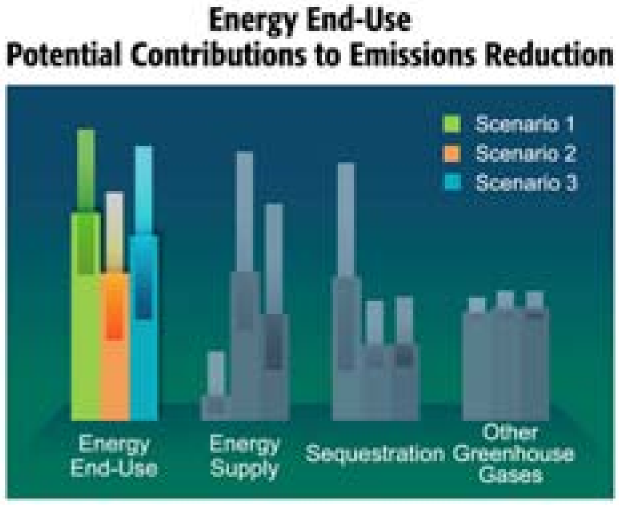
4 Reducing Emissions from Energy End Use and Infrastructure



Potential contributions of Energy End Use reduction to cumulative GHG emissions reductions to 2100, across a range of uncertainties, for three advanced technology scenarios. See Chapter 3 for details.

Emissions of carbon dioxide (CO_2) from energy consumption in the end-use sectors (industry, residential and commercial buildings, and transportation) of the global economy can be lowered through energy conservation practices,[1] technological and other economic productivity improvements that lead to increased energy efficiency, and shifts in the composition of output in the economy. Historically, global energy productivity – loosely measured in terms of economic output per unit of energy input – has shown steady increases, averaging gains of about 0.9 percent per year over the period 1971 to 2002 (IEA 2004). Use of more energy-efficient processes and replacement of older, less-efficient capital stock are important contributors to these gains. Another factor in reducing individual country measures of energy intensity, especially in industrialized countries, has been a shift over the past several decades in the composition of economic output toward less energy-intensive goods and services.

In published scenarios, increasing demand for energy services, driven by population and economic growth, results in growth of CO_2 emissions over the 21st century in the absence of GHG emissions constraints. And, in almost all scenarios that explore pathways to emission reductions, energy use reduction[2] plays a key role in achieving future CO_2 emissions reductions. In one set of scenarios, energy end-use reductions led to a decrease of between 3 and 18 thousand exajoules (EJ) of global energy, and between about 100 and 370 gigatons of carbon (GtC) of global carbon emissions, compared to the reference case used in the study (see Chapter 3).

In the United States, the largest end-use sources of CO_2 emissions (see Table 4-1) are the following:

- electricity and fuel use in buildings
- transportation fuels
- electricity and fuel use in industry
- a few industrial processes not related to combustion

This chapter explores energy end-use and carbon emission-reduction strategies and opportunities within each of these end-use categories. Sections 4.1 through 4.3 address transportation, buildings, and industry, respectively. Section 4.4 deals with technology strategies for the electric grid and infrastructure that can facilitate CO_2 emissions reductions in all sectors. All sections provide background information on each of their respective sectors and explain the current and evolving strategy for reducing CO_2 emissions. Note

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[1] In this context, "energy conservation" refers to practices that reduce energy waste, such as turning off lights, equipment, etc., when not in use.

[2] End-use reduction includes improvements in energy efficiency in the end-use sectors, as well as improvements in efficiency of energy conversion, e.g., increased efficiency in electricity generation.

Table 4-1. CO_2 Emissions in the United States by End-Use Sector, 2003 (GtC)

End-Use Sector	Emissions from Electricity	Emissions from Combustion of Fuels	Emissions, Total	% of Total
Transportation	0.009	0.485	0.493	31.1%
Residential and Commercial Buildings	0.410	0.169	0.579	36.5%
Industrial Energy Use	0.211	0.258	0.468	29.5%
Industrial Processes			0.040	2.5%
Waste Disposal Activities		0.005	0.005	0.3%
Total	**0.630**	**0.957**	**1.586**	

Source: EPA 2005, Tables 2-16, 3-44, and 4-1.
Note: Values may not sum to total due to independent rounding of values.

that this chapter focuses on reducing and avoiding CO_2 emissions. Many industrial processes and energy end uses produce significant quantities of other non-CO_2 greenhouse gases (GHGs), which are addressed separately in Chapter 7, "Reducing Emissions of Other Greenhouse Gases." The descriptions of the technologies in this section include active Internet links to an updated version of the CCTP report *Technology Options in the Near and Long Term* (CCTP 2005) at http://www.climatetechnology.gov/library/2005/tech-options/index.htm

4.1 Transportation

The transport of people, goods, and services accounts for a significant share of global energy demand, mostly in the form of petroleum, and is among the fastest growing sources worldwide of emissions of GHGs, mainly CO_2. In the developing parts of Asia and the Americas, emissions from transportation-related use of energy are expected to increase dramatically during the next 25 years. In the United States, from 1991 to 2000, vehicle miles traveled, a measure of highway transportation demand, increased at an average rate of 2.5 percent per year (DOT 2002a), outpacing population growth. In 2003, the U.S. transportation sector accounted for 39 percent of total CO_2 emissions, with the highway modes accounting for more than 82 percent of these (see Table 4-2). Through 2025, future growth in U.S. transportation energy use and emissions is projected to be strongly influenced by the growth in light-duty trucks (pickup trucks, vans, and sport-utility vehicles, under 8,500 lb gross vehicle weight rating) (see Figure 4-1). According to the Federal Highway Administration's *Freight Analysis Framework*, freight tonnage will grow by 70 percent during the first two decades of the 21st century (DOT 2002b).

4.1.1 Potential Role of Technology

Advanced technologies can make significant contributions to reducing CO_2 emissions from transportation activity. In the near term, advanced highway vehicle technologies, such as electric-fuel-engine hybrids ("hybrid-electric" vehicles) and clean diesel engines, could improve vehicle efficiency and, hence, lower CO_2 emissions. Other reductions might result from modal shifts (e.g., from cars to light rail) or higher load factors, improved overall system-level efficiency, or reduced transportation demand. Improved intermodal connections could allow for better mode-shifting and improved efficiency in freight transportation. Application of developing technology will reduce idling and the concomitant emissions

Table 4-2. CO_2 Emissions in the United States from Transportation, by Mode, in 2003 (GtC)

	Emissions	% of Total
Passenger Cars	0.173	35.6%
Light-Duty Trucks	0.131	26.9%
Other Trucks	0.093	19.2%
Aircraft[(a)]	0.047	9.6%
Other[(b)]	0.013	2.6%
Boats and Vessels	0.016	3.2%
Locomotives	0.012	2.4%
Buses	0.002	0.5%
Total [(c)]	**0.477**	**100.0**

(a) Aircraft emissions consist of emissions from all jet fuel (less bunker fuels) and aviation gas consumption.
(b) "Other" CO_2 emissions include motorcycles, pipelines, and lubricants.
(c) Percentages may not sum to 100 percent due to independent rounding of values.

Source: EPA 2005.

