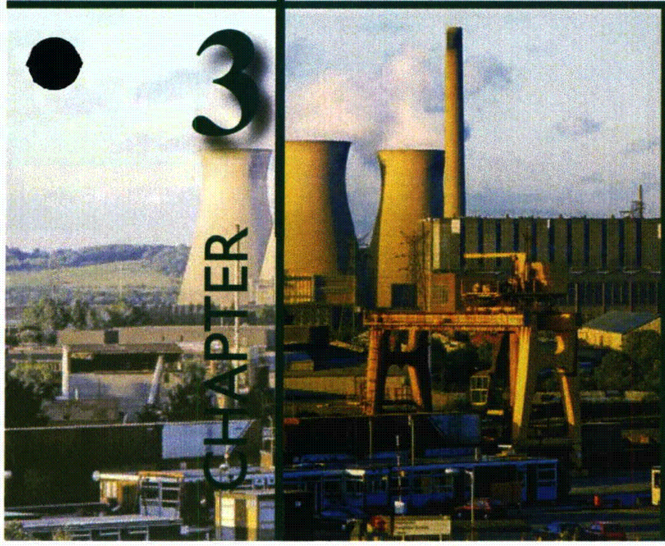


# Effects of Climate Change on Energy Production and Distribution in the United States

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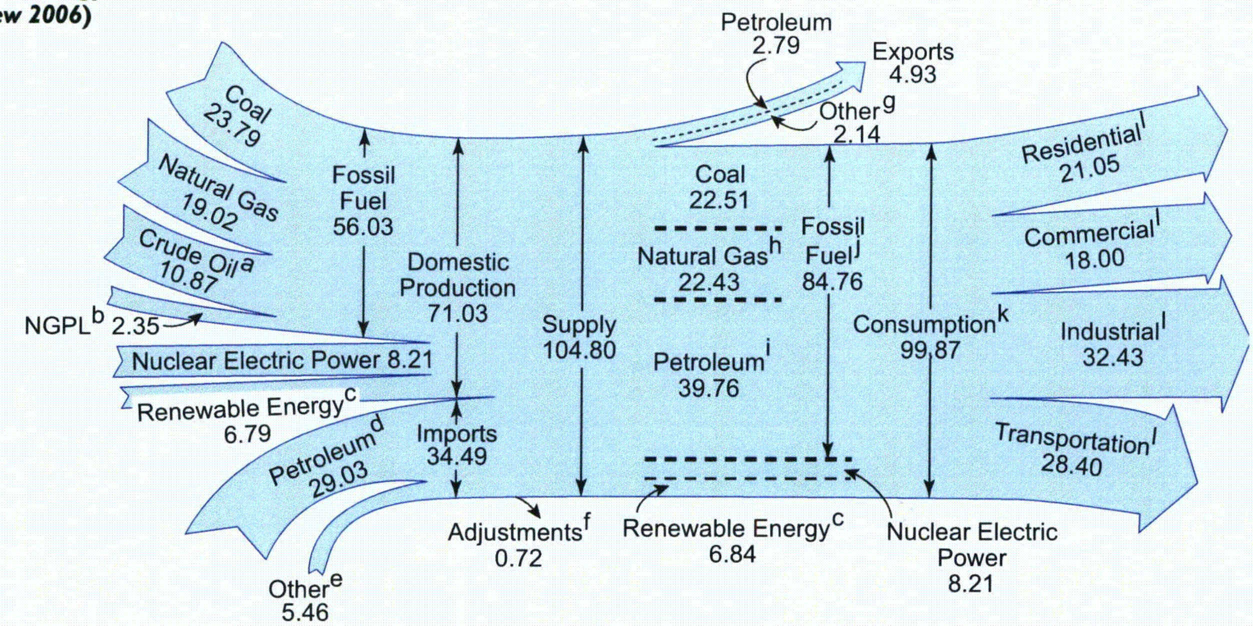
***Energy production in the U.S. is dominated by fossil fuels: coal, petroleum, and natural gas (Fig. 3.1). Every existing source of energy in the United States has some vulnerability to climate variability (Table 3.1). Renewable energy sources tend to be more sensitive to climate variables; but fossil energy production can also be adversely effected by air and water temperatures, and the thermoelectric cooling process that is critical to maintaining high electrical generation efficiencies also applies to nuclear energy. In addition, extreme weather events have adverse effects on energy production, distribution, and fuel transportation.***

This chapter discusses impacts on energy production and distribution in the United States associated with projected changes in temperature, precipitation, water resources, severe weather events, and sea level rise, although the currently available research literatures tend to be limited in most cases. Overall, the effects on the existing infrastructure might be categorized as modest; however, local and industry-specific impacts could be large, especially in areas that may be prone to disproportional warming (Alaska) or weather disruptions (Gulf Coast and Gulf of Mexico). The existing assemblage of power plants and distribution systems is likely to be more affected by ongoing unidirectional changes, compared with possible future systems, if future systems can be designed with the upfront flexibility to accommodate the span of potential impacts. Possible adaptation measures include technologies that minimize the impact of increases in ambient temperatures on power plant equipment, technologies that conserve water use for power plant cooling processes, planning at the local and regional level to anticipate storm and drought impacts, improved forecasting of the impacts of global warming on renewable energy sources at regional and local levels, and establishing action plans and policies that conserve both energy and water.

**Figure 3.1. Energy Flow in the U.S. (EIA, *Annual Energy Review 2006*)**

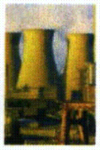
**Energy Flow, 2006**
(Quadrillion Btu)




[a]Includes lease condensate.
[b]Natural gas plant liquids.
[c]Conventional hydroelectric power, biomass, geothermal, solar/PV, and wind.
[d]Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.
[e]Natural gas, coal, coal coke, fuel ethanol, and electricity.
[f]Stock changes, losses, gains, miscellaneous blending components, and unaccounted-for supply.
[g]Coal, natural gas, coal coke, and electricity.
[h]Natural gas only; excludes supplemental gaseous fuels.
[i]Petroleum products, including natural gas plant liquids and crude oil burned as fuel.
[j]Includes 0.06 quadrillion Btu of coal coke net imports.
[k]Includes 0.06 quadrillion Btu of electricity net imports.
[l]Primary consumption, electricity retail sales, and electrical systems energy losses, which are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales.

Notes: •Data are preliminary. •Values are derived from the source data prior to rounding for publication. •Totals may not equal sum of components due to independent rounding.

Sources: Tables 1.1, 1.2, 1.3, 1.4, 2.1a, and 10.1.



## 3.1 EFFECTS ON FOSSIL AND NUCLEAR ENERGY

Climate change can affect fossil and nuclear energy production, conversion, and end-user delivery in a myriad of ways. Average ambient temperatures impact the supply response to changes in heating and cooling demand by affecting generation cycle efficiency, along with cooling water requirements in the electrical sector, water requirements for energy production and refining, and Gulf of Mexico (GOM) produced water discharge requirements. Often these impacts appear "small" based on the change in system efficiency or the potential reduction in reliability, but the scale of the energy industry is vast: fossil fuel-based net electricity generation exceeded 2,500 billion kWh in 2004 (EIA 2006). A net reduction in generation of 1% due to increased ambient temperature (Maulbetsch and DiFilippo 2006) would represent a drop in supply of 25 billion kWh that might need to be replaced somehow. The GOM temperature-related issue is a result of the formation of water temperature-related anoxic zones and is important because that region accounts for 20 to 30% of the total domestic oil and gas production in the U.S. (Figure 3.2). Constraints on produced water discharges could increase costs and reduce production, both in the GOM region and elsewhere. Impacts of extreme weather events could range from localized railroad track distortions due to temperature extremes, to regional-scale coastal flooding from hurricanes, to watershed-scale river flow excursions from weather variations superimposed upon, or possibly augmented by, climate change. Spatial scale can range from kilometers to continent-scale; temporal scale can range from hours to multiyear. Energy impacts of episodic events can linger for months or years, as illustrated by the continuing loss of oil and

**Table 3-1. Mechanisms Of Climate Impacts On Various Energy Supplies In The U.S. Percentages Shown Are Of Total Domestic Consumption;** (T = water/air temperature, W = wind, H = humidity, P = precipitation, and E = extreme weather events)

| Energy Impact Supplies | | Climate Impact Mechanisms |
|---|---|---|
| **Fossil Fuels (86%)** | Coal (22%) | Cooling water quantity and quality (T), cooling efficiency (T, W, H), erosion in surface mining |
| | Natural Gas (23%) | Cooling water quantity and quality (T), cooling efficiency (T, W, H), disruptions of off-shore extraction (E) |
| | Petroleum (40%) | Cooling water quantity and quality, cooling efficiency (T, W, H), disruptions of off-shore extraction and transport (E) |
| | Liquified Natural Gas (1%) | Disruptions of import operations (E) |
| **Nuclear (8%)** | | Cooling water quantity and quality (T), cooling efficiency (T, W, H) |
| **Renewables (6%)** | Hydropower | Water availability and quality, temperature-related stresses, operational modification from extreme weather (floods/droughts), (T, E) |
| | Biomass | |
| | • Wood and forest products | Possible short-term impacts from timber kills or long-term impacts from timber kills and changes in tree growth rates (T, P, H, E, carbon dioxide levels) |
| | • Waste (municipal solid waste, landfill gas, etc.) | n/a |
| | • Agricultural resources (including derived biofuels) | Changes in food crop residue and dedicated energy crop growth rates (T, P, E, H, carbon dioxide levels) |
| | Wind | Wind resource changes (intensity and duration), damage from extreme weather |
| | Solar | Insolation changes (clouds), damage from extreme weather |
| | Geothermal | Cooling efficiency for air-cooled geothermal (T) |

*(Source: EIA, 2004)*

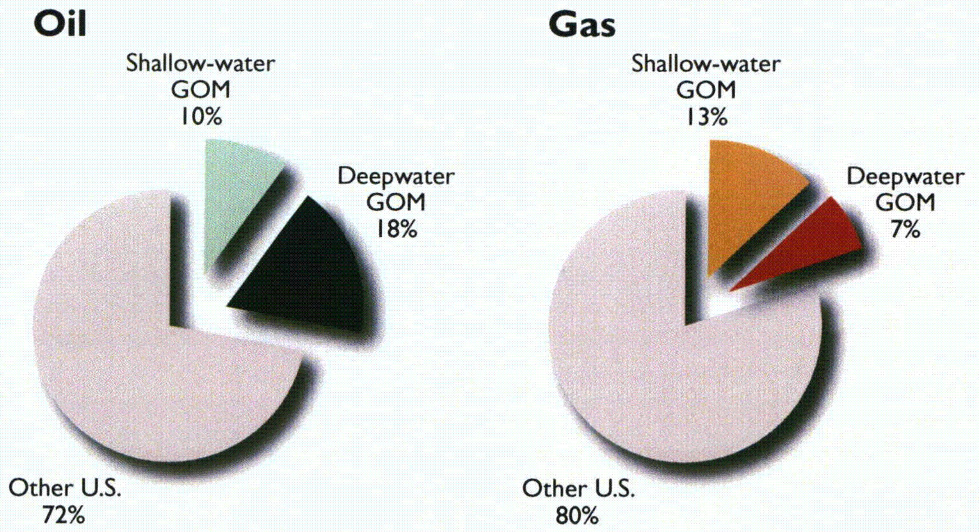
gas production in the GOM (MMS 2006a, 2006b, and 2006c) eight months after the 2005 hurricanes.

### 3.1.1 Thermoelectric Power Generation

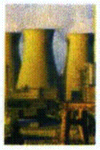
Climate change impacts on electricity generation at fossil and nuclear power plants are likely to be similar. The most direct climate impacts are related to power plant cooling and water availability.

Projected changes in water availability throughout the world would directly affect the availability of water to existing power plants. While there is uncertainty in the nature and amount of the change in water availability in specific locations, there is agreement among climate models that there will be a redistribution of water, as well as changes in the availability by season. As currently designed, power plants require significant amounts of water, and they will be vulnerable to fluctuations in water supply. Regional-scale changes would likely mean that some areas would see significant increases in water availability, while other regions would see significant decreases. In those areas seeing a decline, the impact on power plant availability or even siting of new capacity could be significant. Plant designs are flexible and new technologies for water reuse, heat rejection, and use of alternative water sources are being developed; but, at present, some impact—significant on a local level—can be foreseen. An example of such a potential local effect is provided in Box 3.1—Chattanooga: A Case Study, which shows how

**Figure 3.2. Distribution Of Off-Shore Oil And Gas Wells In The Gulf Of Mexico (GOM) And Elsewhere In The U.S.**




cooling conditions might evolve over the 21st century for generation in one locality. Situations where the development of new power plants is being slowed down or halted due to inadequate cooling water are becoming more frequent throughout the U.S. (SNL, 2006b).



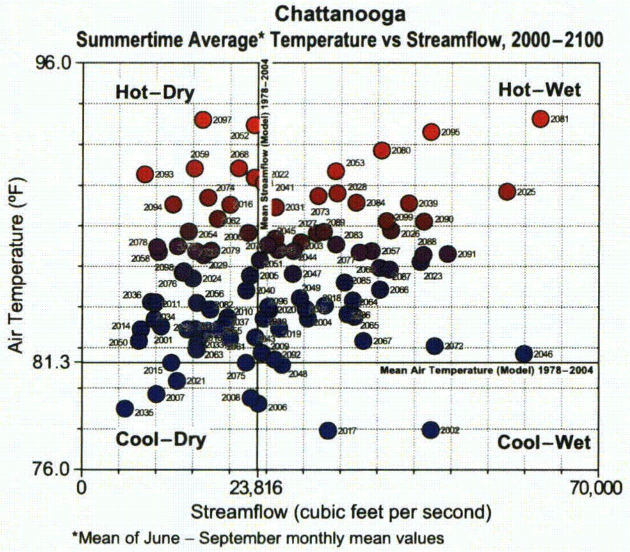
In those areas seeing an increase in stream flows and rainfall, impacts on groundwater levels and on seasonal flooding could have a different set of impacts. For existing plants, these impacts could include increased costs to manage on-site drainage and run-off, changes in coal handling due to increased moisture content or additional energy requirements for coal drying, etc. The following excerpt details the magnitude of the intersection between energy production and water use.

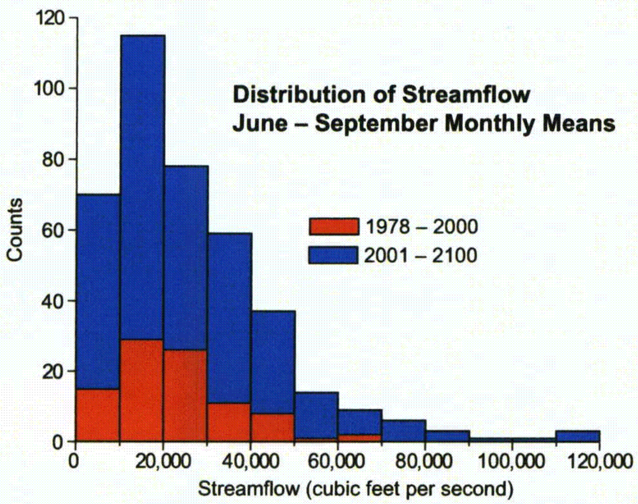
An October 2005 report produced by the National Energy Technology Laboratory stated, in part, that the production of energy from fossil fuels (coal, oil, and natural gas) is inextricably linked to the availability of adequate and sustainable supplies of water. While providing the United States with a majority of its annual energy needs, fossil fuels also place a high demand on the Nation's water resources in terms of both use and quality impacts (EIA, 2005d). Thermoelectric generation is water intensive; on average, each kWh of electricity generated via the steam cycle requires approximately 25 gallons of water, a weighted average that captures total thermoelectric water withdrawals and generation for both once-through and recirculating cooling systems. According to the United States Geological Survey (USGS), power plants rank only slightly behind irrigation in terms of freshwater withdrawals in the United States (USGS, 2004), although irrigation withdrawals tend to be more consumptive. Water is also required in the mining, processing, and transportation of coal to generate electricity all of which can have direct impacts on water quality. Surface and underground coal mining can result in acidic, metal-laden water that must be treated before it can be discharged to nearby rivers and streams. In addition, the USGS estimates that in 2000 the mining industry withdrew approximately 2 billion gallons per day of freshwater. Although not directly related to water quality, about 10% of total U.S. coal shipments were delivered by barge in 2003 (USGS, 2004). Consequently, low river flows can create shortfalls in coal inventories at power plants.

Freshwater availability is also a critical limiting factor in economic development and sustainability, which directly impacts electric-power supply. A 2003 study conducted by the Government Accountability Office indicates that 36 states anticipate water shortages in the next 10 years under normal water conditions, and 46 states expect water shortages under drought conditions (GAO 2003). Water supply and demand estimates by the Electric Power Research Institute (EPRI) for the years 1995 and 2025 also indicate a high likelihood of local and regional water shortages in the United States (EPRI 2003). The area that is expected to face the most serious water constraints is the arid southwestern United States.

### BOX 3.1 Chattanooga: A Case Study of Cooling Effects

A preliminary analysis of one IPCC climate change scenario (A1B) provides one example of how cooling conditions might evolve over the 21st century for generation in the Chattanooga vicinity (ORNL work in progress). In this example, a slight upward trend in stream flow would provide a marginal benefit for once-through cooling, but would be offset by increasing summertime air temperatures that trigger limits on cooling water intake and downstream mixed temperatures. Closed-cycle cooling would also become less effective as ambient temperature and humidity increased. Utilities would need to maintain generation capacity by upgrading existing cooling systems or shifting generation to newer facilities with more cooling capacity. Without technology-based improvements in cooling system energy efficiency or steam-cycle efficiency, overall thermoelectric generation efficiency would decrease.




In any event, the demand for water for thermoelectric generation will increasingly compete with demands from other sectors of the economy such as agriculture, residential, commercial, industrial, mining, and in-stream use. EPRI projects a potential for future constraints on thermoelectric power in 2025 for Arizona, Utah, Texas, Louisiana, Georgia, Alabama, Florida, and all of the Pacific Coast states. Competition over water in the western United States, including water needed for power plants, led to a 2003 Department of Interior initiative to predict, prevent, and alleviate water-supply conflicts (DOI 2003). Other areas of the United States are also susceptible to freshwater shortages as a result of drought conditions, growing populations, and increasing demand.

Concerns about water supply expressed by state regulators, local decision-makers, and the general public are already impacting power projects across the United States. For example, Arizona recently rejected permitting for a proposed power plant because of concerns about how much water it would withdraw from a local aquifer (Land Letter 2004). An existing Entergy plant located in New York is being required to install a closed-cycle cooling water system to prevent fish deaths resulting from operation of its once-through cooling water system (Greenwire, 2003). Water availability has also been identified by several Southern States Energy Board member states as a key factor in the permitting process for new merchant power plants (Clean Air Task Force 2004). In early 2005, Governor Mike Rounds of South Dakota called for a summit to discuss drought-induced low flows on the Missouri River and the impacts on irrigation, drinking-water systems, and power plants (Billingsgazette.com 2005). Residents of Washoe County, Nevada expressed opposition to a proposed coal-fired power plant in light of concerns about how much water the plant would use (Reno-Gazette Journal. 2005). Another coal-fired power plant to be built in Wisconsin on Lake Michigan has been under attack from environmental groups because of potential effects of the facility's cooling-water-intake structures on the Lake's aquatic life (Milwaukee Journal Sentinel, 2005).

Such events point toward a likely future of increased conflicts and competition for the water the power industry will need to operate their thermoelectric generation capacity. These conflicts will be national in scope, but regionally driven. It is likely that power plants in the west will be confronted with issues related to water rights: that is, who owns the water and the impacts of chronic and sporadic drought. In the east, current and future environmental requirements, such as the Clean Water Act's intake structure regulation, could be the most significant impediment to securing sufficient water, although local drought conditions can also impact water availability. If changing climatic conditions affect historical patterns of precipitation, this may further complicate operations of existing plants, and the design and site selection of new units.

EIA 2004a reports net summer and winter capacity for existing generating capacity by fuel source. Coal-fired and nuclear plants have summer/winter ratios of 0.99 and 0.98 and average plant sizes of 220 MW and 1015 MW, respectively. Petroleum, natural gas, and dual fuel-fired plants show summer/winter net capacity ratios of 0.90 to 0.93, indicating higher sensitivity to ambient temperature. Average sizes of these plants ranged from 12 MW to 84 MW, consistent with their being largely peaking and intermediate load units. Although large coal and nuclear generating plants report little degradation of net generating capacity from winter to summer conditions, there are reports (University of Missouri-Columbia 2004) of plant derating and shutdowns caused by temperature-related river water level changes and thermal limits on water discharges. Actual generation in 2004 (EIA, 2004a) shows coal-fired units with 32% of installed capacity provided 49.8% of generation and nuclear units with 10% of installed capacity provided 17.8% of power generated, indicating that these sources are much more heavily dispatched than are petroleum, natural gas, and dual-fired sources. To date, this difference has been generally attributed to the lower variable costs of coal and nuclear generation, indicating that the lower average dispatch has been more driven by fuel costs than temperature-related capacity constraints.

Gas turbines, in their varied configurations, provide about 20% of the electric power produced in the U.S. (EIA 2006). Gas turbines in natural gas simple cycle, combined cycle (gas and steam turbine), and coal-based integrated gasification combined cycle applications are affected by local ambient conditions, largely local ambient temperature and pressure. Ambient temperature and pressure have an immediate impact on gas turbine performance. Turbine performance is measured in terms of heat rate (efficiency) and power output. Davcock et al. (Davcock, DesJardins, and Fennell 2004) found that a 60°F increase in ambient temperature, as might be experienced daily in a desert environment, would have a 1-2 percentage point reduction in efficiency and a 20-25% reduction in power output. This effect is nearly linear; so a 10 degree Fahrenheit increase in ambient temperature would produce as much as a 0.5 percentage point reduction in efficiency and a 3-4% reduction in power output in an existing gas turbine. Therefore, the impact of potential climate change on the fleet of existing turbines would be driven by the impact that small changes in overall performance would have on both the total capacity available at any time and the actual cost of electricity.

