels offer near-term carbon reductions of 19%-44% for a variety of vehicles.

System Concepts

- Alternative fuel vehicles (AFVs) are similar to today's vehicles, except for certain fuel- and emission-related systems.
- Vehicles operating on gaseous fuels like natural gas or liquefied petroleum gas require specific fuel system components including fuel regulators, an air and fuel-mixing apparatus, and modified fuel injectors. Modifications to the fuel tank and fuel supply and infrastructure are also required.

Representative Technologies

- Compressed natural gas buses are widely used by transit fleets nationwide.
- Automakers offer several models of compressed natural gas, and liquefied petroleum gas, and ethanol flexible-fuel vehicles.
- 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 good in-service emissions performance and similar levels of fuel economy in Federal fleet demonstrations. AFV purchase costs vary; natural gas vehicles have significant incremental costs over conventional vehicles.
- Heavy-duty AFVs have shown reductions in particulate emissions. Maintenance costs are higher but are likely to decrease with experience. Natural gas is the alternative fuel of choice in these classes of vehicles when considering 100% replacement of fuel.

Current Research, Development, and Demonstration

RD&D Goals

- Develop light- and heavy-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.
- By 2004, develop two heavy-vehicle engines that use natural gas and achieve emission compliances while being fully competitive with their diesel counterparts.

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, refueling convenience, cold-start performance, and engine efficiency.
- Some alternative fuels have lower energy content, which can reduce the range of the vehicle – particularly if a gaseous fuel is used.
- Challenges to accelerating the integration of AFV technologies into the marketplace must be addressed by working with industry to eliminate near-term technical barriers and to increase availability, acceptance, and awareness of AFV technology and equipment:
  - Assist with the development of additional vehicle platforms that utilize AFV technologies previously developed in partnership with DOE in order to ensure ongoing viable product availability.
  - Maintain efforts to increase efficiency, reduce costs, and improve emissions performance of AFV engines, technologies, and equipment.
  - Enhance AFV infrastructure and vehicle development by addressing near-term technical problems as they are identified and ensure that appropriate solutions are rapidly communicated and adopted in the marketplace.

RD&D Activities

- DOE, in collaboration with engine and truck manufacturers and fuel suppliers, is conducting the Next-Generation Natural Gas Vehicle project to develop advanced medium- and heavy-duty natural gas vehicles.
- With DOE cofunding, heavy-duty engine manufacturers have major alternative-fuel engine R&D efforts.
- The Environmental Protection Agency is developing unique engine designs utilizing renewable fuels and achieving diesel-cycle efficiency levels while meeting Tier 2 emission standards for light vehicles.
- Component manufacturers, national laboratories and research institutions, universities, and state and local governments have sizable alternative-fuel R&D activities.
- Biomass and hydrogen fuels are discussed in other Technology Profiles; see the Table of Contents.

Recent Progress

- 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 underway to improve engine efficiency that reduces carbon emissions. Natural gas transit buses comprise 25% of new bus orders.
- Honda has obtained ultra-low-emission vehicle certification for a dedicated compressed natural gas automobile.
- 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.
- Light-duty alternative-fuel vehicles are currently available from all major automotive manufacturers.

Commercialization and Deployment Activities
• Domestic automobile manufacturers have been producing AFVs since 1991. Currently, 29 light-duty and 20 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 fuel. Prices for gasoline-ethanol, flexible-fuel vehicles have decreased to those of their conventional counterparts. • The Federal government has more than 50,000 AFVs on the road and is expected to lead the deployment of new alternative-fuel vehicles under the direction of DOE, the General Services Administration, and interagency coordinating committees. • Since its inception in 1991, the DOE-sponsored alternative-fuel, heavy-duty truck demonstration program has assisted in placing more than 600 heavy-duty data collection AFVs. Data collection continues to provide valuable feedback to manufacturers and fleets. • The DOE Clean Cities Program actively enables deployment of AFVs through its locally based government/industry partnership, with a goal of 1 million light- and heavy-duty vehicles by the end of 2010 in the United States. **Market Context** • The prices of all these fuels need to be made more attractive to vehicle users.

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.

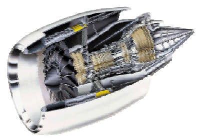
Commercialization and Deployment Activities

- 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

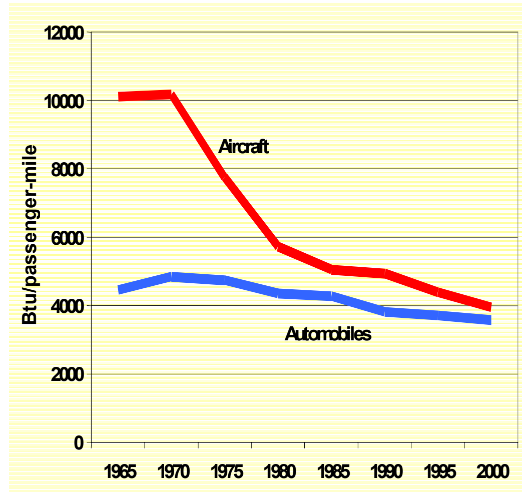


Boeing 777

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

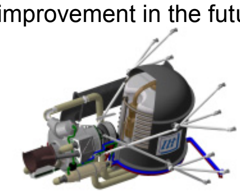
LNG Buses at LAX

New technologies reduce ground emissions



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.

…. 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 calendar years 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.

1.2 BUILDINGS

1.2.1 BUILDING EQUIPMENT, APPLIANCES, AND LIGHTING

Technology Description

A school in North Carolina features daylighting, state-of-the-art lighting controls, and an energy management system, allowing individual teachers to select optimum lighting levels for each room.

Energy use in buildings depends on equipment to transform fuel or electricity into end-use services such as delivered heat or cooling, light, fresh air, vertical transport, cleaning of clothes or dishes, and information processing. (The effects of passive and related systems are discussed in other profiles.) There are energy-saving opportunities within individual pieces of equipment – as well as at the system level – through proper sizing, reduced distribution and standby losses, heat recovery and storage, and optimal control. Another promising opportunity lies in multifunction devices ranging from heat pumps, which provide both refrigeration and hot water, to an office appliance that serves as a networked printer, copier, scanner, and paperless fax machine.

System Concepts

- Major categories of end-use equipment include heating, cooling, and hot water; ventilation and thermal distribution; lighting; home appliances; miscellaneous (process equipment and consumer products); and on-site energy and power.
- Key components vary by type of equipment, but some crosscutting opportunities for efficiency include improved materials, efficient low-emissions combustion and heat transfer, advanced refrigerants and cycles, electrodeless and solid-state lighting, smart sensors and controls, improved small-power supplies, variable-capacity systems, reduction of thermal and electrical standby losses, cogeneration based on modular fuel cells and microturbines, and utilization of waste heat from fuel cells and microturbines.

Representative Technologies

- Residential gas-fired absorption heat pumps, centrifugal chillers, desiccant preconditioners for treating ventilation air, heat-pump water heaters, proton exchange membrane fuel cells, heat pump water heaters, solid-state lighting, and lighting controls.
- Specialized HVAC (heating, ventilating, and air-conditioning) systems for research laboratories, server/data systems, and other buildings housing high technology processes.

Technology Status/Applications

- Technology improvements during the past 20 years – through quality engineering, new materials, and better controls – have improved efficiencies in lighting and equipment by 15% to 75%, depending on the type of equipment. Efficiencies of compact fluorescent lamps are 70% better than incandescent lamps; refrigerator energy use has been reduced by more than three-quarters during the past 20 years; H-axis clothes washers are 50% more efficient than current minimum standards. Electronic equipment has achieved order-of-magnitude efficiency gains, at the microchip level, every two to three years.

Current Research, Development, and Demonstration

RD&D Goals

- By 2025, research, develop, and demonstrate marketable and advanced energy systems required to achieve "net-zero" energy use in new residential and commercial buildings through a 70% reduction in building energy use – via high-performance lighting, HVAC, and appliances – with the balance of energy needs met by renewable energy sources.
- By 2010, heat pumps for residential and small commercial applications are 40% more efficient than condensing gas furnaces.
- By 2010, reduced standby losses, improved heat pump water heating, and application of heat-recovery techniques reduce energy use for domestic water heating by 60% over electric storage water heaters.
- By 2020, photovoltaics offer cost-competitive alternatives to grid electricity, enabling the construction of net-zero energy homes/buildings, when combined with ~70% whole building load reductions.
- By 2020, alternative refrigeration equipment with low greenhouse warming potential (e.g., Stirling cycle, Brayton cycle, acoustic, magnetic, thermal electric) will be commercially introduced.
- By 2008, develop a portfolio of distributed generation technologies (including microturbines) that show an average 25% increase in efficiency (compared to 2000 baseline) with NO_x emissions less than 0.15 lb/MWh.
- By 2013, develop solid-state lighting for general illumination applications with luminous efficacy of 90 lumens per watt by 2008, and 160 LPW by 2013.
- By 2030, all aspects of the building envelope, equipment, and appliances will be integrated and combined with on-site microcogeneration and zero-emission technologies.
- The basic RD&D needed ranges from materials science to solid-state electronics, and from a better understanding of combustion fundamentals to advances in control theory. Research is also needed on behavioral and ergonomic dimensions of the user-machine relationship.

RD&D Activities

- Most Federal R&D on building equipment is performed by DOE.
- International funding is less relevant than state activities such as currently ongoing in California, New York, and other states. This research is synergistic with and complements the DOE research.

Recent Progress

- Recent DOE-sponsored R&D, often with industry participation, includes an improved air-conditioning cycle to reduce oversizing and improve efficiency; a replacement for inefficient, high-temperature halogen up-lights (torchieres), which use only 25% of the power, last longer, and eliminate potential fire hazards; ozone-safe refrigerants, where supported R&D was directed toward lubrication materials problems associated with novel refrigerants and ground-source heat pumps.

Commercialization and Deployment Activities

- Building equipment, appliances, and lighting systems currently on the market vary from 20% to 100% efficient (heat pumps can exceed this level by using "free" energy drawn from the environment). This efficiency range is narrower where cost-effective appliance standards have previously eliminated the least-efficient models.
- The stock and energy intensity of homes are growing faster than the building stock itself, as manufacturers introduce – and consumers and businesses eagerly accept – new types of equipment, more sophisticated and automated technologies, and increased levels of end-use services.
- The rapid turnover and growth of many types of building equipment – especially electronics for computing,

control, communications, and entertainment – represent important opportunities to rapidly introduce new, efficient technologies and quickly propagate them throughout the stock.

- The market success of most new equipment and appliance technologies is virtually ensured if the efficiency improvement has a three-year payback or better and amenities are maintained; technologies with payback of four to eight-plus years also can succeed in the market, provided that they offer other customer-valued features (e.g., reliability, longer life, improved comfort or convenience, quiet operation, smaller size, lower pollution levels).
- Applications extend to every segment of the residential and nonresidential sectors. Major government, institutional, and corporate buyers represent a special target group for voluntary early deployment of the best new technologies.

Market Context

- Building equipment and appliances represent an annual market in the United States, alone, of more than $200B, involving thousands of large and small companies. Certain technologies, such as office and home electronics, compete in global markets with little or no change in performance specifications.

1.2.2 BUILDING ENVELOPE (INSULATION, WALLS, ROOF)

Technology Description

National laboratory exhibits show the benefits of energy-efficient building envelope design (left). This home in Atlanta, Georgia, (right) will use 58% less energy for heating and 53% less energy for cooling than a home of comparable size without energy-efficient design.

The building envelope is the interface between the interior of a building and the outdoor environment. In most buildings, the envelope – along with the outdoor weather – is the primary determinant of the amount of energy used to heat, cool, and ventilate. A more energy-efficient envelope means lower energy use in a building and lower greenhouse gas emissions. The envelope concept can be extended to that of the "building fabric," which includes the interior partitions, ceilings, and floors. Interior elements and surfaces can be used to store, release, control, and distribute energy, thereby further increasing the overall efficiency of the buildings.

System Concepts

- Control of envelope characteristics provides control over the flow of heat, air, moisture, and light into the building. These flows and the interior energy and environmental loads determine the size and energy use of HVAC and distribution systems.
- Materials for exterior walls, roofs, foundations, windows, doors, interior partition walls, ceilings, and floors that can impact future energy use include insulation with innovative formula foams and vacuum panels; optical control coatings for windows and roofs; and thermal storage materials, including lightweight heat-storage systems.

Representative Technologies

- *Superinsulation*: Vacuum powder-filled, gas-filled, and vacuum fiber-filled panels; structurally reinforced beaded vacuum panels; and switchable evacuated panels with insulating values more than four times those of the best currently available materials should soon be available for niche markets. High-thermal-resistant foam insulations with acceptable ozone depletion and global warming characteristics should allow for continued use of this highly desirable thermal insulation.
- *Advanced window systems*: Krypton-filled, triple-glazed, low-E windows; electrochromic glazing; and hybrid electrochromic/photovoltaic films and coatings should provide improved lighting and thermal control of fenestration systems. Advanced techniques for integration, control, and distribution of daylight

should significantly reduce the need for electric lighting in buildings. Self-drying wall and roof designs should allow for improved insulation levels and increase the lifetimes for these components. More durable high-reflectance coatings should allow better control of solar heat on building surfaces.