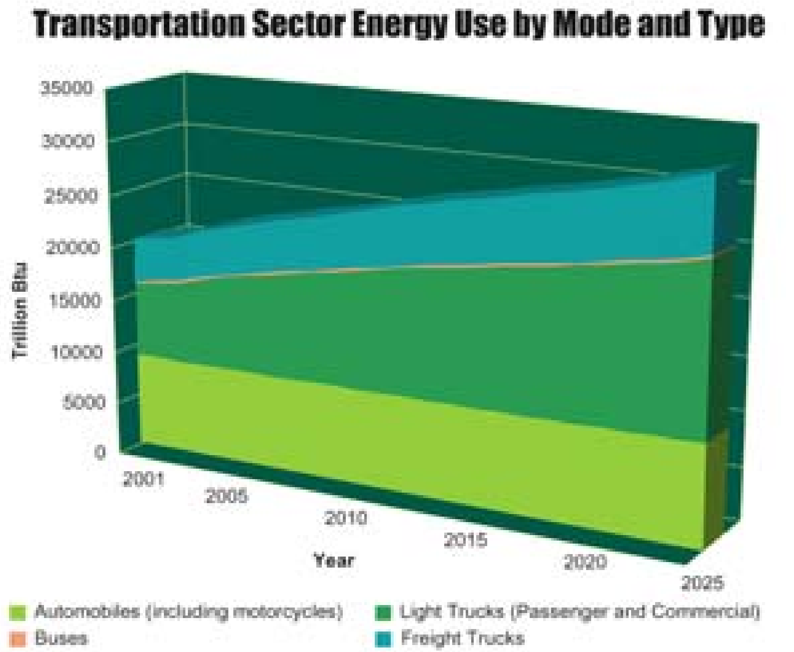

Figure 4-1. Projected Energy Consumption in U.S. Highway Vehicles
(*Source:* EIA 2004)

from heavy-duty vehicles, including vessels, trains, and long-haul trucks. Intelligent transportation systems can reduce congestion, resulting in decreases in fuel use. In the long term, technologies such as cars and trucks powered by hydrogen, bio-based fuels, and electricity show promise for transportation with either no highway CO_2 emissions or no net-CO_2 emissions.

In addition, new communications technologies may alter our concepts about individual mobility. Work locations may be centered near or in residential locations, and work processes and products may be more commonly communicated or delivered via digital media. With global trends toward increasing urbanization in both population concentrations and opportunities for employment, there may be more reliance in the future on improved modes of local, light-rail or intra-city passenger transport, coupled with other advances in electrified intercity transport that would curb the growth of fuel use and emissions from transportation.

4.1.2 Technology Strategy

Realizing these opportunities requires a research portfolio that embraces a combination of advanced vehicle, fuel, and transportation system technologies. Within constraints of available resources, a balanced portfolio needs to address major sources of CO_2 emissions in this sector, including passenger cars, light trucks, and other trucks; key modes of transport, including highway, aviation, and urban transit; system-wide planning and enhancements; and both near- and long-term opportunities.

In the near term, CO_2 emissions and transportation energy use can be reduced through improved vehicle efficiency, clean diesel engines, hybrid propulsion, and the use of hydrogenated low-sulfur gasoline. Other fuels, such as ethanol, natural gas, electricity with storage, and biodiesel, can also provide attractive means for reducing emissions of CO_2. These efficiency gains and fuel alternatives also provide other benefits, such as improving urban and regional air quality and enhancing energy security.

In aviation, emissions could be lowered through new technologies to improve air-traffic management. An example is RVSM – Reduced Vertical Separation Minimums. RVSM has been used for transatlantic flights since 1997, and it became standard in U.S. airspace in January 2005. Full implementation of RVSM may reduce fuel use by ~500 million gallons each year.

In the long term, hydrogen may prove to be a low- or no-net-carbon energy carrier, if it can be cost-effectively produced with few or no GHG emissions, such as with renewable or nuclear energy, or with fossil fuels in conjunction with carbon capture and storage. Hydrogen and biofuels as substitutes for petroleum-based fuels in the transportation and other sectors also offer significant national security benefits. Hydrogen and alternative fuels are discussed in more depth in Chapter 5, "Reducing Emissions from Energy Supply." Hydrogen can be used in internal combustion engines; but use in highly efficient fuel-cell-powered vehicles is considered a very important future option. In aviation, new engines and aircraft will feature enhanced engine cycles, more efficient aircraft aerodynamics, and reduced weight – thereby improving fuel efficiency. Research sponsored by the Federal Government through NASA, in collaboration with the Next Generation Air Transportation System (NGATS) plan, could enable these enhancements. NGATS is a multiagency-integrated effort to ensure that the future air transportation system meets air transportation security, mobility, and capacity needs while reducing environmental impacts.

4.1.3 Current Portfolio

Across the current Federal portfolio of transportation-related R&D, Federal activities are focused on a number of major programs:

- Research on **light vehicles**, organized primarily under the FreedomCAR Partnership program, focuses on materials; power electronics; hybrid vehicles operating on gasoline, diesel, or alternative fuels; high-efficiency, low-emission advanced combustion engines, enabled by improved fuels; and high-volume, cost-effective production of lightweight materials.

  The vehicle technologies research programs have a number of specific goals. They include: (a) electric propulsion systems with a 15-year life capable of delivering at least 55 kW for 18 seconds and 20 kW continuous at a system cost of $12/kW peak; (b) internal combustion engine powertrain systems costing $35/kW, having peak brake engine efficiency of 45 percent, and that meet or exceed emissions standards; (c) electric drivetrain energy storage with a 15-year life at 200 Wh with discharge power of 25kW for 18 seconds and $20/kW; (c) material and manufacturing technologies for high volume production vehicles, which enable/support the simultaneous attainment of 50 percent reduction in the weight of vehicle structure and subsystems, affordability, and increased used of recyclable/renewable materials; and (d) internal combustion engine powertrain systems, operating on hydrogen with a cost target of $45/kW by 2010 and $30/kW in 2015, having a peak brake engine efficiency of 45 percent, and that meet or exceed emissions standards. For more information, see Section 1.1.1 (CCTP 2005):
  http://www.climatetechnology.gov/library/2005/tech-options/tor2005-111.pdf
  See also: http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/transportation.html, and http://www.epa.gov/otaq/technology

- Research areas for **heavy vehicles**, organized primarily under the 21st Century Truck Partnership, include lightweight materials, aerodynamic drag, tire rolling resistance, electrification of ancillary equipment, advanced high efficiency combustion propulsion systems (including energy-efficient emissions reduction), fuel options (both petroleum and nonpetroleum based), hybrid technologies for urban driving applications, and onboard power units for auxiliary power needs. The research objectives are to (1) reduce energy consumption in long-haul operations, (2) increase efficiency and reduce emissions during stop-and-go operations, and (3) develop more efficient and less-polluting energy sources to meet truck stationary power requirements (i.e. anti-idling). By 2007, the goals for heavy vehicles include a commercially viable 5 kW, $200/kW, diesel-fueled, internal combustion engine auxiliary power unit. By 2010, the goals include a laboratory demonstration of an emissions-compliant engine system that is commercially viable for Class 7-8 highway trucks, which improves the system efficiency by 32 percent (37 percent by 2013) from the 2002 baseline. By 2012, the goals include advanced technology concepts that reduce the aerodynamic drag of a Class 8 tractor-trailer combination by 20 percent. See Section 1.1.2 (CCTP 2005):
  http://www.climatetechnology.gov/library/2005/tech-options/tor2005-112.pdf See also:
  http://www.epa.gov/otaq/technology