Turbines for NGCC and IGCC facilities are designed to run 24 hours, 7 days a week; but simple cycle turbines used in topping and intermediate service are designed for frequent startups and rapid ramp rates to accommodate grid dispatch requirements. Local ambient temperature conditions will normally vary by 10 – 20°F on a 24-hour cycle, and many temperate-zone areas have winter-summer swings in average ambient temperature of 25-35°F. Consequently, any long-term climate change that would impact ambient temperature is believed to be on a scale within the design envelope of currently deployed turbines. As noted earlier, both turbine power output and efficiency vary with ambient temperature deviation from the design point. The primary impacts of longer periods of off-design operation will be modestly reduced capacity and reduced efficiency. Currently turbine-based power plants are deployed around the world in a wide variety of ambient conditions and applications, indicating that new installations can be designed to address long-term changes in operating conditions. In response to the range of operating temperatures and pressures to which gas turbines are being subjected, turbine designers have developed a host of tools for dealing with daily and local ambient conditions. These tools include inlet guide vanes, inlet air fogging (essentially cooling and mass flow addition), inlet air filters, and compressor blade washing techniques (to deal with salt and dust deposited on compressor blades). Such tools could also be deployed to address changes in ambient conditions brought about by long-term climate change.

### 3.1.2 Energy Resource Production And Delivery

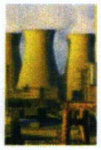
Other than for renewable energy sources, energy resource production and delivery systems are mainly vulnerable to effects of sea level rise and extreme weather events.

IPCC 2001a projected a 50-cm. (20-in.) rise in sea level around North America in the next century from climate change alone. This is well within the normal tidal range and would not have any significant effect on off-shore oil and gas activities. On-shore oil and gas activities could be much more impacted, which could create derivative impacts on off-shore activities. A number of operational power plants are sited at elevations of 3 ft or less, making them vulnerable to these rising sea levels. In addition, low-lying coastal regions are being considered for the siting of new plants due to the obvious advantages in delivering fuel and other necessary feedstocks. Significant percentages of other energy infrastructure assets are located in these same areas, including a number of the nation's oil refineries as well as most coal import/export facilities and liquefied natural gas terminals. Given that a large percentage of the nation's energy infrastructure lies along the coast, rising sea levels could lead to direct losses such as equipment damage from flooding or erosion or indirect effects such as the costs of raising vulnerable assets to higher levels or building future energy projects further inland, thus increasing transportation costs.

IPCC 2001a and USGS 2000 have identified substantial areas of the U.S. East Coast and Gulf Coast as being vulnerable to sea-level rise. Roughly one-third of U.S. refining and gas processing physical plant lies on coastal plains adjacent to the Gulf of Mexico (GOM), hence it is vulnerable to inundation, shoreline erosion, and storm surges. On-shore but noncoastal oil and gas production and processing activities may be impacted by climate change primarily as it impacts extreme weather events, phenomena not presently well understood. Florida's energy infrastructure may be particularly susceptible to sea-level rise impacts. (See Box 3.2 Florida).

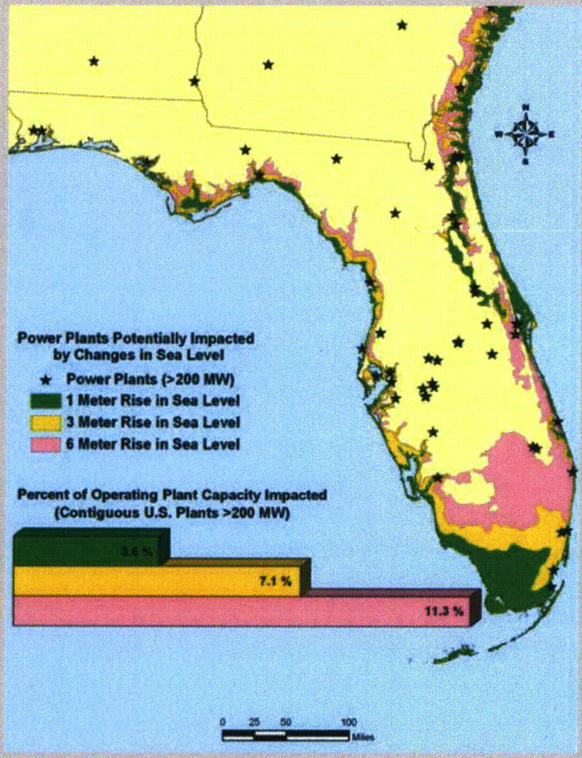
Alaska represents a special case for climate adaptation because the scale of projected impacts is expected to be greater in higher latitudes (See Box 3.3: A Case Study). Extreme weather events, which could represent more significant effects, are discussed in 3.1.4. Even coal production is susceptible to extreme weather events that can directly impact open-cast mining operations and coal cleaning operations of underground mines.

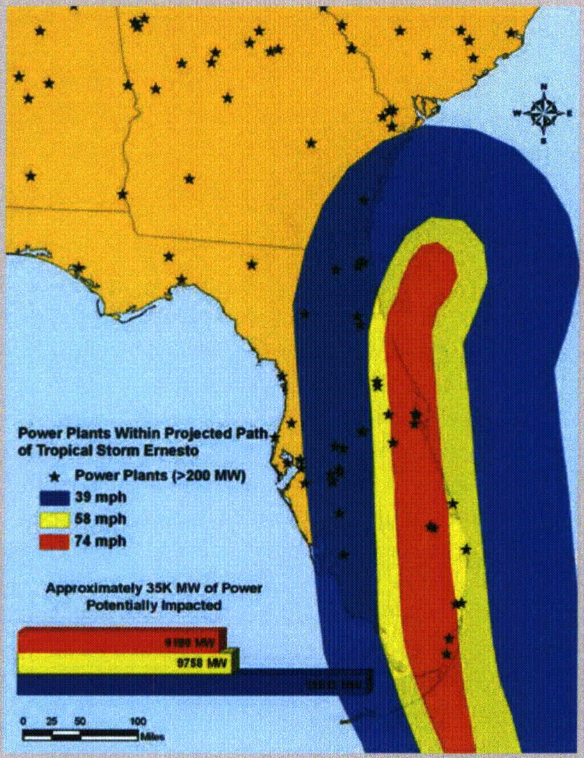
Potential impacts on novel energy resources are speculative at present. Oil shale resource development, which is considered to be water intensive, could be made more difficult if climate change further reduces annual precipitation in an already arid region that is home to the major



**BOX 3.2 Florida**

Florida's energy infrastructure may be particularly susceptible to sea-level rise impacts. Most of the petroleum products consumed in Florida are delivered by barge to three ports (NASEO, 2005) two on the East Coast of Florida and one on the West Coast. The interdependencies of natural gas distribution, transportation fuel distribution and delivery, and electrical generation and distribution were found to be major issues in Florida's recovery from multiple hurricanes in 2004. In addition, major installations such as nuclear power plants are located very close to the seacoast at elevations very close to sea level. The map on the left shows major power plants susceptible to sea-level rise in Florida. The map on the right illustrates power plants in the path of Tropical Storm Ernesto.




oil shale deposits. Water availability (Struck 2006) is beginning to be seen as a potential constraint on synthetic petroleum production from the Canadian oil sands. Coal-to-liquids operations also require significant quantities of water.

### 3.1.3 Transportation of Fuels

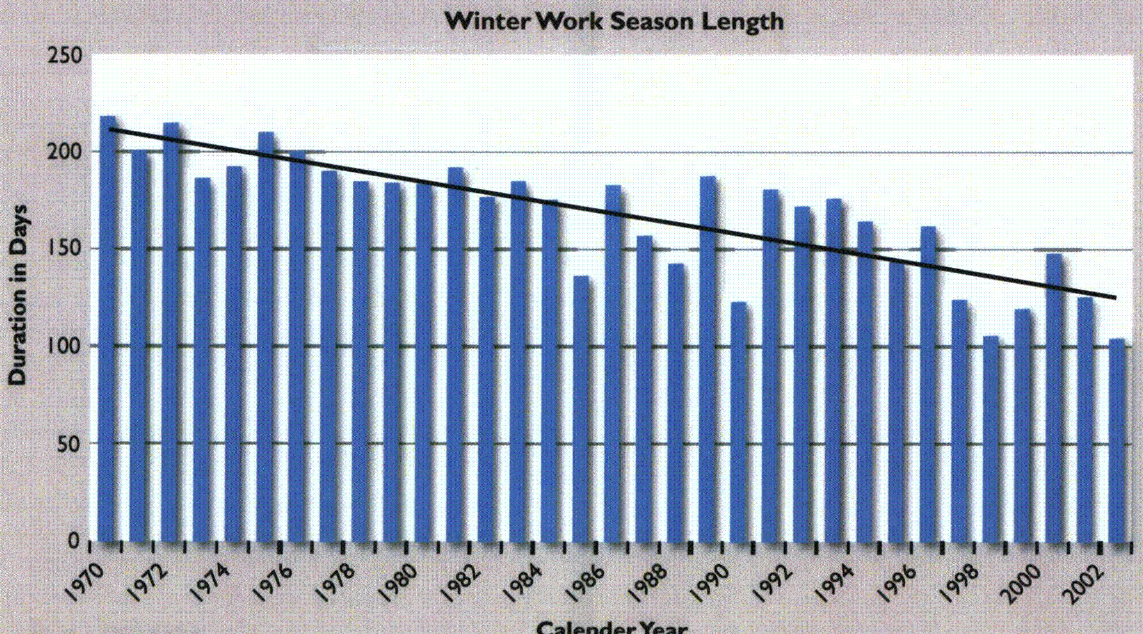
Roughly 65% of the petroleum products supplied in the Petroleum Administration for Defense (PAD) East Coast District (Figure 3.3) arrive via pipeline, barge, or ocean vessel (EIA 2004). Approximately 80% of the domestic-origin product is transported by pipeline. Certain areas, e.g., Florida, are nearly totally dependent on maritime (barge) transport. About 97% of the crude oil charged to PAD I refineries is imported, arriving primarily by ocean vessels. PAD II receives the bulk of its crude oil via pipeline, roughly two-thirds from PAD III and one-third from Canada. Both pipeline and barge transport have been susceptible to extreme weather events, with pipeline outages mostly driven by interdependencies with the electrical grid. In addition (see 3.3.2), increased ambient temperatures can degrade pipeline system performance, particularly when tied to enhanced oil recovery and, if practiced in the future, carbon sequestration. The transportation of coal to end users, primarily electrical generation facilities, is dependent on rail and barge transportation modes (EIA 2004b). Barge transport is

## BOX 3.3 Alaska: A Case Study

Alaska represents a special case for climate adaptation where temperatures have risen (3°C) over the last few decades, a rate that is almost twice that of the rest of the world. Some models predict this warming trend will continue, with temperatures possibly rising as much as 4-7°C over the next 100 years (ACIA 2004).

In areas of Alaska's North Slope, change is already being observed. The number of days allowed for winter tundra travel dropped significantly since the state began to set the tundra opening date in 1969, and a chart of that decline has been widely used to illustrate one effect of a warming Arctic (Alaska Department of Natural Resources 2004). There is a significant economic impact on oil and natural gas exploration from a shorter tundra travel season, especially since exploration targets have moved farther away from the developed Prudhoe Bay infrastructure, requiring more time for ice road building. It is unlikely that the oil industry can implement successful exploration and development plans with a winter work season consistently less than 120 d.

Further, melting permafrost can cause subsidence of the soil, thereby threatening the structural integrity of infrastructure built upon it. It was anticipated that the Trans-Alaska Pipeline System would melt surrounding permafrost in the areas where it would be buried. Therefore, extensive soil sampling was conducted and




*Source: ACIA, 2004.*

in areas where permafrost soils were determined to be thaw-stable, conventional pipeline building techniques were utilized. But in ice-rich soils, the ground is generally not stable after the permafrost melts. Therefore, unique aboveground designs integrating thermal siphons were used to remove heat transferred in the permafrost via the pilings used to support the pipeline. And in a few selected areas where aboveground construction was not feasible, the ground around the pipeline is artificially chilled (U.S. Arctic Research Commission 2003 and Pipeline Engineering 2007). Such extensive soil testing and unique building techniques add substantial cost to large development projects undertaken in arctic climates but are necessary to ensure the long-term viability of the infrastructure.

Exploration in the Arctic may benefit from thinning sea ice. Recent studies indicate extent of sea ice covering the Arctic Ocean may have reduced as much as 10%, and thinned by as much as 15%, over the past few decades. These trends suggest improved shipping accessibility around the margins of the Arctic Basin with major implications for the delivery of goods as well as products such as LNG and oil from high latitude basins (ACIA 2004). A reduction in sea ice may also mean increased off-shore oil exploration (ACIA 2004).

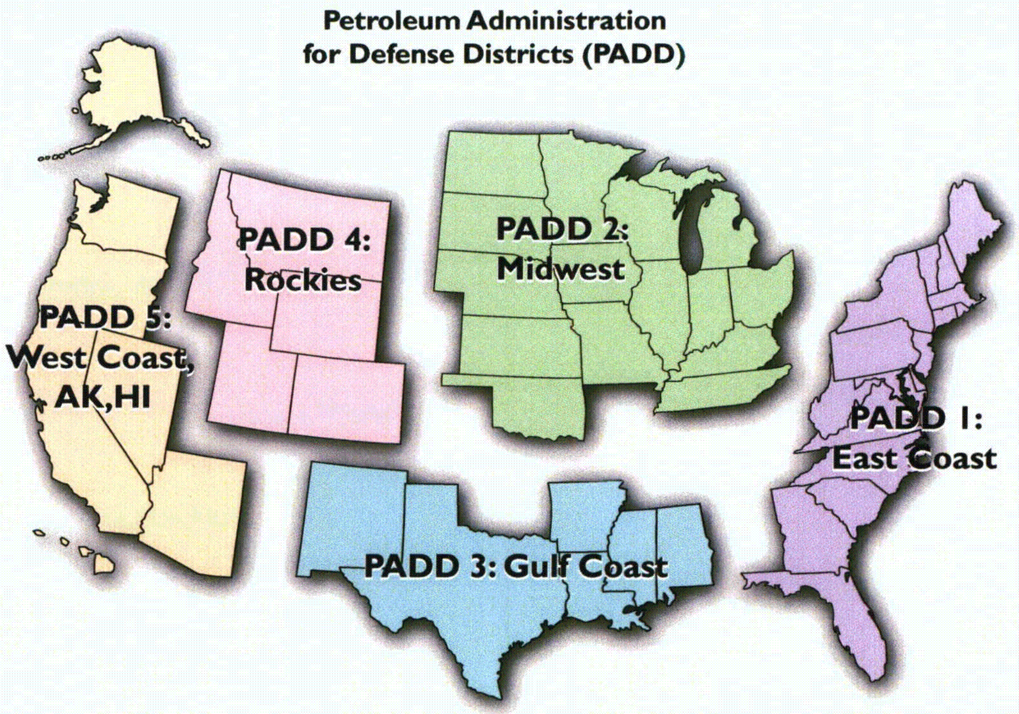



**Figure 3.3. Petroleum Administration for Defense (PAD) Districts**

susceptible to both short term, transient weather events and to longer-term shifts in regional precipitation and snow melt patterns that may reduce the extent of navigability of rivers and reduce or expand the annual navigable periods. In addition, offshore pipelines were impacted by Hurricane Ivan even before the arrival of Hurricanes Katrina and Rita (see 3.1.4).

### 3.1.4 Extreme Events

Climate change may cause significant shifts in current weather patterns and increase the severity and possibly the frequency of major storms (NRC 2002). As witnessed in 2005, hurricanes can have a debilitating impact on energy infrastructure. Direct losses to the energy industry in 2005 are estimated at $15 billion (Marketwatch.com 2006), with millions more in restoration and recovery costs. Future energy projects located in storm prone areas will face increased capital costs of hardening their assets due to both legislative and insurance pressures. For example, the Yscloskey Gas Processing Plant was forced to close for 6 months following Hurricane Katrina, resulting in both lost revenues to the plant's owners and higher prices to consumers as alternative gas sources had to be procured. In general, the incapacitation of energy infrastructure – especially of refineries, gas processing plants and petroleum product terminals – is widely credited with driving a price spike in fuel prices across the country, which then in turn has national consequences. The potential impacts of more severe weather are not, in fact, limited to hurricane-prone areas. Rail transportation lines, which transport approximately 2/3 of the coal to the nation's power plants (EIA 2002), often closely follow riverbeds, especially in the Appalachian region. More severe rainstorms can lead to flooding of rivers that then can wash out or degrade the nearby roadbeds. Flooding may also disrupt the operation of inland waterways, the second-most important method of transporting coal. With utilities carrying smaller stockpiles and projections showing a growing reliance on coal for a majority of the nation's electricity production, any significant disruption to the transportation network has serious implications for the overall reliability of the grid as a whole.

Off-shore production is particularly susceptible to extreme weather events. Hurricane Ivan (2004) destroyed seven GOM platforms, significantly damaged 24 platforms, and damaged 102 pipelines (MMS 2006). Hurricanes Katrina and Rita in 2005 destroyed more than 100 platforms and damaged 558 pipelines (MMS 2006). The two photographs in Figure 3.4 show the

**Figure 3.4 Hurricane damage in the Gulf of Mexico – Mars platform**

*Before Hurricane*

*After Hurricane*

Mars deepwater platforms before and after the 2005 hurricanes. The $250 million Typhoon platform was so severely damaged that Chevron is working with the MMS to sink it as part of an artificial reef program in the GOM; the billion dollar plus Mars platform has been repaired and returned to production about 8 months post hurricane.

### 3.1.5 Adaptation to Extreme Events

Energy assets can be protected from these impacts both by protecting the facility or relocating it to safer areas. Hardening could include reinforcements to walls and roofs, the building of dikes to contain flooding, or structural improvements to transmission assets. However, the high cost of relocating or protecting energy infrastructure drives many companies to hedge these costs against potential repair costs if a disaster does strike. For example, it is currently estimated to cost up to $10 billion to build a new refinery from the ground up (Petroleum Institute for Continuing Education undated), compared with costs to fully harden a typical at-risk facility against a hurricane and with the few million dollars in repairs that may or may not be required if a hurricane does strike. Relocation of rail lines also faces a similar dilemma. BNSF's capacity additions in the Powder River Basin are expected to cost over $200 million dollars to add new track in a relatively flat region with low land prices; changes to rail lines in the Appalachian region would be many times more due to the difficult topography and higher land acquisition costs.

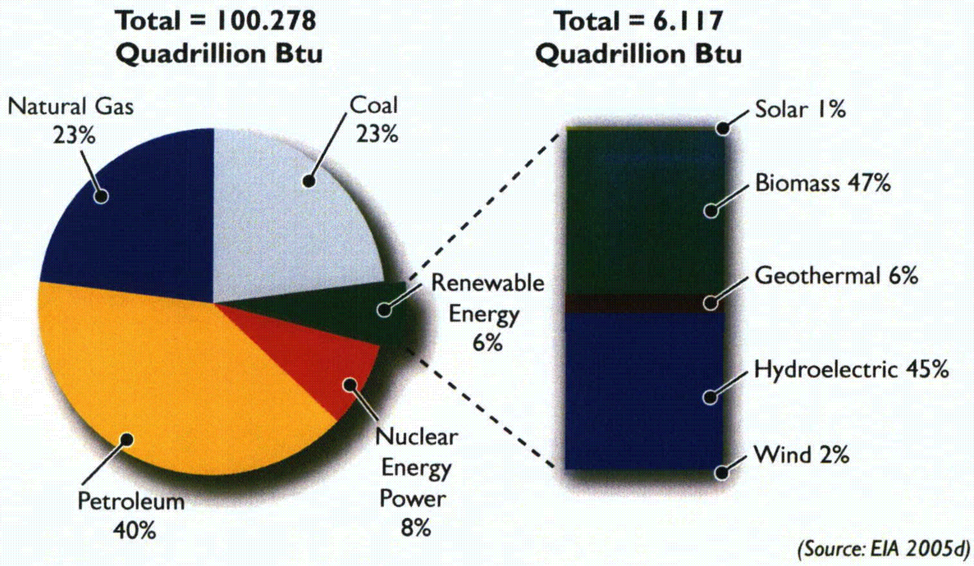
Industry, government agencies, and the American Petroleum Institute met jointly in March 2006 (API 2006a) to plan for future extreme weather events. Interim guidelines for jackup (shallow water) rigs (API 2006b) and for floating rigs (API 2006c) have been developed. MMS, DOT, and several industry participants have formed a Joint Industry Program (JIP) (Stress Subsea, Inc. 2005) to develop advanced capabilities to repair damaged undersea pipelines.