- *Advanced thermal storage materials*: Dry phase-change materials and encapsulated materials should allow significant load distribution over the full diurnal cycle and significant load reduction when used with passive solar systems.

Technology Status/Applications

- Building insulations have progressed from the 2-4 hr ºF ft^2/Btu/in. fibrous materials available before 1970 to foams reaching 7 hr ºF ft^2/Btu/in. Superinsulations of more than 25 ºF ft^2/Btu/in. will be available for niche markets soon. Improvements in window performance have been even more spectacular. In the 1970s, window thermal resistance was 1 to 2 ºF ft^2/Btu. Now, new windows have thermal resistance of up to 6 ºF ft^2/Btu (whole window performance). Windows are now widely available with selective coatings that reduce infrared transmittance without reducing visible transmittance. In addition, variable-transmittance windows under development will allow optimal control to minimize heating, cooling, and lighting loads.

Current Research, Development, and Demonstration

RD&D Goals

- By 2025, research, develop, and demonstrate marketable and advanced energy systems required to achieve "net-zero" energy use in new residential and commercial buildings through a 70% reduction in building energy use – via high-performance walls, windows, roofs and foundations – with the balance of energy needs met by renewable energy sources.
- Commercial-building, low-slope roof options with high insulation qualities (R-30 to R-40) and extended lifetimes (30-plus years).
- By 2008, demonstrate dynamic solar control windows (electrochromics) in commercial buildings.
- By 2010, windows with R10 insulation performance for homes are commercially available.
- Mass-produced (factory-built) customized buildings with integrated envelope and equipment systems designed and sized for specific sites and climates.
- On-site or purchased renewables replacing 15% of purchased energy (see photovoltaics pathway).
- A 30% decrease in the average envelope thermal load of existing residential buildings and a 66% decrease in the average thermal load of new buildings compared to current code requirements.

RD&D Challenges

- Foam insulations that retain high thermal resistance while using blowing agents with zero ozone depletion potential and negligible global warming effect.
- Self-drying wall and roof designs to avoid moisture problems such as materials degradation.
- Electrochromic window films and electrochromic/photovoltaic hybrid window films to control energy flows and generate electricity on site.
- Techniques to distribute and control daylight to reduce electrical energy use for artificial lighting.
- Advanced durable cost-effective superinsulations to reduce heating/cooling loads.
- Self-calibrating multifunction microsensors for monitoring building equipment performance and air-quality monitoring.
- Thermal storage materials: Typically, thermal storage in building components is achieved with heavyweight materials such as masonry. Advanced thermal-storage materials need to be lightweight to integrate with elements similar to drywall, floor, and ceiling panels.
- Scaling electrochromic window technology to commercial-scale window applications.

RD&D Activities

- Key agencies doing building envelope R&D are DOE, National Institute for Standards and Technology, several state agencies, and other institutions such as the Florida Solar Energy Center.

Recent Progress

- A DOE-sponsored RD&D partnership with the Polyisocyanurate Insulation Manufacturers Association, the National Roofing Contractors Association, the Society of the Plastics Industry, and Environmental Protection Agency (EPA) helped the industry find a replacement for chloroflurocarbons (CFCs) in polyisocyanurate foam insulation. This effort enabled the buildings industry to transition from CFC-11 to HCFC-141b by the deadline required by the Montreal protocol.
- Spectrally selective window glazings – which reduce solar heat gain and lower cooling loads – and high-performance insulating materials for demanding thermal applications.

Commercialization and Deployment Activities

- A critical challenge is to ensure that new homes and buildings are constructed with good thermal envelopes and windows when the technologies are most cost effective to implement.
- The market potential is significant for building owners taking some actions to improve building envelopes. Currently, 40% of residences are well insulated, 40% are adequately insulated, and 20% are poorly insulated. More than 40% of new window sales are of advanced types (low-E and gas-filled). In commercial buildings, more than 17% of all windows are advanced types. More than 70% of commercial buildings have roof insulation; somewhat fewer have insulated walls.
- Building products are mostly commodity products. A number of companies produce them; and each has a diverse distribution system, including direct sales, contractors, retailers, and discount stores.
- Another critical challenge is improving the efficiency of retrofits of existing buildings. Retrofitting is seldom cost-effective on a stand-alone basis. New materials and techniques are required.
- Many advanced envelope products are cost-competitive now, and new technologies will become so on an ongoing basis. There will be modest cost reductions over time as manufacturers compete.

Market Context

- Building structures represent an annual market in the United States of more than $70B/year and involve thousands of large and small product manufacturers and a large, diverse distribution system that plays a crucial role in product marketing. Exporting is not an important factor in the sales of most building structure products.

1.2.3 INTELLIGENT BUILDING SYSTEMS

Technology Description

Energy-management system field tests at the Zion National Park Visitor Center (top) and the Bighorn Home Improvement Center complex in Silverthorne, Colorado (bottom), DOE High Performance Buildings Program.

Intelligent building systems (IBS) use data from design (together with sensed data) to automatically configure controls and commission (i.e., start-up and check out) and operate buildings. Control systems use advanced, robust techniques and are based on smaller, less expensive, and much more abundant sensors. These data ensure optimal building performance by enabling control of building systems in an integrated manner and continuously recommissioning them using automated tools that detect and diagnose performance anomalies and degradation. Intelligent building systems optimize operation across building systems, inform and implement energy purchasing, guide maintenance activities, document and report building performance, and optimally coordinate on-site energy generation with building energy demand and the electric power grid, while ensuring that occupant needs for comfort, health, and safety were met at the lowest possible cost.

System Concepts

- The system consists of design tools, automated diagnostics, interoperable control-system components, abundant wireless sensors and controls, and highly integrated operation of energy-using and producing systems.
- These components would work together to collect data, configure controls, monitor operations, optimize control, and correct out-of-range conditions that contribute to poor building performance.
- Intelligent building systems would ensure that essential information, especially the design intent and construction implementation data, would be preserved and shared across many applications throughout the lifetime of the building.
- Equipment and system performance records would be stored as part of a networked building performance knowledge base, which would grow over time and provide feedback to designers, equipment manufacturers, and building operators and owners.
- Optimally integrate on-site power production with building energy needs and the electric-power grid by applying intelligent control to building cooling, heating, and power.

Representative Technologies

- DOE is developing computer-based building commissioning and operation tools to improve the energy efficiency of "existing" buildings. It is also investing in the next generation of building simulation programs that could be integrated into design tools.
- DOE, in collaboration with industry, also is developing and testing technologies for combined cooling, heating, and power; and wireless sensor and control systems for buildings.

Technology Status/Applications

- Savings from improved operation and maintenance procedures could save more than 30% of the annual energy costs of existing commercial buildings, even in many of those buildings thought to be working properly by their owners/operators. These technologies would have very short paybacks because they would ensure that technologies were performing as promised, for a fraction of the cost of the installed technology.
- Savings for new buildings could exceed 70% using integration of building systems and, with combined cooling, heating and power, buildings could become net electricity producers and distributed suppliers to the electric power grid.

Current Research, Development, and Demonstration

RD&D Goals

- Design environments with fully and seamlessly integrated building design tools that support all aspects of design and provide rapid analysis; design suggestions; quick and easily understood data interpretation; automatic generation of all design documents; and a building electronic-data structure that supports start-up, operation, maintenance, and renovation of the building by intelligent building systems.
- Automatic operation of buildings by automatically sensing installed equipment; checking for proper installation; generating control algorithms; implementing optimal adaptive control; diagnosing and correcting operating episodes that produce inefficient, unhealthy or uncomfortable conditions; managing maintenance; and providing performance data in usable forms for operators of new and existing buildings, facility managers, and owners. Have systems appropriate for homes and other small buildings that require little operator attention.
- Highly efficient combined cooling, heating, and power systems that use waste heat from small-scale, on-site, electricity generation to provide heating and cooling for the buildings, as well as exporting excess electricity to the grid.

RD&D Challenges

- Design tools: enhanced analytical capabilities, integration with the design environment, automated design and analysis capability, design databases, visualization, and high-level monitoring and reporting tools.
- Automated diagnostics: diagnosticians, plug-and-play capabilities, automated real-time purchasing, advanced data visualization, automated identification, and correction of the causes of operation problems.
- System interoperability and controls: integrated control networks; plug-and-play control components; adaptive, optimized, self-generating control algorithms; automatic configuration and commissioning of controls; and advanced control techniques.
- Sensors: wireless data acquisition, detection of materials properties, micro-scale sensors, microelectronic sensors, multiple-sensor arrays, protocols for using new sensors, new sensing technologies, order of magnitude lower-cost sensor systems, and ubiquitous use of sensors.
- Visualization: use of supercomputers, networked personal computer to provide distributed super-computer-level performance, advanced computational methods, and virtual reality systems to permit real-time visualization of designs and design changes, including lighting, thermal flows, and air quality.
- Buildings Combined Cooling, Heating, and Power: Technologies for reusing waste energy to provide net-electricity producing buildings.
- Early priorities include enhancing design-tool integration; developing automated diagnosticians; implementing remote data collection and visualization; developing combined cooling, heating, and power; and developing low-cost, wireless sensor, and control technology.
- Advanced building simulation tools to permit better design, construction, commissioning, and operation.

RD&D Activities

- DOE is funding work with the California Energy Commission, California Institute for Energy Efficiency, Honeywell, Johnson Controls, Siemens, Electric Power Research Institute, Southern California Edison, and Pacific Gas and Electric Company. International efforts include an effort funded by the European Union to develop adaptive control techniques for improving the thermal environment for JOULE IIICSEC.

Recent Progress

- Energy 10: models passive solar systems in buildings.
- DOE 2: international standard for whole building energy performance simulation has thousands of users worldwide.
- DOE has recently released Energy Plus, the new standard for building energy simulation and successor to DOE-2.
- The International Alliance for Interoperability is setting international standards for interoperability of computer tools and components for buildings.
- DOE-BESTEST: basis for ANSI/ASHRAE Standard 140, *Method of Test for the Evaluation of Building Energy Simulation Programs.*

Commercialization and Deployment Activities

- Design tools for energy efficiency are used by fewer than 2% of the professionals involved in the design, construction, and operation of commercial buildings in the United States. A larger fraction of commercial buildings have central building-control systems. Few diagnostic tools are available commercially beyond those used for air balancing or integrated into equipment (e.g., Trane Intellipack System) and the recently announced air-conditioning diagnostic hand-held service tool by Honeywell (i.e., Honeywell HVAC Service Assistant). The Department of Energy – in concert with the California Energy Commission – is testing a number of automated diagnostic tools and techniques with commercial building owners, operators, and service providers in an effort to promote commercial use. About 12 software vendors develop, support, and maintain energy design tools; most are small businesses. Another 15 to 20 building automation and control vendors exist in the marketplace – the major players include Johnson Controls, Honeywell, and Siemens.
- Deployment involves four major aspects: seamless integration into existing building design and operation practices and platforms, lowering the cost of intelligent-building and enabling technologies, transforming markets to rapidly introduce new energy-efficient technologies, and a focus on conveying benefits that are desired in the marketplace (not only energy efficiency).

Market Context

- These technologies would apply to all buildings, but especially to existing commercial buildings and all new buildings. In addition, new technologies would be integrated into the building design and operation processes.

1.2.4 URBAN HEAT ISLAND TECHNOLOGIES

Technology Description

Heat islands form as cities replace natural vegetation with pavement for roads, buildings, and other structures necessary to accommodate growing populations. These surfaces absorb – rather than reflect – the sun's heat, causing surface temperatures and overall ambient temperatures to rise. The displacement of trees and shrubs eliminates the natural cooling effects of shading and evapotranspiration. Measures to reduce the urban heat island effect include strategically planting shade trees, installing reflective roofs, and installing reflective pavements. Heat island mitigation measures can reduce greenhouse emissions by reducing ambient air temperatures in urban areas, thereby slowing the chemical formation of smog (ozone and precursors) and reducing demand for electricity for air-conditioning in the cooling seasons. In general, the larger the area implementing heat island reduction measures – and the longer, sunnier, and hotter the summer season – the more substantial the impacts on meteorology and air quality. Meteorological modeling can assist in understanding the effects of such measures, as well as the interactions with other factors.

System Concepts

- Reduced temperatures reduce the need for summertime cooling energy. Reduced air-conditioning reduces power plant emissions, including greenhouse gas emissions and ozone precursors.
- Reduced temperatures decrease biogenic volatile organic compounds emissions and evaporative losses.
- Trees sequester carbon (particularly urban or suburban trees, which can sequester about 18 kg of carbon annually) and precipitate particulates and other airborne pollutants.
- Reduced ambient air temperature reduces photochemical reaction rates, which may reduce ozone production.