- **Fuels research** encompasses the development of new fuel blend formulations that will enable more efficient and cleaner combustion and the development of renewable and nonpetroleum-based fuels that could displace 5 percent of petroleum used by commercial vehicles. See Section 1.1.3 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-113.pdf

- Research on **intelligent transportation systems** infrastructure includes sensors, information technology, and communications to improve efficiency and ease congestion. Intelligent transportation systems goals include improved analysis capabilities that properly assess the impact of ITS strategies and strategies that will improve travel efficiency resulting in lower delays, thereby reducing emissions. See Section 1.1.4 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-114.pdf

- Research on **aviation fuel efficiency** includes engine and airframe design improvements. Aviation fuel efficiency goals include improved aviation fuel efficiency per revenue plane-mile by 1 percent per year through 2008, and new technologies with the potential to reduce CO_2 emissions from future aircraft by 25 percent within 10 years and by 50 percent within 25 years. See Section 1.1.5 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-115.pdf

- Research on **transit buses** and other urban-driving heavy vehicles focuses on hybrid-electric propulsion, weight reduction, and advanced combustion engine concepts to improve efficiency and reduce emissions. By 2012, research program goals for transit buses include development of heavy hybrid propulsion technology that achieves a 60 percent improvement in fuel economy, on a representative driving cycle, while meeting regulated emissions levels. See Section 1.1.6 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-116.pdf

4.1.4 Future Research Directions

The current portfolio supports the main components of the technology development strategy and addresses the highest priority current investment opportunities in this technology area. For the future, CCTP seeks to consider a full array of promising technology options. From diverse sources, suggestions for future research have come to CCTP's attention. Some of these, and others, are currently being explored and under consideration for the future R&D portfolio. These include:

- Strategies and technologies to increase freight transfer and movement efficiency (tons of freight moved 1 mile by a particular unit of energy) in anticipation of large growth in freight volumes.

- Studies of advanced urban-engineering concepts for cities to reduce vehicle miles traveled.

- Concept and engineering studies for large-scale institutional and infrastructure changes required to manage CO_2, electricity, and hydrogen systems reliably and securely.

- Technologies for large-scale hydrogen storage and transportation and electricity storage

In addition, supporting or crosscutting areas for future research include:

- Advanced thermoelectric concepts to convert waste heat from combustion into power.

- New combustion regimes and fuels designed to achieve very high efficiencies, near-zero regulated emissions, and reduced carbon emissions in conventional vehicle propulsion systems.

The public is invited to comment on the current CCTP portfolio, including future research directions, and identify potential gaps or significant opportunities. No assurance can be provided that any suggested concept would meet the criteria for investment. However, CCTP can be assisted by such comments in its desire to consider a full array of promising technology options.

4.2 Buildings

The built environment – consisting of residential, commercial, and institutional buildings – accounts for about one-third of primary global energy demand (IPCC 2000) and represents a major source of energy-related GHG emissions, mainly CO_2. Growth in global energy demand in buildings averaged 3.5 percent per year since 1970 (IPCC 2001).

Over the long term, buildings are expected to continue to be a significant component of increasing global energy demand and a large source of CO_2 emissions. Energy demand in this sector will be driven by growth in population, by the economic expansion that is expected to increase the demand for building services (especially electric appliances, electronic equipment, and the amount of conditioned space per person), and by the continuing trends toward world urbanization. As urbanization occurs, energy consumption increases, because urban buildings usually have electricity access and have a higher level of energy consumption per unit area than buildings in more primitive rural areas. According to a recent projection by the United Nations, the percentage of the world's population living in urban areas will increase from 49 percent in 2005 to 61 percent by 2030 (UN 2005).

In the United States, energy consumption in buildings has been increasing proportionately with increases in population, although this trend masks significant increases in efficiency in some building components that are being offset by new or increased energy uses in others. In the United States in 2003, CO_2 emissions from this sector, including those from both fuel combustion and use of electricity derived from CO_2-emitting sources, accounted for nearly 37 percent of total CO_2 emissions (see Table 4-1). These emissions have been increasing at 1.9 percent per year since 1990 (EIA 2005). Table 4-3 shows a breakdown of emissions from the buildings sector, by fuel type, in the United States.

Table 4-3. Residential and Commercial CO_2 Emissions in the United States, by Source, in 2003 (GtC)

	Emissions	%
Residential		
Electricity	0.2121	66.9
Natural gas	0.0756	23.8
Petroleum	0.0291	9.2
Coal	0.0003	0.1
Total Residential	0.3171	100.0
Commercial		
Electricity	0.2005	76.2
Natural gas	0.0466	17.5
Petroleum	0.0147	5.4
Coal	0.0025	0.9
Total Commercial	0.2643	100

Source: EPA 2005, Tables 2-16 and 3.3.
Note: Percentages may not sum to 100 percent, due to independent rounding of values.

4.2.1 Potential Role of Technology

Many opportunities exist for advanced technologies to make significant reductions to energy-related CO_2 emissions in the buildings sector. In the near term, advanced technologies can improve efficiency of energy-using equipment in the primary functional areas of energy use. In residential buildings, these functional areas include space heating, appliances, lighting, water heating, and air conditioning. In commercial buildings, functional areas are lighting, space heating, cooling and ventilation, water heating, office equipment, and refrigeration. Through concerted research, major technical advances have occurred during the past 20 years, with many application areas seeing efficiency gains of 15 percent to 75 percent. (See Figure 4-2 for an example of technological improvements that have occurred in refrigerators as an illustration of the kind of gains that have been achieved.)

Over the longer term, more advances can be expected in these areas, and significant opportunities also lie ahead in the areas of new buildings design, retrofits of existing buildings, and the integration of whole building systems and multibuilding complexes through use of sensors, software, and automated maintenance and controls.

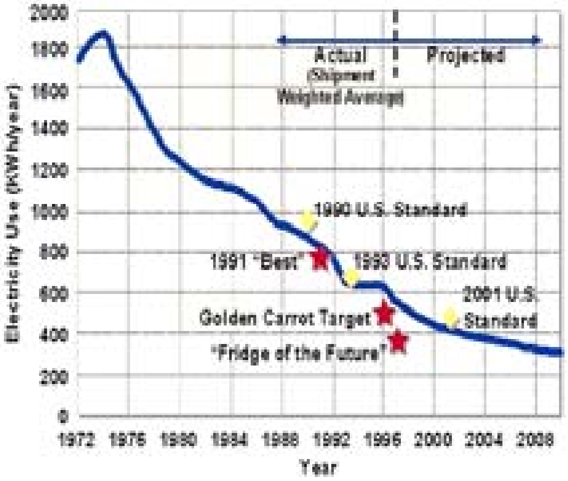

Figure 4-2. Refrigerator Energy Efficiency

(*Source*: Brown 2003)

Note: The curve applies to 18-20 cu. ft. top-mount refrigerator/freezers, which capture the largest market share in the United States. The term,"1991 Best" stands for the 1991 top-mount model with lowest energy use. "Golden Carrot Target" was an EPA/electric utility program in the early 1990s to develop a model that was 25% more efficient than the current technology at the time. "Fridge of the Future" is a refrigerator that had a target energy use of 365 kWh/yr or 1 kWh/day for 18-20 cu. ft. top-mount models based on an cooperative research agreement between Oak Ridge National Laboratory (ORNL) and the Association of Home Appliance Manufacturers; this target was exceeded in a test unit (0.93 kWh/day) in FY 1996.