## 3.2 EFFECTS ON RENEWABLE ENERGY PRODUCTION

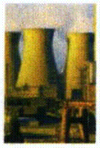
Renewable energy production accounted for about 6% of the total energy production in the United States in 2005 (Figure 3.5); biomass and hydropower are the most significant contributors (EIA 2005d), and the use of renewable energy is increasing rapidly in other sectors such as wind and solar. Biomass energy is primarily used for industrial process heating, with substantially increasing use for transportation fuels

**Figure 3.5. Renewable Energy's Share In U.S. Energy Supply (2005)**

**(http://www.eia.doe.gov/cneaf/solar.renewables/page/trens/highlight1.html)**




*(Source: EIA 2005d)*



and additional use for electricity generation. Hydropower is primarily used for generating electricity, providing 270 billion kWh in 2005 (EIA, 2005d). Wind power is the fastest growing renewable energy technology, with total generation increasing to 14 billion kWh in 2005 (EIA 2006). Because renewable energy depends directly on ambient natural resources such as hydrological resources, wind patterns and intensity, and solar radiation, it is likely to be more sensitive to climate variability than fossil or nuclear energy systems that rely on geological stores. Renewable energy systems are also vulnerable to damage from extreme weather events. At the same time, increasing renewable energy production is a primary means for reducing energy-related greenhouse gas emissions and thereby mitigating the impacts of potential climate change. Renewable energy sources are therefore connected with climate change in very complex ways: their use can affect the magnitude of climate change, while the magnitude of climate change can affect their prospects for use.

### 3.2.1 Hydroelectric Power

Hydropower is the largest renewable source of electricity in the United States. In the period 2000-2004, hydropower produced approximately 75% of the electricity from all renewable sources (EIA 2005d). In addition to being a major source of base-load electricity in some regions of the United States (e.g., Pacific Northwest states), hydropower plays an important role in stabilizing electrical transmission grids, meeting peak loads and regional reserve requirements for generation, and providing other ancillary electrical energy benefits that are not available from other renewables when storage is unavailable. Hydropower project design and operation is very diverse; projects vary from storage projects with large, multipurpose reservoirs to small run-of-river projects that have little or no active water storage. Approximately half of the U.S. hydropower capacity is federally owned and operated (e.g., Corps of Engineers, Bureau of Reclamation, and the Tennessee Valley Authority); the other half is at nonfederal projects that are regulated by the Federal Energy Regulatory Commission. Nonfederal hydropower projects outnumber federal projects by more than 10:1.

The interannual variability of hydropower generation in the United States is very high, especially relative to other energy sources (Figure 3.6). The difference between the most recent high (2003) and low (2001) generation years is 59 billion kWh, approximately equal to the total electricity from biomass sources and much more than the generation from all other non-hydropower renewables (EIA 2006). The amount of water available for hydroelectric power varies greatly from year to year, depending upon weather patterns and local hydrology, as well as on competing water uses, such as flood control, water supply, recreation, and instream flow requirements (e.g., conveyance to downstream water rights, navigation, and protection of fish

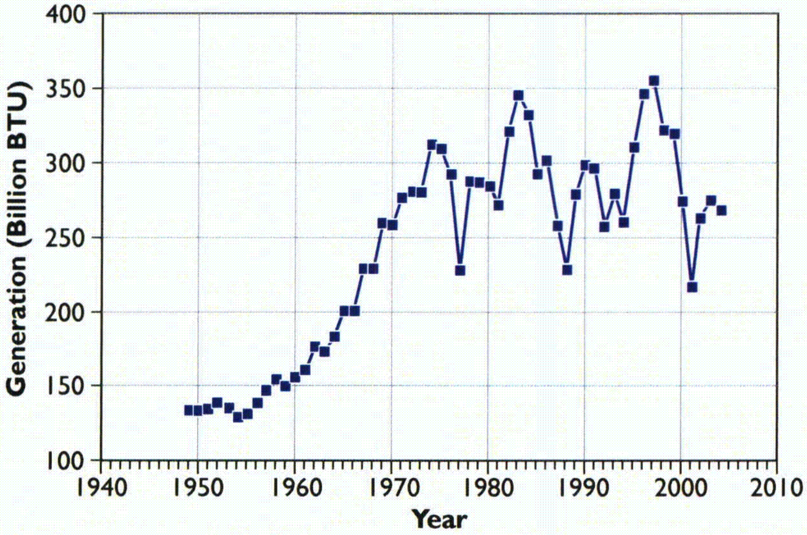



**Figure 3.6. Historical Variability Of Total Annual Production Of Hydroelectricity From Conventional Projects In The U.S. (data from EIA Annual Energy Outlook, 2005).**

and wildlife). The annual variability in hydropower is usually attributed to climate variability, but there are also important impacts from multiple use operational policies and regulatory compliance.

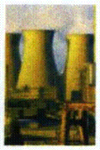
There have been a large number of published studies on the climate impacts on water resource management and hydropower production (e.g., Miller and Brock 1988; Lettenmaier et al. 1999; Barnett et al. 2004). Significant changes are being detected now in the flow regimes of many western rivers (Dettinger 2005) that are consistent with the predicted effects of global warming. The sensitivity of hydroelectric generation to both changes in precipitation and river discharge is high, in the range 1.0 and greater (e.g., sensitivity of 1.0 means 1% change in precipitation results in 1% change in generation). For example, Nash and Gleick (1993) estimated sensitivities up to 3.0 between hydropower generation and stream flow in the Colorado Basin (i.e., change in generation three times the change in stream flow). Such magnifying sensitivities, greater than 1.0, occur because water flows through multiple power plants in a river basin. Climate impacts on hydropower occur when either the total amount or the timing of runoff is altered, for example when natural water storage in snow pack and glaciers is reduced under hotter climates (e.g., melting of glaciers in Alaska and the Rocky Mountains of the U.S.). Projections that climate change is likely to reduce snow pack and associated runoff in the U.S. West are a matter of particular concern.

Hydropower operations are also affected indirectly when air temperatures, humidity, or wind patterns are affected by changes in climate, and these driving variables cause changes in water quality and reservoir dynamics. For example, warmer air temperatures and a more stagnant atmosphere cause more intense stratification of reservoirs behind dams and a depletion of dissolved oxygen in hypolimnetic waters (Meyer et al. 1999). Where hydropower dams have tailwaters supporting cold-water fisheries for trout or salmon, warming of reservoir releases may have unacceptable consequences and require changes in project operation that reduce power production.

Evaporation of water from the surface of reservoirs is another important part of the water cycle that may be will be affected by climate change and may lead to reduced water for hydropower. However, the effects of climate change on evaporation rates is not straight-forward. While evaporation generally increases with increased air or water temperatures, evaporation also depends on other meteorological conditions, such as advection rates, humidity, and solar radiation. For example, Ohmura and Wild (2002) described how observed evaporation rates decreased between 1950 and 1990, contrary to expectations associated with higher temperatures. Their explanation for the decrease was decreased solar radiation. Large reservoirs with large surface area, located in arid, sunny parts of the U.S., such as Lake Mead on the lower Colorado River (Westenburg et al., 2006), are the most likely places where evaporation will be greater under future climates and water availability will be less for all uses, including hydropower.

Competition for available water resources is another mechanism for indirect impacts of climate change on hydropower. These impacts can have far-reaching consequences through the energy and economic sectors, as happened in the 2000-2001 energy crises in California (Sweeney, 2002).

Recent stochastic modeling advances in California and elsewhere are showing how hydropower systems may be able to adapt to climate variability by reexamining management policies (Vicuña et al., 2006). The ability of river basins to adapt is proportional to the total active storage in surface water reservoirs (e.g., Aspen Environmental Group and M-Cubed, 2005). Adaptation to potential future climate variability has both near-term and long-term benefits in stabilizing water supplies and energy production (e.g., Georgakakos et al., 2005), but water management institutions are generally slow to take action on such opportunities (Chapter 4).



### 3.2.2 Biomass Power and Fuels

Total biomass energy production has surpassed hydroelectric energy for most years since 2000 as the largest U.S. source of total renewable energy, providing 47% of renewable or 4% of total U.S. energy in 2005 (EIA, 2006). The largest source of that biomass energy (29%) was black liquor from the pulp and paper industry combusted as part of a process to recover pulping chemicals to provide process heat as well as generating electricity. Wood and wood waste from sources such as lumber mills provide more than 19% (industrial sector alone) and combusted municipal solid waste and recovered landfill gas provide about 16%, respectively, of current U.S. biomass energy (EIA, 2005d). Because energy resource generation is a byproduct of other activities in all these cases, direct impacts of climate change on these or most other sources of biomass power production derived from a waste stream may be limited unless there are significant changes in forest or agricultural productivity that are a source of the waste stream. There are few examples of literature addressing this area, though Edwards notes that climate-change-induced events such as timber die-offs could present a short-term opportunity or a long-term loss for California (Edwards, 1991).

Liquid fuel production from biomass is highly visible as a key renewable alternative to imported oil. Current U.S. production is based largely on corn for ethanol and, to a lesser extent, soybeans for biodiesel. In the longer term, cellulosic feedstocks may supplant grain and oilseed crops for transportation fuel production from biomass. Cellulosic crop residues such as corn stover and wheat straw would likely be affected by climate change the same way as the crops themselves due to a rise in average temperatures, more extreme heat days, and changes in precipitation patterns and timing, with greater impact on fuel production because that would be their primary use. Potential dedicated cellulosic energy crops for biomass fuel, such as grasses and fast-growing trees, would also be directly affected by climate change. As discussed below, limited literature suggests that for at least one region, one primary energy crop candidate—switchgrass—may benefit from climate change, both from increased temperature and increased atmospheric carbon dioxide levels.

Approximately 10% of U.S. biomass energy production (EIA, 2005d), enough to provide about 2% of U.S. transportation motor fuel (Federal Highway Administration, 2003), currently comes from ethanol made predominantly from corn grown in the Midwest (Iowa, Illinois, Nebraska, Minnesota, and South Dakota are the largest ethanol producers). Climate change sufficient to substantially affect corn production would likely impact the resource base, although production and price effects in the longer term are unclear. Production of biodiesel from soybeans—growing rapidly, but still very small—is likely a similar situation. In the long term, however, significant crop changes—and trade-offs between them as they are generally rotated with each other—would likely have an impact in the future. Looking at Missouri, Iowa, Nebraska, and Kansas, with an eye toward energy production, Brown et al., 2000 used a combination of the NCAR climate change scenario, regional climate, and crop productivity models to predict how corn, sorghum, and winter wheat (potential ethanol crops) and soybeans (biodiesel crop) would do under anticipated climate change. Negative impacts from increased temperature, positive impacts from increased precipitation, and positive impacts from increased atmospheric carbon dioxide combined to yield minimal negative change under modest carbon dioxide level increases but 5% to 12% yield increases with high carbon dioxide level increases. This assessment did not, however, account for potential impact of extreme weather events – particularly the frequency and intensity of events involving hail or prolonged droughts – that may also negatively impact energy crop production.

Although ethanol production from corn can still increase substantially (mandated to double under the recently enacted renewable fuel standard), it can still only meet a small portion of the need for renewable liquid transportation fuels to displace gasoline if dependence on petroleum imports is to be reduced. Processing the entire projected 2015 corn crop to ethanol (highly unrealistic, of course) would only yield about 35 billion gallons of ethanol, less than 14% of the gasoline energy demand projected for that year. Biomass fuel experts are counting on cellulosic biomass as the feedstock to make larger scale renewable fuel production possible. A recent joint study by the U.S. Departments of Agriculture and Energy (USDA and DOE), *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, projected that by 2030, enough biomass could be made available to meet 40% of 2004 gasoline demand via cellulosic ethanol production and other technologies. The two largest feedstocks identified are annual crop residues and perennial dedicated energy crops (NREL, 2006).

The primary potential annual crop residues are corn stover—the leaves, stalks, and husks generally now left in the field—and wheat straw. Corn stover is the current DOE research focus in part because it is a residue with no incremental cost to grow and modest cost to harvest, but also particularly because of its potential large volume. Stover volume is roughly equivalent to grain volume, and corn is the largest U.S. agricultural crop. As such, it would be affected by climate change in much the same way as the corn crop itself, as described above.

Frequently discussed potential dedicated perennial energy crops include fast-growing trees such as hybrid poplars and willows and grasses such as switchgrass (ORNL, 2006) Switchgrass is particularly attractive because of its large regional adaptability, fast growth rate, minimal adverse environmental impact, and ease of harvesting with conventional farm equipment. The primary objective of the Brown et al. , 2000 study referenced above for Missouri, Iowa, Nebraska, and Kansas was to see how climate change would affect growth of switchgrass. The study projected that switchgrass may benefit from both higher temperatures (unlike the grain crops) and higher atmospheric carbon dioxide levels, with yield increasing 74% with the modest $CO_2$ increase and nearly doubling with the higher $CO_2$ increase. Care should be taken in drawing definitive conclusions, however, from this one study. One may not expect the projected impact to be as beneficial for southern regions already warm enough for rapid switchgrass growth or more northern areas still colder than optimal even with climate change, but this analysis has not yet been conducted.

### 3.2.3 Wind Energy

Wind energy currently accounts for about 2.5% of U.S. renewable energy generation, but its use is growing rapidly, and it has tremendous potential due to its cost-competitiveness with fossil fuel plants for utility-scale generation and its environmental benefits. In addition, wind energy does not use or consume water to generate electricity. Unlike thermoelectric and fossil fuel generation that is inextricably linked to the availability of adequate, sustainable water supplies, wind energy can offer communities in water-stressed areas the option of economically meeting increasing energy needs without increasing demands on valuable water resources.

Although wind energy will not be impacted by changing water supplies like the other fuel sources, projected climate change impacts--such as changes in seasonal wind patterns or strength--would likely have significant positive or negative impacts because wind energy generation is a function of the cube of the wind speed. One of the barriers slowing wind energy development today is the integration of a variable resource with the utility grid. Increased variability in wind patterns could create additional challenges for accurate wind forecasting for generation and dispatch planning and for the siting of new wind farms.

In addition to available wind resources, state and federal policy incentives have played a key role in the growth of wind energy. Texas currently produces the most wind power, followed by California, Iowa, Minnesota, Oklahoma, and Oregon (AWEA, **www.awea.org/projects**, 2006). These regions are expected to continue to be among the leading wind-power areas in the near term. Although North Dakota and South Dakota have modest wind development, they also have tremendous wind potential, particularly if expanded transmission capacity allows for development of sites further from major load centers.

The siting of utility-scale wind generation is highly dependent on proximity and access to the grid and the local wind speed regime. Changes in wind patterns and intensity due to climate change could have an effect on wind energy production at existing sites and planning for future development, depending on the rate and scale of that change. One study modeled wind speed change for the United States, divided into northern and southern regions under two climate-change circulation models. Overall, the Hadley Center model suggested minimal decrease in average wind speed, but the Canadian model predicted very significant decreases of 10%–15% (30%–40% decrease in power generation) by 2095. Decreases were most pronounced after 2050 in the fall for both regions and in the summer for the northern region (Breslow and Sailor, 2002).

Another study mapped wind power changes in 2050 based on the Hadley Center General Circulation Model—the one suggesting more modest change of the two used by Breslow and Sailor above. For most of the United States, this study predicted decreased wind resources by as much as 10% on an annual basis and 30% on a seasonal basis. Wind power increased for the Texas-Oklahoma region and for the Northern California-Oregon-Washington region, although the latter had decreased power in the summer. For the Northern Great Plains and for the mountainous West, however, the authors predicted decreased wind power (Segal et al. 2001). Edwards suggests that warming-induced offshore current changes could intensify summer winds for California and thus increase its wind energy potential (Edwards, 1991). Changes in diurnal wind patterns could also have a significant impact on matching of wind power production with daily load demands.

### 3.2.4 Solar Energy

Photovoltaic (PV) electricity generation and solar water heating are suitable for much of the United States, with current deployment primarily in off-grid locations and rooftop systems where state or local tax incentives and utility incentives are present. Utility-scale generation is most attractive in the Southwest with its high direct-radiation resource, where concentrating high-efficiency PV and solar thermal generation systems can be used. California and Arizona currently have the only existing utility-scale systems (EIA, 2005d) with additional projects being developed in Colorado, Nevada, and Arizona.

Pan et al. 2004 modeled changes to global solar radiation through the 2040s based on the Hadley Center circulation model. This study projects a solar resource reduced by as much as 20% seasonally, presumably from increased cloud cover throughout the country, but particularly in the West with its greater present resource. Increased temperature can also reduce the effectiveness of PV electrical generation and solar thermal energy collection. One international study predicts that a 2% decrease in global solar radiation will decrease solar cell output by 6% overall (Fidje and Martinsen, 2006). Anthropogenic sources of aerosols can also decrease average solar radiation, especially on a regional or localized basis. The relationship between the climate forcing effect of greenhouse gases and aerosols is complex and an area of extensive research. This field would also benefit from further analysis on the nexus between anthropogenic aerosols, climate change, solar radiation, and impacts on solar energy production.

### 3.2.5 Other Renewable Energy Sources

Climate change could affect geothermal energy production [6% of current U.S. renewable energy (EIA, 2005d) and concentrating solar power Rankine cycle power plants] in the same way that higher temperatures reduce the efficiency of fossil-fuel-boiler electric turbines, but there is no recent research on other potential impacts in this sector due to climate change. For a typical air-cooled binary cycle geothermal plant with a 330°F resource, power output will decrease about 1% for each 1°F rise in air temperature.

The United States currently does not make significant use of wave, tidal, or ocean thermal energy, but each of these could be affected by climate change due to changes in average water temperature, temperature gradients, salinity, sea level, wind patterns affecting wave production, and intensity and frequency of extreme weather events. Harrison observes that wave heights in the North Atlantic have been increasing and discusses how wave energy is affected by changes in wind speed (Harrison and Wallace, 2005), but very little existing research has been identified that directly addresses the potential impact of climate change on energy production from wave, tidal, or ocean thermal technologies.

### 3.2.6 Summary

Of the two largest U.S. renewable energy sources, hydroelectric power generation can be expected to be directly and significantly affected by climate change, while biomass power and fuel production impacts are less certain in the short term. The impact on hydroelectric production will vary by region, with potential for production decreases in key areas such as the Columbia River Basin and Northern California. Current U.S. electricity production from wind and solar energy is modest but anticipated to play a significant role in the future as the use of these technologies increases. As such, even modest impacts in key resource areas could substantially impact the cost competitiveness of these technologies due to changes in electricity production and impede the planning and financing of new wind and solar projects due to increased variability of the resource. Renewable energy production is highly susceptible to localized and regional changes in the resource base. As a result, the greater uncertainties on regional impacts under current climate change modeling pose a significant challenge in evaluating medium to long-term impacts on renewable energy production.

## 3.3 EFFECTS ON ENERGY TRANSMISSION, DISTRIBUTION, AND SYSTEM INFRASTRUCTURE

In addition to the direct effects on operating facilities themselves, networks for transport, electric transmission, and delivery would be susceptible to changes due to climate change in stream flow, annual precipitation and seasonal patterns, storm severity, and even temperature increases (e.g., pipelines handling supercritical fluids may be impacted by greater heat loads if temperatures increase and/or cloud cover diminishes).

### 3.3.1 Electricity Transmission and Distribution

Severe weather events and associated flooding can cause direct disruptions in energy services. With more intense events, increased disruptions might be expected. Electricity reliability might also be affected as a result of increased demand combined with high soil temperatures and soil dryness (IPCC, 2001a). Figure 3.7 illustrates the major grid outage that was initiated by a lightning strike, as one example.

Grid technologies in use today are at least 50 years old and, although "smart grid" technologies exist, they are not often employed. Two such technologies that may be employed to help offset climate impacts include upgrading the grid by employing advanced conductors that are capable of withstanding greater temperature extremes and automation of electricity distribution (Gellings and Yeager, 2004).

### 3.3.2 Energy Resource Infrastructure

A substantial part of the oil imported into the United States is transported over long distances from the Middle East and Africa in supertankers. While these supertankers are able to of-

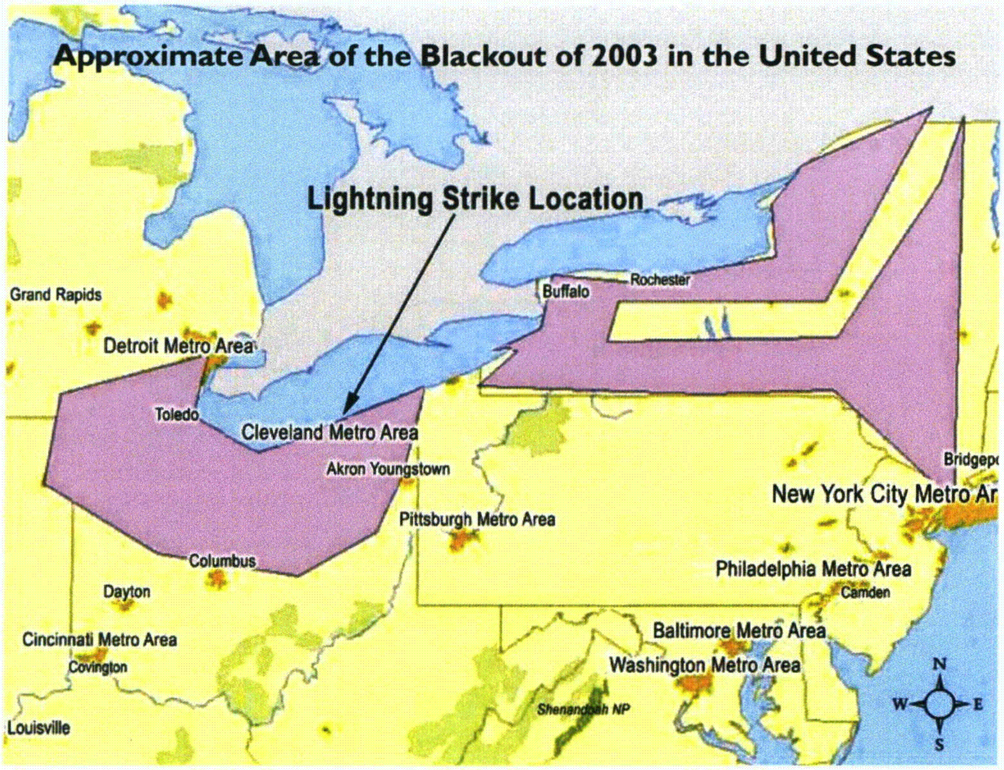
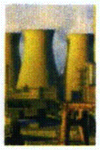



**Figure 3.7. Approximate Area of Blackout of 2003 In The United States.** *Source: NETL*



flood within the ports of other countries, they are too deeply drafted to enter the shallow U.S. ports and waters. This occurs because, unlike most other countries, the continental shelf area of the eastern United States extends many miles beyond its shores and territorial waters. This leads to a number of problems related to operation of existing ports, and to programs (such as NOAA's P.O.R.T.S. Program) to improve efficiency at these ports. In addition, the Deepwater Ports Act, 1975, has led to plans to develop a number of deepwater ports either for petro-


**Figure 3.8. Proposed Deepwater Ports For Petroleum And LNG.** *(Source: U.S. Maritime Administration)*

leum or LNG import. These planned facilities are concentrated in relatively few locations, in particular with a concentration along the Gulf Coast (Figure 3.8). Changes in weather patterns, leading to changes in stream flows and wind speed and direction can impact operability of existing harbors. Severe weather events can impact access to deepwater facilities or might disrupt well-established navigation channels in ports where keel clearance is a concern (DOC/DOE, 2001).