Representative Technologies

- There are more than 200 Energy Star-labeled roof products, which include coatings and single-ply materials, tiles, shingles, and membranes. Energy savings in buildings with reflective roofs range as high as 32% during peak demand, with a summer average of 15%.
- There are several reflective pavement applications being developed, which include new pavement applications, resurfacing pavement applications, asphalt material type, concrete material type, and other material types. For example, white topping involves covering existing asphalt pavement with a layer of concrete (which has approximately 15% higher albedo than asphalt). Also, chip seals are used for maintenance and resurfacing of low-traffic streets and roads; reflective materials can be used to cover the surface. Higher albedos reduce maximum pavement temperatures by about 10°F per 0.1 increase in albedo. In turn, air temperature is reduced by about 1°F if all pavements have albedo increased by 0.2.
- Placing trees on the west-, south-, and east-facing sides of a building can significantly reduce cooling costs for a home or low-rise building during peak summertime demand. Simulations of energy savings benefits for Sacramento and Phoenix found that three mature trees around homes cut annual air-conditioning demand by 25%-40%.

Technology Status/Applications

- A few states (e.g., California, Georgia, and Florida) have incorporated reflective roofs into their state energy codes. Some states (e.g., California) and communities have reflective roof incentive programs. Reflective roofs are given credit in several environmental rating programs including the U.S. Green Building Council's LEED (Leadership in Energy and Environmental Design) rating system.
- Some communities are installing alternative pavement parking lots and alleys – mainly using porous pavement technologies. White-topping is also becoming increasingly popular.
- Nationally, there are numerous tree-planting programs. Some utilities have partnered with urban forestry groups to encourage residential shade tree planting to reduce air-conditioning energy consumption. Further, several communities have implemented shade tree ordinances (e.g., requiring parking lots shade 50% of paved areas 15 years after development).

Current Research, Development, and Demonstration

RD&D Goals
- Better understand and quantify the impacts heat island reduction measures have on local meteorology, energy use and expenditures, greenhouse gas emissions, and air quality.
- Develop an application based on geographic information systems that predicts heat island outcomes from different development scenarios.
- Better understand the relationship between surface and air temperature.
- Better understand the contribution of radiant emissions from vertical surfaces on the heat island effect.
- Quantify net benefits from large-scale tree planting projects (i.e., volatile organic compound contributions, CO_2 sequestration, and removal of other pollutants).
- Develop cool materials for roofs and pavements.
- Assist the Cool Roof Rating Council with developing procedures to measure and rate the optical properties of the roofing materials.
- Work with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), state and Federal agencies to develop implementation plans.

RD&D Challenges
- Better understand interaction between meteorological, land surface, and emission-specific parameters in baseline and modified modeling scenarios.
- Determine albedo and emissivity levels of city surfaces.

RD&D Activities
- Tulane University and a DOE laboratory are modeling the impacts of heat island reduction measures on local meteorology in seven U.S. domains.
- DOE is modeling the impacts of heat island reduction measures on local meteorology, energy savings, CO_2 reductions, and air quality in several cities including Houston, Chicago, and Baton Rouge.
- DOE is analyzing the urban fabric (surface composition) of several cities including Sacramento, Houston, Chicago, Salt Lake City, and Baton Rouge.
- Several groups in California are examining net benefits from trees.
- DOE is working with granule, pigment, and shingle manufacturers to develop cool-colored shingles.
- DOE is working with the pavement industry on developing cool surfaces.
- The Environmental Protection Agency (EPA) and DOE have lead efforts to organize the Cool Roof Rating Council and develop standards for the American Society for Testing and Materials (ASTM) and ASHRAE.
- USDA Forest Service develops methods and models to quantify carbon storage and sequestration, building energy-use effects, and air pollution removal by urban forests at the local to national scale.
- USDA Forest Service conducts analyses in numerous cities and national assessments to quantify the effects of urban forests on carbon storage and sequestration, building energy use, and air pollution removal.

Recent Progress

- EPA and DOE demonstrated the impact of cool roofs on building energy use; EPA developed the Energy Star Roof Products program.
- ASTM and ASHRAE standards have been developed, and prototype cool-roofing materials have been developed.
- The Cool Roof Rating Council was organized and several state and air-quality management districts have adopted heat-island-reduction measures.

Commercialization and Deployment Activities
• Reflective roofing and paving technologies may be broadly applicable to U.S. cities, but benefits will vary. • Several reflective roof programs (e.g., California's Cool Savings Program) require use of Energy Star Labeled Roof Products, thus increasing the demand and deployment of these products. **Market Context** • Heat island reduction strategies including urban reforestation, rooftop gardens, reflective roofs, and alternative pavements have been implemented in Los Angeles, Sacramento, Salt Lake City, Honolulu, Chicago, Miami, and Atlanta – and other cities are interested. • Nationally, reflective roofing materials still comprise less than 10% of the roofing market; asphalt comprises 95% of urban pavements.

1.3 INFRASTRUCTURE

1.3.1 HIGH-TEMPERATURE SUPERCONDUCTIVITY

Technology Description

America's ongoing appetite for clean, reliable, and affordable electricity has increased at a rate that seriously threatens to exceed current capacity. Demand is estimated to increase by 9% through 2004 – however, only a 3% increase in transmission is planned, and there have been no major new investments in transmission during the past 15 years. Witnessing the regional outages being experienced throughout the country – and those most recently highlighted in the northeast – the inadequacies of the investment in infrastructure investments have, in effect, issued a wake-up call for enhancement of the grid. High-temperature superconducting (HTS) wires can carry many more times the amount of electricity of ordinary aluminum or copper wires. HTS materials were first discovered in the mid-1980s and are brittle oxide, or ceramic-like materials, that can carry electricity with virtually no resistance losses. Through years of Federal research in partnership with companies throughout the nation, technology has developed to bond these HTS materials to various metals, providing the flexibility to fashion these ceramics into wires for use in transmission cables, bearings for flywheels, and coils for power transformers, motors, generators, and the like. Superconducting technologies make possible electric power equipment that is half the size of conventional alternatives, with half the energy losses. When HTS equipment becomes pervasive, up to 50% of the energy now lost in transmission and distribution will become available for customer use. HTS also will reduce the impact of power delivery on the environment and is helping create a new high-tech industry to help meet the challenges due to delays in electric utility restructuring. Other increased performance benefits include improved stability, reliability, power quality, and deferred generation expansion.

System Concepts

- HTS cables have almost no resistance losses and can transport 3-5 times as much power as a conventional cable in the same size conduit.
- HTS power transformers have about 30% reduction in total losses, can be 50% smaller and lighter than conventional units, have a total ownership cost that is about 20% lower, are nonflammable, and do not contain oil or any other potential pollutant. In addition, there are electrical performance benefits associated with current limiting capacity and reduced impedance that will yield cost savings to power companies.
- HTS Fault Current Limiters can provide power companies with surge protection within the local distribution system. They are reusable, require minimal maintenance, and do not need replacement after being activated.
- HTS motors with more than 750 kW would save enough energy over their lifetime to pay for the motor. The motors are 50% smaller and lighter than conventional motors, as well.
- HTS generators with more than 100 MVA will be more energy efficient, compact, and lighter than the conventional generator. The generator has characteristics that may help stabilize the transmission grid.

System Components

- HTS cables consist of large numbers of tapes containing HTS materials operating at 65-77 K, insulated thermally and electrically. A cryogenic refrigerating system maintains the temperature of the cable, extracting heat that manages to leak into the assembly.
- HTS transformers use the same types of HTS materials as cables, formed into coils and mounted on conventional transformer cores. Electrical insulation is accomplished by means other than conventional oil-and-paper, and typically involves a combination of solid materials, liquid cryogens, and vacuum.
- HTS motors, generators, magnetic separators, MRI magnets, and current limiters use HTS wires and tapes in a coil form. Rotating cryogenic seals provide cooling for the rotating machines.
- HTS flywheel systems use nearly frictionless bearings made from superconducting "discs," cooled below the transition temperature of the HTS materials.

Technology Status/Applications

- HTS wires: First generation "BSCCO" wires are available today in kilometer lengths at about $200/kA-m. Second-generation "coated conductors" have been made in 1-10 m lengths in the laboratory and are to be scaled up in 2002-2004 to 100-m lengths. The 1-m tapes carry approximately 50 amperes of current in nitrogen.
- HTS cables: Under the DOE Superconductivity Partnership Initiative, a team led by Pirelli Cable installed a 120-m cable in the city of Detroit, Michigan. Southwire has installed and tested a 30-m prototype cable that has been powering three manufacturing plants in Carrollton, Georgia, since February 2000.
- HTS transformers: Waukesha Electric Systems, with partial DOE funding, demonstrated a 1-MVA prototype transformer in 1999 and is leading a team developing a 5/10-MVA, 26.4-kV/4.2-kV three-phase prototype.
- HTS motors: Rockwell Automation demonstrated a prototype 750-kW motor in 2000 and is designing a motor with five times the rating.

Current Research, Development, and Demonstration

RD&D Goals

- Performance: Develop HTS wires with 100 times the capacity of conventional copper/aluminum wires. Design and demonstrate a broad portfolio of electric equipment based on HTS: 50% reduction in energy losses compared to conventional equipment, and 50% size of conventional equipment with the same rating. Low-cost, high-performance YBCO coated conductors will be available in 2005 in kilometer lengths.
- Cost: Wire cost of $0.01/ampere-meter. Equipment premium cost payback (efficiency savings) will be achieved in 2-5 years of operation. Equipment total cost payback will be achieved during the operating lifetime. Coated conductor goals: For applications in liquid nitrogen, the wire cost will be less than $50/kA-m; while for applications requiring cooling to temperatures of 20-60 K, the cost will be less than $30/kA-m. By 2010, the cost-performance ratio will have improved by at least a factor of four.

RD&D Challenges

- The manufacture of promising HTS materials in long lengths at low cost remains a key program challenge.
- Materials for cryogenic insulation and standardized, high-efficiency refrigerators (approaching 30% of Carnot efficiency) are required.
- Scale-up of national laboratory discoveries for "coated conductors" requires the use of film industry or semiconductor industry processing expertise and equipment to make electric wires and is a key activity for the labs and their industry partners.

RD&D Activities

- DOE funding is used for three key program activities: the Accelerated Coated Conductor Initiative, the Superconductivity Partnership Initiative, and Strategic Research. Performers include national laboratories, industry, academia, and other Federal agencies.

Recent Progress

- The development at the national laboratories of ion-beam assisted deposition and rolling-assisted, biaxially textured substrate (RABiTS™) technologies for producing high-performance HTS film conductors suitable

for cables and transformers, and the involvement of four unique industry-led teams to capitalize on it, was a major success story for FY 1997. • The world's first HTS cable to power industrial plants exceeded 13,000 hours of trouble-free operation in Carrollton, Georgia (Southwire Company). The 30-m cable system has been operating unattended since June 2001. • During the summer of 2001, Detroit Edison installed a 120-m HTS cable system in an urban substation that serves 14,000 customers. • Rockwell Automation demonstrated a prototype 1000-HP synchronous motor that exceeded design specifications by 60%, and is now designing a 5000-HP motor.
Commercialization and Deployment Activities
• High-temperature superconducting cables and equipment: Commercialization and market introduction requires development of inexpensive wires for transmission and distribution, and end uses such as electric motors. These wires are now under development under a government-industry partnership but are still years from wide-scale use. Using high-temperature superconductivity wires to replace existing electric wires and cables may be analogous to the market penetration that occurred when the United States moved from copper wire to fiber optics in communications. Some pre-commercial demonstrations have begun, but the Superconductivity Partnership Initiative could be expanded.

1.3.2 TRANSMISSION AND DISTRIBUTION TECHNOLOGIES

Technology Description

The electric utility industry is restructuring itself from a regulated environment to operation under competitive wholesale electricity markets. However, the electric transmission and distribution (T&D) systems remain regulated entities that connect deregulated generation to the end-use customer. Construction of U.S. transmission above 230 kV is expected to increase by only 6% (in line-miles) during the next 10 years, while demand is expected to increase more than 20%. The resulting increase in the intensity of use of existing facilities will increase energy losses and transmission congestion, and is likely to cause grid reliability problems and threaten the continued growth of wholesale electricity trade. Energy losses in the U.S. T&D system were 7.2% in 1995, accounting for 2.5 quads of primary energy and 36.5 MtC. Losses are divided such that about 60% are from lines and 40% are from transformers (most of which are for distribution). Technologies that can improve efficiency and reduce carbon emissions are high-voltage DC (HVDC) transmission, high-strength composite overhead conductors, and power transformers and underground cables that use high-temperature superconductors (see related technology profile). High-efficiency conventional transformers also could have significant impacts on distribution system losses. In addition, energy storage and real-time system monitoring and control systems could improve system reliability and customer access to competitive generation, including renewable power producers. There is no active U.S. program for HVDC development or improved distribution transformer technologies.

System Concepts

- Composite-core, low-sag transmission conductors can transport two to three times as much power as conventional conductors over the same rights-of-way and with no tower modifications.
- Energy storage will facilitate more optimal use of existing infrastructure and increase the dispatchability of renewable resources.
- Real-time grid operations using measured data and automatic, intelligent controllers can improve T&D reliability – and lead to a smart, switchable future network that can anticipate and respond automatically to system contingencies.