By 2025 – with advances in building envelopes, equipment, and systems integration – it may be possible to achieve up to a 70 percent reduction in a building's energy use, compared to the average energy use in an equivalent building today (DOE 2005). If augmented by on-site energy technologies (such as photovoltaics or distributed sources of combined heat and power), buildings could become net-zero GHG emitters and net energy producers.

4.2.2 Technology Strategy

While the built environment is a complex mix of heterogeneous building types (commercial, service, detached dwelling, apartment buildings) and functional uses, all have common features, each of which may benefit from technological research, both as individual components and as integrated systems. Within constraints of available resources, a balanced portfolio needs to address four important aspects of buildings that affect their CO_2 emissions, including the building envelope, building equipment, integrated building design, and the urban heat island effect. The portfolio should look at both near- and long-term opportunities.

In the near term, building energy use and CO_2 emissions could be lowered through building environment-control systems and advanced materials such as insulation, foams, vacuum panels, and optical coatings. Technology to improve the efficiency of lighting, appliances, heating, cooling, and ventilation are other options. Intelligent building systems (such as load balancing and automated sensors and controls) help ensure the comfort, health, and safety of residents, as well as aid in the reduction of CO_2.

In the long term, more advanced research on the building envelope – including panelized housing construction, integration of photovoltaics, and new storage technologies – can drive CO_2 emissions even lower. Distributed power systems, advanced refrigeration and cooling technologies, heat pumps, and solid-state lighting technology are among some of the more promising options for equipment. Among the alternatives, building integration should focus on including sensors and controls, community-scale integration tools, and urban engineering.

4.2.3 Current Portfolio

The current Federal portfolio focuses on four major thrusts. In combination, these activities aim to achieve net-zero energy residential buildings by 2020 and commercial buildings by 2025.

- Research on the **building envelope** (the interface between the interior of a building and the outdoor environment) focuses on systems that determine or provide control over the flow of heat, air, moisture, and light in and out of a building; and on materials that can affect energy use, including insulation, foams, vacuum panels, optical control coatings for windows and roofs, thermal storage, and related controls (such as electrochromic glazings). A major new initiative is a re-engineered attic/roof assembly, which has an equivalent performance of R-50.

  Research program goals in the building envelope area include the following: By 2008, demonstrate dynamic solar control windows (electrochromics) in commercial buildings; and by 2010, demonstrate windows with R10 insulation performance for homes. By 2025, the program goal is to develop marketable and advanced energy systems capable of achieving “net-zero” energy use in new residential and commercial buildings. The long-term goal is to achieve a 30 percent decrease in the average envelope thermal load of existing residential buildings and a 66 percent decrease in the average thermal load of new buildings. See Section 1.2.2 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-122.pdf

- Research on **building equipment** focuses on means to significantly improve efficiency of heating, cooling, ventilating, thermal distribution, lighting, home appliances, on-site energy and power devices, and a variety of miscellaneous consumer products. This area also includes a number of crosscutting elements, including geothermal heat pumps with enhanced earth-heat exchangers, advanced refrigerants and cycles, solid-state lighting, smart sensors and controls, small power supplies, microturbines, heat recovery, and other areas.

Specific goals include: (a) for distributed electricity generation technologies (including microturbines), by 2008, enable a portfolio of equipment that shows an average 25 percent increase in efficiency; (b) for solid-state lighting in general illumination applications, by 2008, develop equipment with luminous efficacy of 79 lumens per watt (LPW); and for laboratory devices by 2025, luminous efficacy of 200 LPW. The long-term goals are: (a) by 2025, develop and demonstrate marketable and advanced energy systems that can achieve "net-zero" energy use in new residential and commercial buildings through a 70 percent reduction in building energy use; and (b) by 2030, enable the integrations of all aspects of the building envelope, equipment, and appliances with on-site micro-cogeneration and zero-emission technologies. See Section 1.2.1 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-121.pdf

- Research on **whole building integration** focuses on load balancing and automated sensors and controls, sometimes referred to as intelligent building systems. Such systems continuously monitor building performance, detect anomalies or degradations, optimize operations across all building systems, guide maintenance, and document and report results. They can also be extended to coordinate on-site energy generation and internal loads, with external power (grid) demands and circumstances, allowing responsiveness to time-variant cost savings, system efficiencies, and grid contingencies. They also ensure occupant comfort, health, and safety, met at lowest possible cost.

  Whole building integration goals include fully and seamlessly integrated building design tools that support all aspects of design and provide rapid analysis of problems. Also included are the development of automatic operation of buildings systems that require little operator attention and 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 export excess electricity to the grid. See Section 1.2.3 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-123.pdf

- Research related to the **urban "heat island"** includes the causes of, and mitigation strategies for, the heating and energy loading effects of the built environment in this paved and often treeless environment. Urban heat island goals include improved understanding and quantification of the impacts heat island reduction measures have on local meteorology, energy use and expenditures, greenhouse gas emissions, and air quality. Specific products include a GIS application that predicts heat island outcomes from different development scenarios (e.g., benefits from large-scale tree planting) and cool materials for roofs and pavements. See Section 1.2.4 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-124.pdf

4.2.4 Future Research Directions

The current portfolio supports the main components of the technology development strategy and addresses the highest priority current investment opportunities in this technology area. For the future, CCTP seeks to consider a full array of promising technology options. From diverse sources, suggestions for future research have come to CCTP's attention. Some of these, and others, are currently being explored and under consideration for the future R&D portfolio. These include:

- **Building Envelope**. Improved panelized housing construction; methods for integrating photovoltaic systems in building components such as roofs, walls, skylights, and windows, and with building loads and utilities; and exploration of fundamental properties and behaviors of novel materials for the storage and release of energy.

- **Building Equipment**. Fuel cells, microturbines, and reciprocating engines; advanced commercial refrigeration display cases, refrigerants, and materials; advanced desiccants and commercial chiller improvements, including absorption systems; advanced magnetic or solid-state cooling technologies, highly efficient geothermal heat pumps, residential heat pump water heater and hot water circulation improvements; solid-state lighting technology and improved lighting distribution systems.

- **Whole Building Integration**. Further development and widespread implementation of building design tools for application in new and retrofit construction; tools and technologies for systems integration in buildings, with a particular focus on sensors and controls for supply and end-use system integration; development of pre-engineered, optimized net-zero energy buildings; community-scale design and system integration tools; and urban engineering to reduce transport energy use and congestion.

The public is invited to comment on the current CCTP portfolio, including future research directions, and identify potential gaps or significant opportunities. No assurance can be provided that any suggested concept would meet the criteria for investment. However, CCTP can be assisted by such comments in its desire to consider a full array of promising technology options.

4.3 Industry

Industrial activities were estimated to account for about 41 percent of primary global energy consumption in 1995 (IPCC 2000) and a commensurate share of global CO_2 emissions. Certain activities are particularly energy-intensive, including metals industries, such as iron, steel, and aluminum; petroleum refining; basic chemicals and intermediate products; fertilizers; glass; pulp, paper, and other wood products; and mineral products, including cement, lime, limestone, and soda ash. Others are less energy-intensive, including the manufacture or assembly of automobiles, appliances, electronics, textiles, food and beverages, and others. Each regional or national economy varies in the structure, composition, and growth rates of these industries; shaped, in part, by its state of economic development and, in part, by regional advantages in international trade. The industrial sector worldwide is expected to expand in the future and will likely continue to account for a substantial portion of future CO_2 emissions.