Climate change may also affect the performance of the extensive pipeline system in the United States. For example, for $CO_2$-enhanced oil recovery, experience has shown that summer injectivity of $CO_2$ is about 15% less than winter injectivity into the same reservoir. The $CO_2$ gas temperature in Kinder Morgan pipelines during the winter is about 60°F and in late summer about 74oF. At higher temperatures, compressors and fan coolers are less efficient and are processing a warmer gas. Operators cannot pull as much gas off the supply line with the given horsepower when the $CO_2$ gas is warm (Source: personal communication from K. Havens of Kinder Morgan $CO_2$).

Efficiencies of most gas injection are similar, and thus major gas injection projects like produced gas injection on the North Slope of Alaska have much higher gas injection and oil production during cold winter months. Persistently higher temperatures would have an impact on deliverability and injectivity for applications where the pipeline is exposed to ambient temperatures.

### 3.3.3 Storage and Landing Facilities

Strategic Petroleum Reserve storage locations (EIA 2004b) that are all along the Gulf Coast were selected because they provide the most flexible means for connecting to the commercial oil transport network. Figure 3.9 illustrates their locations along the Gulf Coast in areas USGS 2000 sees as being susceptible to sea-level rise, as well as severe weather events. Similarly located on the Sabine Pass is the Henry Hub, the largest gas transmission interconnection site in the U.S., connecting 14 interstate and intrastate gas transmission pipelines. Henry Hub was out of service briefly from Hurricane Katrina and for some weeks from Hurricane Rita, which made landfall at Sabine Pass.

### 3.3.4 Infrastructure Planning And Considerations For New Power Plant Siting

Water availability and access to coal delivery are currently critical issues in the siting of new coal-fired generation capacity. New capacity, except on coasts and large estuaries, will generally require cooling towers rather than once-through cooling water usage based on current and expected regulations (EPA, 2000) independent of climate change issues. New turbine capacity will also need to be designed to respond to the new ambient conditions.

Siting of new nuclear units will face the same water availability issues as large new coal-fired units; they will not need to deal with coal deliverability but may depend on barge transport to allow factory fabrication rather than site fabrication of large, heavy wall vessels, as well as for transportation of any wastes that need to be stored off-site.

Capacity additions and system reliability have recently become important areas for discussion. A number of approaches are being considered, such as to run auctions (or other approaches) to stimulate interest in adding new capacity, such as efforts by FERC to encourage capacity investments through regional independent system operator (ISO) organizations, without sending signals that would result in overbuilding (as has happened in the past). Planning to ensure that both predictions of needed capacity and mechanisms for stimulating companies to build such capacity (while working through the process required to announce, design, permit, and build it) will become more important as future demand is affected by climatic shifts. Similarly, site selection may need to factor in longer-term climatic changes for technologies as long-lived as coal-fired power plants (which may last for 50 - 75 years) (NARUC, 2006).

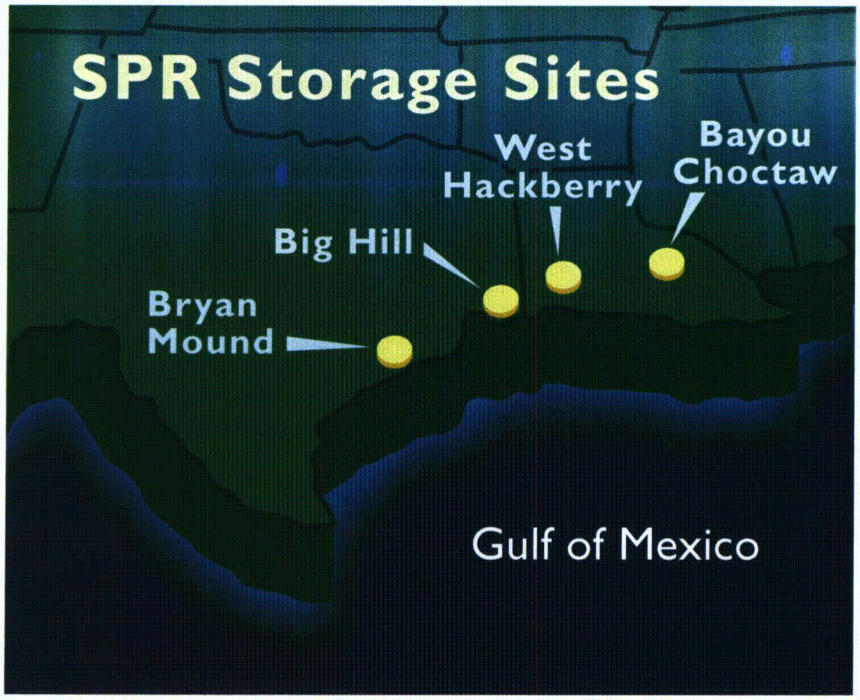
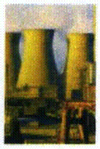



**Figure 3.9. Strategic Petroleum Reserve Storage Sites** *(Source: NETL)*



## 3.4 SUMMARY OF KNOWLEDGE ABOUT POSSIBLE EFFECTS

Significant uncertainty exists about the potential impacts of climate change on energy production and distribution, in part because the timing and magnitude of climate impacts are uncertain. This report summarizes many of the key issues and provides information available on possible impacts; however this topic represents a key area for further analysis.

Many of the technologies needed for existing energy facilities to adapt to increased temperatures and decreased water availability are available for deployment; and, although decreased efficiencies and lower output can be expected, significant disruptions seem unlikely. Incorporating potential climate impacts into the planning process for new facilities will strengthen the infrastructure. This is especially important for water resources, as electricity generation is one of many competing applications for what may be a (more) limited resource.

There are regionally important differences in adaptation needs. This is true for the spectrum of climate impacts from water availability to increased temperatures and changing patterns of severe weather events. The most salient example is for oil and gas exploration and production in Alaska, where projected temperature increases may be double the global average, and melting permafrost and changing shorelines could significantly alter the landscape and available opportunities for oil and gas production

Increased temperatures will also increase demand-side use, and the potential system-wide impacts on electricity transmission and distribution and other energy system needs are not well understood. Future planning for energy production and distribution may therefore need to accommodate possible impacts


# Possible Indirect Effects of Climate Change on Energy Production and Use in the United States

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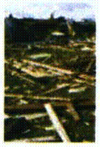
## 4.1 INTRODUCTION

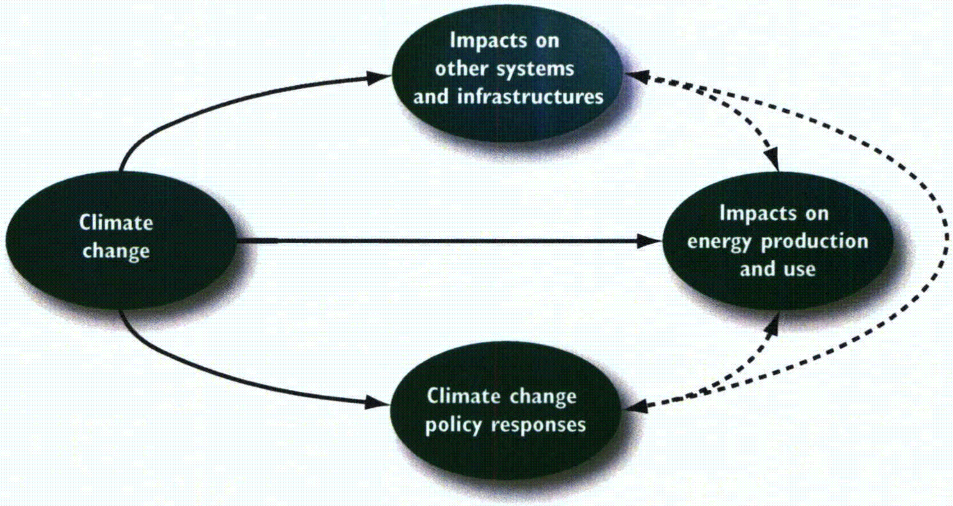
***Changes in temperature, precipitation, storms, and/or sea level are likely to have direct effects on energy production and use, as summarized above; but they may also have a number of indirect effects—as climate change affects other sectors and if it shapes energy and environmental policy-making and regulatory actions (Fig. 4.1). In some cases, it is possible that indirect effects could have a greater impact, positive or negative, on certain institutions and localities than direct effects.***



In order to provide a basis for such a discussion, this chapter of SAP 4.5 offers a preliminary taxonomy of categories of indirect effects that may be of interest, along with a summary of existing knowledge bases about such indirect effects. Some of these effects are from climate change itself, e.g., effects on electricity prices of changing conditions for hydropower production or of more intense extreme weather events. Other effects could come from climate change related **policies** (e.g., effects of stabilization-related emission ceilings on energy prices, energy technology choices, or energy sector emissions) (Table 4.1).

Most of the existing literature is concerned with implications of climate change mitigation policies on energy technologies, prices, and emissions in the U.S. Because this literature is abundant, relatively well-known, and in some cases covered by other SAPs (such as SAP 2.2), it will be only briefly summarized here, offering links to more detailed discussions. Of greater interest to some readers may be the characterization of other possible indirect effects besides these.

**Figure 4.1 This Chapter Is Concerned With The Dashed Lines In This Flow Diagram Of Connections Between Climate Change And Energy Production And Use**




## 4.2 CURRENT KNOWLEDGE ABOUT INDIRECT EFFECTS

### 4.2.1 Possible Effects On Energy Planning

Climate change is likely to affect energy planning, nationally and regionally, because it is likely to introduce new considerations and uncertainties to institutional (and individual) risk management. Such effects can arise either through anticipated changes in climate-related environmental conditions, such as hydropower potentials, possible exposure to storm damages (see Chapter 3), or changed patterns of energy demand (see Chapter 2), or through possible changes in policies and regulations.

For instance, a path-breaking study supported by EPRI and the Japanese Central Research Institute of Electric Power Industry (CRIEPI) assessed possible impacts of global climate change on six utilities, five of them in the United States (ICF, 1995). The study considered a variety of scenarios depicting a range of underlying climate, industry, and policy conditions. It found that GHG emission reduction policies could cause large increases in electricity prices, major changes in a utility's resource mix related to requirements for emission controls, and significant expansions in demand-side management programs. Major impacts are likely to be on Integrated Resource Planning regarding resource and capacity additions and/or plant retirements, along with broader implications of increased costs and prices. In another

**Table 4.1. Overview Of The Knowledge Base About Possible Indirect Effects Of Climate Change And Climate Change Policy On Energy Systems In The U.S.**

| Indirect Effect On Energy Systems | From Climate Change | From Climate Change Policy |
|---|---|---|
| On energy planning and investment | Very limited | Considerable literature |
| On technology R&D and preferences | Very limited | Considerable literature |
| On energy supply institutions | Very limited | Limited |
| On energy aspects of regional economies | Very limited | Some literature |
| On energy prices | Almost none | Considerable literature |
| On energy security | Almost none | Very limited |
| On environmental emissions from energy production/use | Very limited | Considerable literature |
| On energy technology/service exports | Almost none | Very limited |

example, Burtraw et al., 2005 analyzed a nine-state northeastern regional greenhouse gas initiative (RGGI), an allowance-based regional GHG cap-and-trade program for the power sector. They found that how allowances are allocated has an effect on electricity price, consumption, and the mix of technologies used to generate electricity. Electricity prices increase in most of the cases. They also note that any policy that increases energy costs in the region is likely to cause some emission leakage to other areas outside the region as electricity generation or economic activity moves to avoid regulation and associated costs.

Electric utilities in particular are already sensitive to weather as a factor in earnings performance, and they utilize weather risk management tools to hedge against risks associated with weather-related uncertainties. Issues of interest include plans for capacity additions, system reliability assurance, and site selection for long-lived capital facilities (O'Neill, 2003). Even relatively small changes in temperature/demand can affect total capacity needs across the U.S. power sector, especially in peak periods.

Some current policy initiatives hint at what the future might be like, in terms of their possible effects on energy planning. U.S. national and state climate policy actions include a variety of traditional approaches such as funding mechanisms (incentives and disincentives); regulations (caps, codes, and standards); technical assistance (direct or in kind); research and development; information and education; and monitoring and reporting (including impact disclosure) (Rose and Zhang, 2004). Covered sectors include power generation, oil and gas, residential, commercial, industry, transportation, waste management, agriculture, and forestry. These sectors cut across private and public sector facilities and programs, as well as producers and consumers of energy (Peterson and Rose, 2006).

A variety of policy alternatives and mechanisms are described and analyzed in published literatures, including production tax credits (incorporated in the Energy Policy Act of 2005), investment tax credits, renewable energy portfolio standards, and state or regional greenhouse gas initiatives.

### 4.2.2 Possible Effects On Energy Production And Use *Technologies*

Perhaps the best-documented case of indirect effects of climate change on energy production and use in the United States is effects of climate change policy on technology research and development and on technology preferences and choices.

For instance, if the world moves toward concerted action to stabilize concentrations of greenhouse gases (GHG) in the earth's atmosphere, the profile of energy resources and technologies being used in the U.S. – on both the production and use sides – would have to change significantly (CCTP, 2005). Developing innovative energy technologies and approaches through science and technology research and development is widely seen as a key to reducing the role of the energy sector as a driver of climate change. Considering various climate change scenarios, researchers have modeled a number of different pathways for the world and for various regions, including the U.S., in order to inform discussions about technology options that might contribute to energy system strategies (e.g., Edmonds et al., 1996; Akimoto et al., 2004; Hoffert et al., 2002; van Vuuren et al., 2004; Kainuma et al., 2004; IPCC, 2005a; Kurosawa, 2004; Pacala and Socolow, 2004 and Paltsev et al., 2005). Recently published scenarios in CCSP SAP 2.1a, explore the U.S. implications of alternative stabilization levels of anthropogenic greenhouse gases in the atmosphere, and they explicitly consider the economic and technological foundations of such response options (CCSP, 2007a). In addition, there have been important recent developments in scenario work in the areas of non-carbon dioxide GHGs, land use and forestry emission and sinks, emissions of radiatively important non-GHGs such as black and organic carbon, and analyses of uncertainties, among many issues in increasing mitigation options and reducing costs (Nakicenovic and Riahi, 2003; IPCC, 2005b; van Vuuren et al., 2006; Weyant et al., 2006; and Placet et al., 2004).

These references indicate that an impressive amount of emissions reductions could be achieved through combinations of many different technologies, especially if diversified tech-

nology advancement is assumed. Although the full range of effects in the future is necessarily speculative, it is possible that successful development of such advanced technologies could result in potentially large economic benefits, compared with emission reductions without significant technological progress. When the costs of achieving different levels of emission reductions have been compared for cases with and without advanced technologies, many of the advanced technology scenarios projected that the cost savings from advancement would be significant (CCTP, 2005; Weyant, 2004; IPCC, 2007; CCSP, 2007a). Note, however, that there is considerable "inertia" in the nation's energy supply capital stock because institutions that have invested in expensive facilities prefer not to have them converted into "stranded assets." Note also that any kind of rapid technological transformation would be likely to have cross-commodity cost/price effects, e.g., on costs of specialized components in critical materials that are in greater demand.

### 4.2.3 Possible Effects On Energy Production And Use Institutions

Climate change could affect the institutional structure of energy production and use in the United States, although relatively little research has been done on such issues. Institutions include energy corporations, electric utilities, governmental organizations at all scales, and nongovernmental organizations. Their niches, size and structure, and operation tend to be sensitive to changes in "market" conditions from any of a variety of driving forces, these days including such forces as globalization, technological change, and social/cultural change (e.g., changes in consumer preferences). Climate change is likely to interact with other driving forces in ways that could affect institutions concerned with energy production and use.

Most of the very limited research attention to this type of effect has been focused on effects of climate change policy (e.g., policy actions to reduce greenhouse gas emissions) on U.S. energy institutions, such as on the financial viability of U.S. electric utilities (see, for instance, WWF, 2003). Other effects could emerge from changes in energy resource/technology mixes due to climate change: e.g., changes in renewable energy resources and costs or changes in energy R&D investment patterns.

Most of these issues are speculative at this time, but identifying them is useful as a basis for further discussion. Issues would appear to include effects on planning, above.

#### 4.2.3.1 Effects on the Institutional Structure of the Energy Industry

Depending on its impacts, climate change could encourage large energy firms to move into renewable energy areas that have been largely the province of smaller firms, as was the case in some instances in the wake of the energy "shocks" of the 1970s (e.g., Flavin and Lenssen, 1994). This kind of diversification into other "clean energy" fields could be reflected in horizontal and/or vertical integration. Possible effects of climate change on these and other institutional issues (such as organizational consolidation vs fragmentation) have not been addressed systematically in the research literature; but some large energy firms are exploring a wider range of energy technologies and some large multinational energy technology providers are diversifying their product lines to be prepared for possible changes in market conditions.

#### 4.2.3.2 Effects on Electric Utility Restructuring

Recent trends in electric utility restructuring have included increasing competition in an open electricity supply marketplace, which has sharpened attention to keeping O&M costs for infrastructure as low as possible. Some research literature suggests that one side-effect of restructuring has been a reduced willingness on the part of some utilities to invest in environmental protection beyond what is absolutely required by law and regulation (Parker, 1999; Senate of Texas, 1999), although this issue needs further study. If climate change introduces new risks for utility investment planning and reliability, it is possible that policies and practices could encourage greater cooperation and collaboration among utilities.

#### 4.2.3.3 Effects on the Health of Fossil Fuel-Related Industries

If climate change is associated with policy and associated market signals that decarbonization of energy systems, industries focused on the production of fossil fuels, converting them into useful energy forms, transporting them to demand centers, and providing them to users could face shrinking markets and profits. The coal industry seems especially endangered in such an eventuality. In the longer run, this type of effect depends considerably on technological change: e.g., affordable carbon capture and sequestration, fuel cells, and efficiency improvement. It is possible that industries (and regions) concentrated on fossil fuel extraction, processing, and use will seek to diversify as a hedge against risks of economic threats from climate change policy.

#### 4.2.3.4 Effects on Other Supporting Institutions Such as Financial and Insurance Industries

Many major financial and insurance institutions are gearing up to underwrite emission trading contracts, derivatives and hedging products, wind and biofuel crop guarantee covers for renewable energy, and other new financial products to support carbon emission trading, while they are concerned about exposure to financial risks associated with climate change impacts. In recent years, various organizations have tried to engage the global insurance industry in the climate change debate. Casualty insurers are concerned about possible litigation against companies responsible for excessive GHG emissions, and property insurers are concerned about future uncertainties in weather damage losses. However, it is in the field of adaptation where insurers are most active, and have most to contribute. Two hundred major companies in the financial sector around the world have signed up to the UN Environment Program's - Finance Initiative, and 95 institutional investment companies have so far signed up to the Carbon Disclosure Project. They ask businesses to disclose investment-relevant information concerning their GHGs. Their website provides a comprehensive registry of GHGs from public corporations. More than 300 of the 500 largest companies in the world now report their emissions on this website, recognizing that institutional investors regard this information as important for shareholders (Crichton, 2005).

## 4.3 POSSIBLE EFFECTS ON ENERGY-RELATED DIMENSIONS OF REGIONAL AND NATIONAL ECONOMIES

It is at least possible that climate change could have an effect on regional economies by impacting regional comparative advantages related to energy availability and cost. Examples could include regional economies closely associated with fossil fuel production and use (especially coal) if climate change policies encourage decarbonization, regional economies dependent on affordable electricity from hydropower if water supplies decrease or increase, regional economies closely tied to coastal energy facilities that could be threatened by more intense coastal storms (Chapter 3), and regional economies dependent on abundant electricity supplies if demands on current capacities increase or decrease due to climate change.

Attempts to estimate the economic impacts that could occur 50–100 years in the future have been made using various climate scenarios, but the interaction of climate and the nation's economy remains very difficult to define. Most studies of the economic impacts of global warming have analyzed the impacts on specific sectors (such as agriculture) or on regional ecosystems (e.g. Fankhauser, 1995; Mendelsohn and Neumann, 1999; Nordhaus and Boyer, 2000; Mendelsohn et al., 1994; Tol, 2002; Nordhaus, 2006). However, not many impact studies have concentrated on the energy sector. Significant uncertainties therefore surround projections of climate change induced energy sector impacts on the U.S. or regional economies. Changnon estimated that annual national economic losses from the energy sector will outweigh the gains in years with major weather and climate extremes (Changnon, 2005). Jorgenson et al., 2004, studied impacts of climate change on various sectors of the U.S. economy from 2000 – 2100. In three optimistic scenarios, they conclude that increased energy availability and cost savings from reduced natural gas-based space heating more than compensate for increased expenditures on electricity-based space cooling. These unit cost reductions appear as productivity increases and, thus, improve the economy, whereas other three pessimistic scenarios show that electricity-based space conditioning expe-

riences relatively larger productivity losses than does space conditioning from coal, wood, petroleum or natural gas; accordingly its (direct) unit cost rises faster and thus produces no benefits to the economy. Additionally, higher domestic prices discourage exports and promote imports leading to a worsening real trade balance. According to Mendelsohn et al., 2000, the U.S. economy could benefit from the climate change induced energy sector changes. However, Mendelsohn and Williams, 2004 suggest that climate change will cause economic damages in the energy sector in every scenario. They suggest that temperature changes cause most of the energy impacts. Larger temperature increases generate significantly larger economic damages. The damages are from increased cooling expenditures required to maintain desired indoor temperatures. In the empirical studies, these cost increases outweighed benefits of the reduced heating expenditures unless starting climates are very cool (Mendelsohn and Neumann, 1999; Mendelsohn, 2001) (also see Chapter 2).