System Components

- One advanced composite overhead conductor consists of an aluminum metal matrix composite core (replacing the steel core of a conventional cable) surrounded by temperature-resistant aluminum alloy wires.
- Several large- and medium-scale energy-storage systems, using different electrochemistries, have been developed.
- Real-time control uses wide-area measurement systems, synchronized by global positioning system (GPS) satellite clocks that feed system information to artificial neural net controllers. The controllers reconfigure the system in real time, preventing outages and allowing maximum use of available transmission capacity.

Technology Status/Applications

- Aluminum composite-core conductors, terminations, and suspensions have been developed by 3M Company and demonstrated in the field by leading U.S. and European utilities. Additional field trials in the United States and accelerated thermal cycling tests are planned in 2003-2005. This extensive mechanical and electrical testing is required to predict the 40-year life responses of this new conductor technology. Niche applications including long-span river crossings and short lead-time reconductoring over congested existing rights-of-way are now cost-effective. In addition, the conductor's core has 25% lower electrical resistances than steel, enabling higher transmission efficiencies.

- Large-scale energy-storage systems are entering field demonstrations.
- Wide-area measurement systems used for monitoring, event analysis, and system model studies have been deployed in the Western United States power grid to help analyze system disturbances.

Current Research, Development, and Demonstration

RD&D Goals

- Accelerated thermal-cycle testing for 3M's composite conductor in 2003-2005. Field-testing of this conductor began in 2002 on a 230kV transmission line on DOE's Western Area Power Administration grid. Other advanced conductors are expected to undergo similar high-current and field tests in 2003-2006.
- Demonstration of the reliability of energy-storage systems, and reduction of the cost of such systems by 30%.
- Operation of a prototype smart, switchable grid on a region on the U.S. transmission grid by 2010. The market for conventional utility-control systems approaches $300 M/year.

RD&D Challenges

- Development of large-diameter composite conductors for high-voltage transmission lines that are both low-cost and high capacity, so as to yield the highest payoffs in grid reliability and competitive market efficiency.
- Energy-storage systems with reduced costs that can meet several applications while using a single system.
- Neural net networks that can be trained in parallel to perform control functions in real-time control systems.
- A regulatory framework that will allow investors to make credible projections of the return on investment in new transmission capacity.

RD&D Activities

- For composite conductors, 3M Company cost-shared on a DOE effort in FY2002 and FY2003 to perform field tests and accelerated, controlled thermal tests on several conductor sizes.
- DOE is cost-sharing an energy-storage effort with industry. EPRI has a newly reformed energy storage target.

Recent Successes

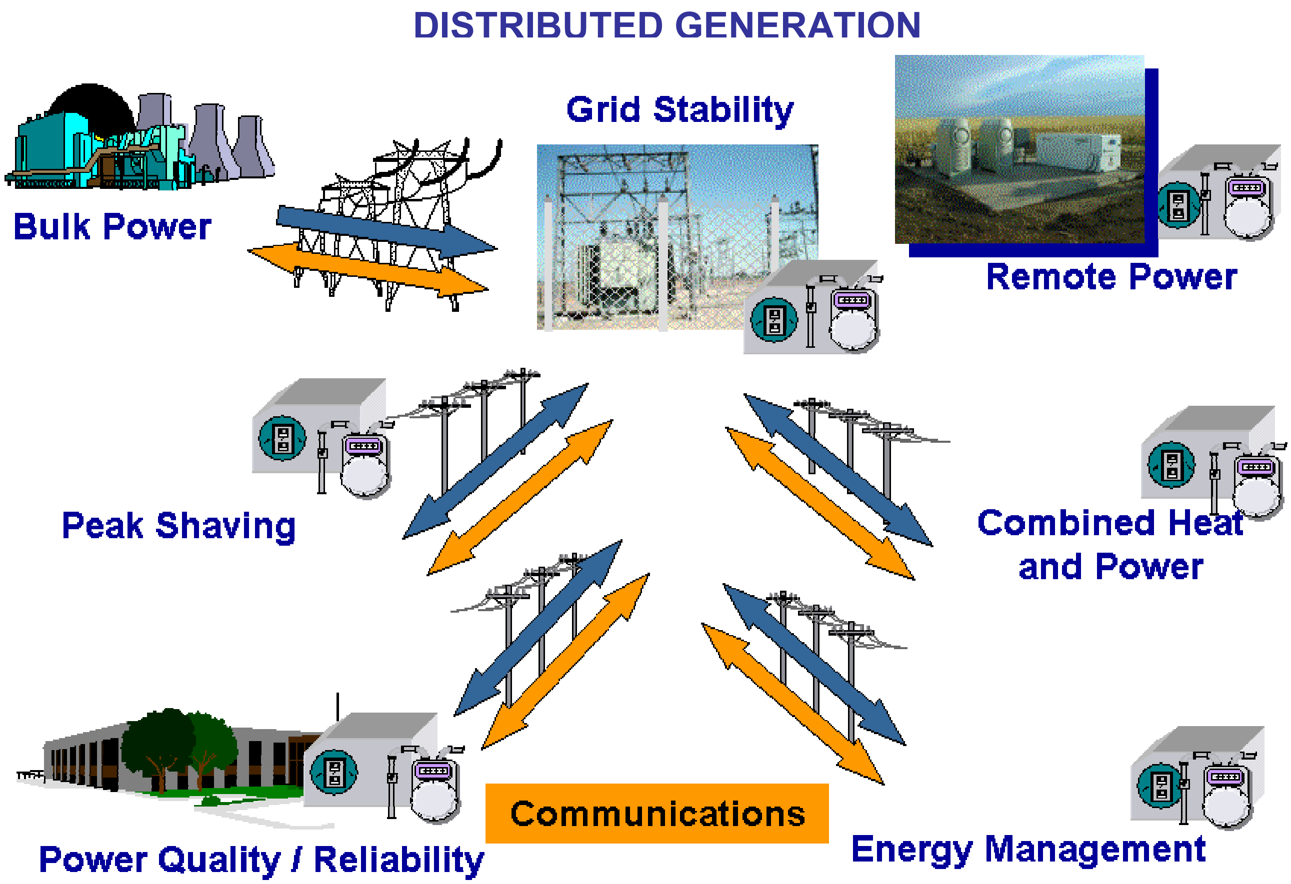
- DOE's *National Transmission Grid Study*, released in May 2002, examined issues surrounding U.S. transmission system upgrades and expansion, and contains 51 recommendations for actions to remove constraints on the U.S. transmission grid.
- Real-time monitoring tools have been developed by DOE and installed in California with funding by the California Energy Commission, and at the North American Electric Reliability Council (NERC) to monitor and display voltage and frequency over wide areas.
- Demand response (DR) projects are assisting independent transmission system operators (ISOs) with DR program design, and identifying DR capabilities to respond to markets for energy and contingency reserves.

Commercialization and Deployment Activities

- Commercial deployment of high-current composite conductors awaits U.S. field trial results, and manufacturing cost reductions for all but high-value niche applications.

1.3.3 DISTRIBUTED GENERATION AND COMBINED HEAT AND POWER

Technology Description



Distributed generation, including combined heat and power (CHP), can be distinguished from central energy resources in several respects. These distributed energy resources are small, modular, and come in a range of capacities from kilowatts to megawatts. They comprise a portfolio of technologies that can be located onsite or nearby the location where the energy is used. They provide the consumer with a greater choice, local control, and more efficient waste utilization to boost efficiency and lower emissions.

System Concepts

- The portfolio of distributed generation technologies includes, for example, photovoltaic systems, fuel cells, natural gas engines, industrial turbines, microturbines, energy-storage devices, wind turbines, and concentrating solar power collectors. These technologies can meet a variety of consumer energy needs including continuous power, backup power, remote power, and peak shaving. They can be installed directly on the consumer's premise or located nearby in district energy systems, power parks, and mini-grids.
- CHP technologies have the potential to take all of the distributed generation technologies one step further in pollution prevention by utilizing the waste heat from the generation of electricity for the making of steam, heating of water, or for the production of cooling energy. The average power plant in the United States converts approximately one-third of the input energy into output electricity and then discards the remaining two-thirds of the energy as waste heat. CHP systems similarly produce electricity, but then capture up to half or more of this waste heat to make steam, heat or cool water, or meet other thermal needs, thus making use of two-thirds or more of the input energy. CHP technologies make greater use of the fuel input by producing multiple products – electricity and reusable thermal energy, reaching efficiency levels of 70% or greater.

System Components

- Advanced industrial turbines and microturbines – combustion turbines are a class of electric-generation devices that produce high temperature, high-pressure gas to induce shaft rotation by impingement of the gas on a series of specially designed blades. Simple cycle efficiencies range from 21% to 40%. Turbines produce high-quality heat and can be used for CHP production. Microturbines are small combustion turbines with outputs of 25-1,000 kW. Microturbines evolved from automotive and truck turbochargers.
- Energy-storage systems – the combination of an energy-storage device (e.g., a battery or a flywheel) and a power-conversion system to connect the storage device with the local grid.
- Concentrating solar power – concentrating solar power systems use suntracking mirrors to reflect and concentrate sunlight into receivers where it is converted to high-temperature thermal energy, which can then be used to drive turbines to generate electricity.
- Fuel cells – power is produced in fuel cells electrochemically by passing a hydrogen-rich fuel over an anode and air over a cathode and separating the two by an electrolyte in producing electricity. The only byproducts are heat, water, and carbon dioxide.
- Natural Gas Engines – the reciprocating engine is widespread and well-known technology. Spark ignition gas-fired units (the focus here) typically use natural gas or propane. Capacities are typically in the 0.5- to 5-megawatt range.
- Photovoltaic Systems – photovoltaic systems use semiconductor-based cells to convert sunlight directly to electricity.
- Hybrid Systems – hybrid systems consist of two or more types of distributed energy technologies.
- Wind Energy Systems – wind turbines convert the kinetic energy of wind into electricity.

Technology Status/Applications

- Industrial gas turbines and natural gas reciprocating engines are existing technologies that are being utilized and have a great deal of potential.
- Microturbines, concentrating solar power, fuel cells, wind energy, photovoltaic systems, and hybrid systems are currently under development.
- CHP is a proven technology, responsible for 8% of U.S. electricity generation. The potential for expanding the use of CHP in the United States is enormous – the Department of Energy and the Environmental Protection Agency have a goal of doubling CHP capacity to 92 GW by 2010.

Current Research, Development, and Demonstration

RD&D Goals

- Near-term goals are to develop next-generation distributed energy technologies and address the institutional regulatory barriers that interfere with siting, permitting, and interconnection of distributed energy. The long-term goal for 2020 is to reduce the cost and emissions and increase the efficiency of distributed energy technologies to achieve 20% of the new electric generation capacity in the United States.

RD&D Challenges

- Provide lower cost and more efficient systems.
- Improve the reliability.
- Solve the institutional and regulatory barriers such as a lack of widely used technical interconnection standards.
- Enhance the implementation of CHP with technologies such as microturbines, fuel cells, gas turbines and reciprocating engines.

RD&D Activities

- Direct and coordinate a diverse portfolio of research development and demonstration investments in distributed natural gas technologies.
- Conduct supporting RD&D and enabling technologies.
- Direct and coordinate a diverse portfolio of RD&D energy generation and delivery systems architecture for distributed energy.
- Coordinate activities with RD&D and renewable energy technologies.

- Conduct system integration, implementation, and outreach activities aimed at addressing infrastructure, institutional, and regulatory needs.

Recent Progress

- DOE's advanced turbine system program has developed an industrial gas turbine with Solar Turbines, Inc., for a 48%-efficient simple-cycle machine. CHP is currently at 50 GW of installed capacity.
- Wind energy systems have been installed in various western and eastern United States locations.
- Microturbines have achieved more than 10,000 hours of operations and preliminary tests.
- The Southern Company recently accepted a SAFT/SatCon LiIon System developed by the DOE ESS program that provided three times the 100kW/1 minute rated performance. Southern agreed to test the battery system at no cost, because it can supplement a distributed energy resource (in this case a microturbine) and provide load-following capability.

Commercialization and Deployment Activities

- Advanced industrial gas turbines in the range of 1 to 50 MW are starting to be deployed.
- Natural gas reciprocating engines of 0.5-5 MW with efficiencies of 30%-40% are now being deployed.
- The DOE and EPA CHP programs are cooperating to actively promote the use of CHP to add about 46 GW of new CHP capacity by 2010.

Markets

- Distributed generation, including CHP, is currently helping the U.S. economy and has the potential to enhance the electric infrastructure. These technologies could produce more than 100 GW of generated capacity for the U.S. electric system..

1.3.4 ENERGY STORAGE

Technology Description

A 5-MVA battery energy-storage system for power quality and peak shaving.

Advanced storage technologies under active development include processes that are mechanical (flywheels, pneumatic), electrochemical (advanced batteries, reversible fuel cells, hydrogen, ultracapacitors), and purely electrical (superconducting magnetic storage). Energy storage devices are added to the utility grid to improve productivity, increase reliability or defer equipment upgrades. Energy storage devices must be charged and recharged with electricity generated elsewhere. Because the storage efficiency (output compared to input energy) is less than 100%, on a kilowatt-per-kilowatt basis, energy storage does not directly decrease CO_2 production. The exception to this rule is the use of advanced energy storage in conjunction with intermittent renewable energy sources, such as photovoltaics and wind, that produce no direct CO_2. Energy storage allows these intermittent resources to be dispatchable.