In the United States in 2003, industry accounted for about one-third of total U.S. CO_2 emissions (see Table 4-1). These are attributed to combustion of fuels (51 percent), use of electricity derived from CO_2-emitting sources (41 percent), and industrial processes that emit CO_2 (8 percent). (See Table 4-4[3]).

4.3.1 Potential Role of Technology

The industrial sector presents numerous opportunities for advanced technologies to make significant contributions to the reductions of CO_2 emissions to the Earth's atmosphere. In the near term, advanced

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[3] Emissions of GHGs other than CO_2 from industry and agriculture are discussed in Chapter 7, "Reducing Emissions of Other Greenhouse Gases."

Table 4-4. CO_2 Emissions in the United States from Industrial Sources in 2003 (GtC)
(Excludes Indirect Emissions from Industrial Use of Centrally Generated Electric Power)

	Emissions 10^9 Tonnes C	**Share of Industry Total (%)**	**Share of Industrial Processes (%)**
Industrial Fuel Combustion	**0.258**	**50.7**	
Coal	*0.034*	6.6	
Petroleum	*0.087*	17.1	
Natural Gas	*0.111*	21.9	
Industrial Electricity	**0.211**	**41.4**	
Industrial Processes (excluding fuel combustion emissions above)	**0.040**	7.9	(See Breakout Below)
Total Industrial CO_2	**0.509**	**100.0**	
Breakout of Emissions from Industrial Processes:			
Iron and Steel Production	0.0147		36.5
Cement Manufacture	0.0117		29.2
Ammonia Manufacture & Urea Application	0.0043		10.6
Lime Manufacture	0.0035		8.8
Limestone and Dolomite Use	0.0013		3.2
Aluminum Production	0.0011		2.9
Soda Ash Manufacture and Consumption	0.0011		2.8
Petrochemical Production	0.0008		1.9
Titanium Dioxide Production	0.0005		1.4
Phosphoric Acid Production	0.0004		1.0
Ferroalloy Production	0.0004		1.0
Carbon Dioxide Consumption	0.0004		0.9
Total Industrial Process CO_2	**0.0402**		**100.0**

Source: EPA 2005, Tables 2-14, 2-16, 3-44, and 4-1.
Note: Percentages may not sum to 100 percent due to independent rounding of values.

technologies can increase the efficiency with which process heat is generated, contained, transferred, and recovered. Process and design enhancements can improve quality, reduce waste, minimize reprocessing, reduce the intensity of material use (with no adverse impact on product or performance), and increase in-process material recycling. Cutting-edge technologies can significantly reduce the intensity with which energy and materials (containing embedded energy) are used. Industrial facilities can implement direct manufacturing processes, which can eliminate some energy-intensive steps, thus both avoiding emissions and enhancing productivity. On the supply side, industry can self-generate clean, high-efficiency power and steam; and create products and byproducts that can serve as clean-burning fuels. The sector can also make greater use of coordinated systems that more efficiently use distributed energy generation, combined heat and power, and cascaded heat.

In the long term, fundamental changes in energy infrastructure could affect significant CO_2 emissions reductions. Revolutionary changes may include novel heat and power sources and systems, including renewable energy resources, hydrogen, and fuel cells. Innovative concepts for new products and high-efficiency processes may be introduced that can take full advantage of recent and promising developments in nanotechnology, micro-manufacturing, sustainable biomass production, biofeedstocks, and bioprocessing. As global industry's existing, capital-intensive equipment stock nears the end of its useful service life – and as industry expands in rapidly emerging economies in Asia and the Americas – this sector will have an opportunity to adopt novel technologies that could revolutionize basic manufacturing. Advanced technologies will likely involve a mix of pathways, such as on-site energy generation, conversion, and utilization; process efficiency improvements; innovative or enabling concepts, such as advanced sensors and controls, materials, and catalysts; and recovery and reuse of materials and byproducts (See Figure 4-3). In the United States, the development and adoption of advanced industrial technologies can provide not only GHG benefits but also help to maintain U.S. competitiveness.

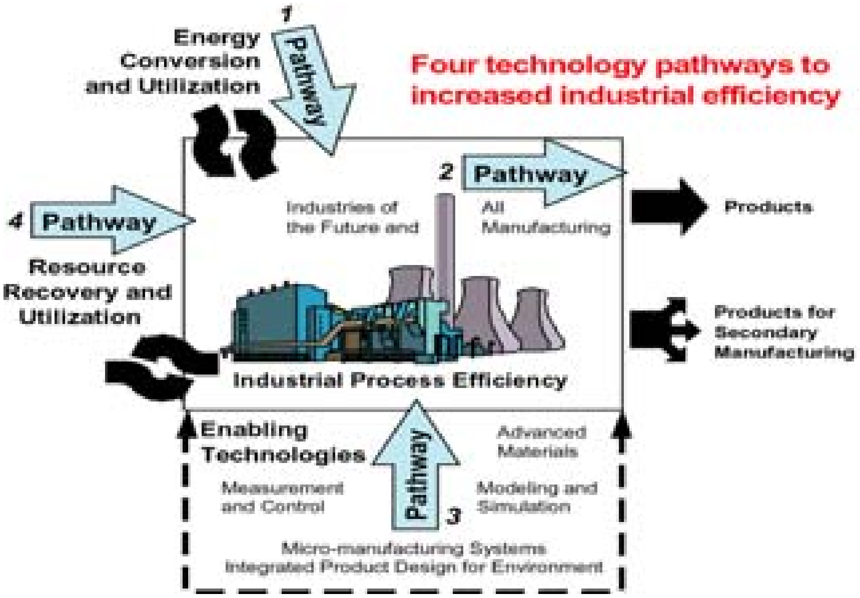

Figure 4-3. Four Possible Pathways to Increased Industrial Efficiency
(*Source:* DOE 1997)

4.3.2 Technology Strategy

Within constraints of available resources, a balanced portfolio needs to address the more important current and anticipated sources of CO_2 emissions in this sector. Some of the largest sources of CO_2 emissions today, and expected in the future, arise from energy conversion to power industrial processes, inefficiencies in the processes themselves, and ineffective reuse of materials or feedstocks; and, in some cases, the intensive use of fossil fuels, especially natural gas.

In the near term, industrial energy use and CO_2 emissions could be lowered through improvements in the industrial use of electricity and fuels to produce plant process heat and steam, including steam boilers, direct-fired process heaters, and motor-driven systems, such as pumping and compressed air systems. Opportunities for reducing emissions in these areas lie with the adoption of best energy-management practices; adopting more modern and efficient power and steam generating systems; integrated approaches that combine cooling, heating, and power needs; and capture and use of waste heat. Other areas of opportunity include improvements in specific energy-intensive industrial processes, including hybrid distillation systems; process intensification by combining or removing steps, or designing new processes altogether while producing the same or a better product; the recovery and utilization of waste and feedstocks, which can reduce energy and material requirements; and crosscutting opportunities, such as improved operational capabilities and performance.