In California, a preliminary assessment of the macroeconomic impacts associated with the climate change emission reduction strategies (CEPA, 2006) shows that, while some impacts on the economy could be positive if strategies reduce energy costs, other impacts might be less positive. For example, the study emphasizes that even relatively small changes in in-state hydropower generation result in substantial extra expenditure burdens on an economy for energy generation, because losses in this "free" generation must be purchased from other sources; for example, a 10% decrease in hydroelectric supply would impose a cost of approximately $350 million in additional electricity expenditures annually (Franco and Sanstad, 2006). Whereas electricity demand is projected to rise in California between 3 to 20 % by the end of this century, peak electricity demand would increase at a faster rate. Since annual expenditures of electricity demand in California represent about $28 billion, even such a relatively small increase in energy demand would result in substantial extra energy expenditures for energy services in the state; a 3 % increase in electricity demand by 2020 would translate into about $930 million (in 2000 dollars) in additional electricity expenditures (Franco and Sanstad, 2006). Particular concerns are likely to exist in areas where summer electricity loads already strain supply capacities (e.g., Hill and Goldberg 2001; Kelly et al. 2005; Rosenzweig and Solecki, 2001) and where transmission and distribution networks have limited capacities to adapt to changes in regional demands, especially seasonally (e.g., London Climate Change, Partnership 2002).

Rose and others have examined effects of a number of climate change mitigation policies on U.S. regions in general and the Susquehanna River basin in particular (Rose and Oladosu, 2002; Rose and Zhang, 2004; Rose et al., 1999; Rose et al., 2006). In general, they find that such policy options as emission permits tradable among U.S. regions might have less than expected effects, with burdens impacting at least one Southern region that needs maximum permits but whose economy is not among the nation's strongest. Additionally, they discuss Pennsylvania's heavy reliance on coal production and use infrastructure that increases the price of internal carbon dioxide mitigation. They suggest that the anomalies stem from the fact that new entrants, like Pennsylvania, into regional coalitions for cap-and-trade configuration may raise the permit price, may undercut existing states' permit sales, and may be able to exercise market power. Particularly, they raise an issue of the "responsibility" for emissions. Should fossil fuel producing regions take the full blame for emissions, or are the using regions also responsible? They find that aggregate impacts of a carbon tax on the Susquehanna River Basin would be negative but quite modest.

Concerns remain, however, that aggressive climate policy interventions to reduce GHG emissions could negatively affect regional economies linked to coal and other fossil energy production. Concerns also exist that climate change itself could affect the economies of areas exposed to severe weather events (positively or negatively) and areas whose economies are closely linked to hydropower and other aspects of the "energy-water nexus."

## 4.4 POSSIBLE RELATIONSHIPS WITH OTHER ENERGY-RELATED ISSUES

Many other types of indirect effects are possible, although relatively few have received research attention. Without asserting that this listing is comprehensive, such effects might include the following types.

### 4.4.1 Effects Of Climate Change In Other Countries On U.S. Energy Production And Use

We know from recent experience that climate variability outside the U.S. can affect energy conditions in the U.S.; an example is an unusually dry year in Spain in 2005 that led the country to enter the international LNG market to compensate for scarce hydropower, which in turn raised LNG prices for U.S. consumption (Alexander's Gas & Oil Connections, 2005). It is important, therefore, to consider possible effects of climate change not only on international energy product suppliers and international energy technology buyers but also on other countries whose participation in international markets could affect U.S. energy availability and prices from international sources, which could have implications for energy security (see below). Climate change-related energy supply and price effects could be coupled with other price effects of international trends on U.S. energy, infrastructures, such as effects of aggressive programs of infrastructure development on China and India.

As indicated in Chapter 2, a particularly important case is U.S. energy inputs from Canada. Canada is the largest single source of petroleum imports by the U.S. (about 2.2 million barrels per day) and exports more than 15% of the natural gas consumed in the U.S. (EIA 2005a, 2006). In 2004, it exported to the U.S. 33 MWh of electricity, compared with imports of 22.5 MWh (EIA, 2005b). Climate change could affect electricity exports and imports, for instance if electricity demands for space cooling increase in Canada or if climate change affects hydropower production in that country.

### 4.4.2 Effects Of Climate Change On Energy Prices*

A principal mechanism in reducing vulnerabilities to climate-related (and other) changes potentially affecting the energy sector is the operation of the energy market, where price variation is a key driver. Effects of climate change on energy prices are in fact interwoven with effects of energy prices on risk management strategies, in a dynamic that could work in both directions at once; and it would be useful to know more about roles of energy markets in reducing vulnerabilities to climate change impacts, along with possible adaptations in the functioning of those markets. Although price effects of climate change itself are not analyzed in the literature, aside from effects of extreme events such as Hurricane Katrina, substantial research has been done on possible energy price effects of greenhouse gas emission reductions.

Estimates of costs of emission reduction vary widely according to assumptions about such issues as how welfare is measured, ancillary benefits, and effects in stimulating technological innovation; and therefore any particular set of cost estimates includes considerable uncertainty. According to an Interlaboratory Working Group (IWG, 2000), benefits of emission reduction would be comparable to costs, and the National Commission on Energy Policy 2004 estimates that its recommended policy initiatives would be, on the whole, revenue-neutral with respect to the federal budget. Other participants in energy policymaking, however, are convinced that truly significant carbon emission reductions would have substantial economic impacts (GAO, 2004).

Globally, IPCC, 2001 projected that total $CO_2$ emissions from energy supply and conversion could be reduced in 2020 by 350 to 700 Mt C equivalents per year, based on options that could be adopted through the use of generally accepted policies, generally at a positive direct cost of less than U.S.$100 per t C equivalents. Based on DOE/EIA analyses in 2000, this study includes estimates of the cost of a range of specific emission-reducing technologies for power

* Adapted in part from *CCSP SAP 2.2. State of the Carbon Cycle Report*, Chapter 6, "Energy Conversion."

generation, compared with coal-fired power, although the degree of uncertainty is not clear. Within the United States, the report estimated that the cost of emission reduction per metric ton of carbon emissions reduced would range from –$170 to +$880, depending on the technology used. Marginal abatement costs for the total United States economy, in 1990 U.S. dollars per metric ton carbon, were estimated by a variety of models compared by the Energy Modeling Forum at $76 to $410 with no emission trading, $14 to $224 with Annex I trading, and $5 to $123 with global trading.

Similarly, the National Commission on Energy Policy 2004 considered costs associated with a tradable emission permit system that would reduce United States national greenhouse gas emission growth from 44% to 33% from 2002 to 2025, a reduction of 760 Mt $CO_2$ (207 Mt C) in 2025 compared with a reference case. The cost would be a roughly 5% increase in total end-use expenditures compared with the reference case. Electricity prices would rise by 5.4% for residential users, 6.2% for commercial users, and 7.6% for industrial users.

The IWG 2000 estimated that a domestic carbon trading system with a $25/t C permit price would reduce emissions by 13% compared with a reference case, or 230 Mt $CO_2$ (63 Mt C), while a $50 price would reduce emissions by 17 to 19%, or 306 to 332 Mt $CO_2$ (83-91 Mt C). Both cases assume a doubling of United States government appropriations for cost-shared clean energy research, design, and development.

Net costs to the consumer, however, are balanced in some analyses by benefits from advanced technologies that are developed and deployed on an accelerated schedule due to policy interventions and changing public preferences. The U.S. Climate Change Technology Program, 2005: pp. 3–19, illustrates how costs of achieving different stabilization levels can conceivably be reduced substantially by the use of advanced technologies, and IWG (2000) estimates that net end-user costs of energy can actually be reduced by a domestic carbon trading system if it accelerates the market penetration of more energy-efficient technologies (see Section 4.2.2 above).

### 4.4.3 Effects Of Climate Change On Environmental Emissions

Climate change is very likely to lead to reductions in environmental emissions from energy production and use in the U.S., although possible effects of climate change responses are complex. For instance, cap and trade policy responses might not translate directly into lower total emissions. In general, however, the available research literature indicates that climate change policy will affect choices of energy resources and technologies in ways that, overall, reduce greenhouse gas and other environmental emissions (see indirect impacts on technologies above).

### 4.4.4 Effects Of Climate Change On Energy Security

Climate change relates to energy security because different drivers of energy policy interact. As one example, some strategies to reduce oil import dependence, such as increased use of renewable energy sources in the U.S., are similar to strategies to reduce GHG emissions as a climate change response (e.g., IEA, 2004; O'Keefe, 2005). Other strategies such as increased domestic fossil fuel production and use could be contradictory to climate change policies. The complexity of connections between climate change responses and energy security concerns can be illustrated by choices between uses of biomass to reduce fossil fuel use in electricity generation, a priority for net greenhouse gas emissions, and uses of biomass to displace oil and gas imports, a priority for energy security policy. Although the relative effects of the two options are not entirely unrelated (i.e., both could have some effect in reducing oil and gas imports and both could have some effect in reducing net greenhouse gas emissions), the balance in contributions to these two policy priorities would be different.

As another example, energy security relates not only to import dependence but also to energy system reliability, which can be threatened by possible increases in the intensity of severe weather events. A different kind of issue is potential impacts of abrupt climate change in the longer run. One study has suggested that abrupt climate change could lead to very serious international security threats, including threats of global energy crises, as countries act to defend and secure supplies of essential commodities (Schwarz and Randall, 2004). Clearly, then, relationships between climate change response and energy security are complex, but they are potentially important enough to deserve further study.

### 4.4.5 Effects Of Climate Change On Energy Technology And Service Exports

Finally, climate change could affect U.S. energy technology and service exports. It is very likely that climate change will have some impacts on global energy technology, institutional, and policy choices. Effects of these changes on U.S. exports would probably be determined by whether the U.S. is a leader or a follower in energy technology and policy responses to concerns about climate change. More broadly, carbon emission abatement actions by various countries are likely to affect international energy flows and trade flows in energy technology and services (e.g., Rutherford, 2001). In particular, one might expect flows of carbon-intensive energy forms and energy technologies and energy-intensive products to be affected.

## 4.5 SUMMARY OF KNOWLEDGE ABOUT INDIRECT EFFECTS

Regarding indirect effects of climate change on energy production and use in the United States, the available research literature tells us the most about possible changes in energy resource/technology preferences and investments, along with associated reductions in GHG emissions and effects on energy prices. Less-studied but also potentially important are possible impacts on the institutional structure of energy supply in the United States, responding to changes in perceived investment risks and emerging market and policy realities, and possible interactions between energy prices and roles of energy markets in managing risks and reducing vulnerabilities. Perhaps the most important insight from the limited current research literature is that climate change will affect energy production and use not only as a driving force in its own right but in its interactions with other driving forces such as energy security. Where climate change response strategies correspond with other issue response strategies, they can add force to actions such as increased reliance on domestic noncarbon energy supply sources. Where climate change impacts contradict other driving forces for energy decisions, it is much less clear what their net effect would be on energy production and use.


# Conclusions and Research Priorities

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## 5.1 INTRODUCTION

*The previous chapters have summarized a variety of currently available information about effects of climate change on energy production and use in the United States. For two reasons, it is important to be careful about drawing firm conclusions about effects at this time. One reason is that the research literatures on many of the key issues are limited, supporting an identification of issues but not a resolution of most uncertainties. A second reason is that, as with many other categories of climate change effects in the U.S., the effects depend on a wide range of factors beyond climate change alone, such as patterns of economic growth and land use, patterns of population growth and distribution, technological change, and social and cultural trends that could shape policies and actions, individually and institutionally.*

Accordingly, this final chapter of SAP 4.5 will sketch out what appear, based on the current knowledge base, to be the most likely types of effects on the energy sector. These should be considered along with effects on other sectors that should be considered in risk management discussions in the near term. As indicated in Chapter 1, conclusions are related to degrees of likelihood: likely (2 chances out of 3), very likely (9 chances out of 10), or virtually certain (99 chances out of 100). The chapter will then discuss issues related to prospects for energy systems in the U.S. to adapt to such effects, although literatures on adaptation are very limited. Finally, it will suggest a limited number of needs for expanding the knowledge base so that, when further assessments on this topic are carried out, conclusions about effects can be offered with a higher level of confidence.

## 5.2 CONCLUSIONS ABOUT EFFECTS

Based on currently available projections of climate change in the United States, a number of conclusions can be suggested about likely effects on energy *use* in the U.S. over a period of time addressed by the research literature (near to midterm). Long-term conclusions are difficult due to uncertainties about such driving forces as technological, change, institutional change, and climate change policy responses.

- Climate change will mean reductions in total U.S. energy demand for space heating for buildings, with effects differing by region (virtually certain).
- Climate change will mean increases in total U.S. energy demand for space cooling, with effects differing by region (virtually certain).
- Net effects on energy use will differ by region, with net lower total energy requirements for buildings in net heating load areas and net higher energy requirements in net cooling load areas, with overall impacts affected by patterns of interregional migration – which are likely to be in the direction of net cooling load regions – and investments in new building stock (virtually certain).

- Temperature increases will be associated with increased peak demands for electricity (very likely).
- Other effects of climate change are less clear, but some could be nontrivial: e.g., increased energy use for water pumping and/or desalination in areas that see reductions in water supply (very likely).
- Lower winter energy demands in Canada could add to available electricity supplies for a few U.S. regions (likely).

A number of conclusions can be offered with relatively high levels of confidence about effects of climate change on energy *production and supply* in the U.S., but generally the research evidence is not as strong as for effects on energy use:

- Changes in the distribution of water availability in the U.S. will affect power plants; in areas with decreased water availability, competition for water supplies will increase between energy production and other sectors (virtually certain).
- Temperature increases will decrease overall thermoelectric power generation efficiency (virtually certain).
- In some regions, energy resource production and delivery systems are vulnerable to effects of sea level rise and extreme weather events, especially the Gulf Coast and the East Coast (virtually certain).
- In some areas, the siting of new energy facilities and systems could face increased restrictions, related partly to complex interactions among the wider range of water uses as well as sea-level rise and extreme event exposures (likely
- Incorporating possible climate change impacts into planning processes could strengthen energy production and distribution system infrastructures, especially regarding water resource management (likely).
- Hydropower production is expected to be directly and significantly affected by climate change, especially in the West and Northwest (very likely).
- Climate change is expected to mean greater variability in wind resources and direct solar radiation, substantially impacting the planning, siting, and financing of these technologies (likely).
- Increased temperatures and other climate change effects will affect energy transmission and distribution requirements, but these effects are not well-understood.

Overall, the current energy supply infrastructure is often located in areas where climate change impacts might occur, but large-scale disruptions are not likely except during extreme weather events. Most of the effects on fossil and nuclear electricity components are likely to be modest changes in water availability and/or cycle efficiency.

California is one U.S. state where impacts on both energy use and energy production have been studied with some care (See Box 5.1: California: A Case Study).

About *indirect effects of climate change on energy production and use* in the U.S., conclusions are notably mixed. Conclusions related to possible impacts of climate change policy interventions on technology choice and emissions can be offered with relatively high confidence based on published research:

- Climate change concerns are very likely to affect perceptions and practices related to risk management behavior in investment by energy institutions (very likely).
- Climate change concerns, especially if they are expressed through policy interventions, are almost certain to affect public and private sector energy technology R&D investments and energy resource/technology choices by energy institutions, along with associated emissions (virtually certain).
- Climate change can be expected to affect other countries in ways that in turn affect U.S. energy conditions (very likely).

Other types of possible indirect effects can be suggested as a basis for discussion, but conclusions must await further research:

- Climate change effects on energy production and use could in turn affect some regional economies, either positively or negatively (likely).
- Climate change may have some effects on energy prices in the U.S., especially associated with extreme weather events (very likely).
- Climate change concerns are likely to interact with some driving forces behind policies focused on U.S. energy security, such as reduced reliance on conventional petroleum products (likely).

These conclusions add up to a picture that is cautionary rather than alarming. Since in many cases effects that could be a concern to U.S. citizens and U.S. energy institutions are some decades in the future, there is time to consider strategies for adaptation to reduce possible negative impacts and take advantage of possible positive impacts.

**BOX 5.1 California: A Case Study**

California is unique in the United States as a state that has examined possible effects of climate change on its energy production and use in some detail (also see Box 2.2). Led by the California Energy Commission and supported by such nearby partners as the Electric Power Research Institute, the University of California–Berkeley, and the Scripps Institution of Oceanography, the state is developing a knowledge base on this subject that could be a model for other states and regions (as well as the nation as a whole).

Generally, the analyses to date (many of which are referenced in Chapters 2 and 3) indicate that electricity demand will grow due to climate change, with an especially close relationship between peak electricity demand and temperature increases (Franco and Sanstad 2006), and water supply – as an element of the "energy-water nexus" – will be affected by a reduction in the Sierra snowpack (by as much as 70-90 % over the coming century: Vicuña et al. 2006). Patterns of urbanization could add to pressures for further energy supplies. Adaptations to these and other climate change impacts appear possible, but they could be costly (Franco 2005). Overall economic impacts will depend considerably on the effectiveness of response measures, which tend currently to emphasize emission reduction but also consider impact scenarios and potential adaptation measures (CEPA 2006).

Other relevant studies of the California context for climate change effects reinforce an impression that effects of warming and snowpack reduction could be serious (Hayhoe et al. 2004) and that other ecosystems related to renewable energy potentials could be affected as well (Union of Concerned Scientists 1999).

## 5.3 CONSIDERING PROSPECTS FOR ADAPTATION

The existing research literature tends to treat the U.S. energy sector mainly as a *driving force* for climate change rather than a sector *subject to impacts* from climate change. As a result, there is very little literature on adaptation of the energy sector to effects of climate change, and the following discussion is therefore largely speculative.

Generally, both energy users and providers in the U.S. are accustomed to changes in conditions that affect their decisions. Users see energy prices fluctuate with international oil market conditions and with Gulf Coast storm behavior, and they see energy availability subject to short-term shortages for a variety of reasons (e.g., the California energy market crises of 2000/2001 or electricity blackouts in some Northeastern cities in 2003). Energy providers cope with shifting global market conditions, policy changes, financial variables such as interest rates for capital infrastructure lending, and climate variability. In many ways, the energy sector is among the most resilient of all U.S. economic sectors, at least in terms of responding to changes within the range of historical experience. For instance, electric utilities routinely consider planning and investment strategies that consider weather variables (Niemeyer, 2005); and one important guide to adaptation to climate *change* is what makes sense in adapting to climate *variability* (Franco 2005).

On the other hand, such recent events as Hurricane Katrina (Box 5.2: Hurricane Katrina and the Gulf Coast: A Case Study) suggest that the U.S. energy sector is better at responding to relatively short-term variations and uncertainties than to changes that reach beyond the range of familiar short-term variabilities (Niemeyer 2005). In fact, the confidence of U.S. energy institutions about their ability to reduce exposure to risks from short-term variations might tend to reduce their resilience to larger long-term changes, unless an awareness of risks from such long-term changes is heightened.

Adaptations to effects of climate change on energy *use* may focus on increased demands for space cooling in areas affected by warming and associated increases in total energy consumption costs. Alternatives could include reducing costs of cooling for users through energy efficiency improvement in cooling equipment and building envelopes; responding to likely increases in demands for electricity for cooling through expanded generation capacities, expanded interties, and possibly increased capac-

**BOX 5.2 Hurricane Katrina and the Gulf Coast: A Case Study**

It is not possible to attribute the occurrence of Hurricane Katrina, August 29, 2005, to climate change; but projections of climate change say that extreme weather events are very likely to become more intense. If so (e.g., more of the annual hurricanes at higher levels of wind speed and potential damages), then the impacts of Katrina are an indicator of possible impacts of one manifestation of climate change.

Impacts of Katrina on energy systems in the region and the nation were dramatic at the time, and some impacts remained many months later. The hurricane itself impacted coastal and offshore oil and gas production, offshore oil port operation (stopping imports of more than one million bbl/d of crude oil), and crude oil refining along the Louisiana Gulf Coast (Figures 3.4 a-d). Within only a few days, oil product and natural gas prices had risen significantly across the U.S. As of mid-December 2005, substantial oil and gas production was still shut-in, and refinery shutdowns still totalled 367, 000 bbl/d (EIA 2005) (see Chapter 3).

Possibilities for adaptation to reduce risks of damages from future Katrinas are unclear. They might include such alternatives as hardening offshore platforms and coastal facilities to be more resilient to high winds, wave action, and flooding (potentially expensive) and shifting the locations of some coastal refining and distribution facilities to less vulnerable sites, reducing their concentration in the Gulf Coast. (potentially very expensive).

ities for storage; and responding to concerns about increased peak demand in electricity loads, especially seasonally, through contingency planning for load-leveling. Over a period of several decades, for instance, technologies are likely to respond to consumer concerns about higher energy bills where they occur.