Energy-storage devices do positively affect CO_2 production on an industrial output basis by providing high-quality power, maximizing industrial productivity. New battery technologies, including sodium sulfur and flow batteries, significantly improve the energy and power densities for stationary battery storage as compared to traditional flooded lead-acid batteries.

System Concepts

- *Utilities:* The efficiency of a typical steam plant falls from about 38% at peak load to 28%-31% at night. Utilities and customers could store electrical energy at off-peak times, allowing power plants to operate near peak efficiency. The stored energy could be used during high-demand periods displacing low-efficiency peaking generators. CO_2 emissions would be reduced if the efficiency of the energy storage were greater than 85%. Energy storage also can be used to alleviate the pressure on highly loaded components in the grid (transmission lines, transformers, etc.) These components are typically only loaded heavily for a small portion of the day. The storage system is placed downstream from the heavily loaded component. This reduces electrical losses of overloaded systems. Equipment upgrades also are postponed, allowing the most efficient use of capital by utility companies.
- *Industrial:* The operation of modern, computerized manufacturing depends directly on the quality of power the plant receives. Any voltage sag or momentary interruption can trip off a manufacturing line and electronic equipment. Industries that are particularly sensitive are semiconductor manufacturing, plastics and paper manufacturing, electronic retailers, and financial services such as banking, stock brokerages, and credit card-processing centers. If an interruption occurs that disrupts these processes, product is often lost, plant cleanup can be required, equipment can be damaged, and transactions can be lost. Any loss must be made up decreasing the overall efficiency of the operation, thereby increasing the amount of CO_2 production required for each unit of output. Energy-storage value is usually measured economically with the cost of power-quality losses, which is estimated in excess of $1.5 B/year in the United States alone.

Industry is also installing energy-storage systems to purchase relatively cheap off-peak power for use during on-peak times. This use dovetails very nicely with the utilities' interest in minimizing the load on highly loaded sections of the electric grid. Many energy-storage systems offer multiple benefits. (An example is shown in the photo.) This 5-MVA, 3.5-MWh valve-regulated lead-acid battery system is installed at a lead recycling plant in the Los Angeles, California, area. The system provides power-quality protection for the plant's pollution-control equipment, preventing an environmental release in the event of a loss of power. The system carries the critical plant loads while an orderly shutdown occurs. The battery system also in discharged daily during the afternoon peak (and recharged nightly), reducing the plant's energy costs.

Representative Technologies

For utilities, the most mature storage technology is pumped hydro; however, it requires topography with significant differences in elevation, so it's only practical in certain locations. Compressed-air energy storage uses off-peak electricity to force air into underground caverns or dedicated tanks, and releases the air to drive turbines to generate on-peak electricity; this, too, is location specific. Batteries, both conventional and advanced, are commonly used for energy-storage systems. Advanced flowing electrolyte batteries offer the promise of longer lifetimes and easier scalability to large, multi-MW systems. Superconducting magnetic energy storage (SMES) is largely focused on high-power, short-duration applications such as power quality and transmission system stability. Ultracapacitors have very high power density but currently have relatively low total energy capacity and are also applicable for high-power, short-duration applications. Flywheels are now commercially viable in power quality and UPS applications, and emerging for high power, high-energy applications.

Technology Status - Utilities

Technology	Efficiency [%]	Energy density [W-h/kg]	Power density [kW/kg]	Sizes [MW-h]	Comments
Pumped hydro	75	0.27/100 m	low	5,000-20,000	37 existing in U.S.
Compressed gas	70	0	low	250-2,200	1 U.S., 1 German
SMES	90+	0	high	20 MW	high-power applications
Batteries	70–84	30-50	0.2-0.4	17-40	Most common device
Flywheels	90+	15-30	1-3	0.1-20 kWh	US & foreign development
Ultracapacitors	90+	2-10	high	0.1-0.5 kWh	High-power density

System Components

Each energy-storage system consists of four major components: the storage device (battery, flywheel, etc.); a power-conversion system; a control system for the storage system, possibly tied in with a utility SCADA (Supervisory Control And Data Acquisition) system or industrial facility control system; and interconnection hardware connecting the storage system to the grid. All common energy-storage devices are DC devices (battery) or produce a varying output (flywheels) requiring a power conversion system to connect it to the AC grid. The control system must manage the charging and discharging of the system, monitor the state of health of the various components and interface with the local environment at a minimum to receive on/off signals. Interconnection hardware allows for the safe connection between the storage system and the local grid.

Current Research, Development, and Demonstration

RD&D Goals

- Utilities require high reliability, and costs less than or equal to those of new power generation ($400–$600/kW). Compressed gas energy storage can cost as little as $1-$5/kWh, while pumped hydro ranges from $10-$45/kWh. Battery storage systems range from $300-$2000/kW.

RD&D Challenges

- The major hurdles for all storage technologies are cost reduction and developing methods of accurately identifying all the potential value streams from a given installation. Advanced batteries need field experience and manufacturing increases to bring down costs. Flywheels need further development of fail-safe designs and/or lightweight containment. Magnetic bearings could reduce parasitic loads and make flywheels attractive for small uninterruptible power supplies and possibly larger systems using multiple individual units. Ultracapacitor development requires improved large modules to deliver the required larger energies. Advanced higher-power batteries with greater energy storage and longer cycle life are necessary for economic large-scale utility and industrial applications.

RD&D Activities

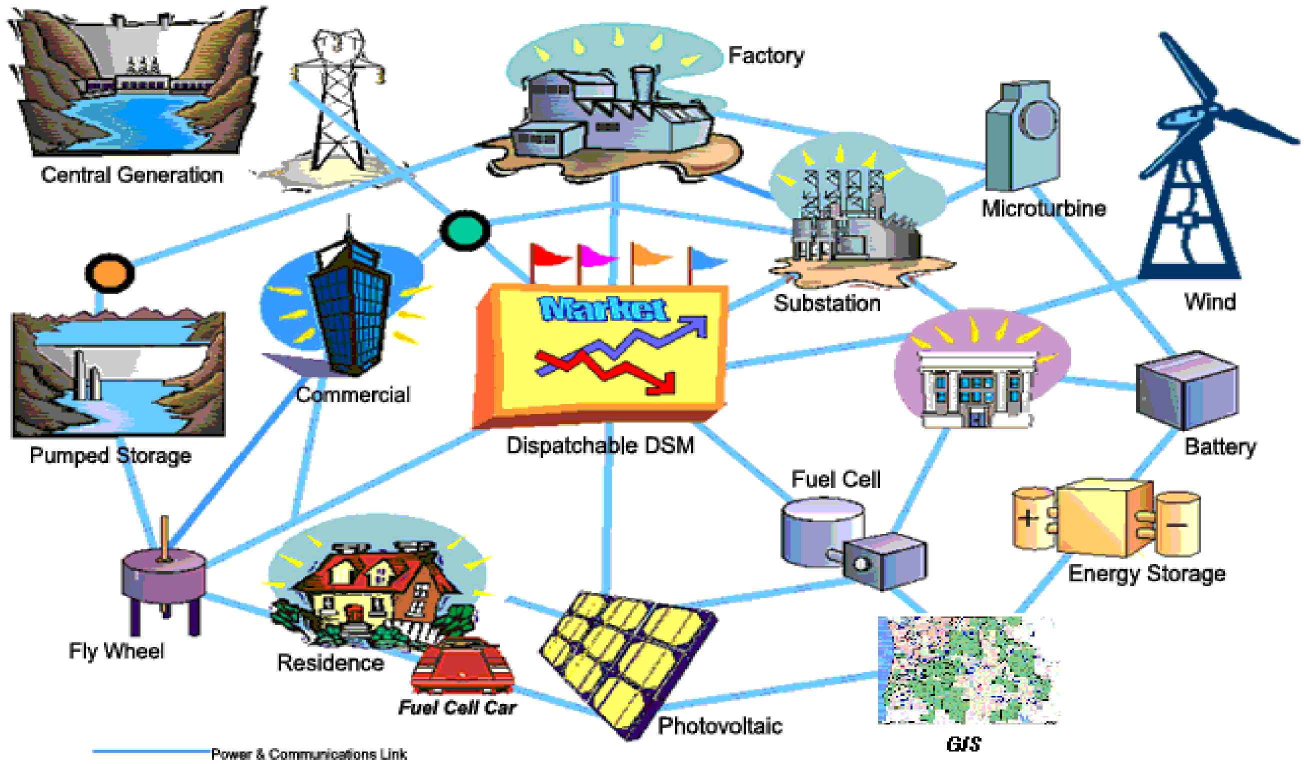
- The Japanese are investing heavily in high-temperature, sodium-sulfur batteries for utility load-leveling applications. They also are pursuing large-scale vanadium reduction-oxidation battery chemistries. The British are developing a utility-scale flow battery system based on sodium bromine/sodium bromide chemistry. DOE's Energy Storage Systems Program works on improved and advanced electrical energy storage for stationary (utility, customer-side, and renewables) applications. It focuses on three areas: system integration using near-term components including field evaluations, advanced component development, and systems analysis. This work is being done in collaboration with a number of universities and industrial partners.

Commercialization and Deployment Activities

- For utilities, only pumped hydro has made a significant penetration with approximately 37 GW.
- Approximately 150 MW of utility peak-shaving batteries are in service in Japan.
- Two 10-MW flow battery systems are under construction – one in the United Kingdom and the other in the United States.
- Megawatt-scale power quality systems are cost effective and entering the marketplace today.

1.3.5 SENSORS, CONTROLS, AND COMMUNICATIONS

Technology Description



Improved sensors and controls, as part of the next-generation electricity transmission and distribution system, could significantly increase the efficiency of electricity generation and delivery, thereby reducing the greenhouse gas emissions intensity associated with the electric grid. Sensors and controls will play a key role in the development of the nation's next-generation electric T&D system. In the grid of the future, distributed energy resources will be fully integrated into grid operations, providing a robust energy infrastructure enhanced by local protection and control measures. The communication and control challenges associated with this evolution are significant. Local system conditions will be sensed, and local intelligent agents will process the data and communicate decision commands to local controllers for problem rectification and performance optimization. These local sensors and distributed software agents will assess adequacy and security with only high-level oversight from the central control authority. Distribution system and transmission grid reliability will be significantly improved by higher levels of local distributed energy generation using power electronics to control and manage two-way power flow as directed by local sensors and intelligent agents.

System Concepts

- In the future, there must be a rapid, widespread measurement and control system that enables distributed energy generation to provide highly reliable services under all disturbance scenarios. Local control of such highly reliable services will improve local power quality and improve the efficiency of the distribution system. This will be done with local sensors and "intelligent agents" that monitor local conditions and provide local responses.
- Conventional utility sensors, while robust and reliable, are quite expensive. Low-cost, reliable and robust sensors must be developed that can monitor current flow, voltage, and phase angle throughout the distribution system. These sensors would provide the intelligent agents with the information they need to make rapid, correct decisions.

Representative Technologies

- Low-cost physical sensors will be used to measure voltage, current, temperature, phase angle, and for other electric distribution and grid system characterization applications.
- The system architecture will be dependent on the ability of intelligent agents to diagnose and forecast local faults. This will involve placing a number of sensors, intelligent agents, and controllers at strategic locations.
- The sensing, communication, and information analysis required for intelligent decision making must happen in real time or near real time (in seconds), sufficiently faster than the time required to affect coordination, control, and protection schemes.
- Communications must take place to advise the central controller of the local system status, perform critical nonrepudiating functions to manage the electricity commerce, and enable real-time markets for energy and ancillary services.

Technology Status/Applications

- The variety of transduction methods and the capability to fabricate small, rugged sensor devices has advanced tremendously during the past five years. Modern techniques for fabricating electronic devices allow unprecedented miniaturization of sensors and electronic controls.
- Rapid analysis of sensor data and feedback control is also advancing, often enabled by microprocessor technology.
- Rapid, low-cost communications methods are also undergoing fast-paced advancement in wireless and fiber-optic technologies.

Current Research, Development, and Demonstration

RD&D Goals

- The first step in the research plan will be to develop computer simulation models of the distribution system to assess the alternative situations. To validate these models, prototype sensors and communication systems, as well as assessment methods for the intelligent agents, will be required. The simulation models will be tested in the laboratory and then in the field. When the models have been validated on a sufficiently large scale, the functional requirements and architecture specifications can be completed, and final technology solutions that conform to the established architecture can be explored.

RD&D Challenges

- A challenge will be the development of cost-effective fault detection and control systems that can be readily implemented in the nation's power grid. The electricity market with an ever-increasing demand for highly reliable services is a key factor in the development of the new control system.
- In response to market communications, distributed energy generation must be capable of supplying the highly reliable services presently provided by large turbine generators, such as spinning reserves, reactive power supply, and voltage and frequency regulation. The entire control scheme is now based on the response of the large generation stations to supply these services. Traditionally, it has been considered to be too difficult to use distributed energy generation to supply these services because there are simply too many units to control reliably and quickly.