In the long term, highly efficient coal gasifiers coupled with CO_2 sequestration technology could provide an alternative to natural gas, and even export electricity and hydrogen to the utility grid and supply pipelines. Bioproducts could replace fossil feedstocks for manufacturing fuels, chemicals, and materials; while biorefineries could utilize fuels from nonconventional feedstocks to jointly produce materials and value-added chemicals. Furthermore, integrated modeling of fundamental physical and chemical properties, along with advanced methods to simulate processes, will stem from advances in computational technology.

4.3.3 Current Portfolio

The current Federal portfolio focuses on four major thrusts.

- Research on **energy conversion and utilization** focuses on a diverse range of advanced and integrated systems. These include advanced combustion technologies, gasification technologies, high-efficiency burners and boilers, thermoelectric technologies to produce electricity using industrial waste heat streams, co-firing with low-GHG fuels, advanced waste heat recovery heat exchangers, and heat-integrated furnace designs. Integrated approaches include combined-cycle power generation, and cogeneration of power and process heat or cooling.

  The overall research program goal in this area is to contribute to a 20 percent reduction in the energy intensity (energy per unit of industrial output, as compared to 2002) of energy-intensive industries by 2020. Several specific goals include: (1) by 2006, demonstrate a greater than 94 percent packaged boiler; and by 2010, the packaged boilers will be commercially available with thermal efficiencies of 10-12 percent higher than conventional technology; (2) by 2008, demonstrate high-efficiency pulping technology in the pulp and paper industry that redirects green liquor to pretreat pulp and reduce lime kiln load and digester energy intensity; and (3) by 2011, demonstrate isothermal melting technology, which could improve efficiency significantly in the aluminum, steel, glass, and metal-casting industries. See Section 1.4.1 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-141.pdf

- Research on **specific, energy-intensive and high-CO_2-emitting industrial processes** focuses on identifying (compared to theoretical minimum energy requirements) and removing process inefficiencies, lowering overall energy requirements for heat and power, and reducing CO_2 emissions. One example under development is a means to produce high-quality iron without the use of metallurgical coke, which – under current methods of steelmaking – is a significant source of CO_2 emissions. Other areas of research focus on processes that may also improve product yield, including oxidation catalysis, advanced processes, and alternative processes that take a completely different route to the same end product, such as use of noncarbon inert anodes in aluminium production.

  Industrial process efficiency goals are focused on industry partnerships. The overall research program goal in this area is to realize, before 2020, a 20 percent improvement in energy intensity by the energy-intensive industries through the development and implementation of new and improved processes, materials, and manufacturing practices. Specific goals for the pulp and paper industry include, by 2010, to assist efforts to implement advanced water-removal technologies in papermaking, resulting in an energy efficiency improvement of 10 percent in paper production. For the iron and steel industry, by 2010, assist efforts to develop a commercially viable technology that will eliminate the use of blast furnaces and natural gas-driven iron-making processes. More generally, in the separations area, demonstrate advanced hybrid separations technology by 2016, including separations combined with distillation (membranes, adsorption, and extraction), reactive separations, and separative reactors for use across various industries (chemicals, refining, pulp and paper). See Section 1.4.3 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-143.pdf

- Research on **enabling technologies** includes an array of advanced materials that resist corrosion degradation and deformation at high temperatures and pressures; inferential sensors, controls, and automation, with real-time nondestructive sensing and monitoring; and new computational techniques for modeling and simulating chemical pathways and advanced processes.

  Research program goals for this area target new enabling technologies that meet a range of cost goals depending on the technologies and on the applications where they are to be used. Specific goals include: (a) by 2010, demonstrate production and application for nano-structured diamond coatings and composites and other ultra-hard materials for use in wear-intensive industrial applications; and develop materials for use in a wide array of severe industrial environments (corrosive, high temperature, and pressure); (b) by 2012, demonstrate the generation of efficient power from high-temperature waste heat using systems with thermoelectric materials; and (c) by 2017, develop and demonstrate integration of sensing technologies with information processing to control plant production. See Section 1.4.4 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-144.pdf

- Research on **resource recovery and utilization** focuses on separating, capturing, and reprocessing materials for feedstocks. Recovery technologies include materials designed for recyclability, advanced separations, new and improved process chemistries, and sensors and controls. Reuse technologies include recycling, closed-loop process and plant designs, catalysts for conversion to suitable feedstocks, and post-consumer processing.

  Research program goals in this area 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 percent. Additional goals target 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. For more information, see Section 1.4.2 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-142.pdf

4.3.4 Future Research Directions

The current portfolio supports the main components of the technology development strategy and addresses the highest priority current investment opportunities in this technology area. For the future, CCTP seeks to consider a full array of promising technology options. From diverse sources, suggestions for future research have come to CCTP's attention. Some of these, and others, are currently being explored and under consideration for the future R&D portfolio. These include:

- **Industrial Alternatives to Natural Gas**. Research could be conducted to develop coal gasification systems for large industrial plants (e.g., 100 megawatts [MW]). The coal gasifiers would be highly integrated into complex manufacturing plants (e.g., chemical or glass plants). The industrial plant's feedstock, process heat, and power requirements could be accommodated from the coal gasifier, which could also export electricity, hydrogen, or other fuels to the utility grid and gas supply pipelines.

- **Cement and Related Products**. Research could focus on various means to reduce or eliminate CO_2 emissions from high-emitting industrial processes, including the cement, lime, limestone, and soda ash industries. Worldwide infrastructure building over the 21st century can be expected to create high demands for these mineral products, the production of which releases CO_2 as a consequence of the calcining process. In the United States in 2003, CO_2 emissions from these sources accounted for 44 percent of the non-energy related industrial emissions and about 1 percent of total U.S. emissions. Research could be focused on carbon capture and sequestration and on the exploration of substitutes for the end product. Carbon matrixes for construction, for example, might be lighter and stronger than concrete and would provide a means for carbon sequestration.

- **Computational Technology**. Process simulation enables more effective design and operation, leading to increased efficiency and improved productivity and product quality. Integrated modeling of fundamental physical and chemical properties can enhance understanding of industrial material properties and chemical processes.

The public is invited to comment on the current CCTP portfolio, including future research directions, and identify potential gaps or significant opportunities. No assurance can be provided that any suggested concept would meet the criteria for investment. However, CCTP can be assisted by such comments in its desire to consider a full array of promising technology options.

4.4 Electric Grid and Infrastructure

Large reductions in future CO_2 emissions may require that a significant amount of electricity be generated from carbon-free or carbon-neutral sources, including nuclear power and renewable electricity producers such as wind energy, geothermal energy, and solar-based power generating systems. Some renewable energy resources are concentrated in regions of the country that are distant from large urban markets. To accommodate such sources, the future electricity distribution infrastructure (the "grid") would need to extend its capacity and evolve to an intelligent and flexible system that enables the use of a wide and varied set of base load, peaking, and intermittent generation technologies.

In recent years, the demand for electricity in the United States has increased at a rate such that it could eventually exceed current transmission capacity. Demand is projected to increase by 19 percent from 2003-2012 (EIA 2005); only a 6 percent increase in transmission is planned for 2002-2012 (DOE 2002). There have been few major new investments in transmission during the past 15 years. Outages experienced in parts of the country – including the August 2002 blackout in the Midwest and Northwest – highlighted the need to enhance grid reliability.