Many technologies that can enable adaptations to effects on energy *production and supply* are available for deployment. The most likely adaptation in the near term is an increase in perceptions of uncertainty and risk in longer-term strategic planning and investment, which could seek to reduce risks through such approaches as diversifying supply sources and technologies and risk-sharing arrangements.

Adaptation to *indirect effects* of climate change on the energy sector is likely to be bundled with adaptation to other issues for energy policy and decision-making in the U.S., such as energy security: for instance, in the development of lower carbon-emitting fossil fuel use technology ensembles, increased deployment of renewable energy technologies, and the development of alternatives to fossil fuels and effects on energy institutional structures. Issues related to effects of climate change on other countries linked with U.S. energy conditions are likely to be addressed through attention by both the public and private sectors to related information systems and market signals.

It seems possible that adaptation challenges would be greatest in connection with possible increases in the intensity of extreme weather events and possible significant changes in regional water supply regimes. More generally, adaptation prospects appear to be related to the magnitude and rate of climate change (e.g., how much the average temperature rises before stabilization is achieved, how rapidly it moves to that level, and how variable the climate is at that level), with adaptation more likely to be able to cope with effects of lesser amounts, slower rates of change, and less variable climate (Wilbanks et al., 2007).

Generally, prospects for these types of adaptations depend considerably on the level of awareness of possible climate changes at a relatively localized scale and possible implications for energy production and use – the topic of this study. When the current knowledge base to support such awareness is so limited, this suggests that expanding the knowledge base is important to the energy sector in the United States.

## 5.4 NEEDS FOR EXPANDING THE KNOWLEDGE BASE

Expanding the knowledge base about effects of climate change on energy production and use in the United States is not just a responsibility of the federal government. As the work of such institutions as the Electric Power Research Institute and the California Energy Commission demonstrates, a wide variety of parts of U.S. society have knowledge, expertise, and data to contribute to what should be a broad-based multi-institutional collaboration.

Recognizing that roles in these regards will differ among federal and state governments, industry, nongovernmental institutions, and academia and that all parties should be involved in discussions about how to proceed, this study suggests the following needs for expanding the knowledge base on its topic, some of which are rooted in broader needs for advances in climate change science.

### 5.4.1 General Needs

- Improved capacities to project climate change and its effects on a relatively fine-grained geographic scale, especially of precipitation changes and severe weather events: e.g., in order to support evaluations of impacts at local and small-regional scales, not only in terms of gradual changes but also in terms of extremes, since many energy facility decisions are made at a relatively localized scale;
- Research on and assessments of implications of extreme weather events for energy system resiliency, including strategies for both reducing and recovering from impacts;
- Research on and assessments of potentials, costs, and limits of adaptation to risks of adverse effects, for both supply and use infrastructures;
- Research on efficiency of energy use in the context of climate warming, with an em-

phasis on technologies and practices that save cooling energy and reduce electrical peak load;

- Research on and assessments of implications of changing regional patterns of energy use for regional energy supply institutions and consumers;
- Improvements in the understanding of effects of changing conditions for renewable energy and fossil energy development and market penetration on regional energy balances and their relationships with regional economies;
- In particular, improvements in understanding likely effects of climate change in Arctic regions and on storm intensity to guide applications of existing technologies and the development and deployment of new technologies and other adaptations for energy infrastructure and energy exploration and production in these relatively vulnerable regions; and
- Attention to linkages and feedbacks among climate change effects, adaptation, and mitigation; to linkages between effects at different geographic scales; and relationships between possible energy effects and other possible economic, environmental, and institutional changes (Parson et al., 2003; Wilbanks, 2005).

### 5.4.2 Needs Related To Major Technology Areas

- Improving the understanding of potentials to increase efficiency improvements in space cooling;
- Improving information about interactions among water demands and uses where the quantity and timing of surface water discharge is affected by climate change;
- Improving the understanding of potential climate change and localized variability on energy production from wind and solar technologies;
- Developing strategies to increase the resilience of coastal and offshore oil and gas production and distribution systems to extreme weather events;
- Pursuing strategies and improved technology potentials for adding resilience to energy supply systems that may be subject to stress under possible scenarios for climate change;
- Improving understandings of potentials to improve resilience in electricity supply systems through regional intertie capacities and distributed generation; and
- Research on and assessments of the impacts of severe weather events on sub-sea pipeline systems, especially in the Gulf of Mexico, and strategies for reducing such impacts.[4]

Other needs for research exist as well, and the process of learning more about this topic in coming years may change perceptions of needs and priorities; but based on current knowledge, these appear to be high priorities in the next several years.

[4] Note that CCSP SAP 4.7, The Impacts of Climate Change on Transportation: A Gulf Coast Study, considers imacts on pipelines and other transportation infrastructures in the Gulf Coast region (CCSP, 2007b).

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## TECHNICAL NOTE: METHODS FOR ESTIMATING ENERGY CONSUMPTION IN BUILDINGS

Previous authors have used a number of approaches to estimate the impact of climate change on energy use in U.S. buildings. Many of the researchers translate changes in average temperature change on a daily, seasonal, or annual basis into heating and cooling degree days, which are then used in building energy simulation models to project demand for space heating and space cooling (e.g., Rosenthal et al. 1995, Belzer et al. 1996, and Amato et al. 2005). Building energy simulation is often done directly with average climate changes used to modify daily temperature profiles at modeled locations (Scott et al. 2005, and Huang 2006). (See Box A.1 on heating and cooling degree-days.)

Building energy simulation models such as CALPAS3 (Atkinson et al. 1981), DOE-2 (Winkelmann et al. 1993), or FEDS and BEAMS (PNNL 2002, Elliott et al. 2004) have been used to analyze the impact of climate warming on the demand for energy in individual commercial buildings only (Scott et al. 1994) and in groups of commercial and residential buildings in a variety of locations (Loveland and Brown 1990, Rosenthal et al. 1995, Scott et al. 2005, and Huang 2006).

Other researchers have used econometrics and statistical analysis techniques (most notably the various Mendelsohn papers discussed in Chapter 2, but also the Belzer et al. 1996 study using the CBECS microdata, and Sailor and Muñoz 1997, Sailor 2001, Amato et al. 2005, Ruth and Lin 2006, and Franco and Sanstad 2006, using various state-level time series.) A subcategory of the econometric technique is cross-sectional analysis. For example, Mendelsohn performed cross-sectional econometric analysis of the RECS and CBECS microdata sets to determine how energy use in the residential and commercial building stock relates to climate (Morrison and Mendelsohn 1999; Mendelsohn 2001), and then used the resulting equations to estimate the future impact of warmer temperatures on energy consumption in residential and commercial buildings. Mendelsohn 2003 and Mansur et al. 2005 subsequently elaborated the approach into a complete and separate set of discrete-continuous choice models of energy demand in residential and commercial buildings.

Finally, Hadley et al. 2004, 2006, directly incorporated changes in heating degree-days and cooling degree-days expected as a result of climate change into the residential and commercial building modules of the Energy Information Administration's National Energy Modeling System, so that their results incorporated U.S. demographic trends, changes in building stock and energy-using equipment, and (at least some) consumer reactions to energy prices and climate at a regional level. Hadley et al. translated temperatures from a single climate scenario of the Parallel Climate Model

**BOX A.1 Heating and Cooling Degree-Days and Building Energy Use**

Energy analysts often refer to concepts called heating and cooling degree-days when calculating the impact of outdoor temperature on energy use in buildings. Buildings are considered to have a minimum energy use temperature where the building is neither heated nor cooled, and all energy use is considered to be nonclimate sensitive. This is called the "balance point" for the building. Each degree deviation from that balance point temperature results in heating (if the temperature is below the balance point) or cooling (if the temperature is above the balance point). For example, if the balance point for a building is 60°F and the average outdoor temperature for a 30-d period is 55°F, then there are 5 x 30 heating degree days for that period. Energy demand is usually considered to increase or decrease proportionately with increases in either heating degree-days or cooling degree-days.

Balance points by default are usually considered to be 65°F because many weather datasets come with degree-days already computed on that basis (See Amato et al 2005). However, empirical research on regional datasets and on the RECS and CBECS microdata sets suggests that regional variations are common. In Massachusetts, for example, Amato et al. found a balance point temperature for electricity in the residential sector of 60°F and 55°F for the residential sector. Belzer et al. (1996) found that the newer commercial buildings have even lower balance point temperatures, probably because of tighter construction and the dominance of lighting and other interior loads that both aid with heating and make cooling more of a challenge.

into changes in heating degree days (HDDs) and cooling degree-days (CDDs) that are population-averaged in each of the nine U.S. Census divisions (on a 65° F base –against the findings of Rosenthal et al., Belzer et al., and Mansur et al. 2005, all of which projected a lower balance point temperature for cooling and a variation in the balance point across the country). They then compared these values with 1971-2000 average HDDs and CDDs from the National Climate Data Center for the same regions. The changes in HDD and CDD were then used to drive changes in a special version (DD-NEMS) of the National Energy Modeling System (NEMS) of the U.S. Energy Information Administration, generally used to provide official energy consumption forecasts for the Annual Energy Outlook (EIA 2006). Table A.1 contains a summary of methods used in the various studies employed in this chapter.

**Table A.1 Methods Used in U.S. Studies of the Effects of Climate Change on Engergy Demand in Buildings**

| Authors | Methods | Comments |
|---|---|---|
| **National Studies** | | |
| Linder-Inglis 1989 | Electric utility planning model | Electricity only. Results available for 47 state and substate service areas. Calculates peak demand. |
| Rosenthal et al. 1995 | Reanalysis of building energy consumption in EIA Annual Energy Outlook | Energy-weighted national averages of census division-level data |
| Belzer et al. 1996 | Econometrics on CBECS commercial sector microdata | Used HDD and CDD and estimated energy balance points |
| Mendelsohn 2001 | Econometric analysis of RECS and CBECS microdata | Takes into account energy price forecasts, market penetration of air conditioning. Precipitation increases 7%. |
| Scott et al. 2005 | Building models (FEDS and BEAMS) | Varies by region. Allows for growth in residential and commercial building stock, but not increased adoption of air conditioning in response to warming |
| Mansur et al. 2005 | Econometric analysis of RECS and CBECS microdata | Takes into account energy price forecasts, market penetration of air conditioning. Precipitation increases 7%. Affects both fuel choice and use. |
| Hadley et al. 2004; 2006 | NEMS energy model, modified for changes in degree-days | Primary energy, residential and commercial combined. Allows for growth in residential and commercial building stock. |
| Huang et al. 2006 | DOE-2 building energy model | Impacts vary by region, building type. |
| **Regional Studies** | | |
| Loveland and Brown 1990 | CALPAS3 Building Energy Model | Single family detached house, commercial building, 6 individual cities |
| Baxter and Calandri 1992 | Building energy model | Electricity only, California. |
| Scott et al. 1994 | DOE-2 building energy model | Small office building, 4 specific cities |
| Sailor 2001 | Econometric on state time series | Total electricity per capita in 7 out of 8 energy-intensive states; one state (Washington) used electricity for space heating |
| Sailor and Pavlova 2003 | Econometric on state-level time series | Four states. Includes increased market saturation of air conditioning |
| Mendelsohn 2003 | Econometric on national cross sectional data on RECS and CBECS data | Impacts for California only. Residential and commercial. Expenditures on energy. |
| Amato et al. 2005 | Time series econometric on state data | Massachusetts (North), Winter monthly residential capita consumption, commercial monthly per employee consumption |
| Ruth and Lin 2006 | Time series econometric on state data | Maryland (borderline North-South), residential natural gas, heating oil, electricity expenditures |
| Franco and Sanstad 2006 | Regression of electricity demand in California Independent System Operator with average daily temperature anddaily consumption in the CallSO area in 2004, and the relationship between peak demand and average daily maximum temperature over the period 1961–1990 | Electricity only |

## ORGANIZATIONS AND INDIVIDUALS CONSULTED

| | |
|---|---|
| **Vicki Arroyo** | Pew Center |
| **Malcolm Asadoorian** | Massachusetts Institute of Technology |
| **Kelly Birkinshaw** | California Energy Commission |
| **Benjamin J. DeAngelo** | U.S. Environmental Protection Agency |
| **Richard Eckaus** | Massachusetts Institute of Technology |
| **Bill Fang** | Edison Electric Institute |
| **Guido Franco** | California Energy Commission |
| **Howard Gruenspecht** | Energy Information Administration |
| **Jay Gullege** | Pew Center |
| **Richard C Haut** | Houston Advanced Research Center |
| **Haroon S. Kheshgi** | ExxonMobil Research and Engineering Co. |
| **Joe Loper** | Alliance to Save Energy |
| **Sasha Mackler** | National Commission on Energy Policy |
| **Victor Niemeyer** | Electric Power Research Institute |
| **Paul Pike** | Ameren Corporation |
| **Will Polen** | U.S. Energy Association |
| **Walt Retzch** | American Petroleum Institute |
| **Terry Surles** | University of Hawaii |
| **Tom Wilson** | Electric Power Research Institute |
| **Laurie ten Hope** | California Energy Commission |
| **Barry Worthington** | U.S. Energy Association |
| **Kate Zyla** | Pew Center |

## GLOSSARY

# A

### Adaptation
In climate change discussions, refers to actions that respond to climate change risks and/or impacts by reducing sensitivity to climate variables and/or increasing coping capacity

### Aerosols
A substance packaged under pressure with a gaseous propellant for release as a spray of fine particles

### Ambient temperatures
The temperature of the air surrounding a power supply or heating/cooling medium

### Analytic-deliberative practices
Combining systematic analysis with processes for collective qualitative consideration of broader issues

### Aquifer
An underground bed or layer of earth, gravel, or porous stone that yields water

# B

### Biodiesel
An oxygenated fuel, primarily alkyl (methyl or ethyl) esters, produced from a range of biomass-derived feedstocks including oilseeds, waste vegetable oils, cooking oil, animal fats and trap grease, which can be used in blends or in "neat" form in compression-ignition engines to reduce emissions and improve engine performance

### Btus
British thermal units, a quantity of energy

### Building equipment
Energy-using equipment within a building, such as electric appliances

### Building shell
The external envelope of a building, including foundation, floor, walls, windows, outside doors, and roof

### Building stock
The total quantity of buildings in an area or sector of interest

# C

### Canadian model
A climate change projection model from the Canadian Climate Change Centre (CGCM1), used in the U.S. National Assessment of Possible Consequences of Climate Variability and Change (2001)

### Cap-and-trade
A market-based system of limiting emissions in which a limited number of emissions permits are issued in the aggregate (cap); these permits are then freely exchangeable in markets (trade)

### Cellulosic
Pertaining to cellulose, a constituent of plant tissues and fibers

### Climate change
Changes in climate that depart from normal variability, representing significant changes in averages and/or extremes

### Climate change impacts
Effects of climate changes such as temperature change, precipitation change, severe weather events, and sea level rise on human and/or natural systems

### Climate change related policies
Public policy interventions in response to concerns about or impacts of climate change

### Climate forcing effect
Increases in certain trace gas molecules in the atmosphere that change the balance between incoming solar radiation and re-radiation of energy into space, leading to long-term atmospheric warming

### Climate variability
Changes in climate around averages, not necessarily associated with climate change

### Climate-sensitive
Refers to systems or phenomena whose behavior is noticeably affected by differences in climate

### Closed-cycle cooling
A method of cooling power plants in which water is withdrawn from a body of water, passed through the facility to cool power-production processes, cooled down in a cooling tower or similar method, and then reused for cooling

### Combined cycle
An electric-power generating method in which combustible gases are burned in a combustion turbine (topping cycle) and high-temperature gases from that operation are used to raise steam that is passed through a steam turbine (bottoming cycle). Both cycles drive electric generators

## D

### Delivery forms
Forms in which energy is delivered to users: solid, liquid, gaseous, electricity

### Demographic
Related to the size, growth, and distribution of human populations

### Discrete-continuous choice models
A family of economic models in which the probability of a handful of choices (e.g., whether or not to select a particular heating technology) are modeled mathematically as a function of continuous variables such as income and price

### Distribution systems
Systems for moving energy delivery forms from producers to users

## E

### Econometric
A field of economics that applies statistical procedures to mathematical models

### Elasticities
Refers to changes in one variable as the result of changes in another variable

### Empirical
Derived from observation or experiment, generally implying quantitative data

### Energy consumption
The amount of fuels and electricity (measured in common units such as British thermal units or Btus) utilized during a period of time to provide a useful service such as heating, cooling, or transportation

### Energy conversion
Changing energy-bearing substances from one form to another; e.g., petroleum refining or electric power generation

### Energy demand
The quantities of energy desired in the marketplace at various prices.

### Energy infrastructure
The capital equipment used to supply energy; e.g., power plants, refineries, natural gas pipelines, electric power lines and substations, etc.
Energy intensity

The amount of energy consumed per unit of desired service

### Energy markets
Groups of buyers and sellers of energy goods and services and the institutions that make such exchanges possible

### Energy prices
Prices of petroleum and petroleum fuels, natural gas and manufactured gases, coal, uranium fuels, other fuels, and electricity, formed in energy markets via buying and selling processes

### Energy production
Extraction, conversion, and transportation of fuels and electricity to ultimate end use

### Energy security
Reliable and predictable supplies of fuels and electricity in national markets at stable prices, usually associated with the concerns about reliability of foreign supplies

### Energy use
See energy consumption

### Ethanol
An alcohol fuel produced chemically from ethylene or biologically from the fermentation of various sugars from carbohydrates found in agricultural crops and cellulosic residues from crops or wood. Often made from plants such as corn and typically blended in various proportions with conventional gasoline to make transportation fuel (gasohol)

### Extreme weather events
Weather events that are infrequent or unusual in their magnitude or intensity

## F

**Fossil fuels**
Hydrocarbon fuels derived from fossils: coal, petroleum, natural gas

**Fuel types**
End-use delivery forms for energy: solid, liquid, gaseous, electricity

## G

**Gas turbine**
A rotary engine that extracts energy from a flow of combustion gas

**Global Change Research Act of 1990**
An act of the U.S. Congress that established the U.S. Global Change Research Program and called for periodic assessments of climate change implications for the U.S.

## H

**Hadley Centre Model**
A well-known British model for projecting climate change

**Heating loads**
The amounts of energy necessary to keep the internal temperature in a building above a specific temperature range

**Hydropower**
Hydroelectric power, derived from the energy value of running water

## I

**Indirect effects**
Effects derived not from the primary driver of interest but from effects of that driver on another system, process, or phenomenon

**Integrated Resource Planning**
An approach to electric utility planning that integrates demand-side planning with supply-side planning

**Intensity**
A measure of concentration, such as the amount of energy consumed for a particular purpose

## K

**Knowledge base**
The stock of knowledge about a particular topi

**kWh**
Kilowatt hour, a measure of electricity delivered or consumed

## L

**Likelihood**
A measure of probability and/or level of confidence

**Long-run**
The relatively far future

## M

**Market penetration**
The degree to which a new technology or practice enters a market for a type of equipment or service, usually measured as a percentage of sales

**Market saturation**
The highest percentage of a market that can be captured by a type of equipment, practice, or process

**Mitigation**
In climate change discussions, refers to actions that respond to concerns about climate change by reducing greenhouse gas emissions or enhancing sinks

## O

**Once-through cooling**
As distinct from the use of cooling towers, the practice in power plants of taking in water from a body of water (e.g., a river), using it to cool the power plant, and releasing the water back to the body of water after a single pass through the plant

## P

**Peaking load units**
Electricity supply units designed to respond to demands, often short-lived, that are significantly above normal base loads

**Portfolio standards**
Guidelines or requirements that total electricity supply include one or more set minimums for particular sources, such as renewable energy

**Power plants**
Facilities that produce electricity

**Primary energy**
The amount of energy embodied in natural resources (e.g., coal, crude petroleum, sunlight) before transformation by humans. Also known as source energy

**Projections**
Characterizations of the future, often quantitative either from extrapolations of historical trends or from models

**Prospectus**
A formal summary of a proposed venture or project or a document describing the chief features of a proposed activity

## Q

**Quad**
Quadrillion Btus

**Qualitative**
Characterized by units of measure that are not numerical

## R

**R&D**
Research and development

**Renewable energy**
Energy based on resources that are naturally renewed over time periods equivalent to resource withdrawals

**Risk management**
Practices followed by companies and individuals to limit exposure to hazards and to limit the consequences of remaining exposure

## S

**Scenario**
A characterization of changes in the future, often associated with quantitative projections of variables of interest

**Seasonal**
Pertaining to a season of the year, as in winter or summer

**Sectors**
Subdivisions of a larger population, most often subdivisions of an economy such as residential, commercial, and industrial

**Shell**
See "building shell"

**Short-run**
The relatively near future

**Simulation models**
Mathematical models designed to approximate the performance of a system (e.g., the energy market or the world's climate) and commonly used to quantitatively forecast elements of that system's performance

**Site energy consumption**
The amount of energy consumed at the point of end use, not accounting for conversion losses

**Solar radiation**
The Sun's radiant energy (in the context of this study) as deposited on the Earth in all wavelengths

**Space conditioning**
Human interventions to modify the temperature of built spaces, including cooling and heating

**Space cooling**
Space conditioning processes used to reduce the temperature in built spaces

**Space heating**
Space conditioning processes used to increase the temperature in built spaces

**Spatial scale**
Geographical size

**Stakeholders**
Individuals, groups, and/or institutions with a stake in the outcome of a decision-making process

**Statistical analysis**
Analyzing collected data for the purposes of summarizing information to make it more usable and/or making generalizations about a population based on a sample drawn from that population

**Stochastic**
Characterized by risk, randomness, or uncertainty. Random or probabilistic but with some direction

**Strategic Petroleum Reserve**
A U.S. national program and set of facilities to store petroleum as a protection against risks of supply disruptions

# T

### Take back
A consumer reaction wherein beneficiaries of cost reductions from improvement to a technology or process undermine the improvement by using more of the improved technology or process; e.g., be setting the thermostat higher when a building is better insulated and therefore less expensive to heat

### Thermal power plant
A facility that produces electricity from heat

### Thermoelectric
See thermal power plant

### Time series
A series of measurements occurring over a period of time

### Transient weather events
Very short-lived weather happenings (e.g., thunderstorms, tornadoes) as opposed to general, long-term changes in temperature, precipitation, etc.