RD&D Activities

- Within DOE, sensor and control programs are being developed to focus on issues related to system architecture, distributed intelligence, interconnection technologies and standards, simulation and modeling of the distribution system, load/demand management, and aggregation testing and control of a suite of distributed energy resources.
- Workshops have been held with utilities; energy service companies; and providers of communications, sensor, control, and information technologies to plan strategies and develop roadmaps.

Recent Progress

- A Grid-Friendly™ appliance controller, based on the gate array chip, is being developed to monitor the power grid while controlling on-off operations of household appliances (refrigerators, air conditioners,

water heaters, etc.) in response to power grid overload. This device has been tested in a laboratory environment and is ready for installation in the next generation of appliances.
- A wireless end-device controller is being installed at more than 200 facilities in southwest Connecticut, with the goal of controlling 2-3 megawatts of electricity on a real-time dispatchable basis. The controller collects real-time energy-use information and controls end-use loads (lighting, vending machines, etc.) to manage system peak demand.

Commercialization and Deployment Activities

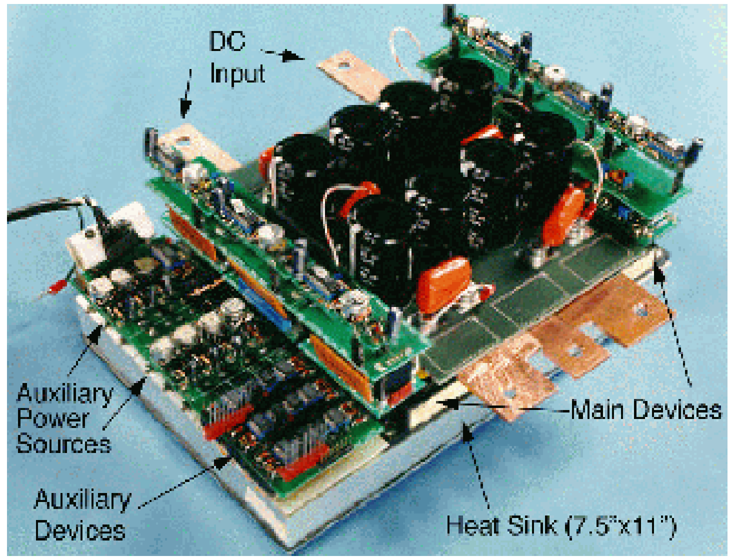
- There are more than 4,200 sensor and control companies in the United States. Commercialization of sensor technology depends on demonstrating economic viability at a level commensurate with the risks small businesses can assume.

Market Context

- The market for improved sensors and controls cuts across all industrial and transportation sectors. Nuclear, fossil, and end-use efficiency technologies would all benefit.

1.3.6 POWER ELECTRONICS

Technology Description



Improved power electronics, as part of the next-generation electricity T&D system, could significantly increase the efficiency of electricity generation and delivery, thereby reducing the greenhouse gas emissions intensity associated with the electric grid. Power electronics is the technology that is used to provide the interface between different types of electrical power, such as DC and 60-Hz AC. Power electronics equipment transforms frequency, voltage, and power factor. Power levels and voltages from a few kilowatts and 120 volts – all the way up to transmission-level powers and voltages – are now possible with today's technology. Power electronics can enable the simple connection of various types of electrical infrastructure links like distributed energy resources. It can help to regulate voltage in the distribution system and transmission grid, and can solve power-quality and voltage-dip problems. Most important, power electronics can provide for an integrated approach to reliability, where all the components – energy conversion, energy storage, control, and power electronics – work together.

About 60%-70% of the nation's electrical power is used to drive motors and motors are reasonably efficient at their designed or rated speed and load. However, efficiencies can be tremendously improved by operating motors at variable speeds that match the system requirements. Motors driven by power electronics to achieve variable speed capability are increasing dramatically in numbers as the technologies become available. Continued development of power electronic devices with higher power-handling capability and reliability will offer an unprecedented opportunity for U.S. industry and utilities to reduce energy consumption and improve competitiveness.

Power electronic structures have been developed to overcome shortcomings in solid-state switching device ratings so that they can be applied to high-voltage electrical systems. The unique structure of multilevel voltage source power electronics allows them to reach high voltages with low harmonics without the use of transformers. This makes these power electronics suitable for flexible AC transmission systems (FACTS) and custom power applications. The use of power electronics to control the frequency, voltage output (including phase angle), and real and reactive power flow at a DC/AC interface provides significant opportunities in the control of distributed power systems.

As distributed power sources become increasingly prevalent in the near future, power electronics will be able to provide significant advantages in processing power from renewable energy sources using fast response and autonomous control. Additionally, power electronics can control real and reactive power flow from a utility-connected renewable energy source. These power electronic topologies are attractive for continuous control of system dynamic behavior and to reduce problems such as voltage harmonics, voltage imbalance, or sags.

System Concepts

- Advanced inverter topologies: Inverter circuitry that accommodates and takes advantage of advanced solid-state devices while further improving the overall efficiency, packaging, and performance of the inverter.

Representative Technologies

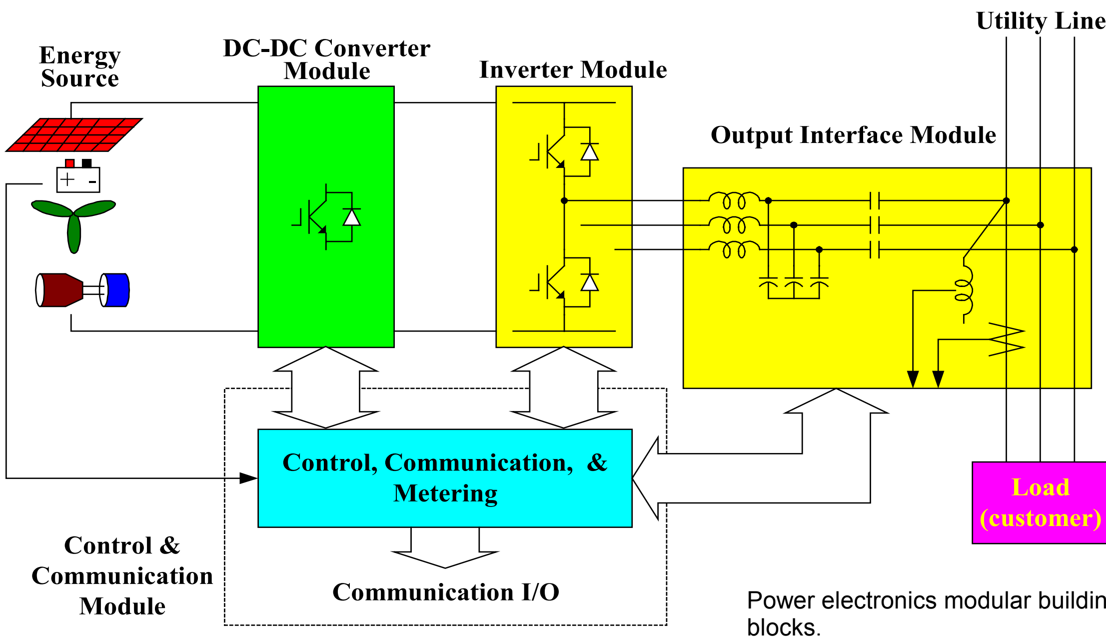
- Soft-switching inverters, multilevel inverters, buck/boost converters, capacitors, magnetic materials, and other materials for improved power electronics.

Technology Status/Applications

- Transportation: Displacement of internal combustion engines and enabling power electronic components for alternate approaches to standard vehicle systems (traction drives, flywheels, auxiliary drives, alternators).

- Industrial: Enabling components for more efficient motors and introduction of adjustable speed drives to match drives to loads for fans, pumps, and compressors.
- Utilities: Power-quality systems, high-voltage DC power transmission systems.
- Renewable energy: Inverters to convert DC power from photovoltaics and wind turbines to AC power.
- Power supplies: Converters embedded in systems to alter the electrical power from one type to another.
- Defense: Grid and equipment interfaces to allow for mobile and emergency backup of transmission and distribution infras.

Current Research, Development, and Demonstration



Power electronics modular building blocks.

RD&D Goals

- Build a power electronic system on a base of modules. Each module or block is a subsystem containing several components, and each one has common power terminals and communication connections. A systems engineer can pick up one module to hook up to the system without knowing much detail of what is inside the module. Each manufacturer can perfect their blocks and work more independently of the other manufacturers once standardized ratings have been determined.
- The figure represents a strategy in which the interface is partitioned into four basic blocks with each one performing a different system function: (1) DC-DC converter; (2) power electronics, (3) output interface and filtering; and (4) control, communication, and metering. Each of the power blocks will have their own control and communication interface such that a group of modules can coordinate their actions to act as an ideal interface to interconnect distributed energy resources to the utility system. Also, with each block having its own control and communication interface, these modules can be combined to form a multilevel configuration as well as other series/parallel connections as necessary to meet the voltage and current requirements for the particular installation. In addition, this approach will allow for future capacity increases, enhancement to functionality, redundancy, and reconfiguration.

RD&D Challenges

- Smaller, lighter, more efficient, and lower-cost inverters.
- Increase reliability and lower cost.
- Improved materials and devices: Solders, capacitors, ferrite semiconductors, low-loss drivers, thermal

management, passive devices, DC disconnects, connectors, and new semiconductor materials such as silicon carbide.

- Increase modularity of power electronic components.
- Present-day power electronics exhibit a number of serious problems and limitations. Some of the most significant of these are (1) the need for difficult-to-meet switching device ratings (and associated reliability issues), (2) the need for transformers (and associated design limitations), (3) high cost, (4) control limitations, (5) limitations on voltages that can be attained, (6) creation of high levels of harmonic distortion.
- USCAR is pursuing the development of electric devices as an enabling technology.
- Developing power electronic building blocks.
- The Federal initiatives in transmission and distribution system long-range R&D were canceled.

RD&D Activities

- The DOE Energy Storage Program supports research in power electronics for megawatt-level inverters, fast semiconductor switches, sensors, and devices for Flexible AC Transmission Systems (FACTS). Projects in these areas recently won two R&D 100 awards.
- Office of Naval Research and DOE have a joint program to develop power electronic building blocks.
- The military is developing more electricity-intensive aircraft, ships, and land vehicles, providing power electronic spin-offs for infrastructure applications.
- The Superconductivity Technology Program funds R&D of more efficient motor technology under the Superconductivity Partnership Initiative.

Recent Progress

- Soft-switching inverter topologies have been recently developed for improved inverter efficiency, reliability, and performance.
- High-power solid-state inverters with improved efficiency and reduced cost and size have been developed.
- A multilevel inverter has been developed, which when deployed will allow 26% more energy to be extracted from photovoltaic or other renewable energy sources.

Commercialization and Deployment Activities

- Major U.S. motor and drive manufacturers are beginning to expand their product lines to include improved power electronics.
- U.S. power semiconductor manufacturers are expanding product lines and facilities to regain market position from foreign competitors.

1.4 INDUSTRY

1.4.1 ENERGY CONVERSION AND UTILIZATION

Technology Description

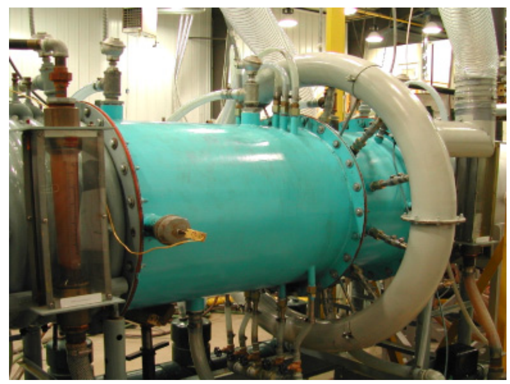
Energy conversion and use account for a large share of carbon emissions from the industrial sector. An integrated systems approach to energy conversion and utilization incorporating the best technologies could significantly reduce greenhouse gas (GHG) emissions and improve industrial competitiveness. Energy utilization gains can be achieved through the increased adoption of existing technology in the areas of combined-cycle power generation and cogeneration of power and heat, referred to as combined cooling, heating, and power (CHP). Many opportunities also exist for improving the efficiency of energy generation, including advanced combustion technologies, fuel cells, gasification technologies, and advanced steam cycles. GHG reductions also can be achieved through increased use of fuels with low or no net GHG products, such as biomass and hydrogen. Opportunities in energy utilization include making economical use of waste heat and minimizing generation of low-level heat.

System Concepts

- The industrial sector could significantly reduce GHG emissions by improving energy utilization efficiency; switching to low-GHG fuels; gasifying waste materials to create useful fuels; and using high-efficiency, distributed generation technologies with low-GHG emissions (such as fuel cells).
- Modern design techniques and an integrated systems approach to mill or plant design could minimize the generation of low-level heat that cannot be used economically.

Representative Technologies

- Energy conversion technologies include high-efficiency burners and boilers; advanced steam cycles; oxy-fuel combustion, with or without flue gas recirculation; gasification of in-plant process streams and cofiring of biomass with fossil fuels; hydrogen-enriched combustion and fuel cells; and reforming of liquid and gaseous fuels to hydrogen, combined with carbon management. As an example of DOE-supported technology, ITP is working with the Gas Technology Institute and other industry partners to develop a revolutionary super boiler that could save several hundred trillion Btu of energy annually and reduce emissions (see inset).