Enhancements for grid reliability will likely go hand in hand with improved efficiency of electricity transmission. Energy losses in the U.S. transmission and distribution (T&D) system were 5.5 percent in 2003, accounting for 201 billion kilowatt hours of electricity generation and 133 million metric tons of

CO_2 emissions (EIA 2005, Table A8 and EPA 2005 Table 2-14). About 10 percent of GHG emissions resulting from transmission and distribution are SF_6 emissions from certain specified high-voltage transmission equipment. The remainder of GHG emissions is from increased operations needed to compensate for energy losses.

4.4.1 Potential Role of Technology

There are many T&D technologies that can improve efficiency and reduce GHG emissions. In the near term, these include high-voltage DC (HVDC) transmission, high-strength composite overhead conductors, solid-state transmission controls such as Flexible AC Transmission System (FACTS) devices that include fault current limiters, switches and converters, and information technologies coupled with automated controls (i.e., a “Smart Grid”). High-efficiency conventional transformers – commercially available although not widely used – also could have impacts on distribution system losses.

Advanced conductors integrate new materials with existing materials and other components and subsystems to achieve better technical, environmental, and financial performance – e.g., higher current carrying capacity, more lightweight, greater durability, lower line losses, and lower installation and operations and maintenance costs. Improved sensors and controls, as part of the next-generation electricity T&D system, could significantly increase the efficiency of electricity generation and delivery, thereby reducing the GHG emissions intensity associated with the electric grid. Outfitting the system with digital sensors, information technologies, and controls could further increase system efficiency, and allow greater use of more efficient and low-GHG end-use and other distributed technologies. High-temperature superconductors may be able to be utilized in key parts of the T&D system to reduce or eliminate line losses and increase efficiency. Energy storage allows intermittent renewable resources, such as photovoltaics and wind, to be dispatchable.

Advanced storage concepts and particularly high-temperature superconducting wires and equipment represent longer-term solutions with great promise. Digital sensors, information technologies, and controls may eventually enable real-time responses to system loads. HTS electrical wires might be able to carry 100 times the amount of electricity compared to the same-sized conventional copper wires. Such possibilities may create totally new ways to operate and configure the grid. Power electronics will be able to provide significant advantages in processing power from distributed energy sources using fast response and autonomous control.

4.4.2 Technology Strategy

Realizing these opportunities requires a research portfolio that focuses on balance of advanced transmission grid and distributed-generation technologies. Within constraints of available resources, a balanced portfolio needs to address conductor technology, systems and controls, energy storage, and power electronics to help reduce CO_2 emissions in this sector.

Early research is likely to focus on ensuring reliability, e.g., establishing “self-healing” capabilities for the grid, including intelligent, autonomous device interactions, and advanced communication capabilities. Additional technologies would be needed for wide-area sensing and control, including sensors, secure communication and data management; and for improved grid-state estimation and simulation. Simulation linked to intelligent controllers can lead to improved protection and discrete-event control. Digitally enabled load-management technologies, wireless communications architecture and algorithms for system automation, and advanced power storage technologies will allow intermittent and distributed energy resources to be efficiently integrated.

Longer-term research is likely to focus on the development of fully operational, pre-commercial prototypes of energy-intensive power equipment that, by incorporating HTS wires, will have greater capacity with lower energy losses and half the size of conventional units. Over the long term, the T&D system would also be enhanced by integrating storage and power electronics.

4.4.3 Current Portfolio

Across the current Federal portfolio of electric infrastructure-related R&D, multiagency activities are focused on a number of major thrusts in high-temperature superconductivity, T&D technologies, distributed generation and combined heat and power, energy storage, sensors, controls and communications, and power electronics. For example:

- Research on **high-temperature superconductivity** (HTS) is focused on improving the current carrying capability of long-distance cables; its manufacturability; and cost-effective ways to use the cable in equipment such as motors, transformers, and compensators. More reliable and robust HTS transmission cables that have three to five times the capacity of conventional copper cables and higher efficiency – which is especially useful in congested urban areas – are being developed and built as pre-commercial prototypes. 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.

  Research program goals in this area include HTS wires with 100 times the capacity of conventional copper/aluminum wires. More broadly, the program aims to develop and demonstrate a diverse portfolio of electric equipment based on HTS, such that the equipment can achieve a 50 percent reduction in energy losses compared to conventional equipment and a 50 percent size reduction compared to conventional equipment with the same rating. Low-cost, high-performance second-generation coated conductors are expected to become available in 2008 in kilometer-scale lengths. Cost goals include: (a) for the conducting wire, the aim for \$0.01/ampere-meter; (b) equipment premium cost payback (efficiency savings) to be achieved in 2-5 years of operation; and (c) equipment total cost payback to be achieved during the operating lifetime. For coated conductor goals for applications in liquid nitrogen, the wire-cost goal is to be less than \$50/kA-m; while for applications requiring cooling to temperatures of 20-60 degrees K, the cost goal is to be less than \$30/kA-m. By 2010, the cost-performance ratio will have improved by at least a factor of 2. See Section 1.3.1 (CCTP 2005):
  http://www.climatetechnology.gov/library/2005/tech-options/tor2005-131.pdf

- Research on **transmission and distribution technologies** is focused on real-time information and control technologies; and systems that increase transmission capability, allow economic and efficient electricity markets, and improve grid reliability. Examples include high-strength composite overhead conductors, grid-status measurement systems that improve reliability by giving early warning of unstable conditions over major geographic regions, and technologies and regulations that enable the customer to participate more in electric markets through a demand response.

Research program goals in this area include, by 2010, demonstrated reliability of energy-storage systems; reduced cost of advanced conductors systems by 30 percent; and operation of a prototype smart, switchable grid on a region on the U.S. transmission grid. See Section 1.3.2 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-132.pdf

- Research on **distributed generation** (DG) includes renewable resources (e.g., photovoltaics), natural gas engines and turbines, energy-storage devices, and price-responsive loads. 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 premises or located nearby in district energy systems, power parks, and mini-grids (see Figure 4-4).

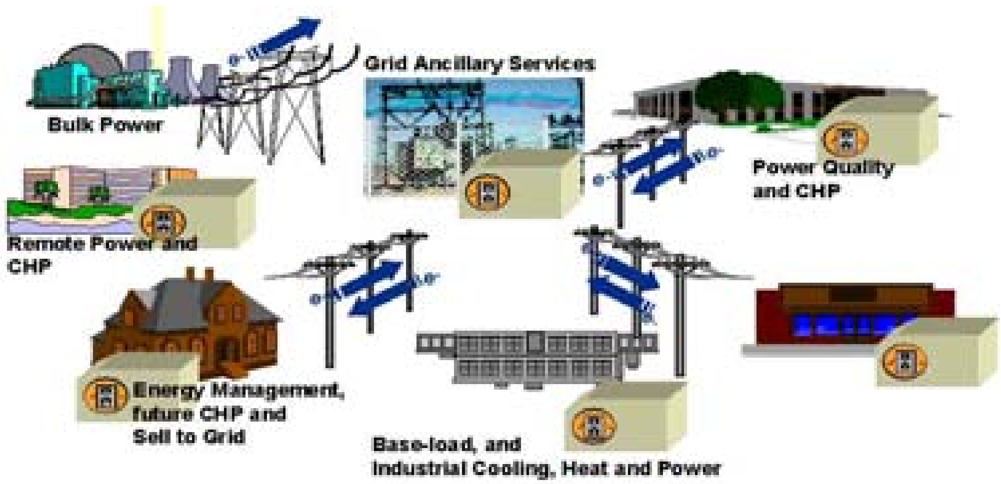

Figure 4-4. A Distributed Energy Future

(*Source:* Personal communication from M.A. Brown, ORNL, Oak Ridge, Tennessee)

Current research focuses on technologies that are powered by natural gas combustion and are located near the building or facility where the electricity is being used. These systems include microturbines, reciprocating engines and larger industrial gas turbines that generate from 25 kW to 10 MW of electricity that is appropriate for hotels, apartment buildings, schools, office buildings, hospitals, etc. Combined cooling, heating, and power (CHP) systems recover and use "waste heat" from distributed generators to efficiently cool, heat, or dehumidify buildings or make more power.