# U

### Uncertainties
Unknowns that limit the completeness of an explanation or the precision and accuracy of a prediction

### Urban form
The physical configuration and pattern of an urbanized area

### Urban heat islands
The semipermanent warming of up to several degrees in urban areas compared to nearby rural areas, due to density of population, high use of energy, and prevalence of solar energy absorbing and reradiating surfaces such as concrete buildings and streets

# V

### Vulnerability
The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity

ANNEX D

## ACRONYMS

**API** American Petroleum Institute
**ASHRAE** American Society of Heating, Refrigerating and Air-Conditioning Engineers
**AWEA** American Wind Energy Association

**BEAMS** a building energy simulation model

**CALPAS** a building energy simulation model
**CBECS** Commercial Building Energy Consumption Survey
**CCSP** Climate Change Science Program
**CCTP** Climate Change Technology Program
**CDD** cooling degree days
**CDM** Clean Development Mechanism
**CEPA** California Environmental Protection Agency
**$CO_2$** carbon dioxide
**CRIEPI** Japanese Central Research Institute of Electric Power Industry

**DD-NEMS** an energy system model based on NEMS (see below)
**DOC** U.S. Department of Commerce
**DOE** U.S. Department of Energy
**DOE-2** building energy simulation software
**DOI** U.S. Department of the Interior
**DOT** U.S. Department of Transportation

**EIA** Energy Information Administration
**EPA** Environmental Protection Agency
**EPRI** Electric Power Research Institute

**FEDS** a building energy simulation model

**GCM** General Circulation Model of the earth's atmosphere
**GHG** greenhouse gas(es)
**GOM** Gulf of Mexico
**GW** gigawatt
**GWh** gigawatt/hour

**HADCM3** Hadley Center Coupled GCM Model, Version 3
**HDD** heating degree days
**HVAC** heating, ventilating, and air conditioning

**ICF** an international consulting firm in Washington, DC
**IEA** International Energy Agency
**IGCC** integrated gasification combined cycle
**IPCC** Intergovernmental Panel on Climate Change
**ITC** investment tax credit

**JIP** Joint Industry Program

**LNG** liquefied natural gas

**MMS** U.S. Minerals Management Service
**MW** megawatt

**NACC** U.S. National Assessment of Implications of Climate Variability and Change
**NARUC** National Association of Regulatory Utility Commissioners
**NCAR** National Center for Atmospheric Research
**NEMS** National Energy Modeling System (Energy Information Administration)
**NGCC** natural gas combined cycle
**NOAA** National Oceanic and Atmospheric Administration
**NRC** Nuclear Regulatory Commission
**NREL** National Renewable Energy Laboratory
**NSTC** National Science and Technology Council

| | |
|---|---|
| **ORNL** | Oak Ridge National Laboratory |
| **PAD** | Petroleum Administration for Defense |
| **PCM** | parallel climate model |
| **PTC** | production tax credit |
| **PV** | photovoltaic |
| **RECS** | Residential Energy Consumption Survey |
| **RGGI** | Regional greenhouse gas initiative |
| **SAP** | Synthesis and Assessment Product |
| **SAP 4.5** | Synthesis and Assessment Product 4.5 (this document) |
| **TRU** | Trailer Refrigeration Units |
| **USDA** | U.S. Department of Agriculture |
| **USGS** | U.S. Geological Survey |
| **WWF** | World Wildlife Fund |

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## CLIMATE CHANGE SCIENCE PROGRAM AND THE SUBCOMMITTEE ON GLOBAL CHANGE RESEARCH

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# GOVERNOR PATERSON RINGS IN NEW ERA TO COMBAT CLIMATE CHANGE

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Governor David A. Paterson today opened the nation's first-ever auction of carbon dioxide allowances when he rang the ceremonial bell at the New York Mercantile Exchange in Manhattan, and by doing so launched the nation's most serious initiative yet to reduce emissions of greenhouse gases. New York and nine other Northeast and Mid-Atlantic states have come together to launch the Regional Greenhouse Gas Initiative (RGGI, pronounced "Reggie"), a mandatory program that covers more than 200 fossil fuel power plants, requiring the owners of those plants pay for the carbon dioxide they emit into the air.

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(Media-Newswire.com) - Governor David A. Paterson today opened the nation's first-ever auction of carbon dioxide allowances when he rang the ceremonial bell at the New York Mercantile Exchange in Manhattan, and by doing so launched the nation's most serious initiative yet to reduce emissions of greenhouse gases. New York and nine other Northeast and Mid-Atlantic states have come together to launch the Regional Greenhouse Gas Initiative (RGGI, pronounced "Reggie"), a mandatory program that covers more than 200 fossil fuel power plants, requiring the owners of those plants pay for the carbon dioxide they emit into the air.

By putting a price on carbon dioxide pollution through the RGGI auction, power plants will now have a financial incentive to reduce pollution. Proceeds from the auction will go toward energy conservation and renewable energy programs in each of the ten participating states, including: New York, Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, Rhode Island and Vermont.

"Global warming is the most pressing environmental issue of our time, and unfortunately the federal government has failed to take comprehensive action to address it. But by coming together with nine other states, New York is showing that we can take our own bold action in reducing greenhouse gas emissions," said Governor Paterson. "With the Regional Greenhouse Gas Initiative, we are attacking global warming in three ways: reducing emissions, fostering energy conservation and stimulating development of a clean energy economy and green jobs."

Under RGGI, ten states have established a cap or limit on the total amount of carbon dioxide pollution that power plants can emit into the air. Power plants over 25 megawatts (MW) that emit carbon dioxide must obtain pollution allowances to do so. These allowances, which are available by auction, give the power plants permission to emit carbon dioxide. The cumulative emissions of all carbon allowances may not exceed the amount set by the cap. Over time, the carbon cap is lowered incrementally, thus bringing down carbon emission levels.

Right Honorable Tony Blair said: "The Regional Greenhouse Gas Initiative is an extremely important part of the overall US effort to address climate change. It represents an acknowledgment on the part of US states that climate change is an urgent problem, and more importantly, it demonstrates the will to take action to solve it. By developing RGGI, the participating states have shown that a US cap and trade program is both possible and beneficial, and I applaud them for their leadership. Such measures are important to help move us towards consensus around a new global deal on climate change."

New Jersey Governor Jon S. Corzine said: "I believe that RGGI is a perfect example of how we – as states – can leverage our ability to tackle the complex challenges of clean energy and climate change by joining in regional collaboration. These issues are among the most pressing facing governors in our region as we strive to resurrect a stable and prosperous economy, and deliver a sustainable quality of life for our citizens."

California Governor Arnold Schwarzenegger said: "I applaud the Regional Greenhouse Gas Initiative for taking action to slow the dangerous impacts of climate change through innovative market solutions. These types of solutions hold polluters responsible, create a financial incentive to reduce emissions to the maximum extent and spur the development of innovative technologies. Like our partners in the Northeastern states, we're committed to taking action locally and regionally in our fight against global warming. I am optimistic that the ground we are laying with the Western Climate Initiative, alongside RGGI, is key to the future development and success of a national climate policy."

RGGI represents the first mandatory program to reduce power plant emissions of carbon dioxide – the principle gas that causes climate change – by instituting a six-year cap on carbon emissions in the participating states, followed by a 10 percent reduction over the next four years.

The auction process makes these carbon dioxide allowances a commodity, which market participants will use for compliance to buy, sell and trade. This market-based approach finds the cheapest place in the electrical generation sector to achieve reductions in carbon emissions. The auction will be open to all who are qualified to bid.

Power plants pump out about 25 percent of the total amount of carbon dioxide emitted annually in New York. Under RGGI, annual carbon discharges from power plants of 25 megawatts or larger would be capped. New York is distributing 64.3 million tons of carbon dioxide to be used for compliance, which is a third of the total RGGI cap. Emissions would be reduced 2.5 percent per year for the following four years, for an overall 10 percent decrease.

RGGI has spurred action elsewhere. Seven western U.S. states and several Canadian provinces have embarked on the Western Climate Initiative, a similar cap-and-trade system that will be implemented by 2012. Florida is also studying a cap-and-trade system, as our several Midwest states. The European Union has recently indicated it wants its members to shift programs to an auction-based format.

Additional quotes provided in support of the Regional Greenhouse Gas Initiative:

Connecticut Governor M. Jodi Rell said: "The roots of today's RGGI auction can be traced back almost ten years to discussions on climate change between Connecticut, other northeastern states and neighboring Canadian provinces. In the absence of federal leadership on this issue, the states have come together through RGGI to demonstrate that we can effectively address climate change in a manner that can help us build a stronger economy. Connecticut is proud to continue its leadership role on climate change as a partner in the RGGI agreement and this first in-the-nation carbon auction."

Delaware Governor Ruth Ann Minner said: "We in Delaware strongly support the launch of the RGGI auction today. As states, we can turn the challenges of energy security and climate change into opportunities that will allow us to create new jobs in clean energy and lead the country to reducing greenhouse gas emissions."

Maine Governor John E. Baldacci said: "In the absence of any leadership on global warming from President Bush, I believe that Maine and other states must continue to be the laboratories for policy implementation. The Regional Greenhouse Gas Initiative is the first mandatory program enacted in the US to address the gravity of the threats posed by climate change. It is a program that is serving as a model for other regional efforts now and can serve as a model for a 50-state federal cap-and-trade system."

Maryland Governor Martin O'Malley said: "Participation in the Regional Greenhouse Gas Initiative auction today will lead to an unprecedented investment in energy efficiency, not only in Maryland but across the Northeast and Mid-Atlantic regions as well. This is good for consumers, and it is also a landmark step to combat climate change."

Massachusetts Governor Deval L. Patrick said: "Massachusetts is proud to participate in the first auction of greenhouse gas emissions allowances in the nation. Through this auction, RGGI is creating a carbon market in the U.S., and generating funds that can be put to work increasing our energy efficiency and growing a clean energy economy in Massachusetts."

New Hampshire Governor John Lynch said: "Cutting our greenhouse gas pollution is the right thing to do for the long-term health of our citizens, our environment and our economy. Economic studies have shown that our participation in RGGI will create jobs and grow our economy through investments made in energy efficiency. The region is taking a lead role in reducing greenhouse gas emissions and setting an example for the rest of the nation to follow through RGGI. We are looking forward to offering allowances in December's auction."

Rhode Island Governor Donald L. Carcieri said: "Rhode Island is exceptionally committed and pleased to be working with the other states to bring the final steps in the Regional Greenhouse Gas Initiative into fruition. My administration has taken many bold actions in the development of offshore wind and distributed generation facilities, which, when coupled with this program, will put Rhode Island in the forefront of governments working on both energy independence and long-term security for our residents and businesses."

Vermont Governor James Douglas said: "Vermont is one of six states offering allowances for sale in today's first-ever cap-and-trade auction. Vermont's sale of more than 1.2 million carbon credit allowances each year is an opportunity to leverage new technology and energy efficiency to reduce greenhouse gas emissions – and grow our economy. The RGGI program will generate new capital to invest in green jobs and inspire innovation for long-term economic growth in Vermont and other RGGI states."

Commissioner of the New York State Department of Environmental Conservation and chair of RGGI Inc., the multi-state entity created to support the states, Pete Grannis, said: "Older, less efficient power plants with high air pollution levels will pay more to comply with RGGI than newer, more efficient power plants. Dirty power plants will be at a competitive disadvantage and there will be more incentive to reduce emissions, make upgrades and build cleaner plants."

Garry Brown, Chairman, New York State Public Service Commission, said: "I congratulate Governor Paterson for his steadfast support of RGGI and its carbon auction. Utility power plants are significant contributors of carbon dioxide emissions. The cap-and-trade of carbon allowances will help reduce global greenhouse gas emissions that threaten our environment. This important and historic regional initiative should be seen as a model for the rest of the nation."

Bob Callender, Vice President for Programs for New York State Energy Research and Development Authority, said: "We are pleased to be a part of this historic day and look forward to a successful auction. Governor Paterson has made fighting global climate change one of the hallmarks of his administration and we look forward to working with our partners to develop and implement the programs that will reduce the emissions of greenhouse gases in New York State."

The Honorable Timothy E. Wirth, President, United Nations Foundation and The Better World Fund, said: "I am impressed with the initiative of ten northeast and mid Atlantic states as they launch a carbon auction in the United States. They are to be commended for looking to the future, regulating greenhouse gases, and moving ahead to stem the threat of climate change."

Jeffrey R. Immelt, Chairman and CEO, General Electric, said: "GE offers its congratulations to the Governors of the Northeast States for their leadership on the Regional Greenhouse Gas Initiative, the Country's first carbon cap and trade program. This kind of market-based approach will encourage the development and deployment of the technologies essential to combating climate change, enhancing our energy security and promoting continued economic growth. With RGGI, the Northeast States have taken a very important first step as we work toward federal legislation to establish a national framework to reduce greenhouse gas emissions."

Frances Beinecke, President of the Natural Resources Defense Council, said: "RGGI sets a hugely important precedent for the nation and the world. This first-of-its-kind market-based system for power plant emissions will promote efficiency and cut pollution while reducing overall energy costs for consumers and creating hundreds of new clean energy jobs. RGGI is the kind of smart energy plan that the entire country needs. Our nation will reap enormous economic benefits if Congress follows the northeast states' lead."

Eileen Claussen, Executive Director, Pew Center on Global Climate Change, said: "Today marks an historic milestone for U.S. climate action. The start of the Regional Greenhouse Gas Initiative (RGGI) auction of emission allowances demonstrates both how far we've come and how far we need to go to effectively address climate change. RGGI and other U.S. state and regional efforts demonstrate that effective cap-and-trade programs can be implemented. These states are paving the path to a comprehensive national program that offers the most cost-effective solution to significantly reduce U.S. greenhouse gas emissions.

"A new President will be elected in less than six weeks, and I'm optimistic that this change will deliver the political leadership required to seriously address climate change. As we await the new Administration and Congress, RGGI leads by example to show government and business leaders that cap and trade is a manageable, economically-efficient approach to reduce GHG emissions."
Jonathan Lash, President, World Resources Institute, said: "With its first-in-the-nation cap-and-trade program, RGGI points the way for other regions and the federal government to take similar steps. Today's auction is an important milestone, because it demonstrates that allowance value can be used to safeguard consumers and make our economy more efficient."

Tom King, Executive Director, Electricity Distribution and Generation, National Grid, said: "National Grid is delighted to celebrate and endorse RGGI and its inaugural carbon dioxide allowance auction. The example set by RGGI will lead others in the nation and, indeed, around the world as we all grapple with increasing greenhouse gas emissions. At National Grid we have "carbon budgets" which incorporate the price of carbon into every investment decision we make. This will ensure that our long-term growth plans reflect the inevitability of a carbon-constrained global economy as we do our part to improve the environment for future generations. Congratulations, RGGI, for the power of action."

Steve Owens, Director, Arizona Department of Environmental Quality and Co-chair of the Western Climate

Initiative, said: "As co-chair of the Western Climate Initiative, I congratulate the ten northeast states in RGGI on their leadership in moving forward with the first U.S. carbon auction. This is a truly incredible feat and a giant step forward in reducing greenhouse gas emissions in this country. The seven U.S. states and four Canadian provinces that make up the WCI have been paying very close attention to RGGI's efforts in this area, and the work the RGGI states have done has been extremely helpful to the WCI as we have designed our own program."

Doug Scott, Director, Illinois Environmental Protection Agency, said: "Illinois and our neighboring states in the Midwest Governor's Association are eagerly anticipating the results of the first carbon allowance auction on September 25 conducted by the Regional Greenhouse Gas Initiative (RGGI) as part of the mandatory, market-based cap and trade program for the power sector in ten Northeastern and Mid-Atlantic States. I commend the RGGI states for moving forward on reducing carbon emissions that contribute to climate change while raising revenues for clean energy investment and the results will be extremely helpful as we address this issue in the Midwest"

Suzanne Watson, Policy Director for The American Council for an Energy-Efficient Economy, said: "The American Council for an Energy-Efficient Economy (ACEEE) is pleased that the Regional Greenhouse Gas Initiative (RGGI) strongly endorses energy efficiency as part of its operation. ACEEE feels that energy efficiency is the most important aspect of any cap and trade initiative - either regional or national - since it is largely due to investments in efficiency that costs to consumers can better be controlled and for the fact that it supports the ultimate purpose of a cap and trade, i.e., actual reductions in greenhouse gases emissions. Thus efficiency can serve multiple purposes: saves on costs to consumers, improves the environment and the economies of the states, and serves as a testing ground to the value of greater efficiency in a future national cap and trade effort."

Kevin Knobloch, President, Union of Concerned Scientists, said: "Governors and legislators in the RGGI states have shown tremendous leadership on climate. Auctioning the allowances and dedicating the revenues to energy efficiency and renewable energy development are critical strategies for ensuring a clean and affordable energy future for the Northeast and sets an important example for federal policymakers."

Fred Krupp, Executive Director of Environmental Defense, said: "The launch of America's first carbon market is proof positive that the U.S. can and will take bold steps to combat climate change."

Joe Kruger, Policy Director Bipartisan Policy Center/National Commission on Energy Policy, said: "The RGGI states have shown great leadership as they have developed their cap and trade program. The RGGI auction will provide valuable lessons to policymakers addressing climate change in the U.S. and around the world."

Jack Winslow, President and CIO of Winslow Management, said: "At Winslow we are extremely excited to witness RGGI's first carbon auction. As investors in low-cost, low-carbon energy solutions of the future, we are firm believers that the market needs to be the primary driver behind the development of renewable energy. The RGGI auction is an historical event, where regional governments are coming together and signaling to the market that carbon emissions have a tangible environmental cost, measured in dollars. Renewable energy solutions are increasingly attractive for energy utilities, industrial consumers, and homeowners. We praise the RGGI states for their foresight and initiative in this endeavor."

Rob Sargent, Environment America's Energy Program Director, said: "Tackling global warming emissions and shifting away from fossil fuels are among society's greatest challenges. Today's auction represents a remarkable precedent that will begin to put this region on a path to a cleaner and more secure energy future. Northeast officials deserve tremendous credit for breaking with the status quo by recognizing that auctioning pollution allowances is the fairest and most economically efficient way to structure a cap and trade program. There is much more work to meet the environmental and energy challenges of the 21st century. But, I am confident that we will look back on today and see it as a defining moment in the struggle to address global warming."

Stephen L. Cowell, CEO of Conservation Services Group, said: "The RGGI auction that has just been completed in the northeast and which Massachusetts was an active participant represents a landmark event in the fight against global warming. It is the first large scale auction of carbon allowances that will allow us to begin putting a real price on the cost of carbon pollution in North America."

Ernest J. Moniz, Director, MIT Energy Initiative Massachusetts Institute of Technology, said: "This first US carbon auction is a seminal event. The ten Northeastern states moving this forward are to be commended for bringing a sense of urgency to limitations on greenhouse gas emissions, hopefully leading the way to a national commitment in the upcoming Administration. RGGI will also benefit the region - one without fossil fuel resources – by accelerating deployment of new efficiency and renewable technologies. The Northeast has enormous research and investment capacity in its universities, laboratories, and entrepreneurial sector to develop and market those technologies."

Robert Moore, Executive Director of Environmental Advocates of New York, said: "Today marks a critical point in the nation's response to climate change--the first-ever auction of carbon dioxide emissions under the Regional

Greenhouse Gas Initiative, or 'RGGI.' The ten states participating in this regional plan to reduce power plant pollution are stepping up to fight global warming while the federal government is stuck in neutral. The governors of the ten RGGI states deserve credit for proving to the rest of the nation that cost-effective solutions to the growing threat of climate change are at hand and the time to act is now."

Laura Haight, Senior Environmental Associate at the New York Public Interest Research Group, said: "Today Governor Paterson and other state leaders will ring the bell for a new approach to reducing greenhouse gas emissions. We are proud of New York's leadership in forging this multi-state regional initiative, and look forward to a successful launch. We commend all the participating states for working together in a spirit of cooperation and innovation."

Mark Tercek, CEO and President of The Nature Conservancy of New York, said: "State leadership is continuing to step up in the absence of national progress on the issue of climate change. We applaud the Northeast and Mid-Atlantic states on this historic day for taking bold steps to curb their own emissions, provide funding for energy efficiency and renewable energy projects, and support strategies to help humans and nature adapt to global warming."

Laurence DeWitt, President of The Commons, said: "RGGI's auction of allowances (permits to pollute) is a quantum design improvement for environmental cap and trade programs. Investing the auction proceeds in energy efficiency and low CO2 technologies will dramatically reduce the cost of the program to consumers, while spawning economic development and jobs in New York in these emerging 'no-CO2, low CO2' industries."

Daniel L. Sosland, Executive Director of Environment Northeast, said: "In the uncharted territory of the first mandatory carbon cap and trade program in the US, the RGGI states are providing critical leadership. This auction will fund investments in essential programs like energy efficiency that will save consumers money and reduce RGGI costs for all. The leadership exhibited by the ten states sends a message that not only is it time for the nation to act on the climate crisis but that the states can and are taking strong first steps."

Cindy Luppi, Clean Water Action, New England Program Director, said: "Today's launch represents one more critical milestone on the road to additional pollution reductions from power plants throughout the Northeast. RGGI has sent up a flare for officials around the country at all levels of government that the time to reduce global warming pollution is here and now."