A revolutionary super boiler now under development should substantially reduce energy use and carbon emissions throughout industry.

- Energy utilization technologies include on-site combined heat and power systems and waste heat-recovery systems.
- Advances in heat exchangers and furnace design also will allow for the more efficient utilization of energy.

Technology Status/Applications

- Technologies with higher efficiencies have been demonstrated in several applications, but have not been uniformly adopted by industry.
- Energy-generation technologies currently used by industry typically have thermal efficiencies ranging from 25% to 55%; the next generation of energy-generation technologies promises substantially higher thermal efficiencies, perhaps ranging from 45% to 80%. This efficiency improvement would significantly reduce the amount of fuel required for industrial heat and power, thus reducing GHG emissions. Additionally, aggressive development and deployment of distributed on-site generation technologies could avoid transmission and distribution losses, which average approximately 7%.
- Use of in-plant wastes and residues from production processes to generate energy is a promising area for reducing energy intensity and GHG emissions. RD&D is needed to increase the use and cost-effectiveness of this technology.

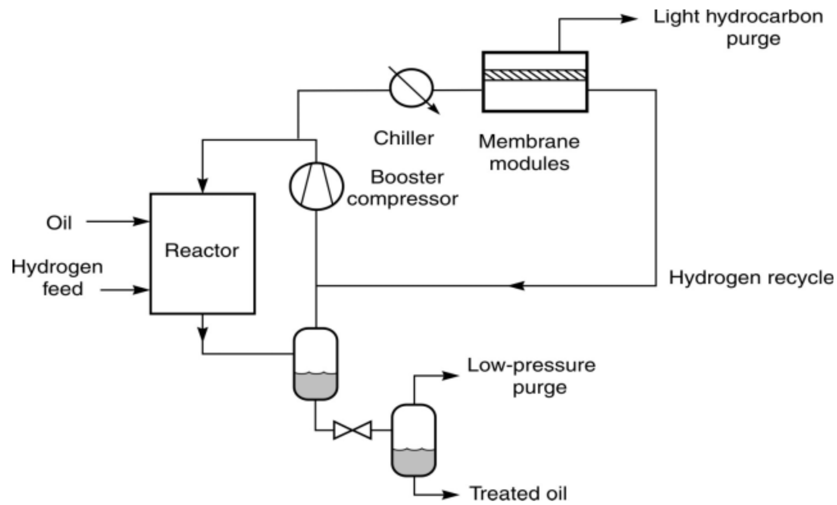
Current Research, Development, and Demonstration
RD&D Goals • Effect an aggressive transition to highly energy-efficient, on-site generation technologies, such as CHP systems, improved boilers and furnaces, and low- or zero-carbon fuels such as natural gas, biomass, or hydrogen to support the overall DOE Industrial Technologies Program goal of contributing to a 30% reduction in the energy intensity (Btu per unit of industrial output as compared to 2002) of energy-intensive industries by 2020. Reductions in energy intensity could significantly reduce industrial GHG emissions. • By 2006, demonstrate a >95% efficient packaged boiler; by 2010, packaged boilers will be commercially available with thermal efficiencies 10%-12% higher than conventional technology. • Continue to focus technology development efforts on key energy-intensive industries, which collectively account for three-quarters of energy use by the industrial sector. • Assist industry efforts to develop advanced glass technologies that will reduce the gap between actual melting energy use (more than 11 million Btu to melt a ton of glass as measured in 1996) and the theoretical minimum (2.5 million Btu per ton) by 50% by 2020. • Develop technical advances in gasification technology and non-combustion, high-efficiency power generation techniques such as fuel cells (requiring advances in fuel reforming technologies). **RD&D Challenges** • Better understanding of enabling technologies will allow developments of processes and equipment for improved energy recovery. • Advanced, low- or zero-GHG-emission, power-generation technologies must be made economically competitive. • Technical advances are required in gasification technology and noncombustion, high-efficiency, power-generation techniques such as fuel cells (requiring advances in fuel-reforming technologies). **RD&D Activities** • DOE is developing and demonstrating advanced, high-efficiency combustion systems, waste heat-utilization technologies, a systems approach to mill or plant design, and gasification technologies. • RD&D activities related to this pathway are sponsored by DOE, the Environmental Protection Agency, the National Institute of Standards and Technology's Advanced Technology Program, and other Federal agencies. This pathway will work closely with these programs and also leverage past investments.
Recent Progress
• The forced internal recirculation burner is beneficial to all industries that generate steam from natural gas burners. This new technology combines several techniques to dramatically reduce NO_x and carbon monoxide emissions from natural gas combustion without sacrificing boiler efficiency. • Waste heat was tapped at two refineries to power absorption refrigeration units. The power generated was used to chill waste fuel streams that contained substantial amounts of propane or heavier hydrocarbons. With chilling, the refineries were able to condense and recover about half of the valuable hydrocarbons in the waste streams for increased profits; and, at the same time, reduce the amount of gas flared off as waste, reducing carbon dioxide emissions to the atmosphere. • A high-luminosity, low-NO_x burner for oxy-fuel fired glass furnaces was developed to reduce NO_x formation by up to 50% and also increase heat transfer compared to conventional burners. The technology has been demonstrated in both fiberglass and float glass plants.

Commercialization and Deployment Activities
• Industry is already making substantial investments in commercializing and deploying economical technologies: combusting wastes and residues, fuel switching in combustion systems, employing oxy-fuel combustion, and energy cascading from high temperature to lower temperature uses within plants. Availability of capital and competition for R&D and demonstration funds will impact deployment of new technology. Cost competitiveness with existing technologies will be achieved when the newer technologies have completed their R&D cycles.
Market Context
• Markets include all manufacturing industries that use boilers or process heating. In 1998, process heating and boiler fuel accounted for at least 6.8 quads of fossil energy consumption in the manufacturing sector alone. Significant potential exists for additional or more efficient on-site generation of electricity in manufacturing.

1.4.2 RESOURCE RECOVERY AND UTILIZATION

Technology Description

Resource recovery and utilization technologies help minimize waste from industrial processes, reducing energy and material requirements. Wastes include materials, process byproducts, chemical reactants, gases, solvents, diluents, wastepaper, plastics, cooling water, and more. These materials can be reprocessed for use as feedstocks, used to make different products, burned as fuels, or recycled. These practices mitigate greenhouse gas (GHG) emissions by improving plant efficiency and eliminating the energy required to treat wastes and to produce the displaced feedstocks. One example of recovery and reuse is a membrane separation process being developed to recover valuable chemicals from gas streams that are currently burned as low-value fuel. The process will efficiently and economically separate light hydrocarbons (ethane, methane, ethylene, propylene) and hydrogen for use as chemical feedstocks, which are two to three times more valuable than the fuel.



Recovery of olefins such as ethylene and propylene reduces the use of fuel and feedstocks.

System Concepts

- Resource recovery and utilization involves cradle-to-grave stewardship over industrial products. In the example cited, the recovery of feedstock chemicals mitigates CO_2 emissions because it increases product yield and displaces some of the fuel energy initially required to produce the feedstock, which is a petroleum fraction.
- The approximate 30 million tons of ironmaking and steelmaking byproducts generated each year – oxide dusts, sludges, scale, and slags – contain nearly 7 million tons of valuable iron units. Currently, about 50% of this volume is recovered and recycled. Research leading to increased internal recycling of these residues can increase the steel industry's primary yield while reducing disposal costs and saving energy.
- Resource recovery and utilization can involve advanced separations, new chemistries, improved catalysts, advanced materials, optimal process and engineering design, sensors and controls, post-consumer processing, market sensitivity, and close coordination among producers, users, and post-consumer processors.
- This pathway includes technologies that impact the other three industry technology pathways, particularly energy conversion and utilization and industrial process efficiency.

Representative Technologies

- Recovery technologies include advanced separations, new and improved chemistries, sensors and controls, capture of methane (coal beds, landfills, agricultural), and the capture of carbon monoxide and NO_x.
- Reuse technologies include recycling; new and improved chemistries; and closed-loop, sustainable plant design.
- Improved understanding of fundamental chemistry allows use of carbon dioxide and other recovered byproducts as feedstocks. Technologies include C1 chemistry (single carbon) to produce chemicals from carbon dioxide, and chemistries to create fuels from plastics and rubber.
- Component technologies include advanced separations, improved chemistry, improved catalysts, advanced materials, optimal process and engineering design, sensors and controls, and post-consumer

processing. An example of DOE-supported component technology is the recovery of thermoplastics via froth flotation, which enables the recycling of plastics from auto shredder waste.

Technology Status/Applications

- Many industries make a concerted effort to reuse wastes to minimize the high cost of handling and disposal. Others, like the refining and pulp-making industries, rely heavily on byproduct fuels produced on site. However, there are still many opportunities to reuse wastes and byproducts that are not captured because technology does not exist, is currently not economical, or is not practical for other reasons.

Current Research, Development, and Demonstration

RD&D Goals

- R&D goals target a range of improved recycling/recovery efficiencies. For example, in the chemicals industry the goal is to improve recyclability of materials by as much as 30%.
- Identify new and improved processes to use wastes or byproducts; improve separations to capture and recycle materials, byproducts, solvents, and process water; identify new markets for recovered materials, including ash and other residuals such as scrubber sludges.

RD&D Challenges

- Specifically target the energy-intensive U.S. industries and contribute to their goals of reducing energy, water use, and toxic and pollutant dispersion per unit of output.
- Enhance understanding of advanced computing; modeling capabilities for improved process and engineering design; and technology transfer.
- Develop efficient and economical separation processes; demonstrate the viability of new markets; improve sensing and control capabilities; analyze process and engineering design for optimized materials use; and develop durable advanced materials.

RD&D Activities

- Solicitations by the Industries of the Future program and the National Industrial Competitiveness Through Energy, Environment, and Economics program have funded projects to improve energy efficiency and reduce waste; participants include industry, DOE laboratories, small businesses, and academia.
- Ongoing activities include novel techniques for effective separation of materials in industrial streams for recovery and reuse, recycling of water and other liquid and solid-waste streams, recycling of wood byproducts and pulping waste into high-value products, and recycling of problematic wastes such as sludges, refractories, slag, and mill scale.
- DOE is working with CQ Inc. and other partners to improve energy recovery and reduce waste in coal processing. By adding a binding agent into the process, mills can improve the physical characteristics of the coal to create a more acceptable fuel, improve processing efficiency, and reduce environmental impact.

Recent Progress

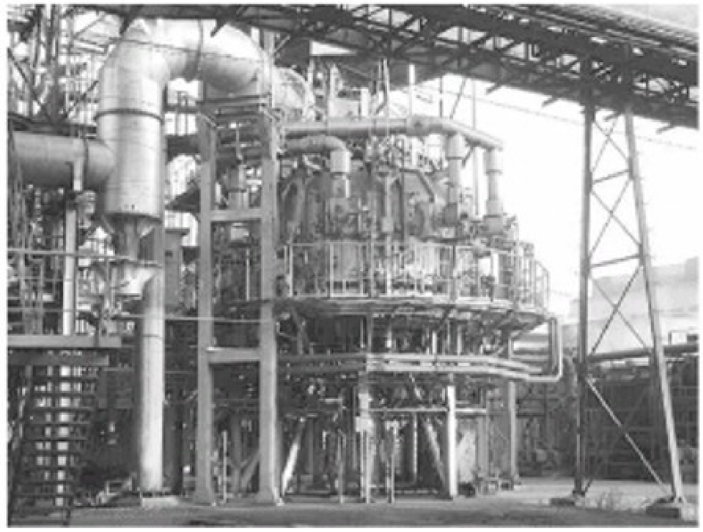
- A new process has been developed to allow the recovery and reuse of caprolactam from waste carpet. Discarded nylon carpets are converted back to virgin-quality caprolactam and used to make new carpets, saving nearly 700,000 barrels of oil annually. The process also saves fuel energy and reduces the amount of carpet that winds up in landfills.
- Researchers have developed a process called froth flotation to cost-effectively separate thermoplastics of various densities without using hazardous chemicals. Recovering and separating various waste plastics can help industries reduce their costs for raw materials, and the process is environmentally sound as it reduces the amount of waste plastic sent to landfills.
- DOE supported development of an energy-efficient process employing pressure swing adsorption refrigeration (PSA) for the recovery of olefins from polyolefin plant vent gases. There already are two commercial applications of the PSA technology. Widespread commercialization could yield a recovery rate of more than 17 million pounds of olefins per year, as well as energy and emission reductions.

Commercialization and Deployment Activities
• Technologies that compete with resource recovery and utilization include waste disposal in landfills, incinerators, and approved hazardous waste-disposal sites. • The economics of resource recovery and utilization technologies are an important factor in deployment. Markets and applications for recovered materials must be well-defined if commercialization is to be successful. **Market Context** • Markets for recovered materials are as diverse as the manufacturing industry and the products it creates. Significant commercial success already has been achieved in various markets, such as the use of recovered post-use steel, aluminum, paper, glass, and plastic. Several new market opportunities are available in these – as well as other – areas and are just now being explored.