Research is needed to increase the efficiency and reduce the emissions from microturbines, reciprocating engines, and industrial gas turbines to allow them to be sited anywhere, even in nonattainment areas. These technologies can meet a variety of consumer energy needs, including continuous power, backup power, remote power, and peak shaving. Microturbines and reciprocating engines can also be utilized to burn opportunity fuels such as landfill gases or biogases from wastewater-treatment facilities or other volatile species from industrial processes that would otherwise be an environmental hazard. See Section 1.3.3 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-133.pdf

Combined heat and power technologies have the potential to take the DG technologies one step further in GHG reduction by utilizing the waste heat from the generation of electricity for making steam, heating water, or producing 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. Integrated DG systems with CHP similarly produce electricity at 30 percent to 45 percent efficiency, but then capture much of the waste heat to make steam, heat, or cool water – or meet other thermal needs and increase the overall efficiency of the system to greater than 70 percent. Research is needed to increase the efficiency of waste-heat-driven absorption chillers and desiccant systems to overall efficiencies well above 80 percent.

The overall research goal of the Distributed Energy Program is to develop and make available, by 2015, a diverse array of high-efficiency, integrated distributed generation and thermal energy technologies, at market-competitive prices, so to enable and facilitate widespread adoption and use by homes, businesses, industry, communities, and electricity companies that may elect to use them. If successful, these technologies will enable the achievement of a 20 percent increase in a building's energy utilization, when compared to a building built to ASHRAE 90.1 standards, using load management, CHP, and energy-storage technologies that are replicable to other localities.

- Research on **energy storage** is focused in two general areas. First, research is striving to develop storage technologies that reduce power-quality disturbances and peak electricity demand, and improve system flexibility to reduce adverse effects to industrial and other users. Second, research is seeking to improve electrical energy storage for stationary (utility, customer-side, and renewable) applications. This work is being done in collaboration with a number of universities and industrial partners. This work is set within an international context, where others are investing in high-temperature, sodium-sulfur batteries for utility load-leveling applications and pursuing large-scale vanadium reduction-oxidation battery chemistries.

  The research program goals in this area focus on energy-storage technologies with high reliability and affordable costs. For capital cost, this is interpreted to mean less than or equal to those of some of lower-cost new power generation options ($400–$600/kW). Battery storage systems range from $300-$2,000/kW. For operating cost, this figure would range from compressed gas energy storage (which can cost as little as $1 to $5/kWh) to pumped hydro storage (which can range between $10 and $45/kWh). See Section 1.3.4 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-134.pdf

- Research on **sensors, controls, and communications** focuses on developing distributed intelligent systems to diagnose local faults and coordinate with power electronics and other existing, conventional protection schemes that will provide autonomous control and protection at the local level. This hierarchy will enable isolation and mitigation of faults before they cascade through the system. The work will also help users and electric power-system operators achieve optimized control of a large, complex network of systems; and will provide remote detection, protection, control, and contingency measures for the electric system.

  The initial research program goals for sensors, controls, and communications will be to develop, validate, and test computer simulation models of the distribution system to assess the alternative situations. Once the models have been validated on a sufficiently large scale, the functional requirements and architecture specifications can be completed. Then more specific technology solutions can be explored that would conform to the established architecture. See Section 1.3.5 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-135.pdf

- Research on **power electronics** is focused on megawatt-level inverters, fast semiconductor switches, sensors, and devices for Flexible AC Transmission Systems (FACTS). The 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, which are providing power electronic spinoffs for infrastructure applications.

  The research program goal in this area is to build a power electronic system on a base of modules. Each module or block would be a subsystem containing several components, and each one has common power terminals and communication connections. See Section 1.3.6 (CCTP 2005): http://www.climatetechnology.gov/library/2005/tech-options/tor2005-136.pdf

4.4.4 Future Research Directions

The current portfolio supports the main components of the technology development strategy and addresses the highest priority current investment opportunities in this technology area. For the future, CCTP seeks to consider a full array of promising technology options. From diverse sources, suggestions for future research have come to CCTP's attention. Some of these, and others, are currently being explored and under consideration for the future R&D portfolio. These include:

- **High-Temperature Superconducting Cables and Equipment**. The manufacture of promising HTS materials in long lengths at low cost remains a key program challenge. New, continuously scanning analytical systems are necessary to ensure uniformly high superconductor characteristics over kilometer lengths of wire. R&D could help develop highly reliable, high-efficiency cryogenic systems to economically cool the superconducting components including materials for cryogenic insulation and standardized high-efficiency refrigerators. Scale-up of national laboratory discoveries for "coated conductors" could be another promising area for the laboratories and their industry partners.

- **Energy Storage**. Energy storage that responds over timescales from milliseconds to hours – and outputs that range from watts to megawatts – is a critical enabling technology for enhancing customer reliability and power quality, more effective use of renewable resources, integration of distributed resources, and more reliable transmission system operation.

- **Real-Time Monitoring and Control**. Introduction of low-cost sensors throughout the power system is needed for real-time monitoring of system conditions. New analytical tools and software must be developed to enhance system observability and power flow control over wide areas.

The public is invited to comment on the current CCTP portfolio, including future research directions, and identify potential gaps or significant opportunities. No assurance can be provided that any suggested concept would meet the criteria for investment. However, CCTP can be assisted by such comments in its desire to consider a full array of promising technology options.

4.5 Conclusions

The development of advanced technologies that can reduce, avoid, substitute for, or improve the efficiency of energy use provides the foundation for most scenarios aimed at achieving significant reductions in CO_2 emissions over the long term. Many technologies discussed in this chapter are under development in the transportation, buildings, and industrial sectors to reduce energy consumption and lower CO_2 emissions. The relative size of the contribution of energy end-use reduction toward GHG emissions reductions would depend on many factors, but is generally considered large.

The scenarios suggest, however, that there are a number of important challenges to be met. The first challenge would be achieving advances in technology to sustain progress in energy productivity improvement during the next 100 years at the historical rate of 1 percent or more per year. Additional energy efficiency improvements would need to be made, above and beyond the historic rate, to make the additional contributions built into the three CCTP scenarios. World transportation energy use is expected to grow substantially, and low-emission technology would have significant leverage in that sector. Another challenge is reducing emission rates from several key CO_2-emitting industrial processes, including the coking, cement, lime, and soda-ash industries. Finally, in the long run, new technologies using new fuels or energy forms derived from low- or near-net-zero CO_2 emitting sources would need to be introduced to achieve further reductions in CO_2 emissions from energy end use and infrastructure.

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