1.4.3 INDUSTRIAL PROCESS EFFICIENCY

Technology Description

Industrial process efficiency is affected by a number of factors: technology design, age and sophistication of equipment, materials of construction, mechanical and chemical constraints, inadequate or overly complex designs, and external factors such as operating environment and maintenance and repair practices. In many cases, processes use a lot more energy than the theoretical minimum energy requirement. In the chemical industry, for example, distillation columns operate at efficiencies as low as 20-30%, and require substantially more energy than the theoretical minimum. In this case, thermodynamic and equipment limitations (e.g., height of the column) directly impact efficiency and increase energy use. Technologies under development focus on removing or reducing process inefficiencies, lowering energy consumption for heat and power, and reducing the associated greenhouse gas emissions. One example is a revolutionary steelmaking process that uses a one-step furnace operation to produce high-quality iron, using substantially less energy than conventional processes. The process under development eliminates the need for the coke oven plant, which is a significant source of emissions in steelmaking.



A new one-step furnace operation could revolutionize iron making and substantially reduce energy use and associated emissions.

System Concepts

- Process efficiency is improved by optimizing individual processes, eliminating process steps, or substituting processes within the principal manufacturing steps for primary conversion of raw materials, secondary or value-added processing, and product separation. Optimizing the overall manufacturing chain also improves process efficiency, including the material and energy balance.

Representative Technologies

- Process redesign can eliminate energy-intensive process steps, as demonstrated by the one-step furnace operation under development for ironmaking. Smaller changes to a process can also result in increased process efficiency. For example, DOE is supporting research to modify steel-casting methods that will reduce energy use and produce cleaner, lower-weight castings of improved quality.
- Advanced separation technologies include membrane separation and pressure swing adsorption, where separation is facilitated by novel materials and is energy-efficient.
- Catalysts with higher selectivities enable the conversion of a larger fraction of the feedstock into the desired product rather than the less desirable byproduct. Lower byproduct generation also can positively impact the energy consumption of separation and purification technologies.
- Alternative processes involve developing a new route to the same product and can incorporate advanced separation technologies and new and improved catalysts. An example of this is the process currently under development to convert natural gas to acetic acid using a new biocatalyst.

Technology Status/Applications

- Components of more efficient processing technologies under development (e.g., membranes) are in limited use today, but many need stronger economics or technical viability to increase their attractiveness to industry. The biggest opportunities to reduce GHG emissions in industrial processing will come from introducing revolutionary technologies as replacements for conventional operations. Examples include direct steelmaking and use of membranes as substitutes for energy-intensive distillation separations. Other options include developing new processes that increase product yields, reduce byproducts and wastes, or use alternative manufacturing pathways.

Current Research, Development, and Demonstration

RD&D Goals

- Between 2002 and 2020, contribute to a 30% improvement in energy intensity by the energy-intensive industries through the development and implementation of new and improved processes, materials, and manufacturing practices.
- By 2010, in partnership with industry, assist efforts to implement advanced water-removal technologies in papermaking resulting in an energy efficiency improvement of 10% in paper production compared to conventional industry practices.
- By 2010, develop advanced aluminum production technologies, such as carbothermic reduction, noncarbon inert anodes, and wettable cathodes, for a 25%-30% energy reduction – and, in some cases, elimination of greenhouse gas emissions from primary production.
- By 2010, develop mining technologies that reduce the energy intensity required to crush a short ton of rock by 20%-30% (from 1998 baseline).
- By 2010, in partnership with industry, assist efforts to develop a commercially viable technology that will eliminate the use of energy-intensive coke as a feedstock in the steelmaking process.
- In partnership with industry, assist efforts to enable major technical advances in the metal-casting industry to implement new design techniques and practices, increase yield, and reduce scrap and energy use.
- In partnership with industry, assist efforts to develop separation and new process chemistry technologies that will increase energy efficiency by up to 30% by 2020, compared to conventional 1998 technologies: Develop advanced chemical reactors, including short contact-time reactors, reactors for nonthermal processes (plasma, microwave, photochemical), reactors for alternative media or dry processing, and flexible processing units; improve catalytic processes including selective oxidation, hydrocarbon activation, byproduct and waste minimization, stereo-selective synthesis, functional olefin polymerization, and alkylation.
- Develop advanced separations technology, including membrane separations (advanced inorganic membranes, ruggedized membranes, selective membranes, anti-fouling), reactive separations, and separative reactors for use across various industries (chemicals, refining, pulp and paper).
- In partnership with industry, assist efforts to reduce energy consumption in carburizing processes, heat treatment of castings, welding processes, and aluminum alloy-forging processes.

RD&D Challenges

- Specific R&D needs are unique to each individual industry. In general, R&D challenges include economic and innovative separation techniques, improved understanding and prediction of chemical and material behavior, materials fabrication methods, in situ and/or rapid analytical protocols and process screening procedures, advanced computational tools, and more efficient process design.

RD&D Activities

- RD&D activities relating to these technology areas are sponsored by DOE, the Department of Commerce, the Department of Defense, the National Science Foundation, and the Environmental Protection Agency. DOE has funded projects to improve energy efficiency and reduce waste; participants include industry, DOE laboratories, small businesses, and academia.
- Ongoing activities include development of technology to enable more efficient processes in the following industries: aluminum, chemicals, forest products, glass, steel, metal casting, mining, and supporting industries such as forging, welding, and others. The primary focus of R&D is the development of economic, energy-efficient, commercially viable, and environmentally sound manufacturing technology. Industrial partners are involved with R&D early on to facilitate deployment and commercialization.
- Michigan Technological University is leading a dozen industrial partners in developing a Total Ore Processing Integration and Management System. This novel system will allow mine and mill personnel to

respond rapidly to upstream and downstream changes to optimize the entire mineral processing stream, reducing mill and mine energy use by 10%.

Recent Progress

- Researchers have developed and tested a nozzle that generates a high-temperature, high-momentum oxygen jet, which provides superior mixing and combustion conditions for blast furnace coal injection in steelmaking. This technology enables increased coal injection into the furnace, allowing steelmakers to displace some of the coke typically used in blast furnaces with coal and thus reduce fugitive emissions associated with coke-making.
- A fiber-optic sensor for on-line measurement of paper basis weight has been developed and tested to improve wet-end control in papermaking and produce fine paper with more uniform basis weight. The sensor enables continuous measurements across the full paper sheet and will minimize raw material and energy requirements in the paper industry.
- DOE has supported the development of a portable gas-imaging device for an advanced leak-detection system designed for use in the petroleum and petrochemical industries. The portable gas leak detector reduces the amount of time required for leak surveys, enabling inspections to be performed more frequently than with current detection methods. Gas leaks can be identified and repaired more quickly, reducing emissions.

Commercialization and Deployment Activities

- Applications of many of the described technologies already have an impact in the marketplace. For example, catalytic processes are responsible for about 75% by value of all chemical and petroleum processing products. Catalytic processes generate about $900B in products annually. The ready acceptance of certain applications of these technologies reduces barriers to implementation of process improvements or their application in new processes. Powerful drivers still exist for implementing advancements in these technologies for GHG reduction. The estimated total annual consumption of energy (fuels and electricity) by the U.S. chemical process industries is 5.8 quads; nearly 43% of that (2.5 quads) is required for separation processes, including distillation, extraction, adsorption, crystallization, and membrane-based technologies. Any process facilitating such separations will result in enormous savings of both energy and waste. Given the scale of many relevant industrial processes, the chief barriers to technology deployment are likely to be the capital expenditures required for any substantial process modifications.

Market Context

- The markets for these technologies are industry-specific. Targets of opportunity are the basic industries, including aluminum, chemicals, forest products, glass, mining, steel, and crosscutting industries such as forging, metal-casting, and welding.

1.4.4 ENABLING TECHNOLOGIES FOR INDUSTRIAL PROCESSES

Technology Description

Improvements in the enabling technologies used broadly throughout industry can provide new operational capabilities, as well as significant energy and carbon savings. Greenhouse gases can be reduced by increasing the efficiency of industrial processes, reducing waste and rework of products, and achieving a longer and more controlled operating lifetime for industrial components. Enabling technologies will increase understanding of the processes and systems required to make products, facilitate improvements, and enable new manufacturing processes. The technologies range from advanced materials, sensors and controls systems, and chemical pathways, to systems and product-oriented design and processing that incorporate environmental and energy benefits in their initial and overall implementation. These types of activities will impact the reduction and more efficient use of energy in current and new industrial processes.

System Concepts

- Enabling technologies will complement and be developed cooperatively with other technology pathways, particularly the energy conversion and utilization – as well as the industrial process efficiency – pathways. Enabling technologies will have a positive impact in many industrial areas.
- Increased understanding of processes, development of new materials and control methods, and innovative techniques for fabricating products will impact the entire industrial sector.

Representative Technologies

- Advanced materials with attributes such as improved corrosion resistance and the ability to operate at higher temperatures and pressures enable more efficient industrial processes. Material categories under investigation include degradation-resistant materials, materials for separations, metal alloys, ceramics, composites, polymers, and nano-materials.
- Sensors, controls, and automation enable more robust industrial process operations. Areas of emphasis include real-time, nondestructive sensing and monitoring; wireless technologies; and distributed intelligence to interpret and integrate data from various sensor types to aid in optimizing process control.
- Other enabling technologies with potentially large industrial impacts include new chemical pathways, combinatorial methods, and modeling and simulations.

Technology Status/Applications

- Advances are being made continuously in the development of new materials, including high-temperature materials, new coatings, smart materials, nano-materials, films, and materials with reactive or self-assembly properties. Abundant opportunities remain for developing new materials that can make a significant impact on industrial energy use and emissions (e.g., catalysts, inorganic-organic hybrids, thin film composites, refractories, sensor materials).
- Intelligent controls have been implemented in industry, but are still technically inadequate in a number of areas. Further impacts can be made in global and remote sensing, and nondestructive on-line evaluation of process parameters and equipment.
- New computational techniques are emerging every day, but have yet to keep pace with the phenomenal increase in computing power. Experimental methods based on combinatorial techniques – such as those used in drug discovery – could revolutionize the way new materials and products are developed, but are only slowly being adapted to industrial use.
- The use of model-based control systems and neural networks that can "learn" and improve process/energy efficiency will lower emissions of GHG from manufacturing processes.

Current Research, Development, and Demonstration
RD&D Goals • Develop new enabling technologies that meet a range of cost goals depending on the technologies and on the applications where they are to be used. Cost targets when considered on a system basis are expected to be between 0.5 to 2 times those of typical technologies. • Develop new classes of advanced materials and sensor and automation technologies. • By 2010, in partnership with industry, develop technology necessary for the aluminum industry to move from batch production to a continuous process using new sensor systems, starting with a demonstration of the technology in the aluminum industry. • By 2010, in partnership with industry, develop for commercial adoption 20 new materials for high-temperature, harsh, corrosive, and other industrial environments. **RD&D Challenges** • Develop new, economic material compositions, measurement technologies, and intelligent control and predictive maintenance systems. • Enable increased understanding of chemical, metallurgical, and biotechnology processes. • Develop functional and protective materials for sensors, actuators, and other devices deployed in industrial environments. • Develop materials property/engineering databases for materials used in industrial applications. • Validate mathematical models to enable improved and integrated process design and operations. • Scaling up of technologies from the laboratory to commercial application while achieving anticipated economies of scale, maintaining performance goals, and ensuring component integrity. • Achieving established targets for equipment service life and performance levels to attract industry interest and investment. • Assuring compatibility with real-world manufacturing environment to avoid degrading performance of existing processing and production systems. **RD&D Activities** • Development of industrial system components including high-temperature and corrosion-resistant production systems used for melting, heat treating, or combustion systems; chemicals and pulp- and paper-processing systems; and boilers and gasifiers. • Ongoing R&D activities on enabling technologies include the Advanced Industrial Materials and Sensors and Automation projects in DOE. Additional applied research activities are in the Department of Commerce Advanced Technology Program and in the Environmental Protection Agency. Basic research activities are in DOE's Office of Science and the National Science Foundation (NSF).
Recent Progress
• Nickel aluminides have been commercialized in several applications. For example, in heat-treating operations, nickel aluminides are being used by Delphi Automotive Systems in heating trays and fixtures. Nickel aluminides are also being used in forging dies and steel transfer rolls. • Advances have been achieved in cathodic arc deposition technology; continuous fiber ceramic composite immersion tubes; ceramic composite radiant burner screens; and new bearings for high-performance machinery.

Commercialization and Deployment Activities
• The industrial segment of the economy is substantial, and enabling technologies are impacting every industrial sector. New materials are being introduced in the manufacturing of steel; new measurement systems and in situ temperature measurements in harsh environments have been developed and are being used in industry; understanding of chemicals processes is leading to improved processes; and new capabilities in design and modeling methodologies are reducing the energy use and greenhouse gas emissions of production plants. • The introduction of new technologies is often sensitive to initial cost, and cost benefits must be evaluated based on life-cycle benefits. **Market Context** • Applications for enabling technologies are many and encompass the various industrial segments of the economy. Every industry segment will benefit from the activities, and the efforts will be coordinated with other pathways.