Seth Kaplan, Vice President for Climate Advocacy, Conservation Law Foundation, said: "The RGGI program has redefined, for the better, cap-and-trade and climate protection regulation through this auction - the prospect of recycling the money it will generate to slash both customer bills and pollution by financing energy efficiency measures is incredibly exciting and provides a model for the rest of the nation."

Rob Garrity, Executive Director, Mass Climate Action Network, said: "The Regional Greenhouse Gas Initiative is a three part success; first by capping and then reducing greenhouse gas emissions, second, through the gains in energy efficiency which will be funded through the auction of allowances, and finally by its multi-state nature, sending an important message to the rest of the country that comprehensive, across the board action is required to address greenhouse gas emissions."

# Update of the MIT 2003 Future of Nuclear Power

AN INTERDISCIPLINARY MIT STUDY

# Update of the MIT 2003 Future of Nuclear Power

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# Update of the MIT 2003 Future of Nuclear Power Study

In 2003 a group of MIT faculty issued a study on *The Future of Nuclear Power.*[1] The study was motivated by growing concern about global warming and the urgency of developing and deploying electricity generating technologies that do not emit $CO_2$ or other greenhouse gases (GHG). The study addressed the steps needed in the near term in order to enable nuclear power to be a viable marketplace option at a time and at a scale that could materially mitigate climate change risks. In this context, the study explicitly assessed the challenges of a scenario in which nuclear power capacity expands from approximately 100 GWe in the United States in 2000 to 300 GWe at mid-century (from 340 to 1000 GWe globally), thereby enabling an increase in nuclear power's approximately 20% share of U.S. electricity generation to about 30% (from 16% to 20% globally).

The important challenges examined were (1) cost, (2) safety, (3) waste management, and (4) proliferation risk. In addition, the report examined technology opportunities and needs, and offered recommendations for research, development, and demonstration.

The 2003 MIT study on *The Future of Nuclear Power*, supported by the Alfred P. Sloan Foundation, has had a significant impact on the public debate both in the United States and abroad and the study has influenced both legislation by the U.S. Congress and the U.S. Department of Energy's (DOE) nuclear energy R&D program.

This report presents an update on the 2003 study. Almost six years have passed since the report was issued, a new administration in Washington is formulating its energy policy, and, most importantly, concern about the energy future remains high. We review what has changed from 2003 to today with respect to the challenges facing nuclear power mentioned above. A second purpose of this Update is to provide context for a new MIT study, currently underway, on *The Future of the Nuclear Fuel Cycle*, which will examine the pros and cons of alternative fuel cycle strategies, the readiness of the technologies needed for them, and the implications for near-term policies.

[1] Massachusetts Institute of Technology, The Future of Nuclear Power: an Interdisciplinary Study (2003). Available at: http://web.mit.edu/nuclearpower/

## SUMMARY FINDING OF CHANGES SINCE THE 2003 REPORT

Concern with avoiding the adverse consequences of climate change has increased significantly in the past five years[2]. The United States has not adopted a comprehensive climate change policy, although President Obama is pledged to do so. Nor has an agreement been reached with the emerging rapidly-growing economies such as China, India, Indonesia, and Mexico, about when and how they will adopt greenhouse gas emission constraints. With global greenhouse gas emissions projected to continue to increase, there is added urgency both to achieve greater energy efficiency and to pursue all measures to develop and deploy carbon free energy sources.

*"The sober warning is that if more is not done, nuclear power will diminish as a practical and timely option for deployment at a scale that would constitute a material contribution to climate change risk mitigation."*

Nuclear power, fossil fuel use accompanied by carbon dioxide capture and sequestration, and renewable energy technologies (wind, biomass, geothermal, hydro and solar) are important options for achieving electricity production with small carbon footprints. Since the 2003 report, interest in using electricity for plug-in hybrids and electric cars to replace motor gasoline has increased, thus placing an even greater importance on exploiting the use of carbon-free electricity generating technologies. At the same time, as discussed in the MIT report *The Future of Coal*[3], little progress has been made in the United States in demonstrating the viability of fossil fuel use with carbon capture and sequestration—a major "carbon-free" alternative to nuclear energy for base-load electricity.

With regard to nuclear power, while there has been some progress since 2003, increased deployment of nuclear power has been slow both in the United States and globally, in relation to the illustrative scenario examined in the 2003 report. While the intent to build new plants has been made public in several countries, there are only few firm commitments outside of Asia, in particular China, India, and Korea, to construction projects at this time. Even if all the announced plans for new nuclear power plant construction are realized, the total will be well behind that needed for reaching a thousand gigawatts of new capacity worldwide by 2050. In the U.S., only one shutdown reactor has been refurbished and restarted and one previously ordered, but never completed reactor, is now being completed. <u>No new nuclear units have started construction.</u>

In sum, compared to 2003, the motivation to make more use of nuclear power is greater, and more rapid progress is needed in enabling the option of nuclear power expansion to play a role in meeting the global warming challenge. The sober warning is that if more is not done, nuclear power will diminish as a practical and timely option for deployment at a scale that would constitute a material contribution to climate change risk mitigation.

[2] Summary for Policymakers. Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. (2007)

[3] http://web.mit.edu/coal/

## 1. STATUS OF NUCLEAR POWER DEPLOYMENT

Today, there are about 44 plants under construction[4] around the world in 12 countries, principally China, India, Korea, and Russia. There are no new plants under construction in the United States.[5] The slow pace of this deployment means that the mid-century scenario of 1000 GWe of operating nuclear power around the globe and 300 GWe in the United States is less likely than when it was considered in the 2003 study.[6]

In the United States, nevertheless, there have been a series of developments that could enable new nuclear deployment in the future:

The performance of the 104 U.S. nuclear plants since 2003 has been excellent. The total number of kWh produced by the reactors has steadily increased over those five years. The fleet-averaged capacity factor since 2003 has been maintained at about 90%.[7]

Extended operating licenses. Nuclear reactors typically have initial operating licenses from the Nuclear Regulatory Commission for 40 years. The earlier trend to obtain license extensions to operate existing nuclear reactors an additional 20 years (total of 60 years) has continued with the expectation that almost all reactors will have license extensions. The NRC has granted 51 license extensions to date with 19 such renewals granted between January 2003 and February 2008.[8] Furthermore, modest power uprates have been granted in that period, adding about 1.5 GWe to the licensed capacity.

Changes in the NRC regulations in the 1990s created a new approach to reactor licensing that included a design certification process, site banking, and combined construction and operation licensing. The Energy Policy Act of 2005 authorized DOE to share the cost with selected applicants submitting licenses to the NRC to help test this new licensing approach — all actions that are consistent with recommendations of the 2003 report.

Seventeen applications[9] for combined construction and operating licenses for 26 reactors have been submitted to the NRC. Preliminary work required before construction is underway for many of these plants such as design, licensing applications development, and procurement of long-lead items. However financing and firm commitment to construction remains ahead. Authority to proceed will undoubtedly be slowed by the current dismal economic situation. Several European countries have announced plans for new reactors while several other European countries are reevaluating their stance on nuclear power plant construction and phase out.[10]

Public acceptance for nuclear power Extension of the public attitudes research carried out in 2003 reinforces a trend towards greater public acceptance of nuclear power.[11]

[4] Forty four plants under construction: China (11), Russia (8), India (6), Korea (5), Bulgaria (2), Taiwan (2), Ukraine (2), Japan (2), Argentina (1), Finland (1) France (1), Iran (1), Pakistan (1), and the United States (1).

[5] However, since 2003 one shutdown reactor (Browns Ferry I) has been refurbished and restarted and one partly complete reactor (Watts Bar 2) is now being completed.

[6] The 2007 JEO suggests that nuclear power will grow 1.3%/year worldwide, but that optimistic forecast remains below the 2003 Study mid-century scenario.

[7] http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1350/v19/sr1350v19.pdf

[8] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/license-renewal-bg.html

[9] http://www.nrc.gov/reactors/new-reactors/new-licensing-files/expected-new-rx-applications.pdf

[10] Sweden and Italy have announced reversals of their prohibitions on new nuclear plant construction. France, Finland, and Great Britain have announced plans for added nuclear power plants. Plants are under construction in France and Finland.

[11] http://www.gallup.com/poll/117025/Support-Nuclear-Energy-Inches-New-High.aspx and http://web.mit.edu/canes/pdfs/nes-008.pdf

## 2. UPDATING NUCLEAR GENERATION ECONOMICS

The 2003 report found that "In deregulated markets, nuclear power is not now cost competitive with coal and natural gas. However, plausible reductions by industry in capital cost, operation and maintenance costs and construction time could reduce the gap. Carbon emission credits, if enacted by government, can give nuclear power a cost advantage." The situation remains the same today. While the U.S. nuclear industry has continued to demonstrate improved operating performance, there remains significant uncertainty about the capital costs, and the cost of its financing, which are the main components of the cost of electricity from new nuclear plants.

Since 2003 construction costs for all types of large-scale engineered projects have escalated dramatically. The estimated cost of constructing a nuclear power plant has increased at a rate of 15% per year heading into the current economic downturn. This is based both on the cost of actual builds in Japan and Korea and on the projected cost of new plants planned for in the United States. Capital costs for both coal and natural gas have increased as well, although not by as much. The cost of natural gas and coal that peaked sharply is now receding. Taken together, these escalating costs leave the situation close to where it was in 2003. The following table updates the cost estimates presented in the 2003 study:[12]

[12] The capital cost estimates do not take into account any possible prospective change to the cost of capital as a result of the current financial crisis or the recent drop in commodity prices for construction materials. Du, Yangbo and John E. Parsons, Update on the Cost of Nuclear Power, MIT Center for Energy and Environmental Policy Research Working Paper 09-004; http://web.mit.edu/ceepr/www/publications/workingpapers.html

Table 1: Costs of Electric Generation Alternatives

| | | | LCOE | | |
|---|---|---|---|---|---|
| | Overnight Cost | Fuel Cost | Base Case | w/ carbon charge $25/ $tCO_2$ | w/ same cost of capital |
| | $/kW | $/mmBtu | ¢/kWh | ¢/kWh | ¢/kWh |
| | [A] | [B] | [C] | [D] | [E] |
| **MIT (2003)** | | | | | |
| $2002 | | | | | |
| [1] Nuclear | 2,000 | 0.47 | 6.7 | | 5.5 |
| [2] Coal | 1,300 | 1.20 | 4.3 | 6.4 | |
| [3] Gas | 500 | 3.50 | 4.1 | 5.1 | |
| | | | | | |
| **Update** | | | | | |
| $2007 | | | | | |
| [4] Nuclear | 4,000 | 0.67 | 8.4 | | 6.6 |
| [5] Coal | 2,300 | 2.60 | 6.2 | 8.3 | |
| [6] Gas | 850 | 7.00 | 6.5 | 7.4 | |

Notes:

[1A], [2A], and [3A] See MIT (2003), Table 5.3, p. 43.

[1B] See MIT (2003) Appendix 5, Table A-5.A4.

[2B], and [3B] See MIT (2003), Table 5.3, p. 43.

[1C], [2C], and [3C] See MIT (2003), Table 5.1, p. 42, Base Case, 40-year. "Gas (moderate)" case is reported here, which was $3.50 escalated at 1.5% real, equivalent to $4.42 levelized real over 40 years.

[1D], [2D], and [3D] See MIT (2003), Table 5.1, p. 42, Carbon Tax Cases, 40-year. We translate results quoted in $/tC into results in $/t $CO_2$.

[1E] See MIT (2003), Table 5.1, p. 42, Reduce Nuclear Costs Cases. The table shows results step-wise for changing 3 assumptions, with the reduction of the cost of capital being the last step. We give the result for just reducing the cost of capital to be equivalent to coal and gas, without the other 2 assumptions being varied.

[4A], [5A], and [6A] From Du and Parsons (2009) Update on the Cost of Nuclear Power.

[4B] Calculated using the methodology in MIT (2003), Appendix 5 and the following inputs: $80/kgHM for natural uranium, $160/SWU, and $6/kgHM for yellow cake conversion and $250/kgHM for fabrication of uranium-oxide fuel. We derive an optimum tails assay of 0.24%, an initial uranium feed of 9.08 kgU and a requirement of 6.99 SWUs, assuming a burn-up of 50 MWd/kgHM. We assume this fuel cost escalates at 0.5% per annum, which means the average real price over the 40 years of delivery is $0.76/mmBtu.

[5B] We assume a coal feed with 12,500Btu/lb, so that this fuel cost translates to $65/short ton delivered in 2007 dollars. We assume this fuel cost escalates at 0.5% per annum, which means the average real price over the 40 years of delivery is $2.94/mvmBtu or $73.42/short ton delivered.

[6B] We assume this fuel cost escalates at 0.5% per annum, which means the average real price over the 40 years of delivery is $7.91/mmBtu.

[4C], [5C] and [6C] Assumptions made in this calculation are described fully in the Du and Parsons (2009) Update on the Cost of Nuclear Power. For all types of generation we assume a 40 year operation and 85% capacity factor. Nuclear heat rate is 10,400 as in the MIT (2003) study. Both coal and natural gas heat rates are improved relative to MIT (2003): coal is 8,870 and gas is 6,800. We assume a general inflation rate of 3%, real escalation of O&M costs of 1%, and a tax rate of 37%. Nuclear is financed at 50% debt, with a debt cost of capital of 8% and an equity cost of capital of 15%. Coal and gas are financed with 60% debt, a debt cost of capital of 8% and an equity cost of capital of 12%. Nuclear construction has a 5 year schedule, coal construction has a 4 year schedule, and gas has a 2 year schedule. Nuclear and gas apply the MACRS 15-year depreciation schedule, while coal applies the 20-year MACRS schedule.

[4D], [5D] and [6D] As in the MIT (2003) study, the carbon intensity assumed for coal is 25.8 kg-C/mmBtu, and for gas is 14.5.

[4E] Recalculates [4C] setting the assumed debt fraction and the equity rate for nuclear to match coal and gas, i.e., a 60% debt fraction and a cost of equity of 12%.

The nuclear costs are driven by high up-front capital costs. In contrast, for natural gas the cost driver is fuel cost. Coal lies in-between.

The track record for the construction costs of nuclear plants completed in the U.S. during the 1980s and early 1990s was poor. Actual costs were far higher than had been projected. Construction schedules experienced long delays, which, together with increases in interest rates at the time, resulted in high financing charges. New regulatory requirements also contributed to the cost increases, and in some instances, the public controversy over nuclear power contributed to some of the construction delays and cost overruns. However, while the plants in Korea and Japan continue to be built on schedule, some of the recent construction cost and schedule experience, such as with the plant under construction in Finland, has not been encouraging. Whether the lessons learned from the past have been factored into the construction of future plants has yet to be seen. These factors have a significant impact on the risk facing investors financing a new build.

For this reason, the 2003 report applied a higher weighted cost of capital to the construction of a new nuclear plant (10%) than to the construction of a new coal or new natural gas plant (7.8%).

Lowering or eliminating this risk-premium makes a significant contribution to making nuclear competitive. With the risk premium and without a carbon emission charge, nuclear is more expensive than either coal (without sequestration) or natural gas (at 7$/MBTU). If this risk premium can be eliminated, nuclear life cycle cost decreases from 8.4¢ /kWe-h to 6.6 ¢/kWe-h and becomes competitive with coal and natural gas, even in the absence of carbon emission charge.

The 2003 report found that capital cost reductions and construction time reductions were plausible, but not yet proven – this judgment is unchanged today. The challenge facing the U.S. nuclear industry lies in turning plausible reductions in capital costs and construction schedules into reality. Will designs truly be standardized, or will site-specific changes defeat the effort to drive down the cost of producing multiple plants? Will the licensing process function without costly delays, or will the time to first power be extended, adding significant financing costs? Will construction proceed on schedule and without large cost overruns? The first few U.S. plants will be a critical test for all parties involved. The risk premium will be eliminated only by demonstrated performance.

## 3. GOVERNMENT INCENTIVES AND REGULATIONS

Both government and industry have their part to play in lowering this risk premium. The 2003 report advocated limited government assistance for "first mover" nuclear plant projects. Three principles underpinned the proposed government assistance: First, financial assistance for nuclear should be comparable to assistance extended to other low-carbon electricity generation technologies, for example wind, geothermal, and solar. Second, an appropriate degree of risk should remain with the private sector so as to motivate cost and schedule discipline. Third, government assistance should be limited to the first mover cohort without the expectation of longer-term assistance. That is, different power generation technologies should compete based on economics in a world where $CO_2$ emissions are priced, and where technologies are not mandated by required quotas for certain types of generation.

The Energy Policy Act of 2005 authorized assistance for new nuclear plant construction including loan guarantees, insurance against delays not caused by the utility, and production tax credits for the first 6 GWe of new plants. However, implementation of the first mover assistance program as proposed in the 2003 study has not yet been effective in moving utilities to make firm reactor construction commitments for three reasons.

First, the DOE has not moved expeditiously to issue the regulations and implement the federal loan guarantee program.

Second, since 2003, emphasis has been placed on renewable portfolio standards (RPS), adopted by many states and proposed at the federal level, as the mechanism for encouraging carbon-free and renewable technologies. RPS require that utilities obtain a certain fraction of their electricity from low-carbon electricity sources. Unfortunately, most RPS programs exclude two important low-carbon technologies, nuclear and coal with $CO_2$ sequestration, confusing the objective of reducing carbon emissions with encouraging renewable energy in electricity generation.

*"However, implementation of the first mover assistance program as proposed in the 2003 study has not yet been effective in moving utilities to make firm reactor construction commitments for three reasons."*

If such RPS remain in place and a carbon emission tax or cap and trade system is implemented in parallel, inefficiencies may result. The RPS requires utilities to adopt technologies, for example wind, rather than select the most economic method to achieve lower carbon emissions. As a consequence, the emission permit prices in the parallel cap and trade system will be lower than prices without a RPS, possibly inhibiting the introduction of low-carbon technologies not included in the RPS.

Third, in a change from 2003, the nuclear industry facing increased cost estimates is arguing that more assistance is needed to demonstrate the economic viability of nuclear. While some modification of the "first mover" program is likely necessary because of the impact of the financial crisis on capital markets, the justification for government "first-mover" assistance is to demonstrate technical performance, cost, and environmental acceptability, not to extend a government subsidy for nuclear (or any other energy technology) indefinitely into the future. Consequently, any expansion of such a federal program should have limited duration. If the purpose of an expanded program is to correct for a market imperfection, in this case the external costs of global warming, the most efficient mechanism is either a carbon emission tax or a cap-and-trade system. An ironic consequence of a parallel RPS could be a call to extend subsidies to nuclear and coal with carbon capture/sequestration because of a poorly crafted policy for efficiently reducing carbon emissions.

## 4. SAFETY

Parallel with the improved operations has been an excellent safety record. Reliability and safety are coupled because (1) reliable operations avoid challenges to the safety systems and (2) the maintenance and operating practices required for reliable operations are generally the same required for safety. Nuclear power displays by far the highest capacity factor among all generation technologies, providing about 20% of U.S. electricity supply with about 10% of the installed capacity. The judgment of the 2003 study that new light water reactor plants, properly operated, meet strenuous safety standards discussed in the 2003 report is unchanged.

*"An ironic consequence of a parallel RPS could be a call to extend subsidies to nuclear and coal with carbon capture/sequestration because of a poorly crafted policy for efficiently reducing carbon emissions."*

## 5. WASTE MANAGEMENT

The 2003 study emphasized the importance of making progress on waste management in the United States.

Interim storage of spent fuel

The 2003 study conclusion "an explicit strategy to store spent fuel for a period of several decades will create additional flexibility in the waste management system" remains valid today. While dry cask spent fuel storage (SFS) has been implemented on a large scale at reactor sites, starting in 1986 and continued since 2003, no federal operated away-from-reactor surface, or near surface, spent fuel storage sites have been opened since they are not permitted by the Nuclear Waste Policy Act of 1987 until the Yucca Mountain repository is licensed.[13]

Geological Disposal of SNF

Following the requirements of the Nuclear Waste Policy Act, the DOE submitted a license application for the Yucca Mountain repository in 2008. Congress mandated and is providing the funding for the NRC to complete a license review. The new administration has stated that Yucca Mountain is no longer an option for nuclear waste disposal. There is no plan for high-level wastes; but the administration has committed to a comprehensive review of waste management. In conclusion, the progress on high-level waste disposal has not been positive.

The U.S. Environmental Protection Agency has developed the repository standard for protection of public health and safety. After decades of debate and lawsuits, it appears that the standard is generally accepted which is significant progress.

The 2003 study urged a broadening of the DOE waste management program for Yucca Mountain to other potential mined repository disposal sites and to other potential technologies such as bore-hole disposal. The 2003 study recommended that the U.S. should undertake a significant R&D program for long-term integrated waste management that includes improved repository performance (such as alternative engineered barriers) and examination of alternatives. The central concern was that the federal programs have had a narrow focus and have not explored an adequate range of technical options.

The need remains for a broader program that creates an understanding of the range of waste management options, is coupled with fuel cycle modeling, and provides a basis for robust long-term waste management policies. This is a central objective of the ongoing *MIT Nuclear Fuel Cycle Study*. It should be noted that both open and closed fuel cycles require the geological disposal of some radioactive waste.

[13] A private fuel storage facility has been issued an NRC license but has not been built.

## 6. FUEL CYCLE ISSUES

Uranium resource availability

Long-term fuel cycle and nonproliferation policy considerations depend upon the future availability and costs of natural uranium ore. The 2003 study argued that uranium was not likely to be a constraint in the development of a very large nuclear enterprise using a once-through fuel cycle for this century. The last domestic[14] and international[15] resource evaluation programs were completed in the early 1980s. Since then there have been major advances in our understanding of uranium geology. Because of the importance of uranium resources in future decisions, the 2003 study recommended undertaking a significant global uranium resource evaluation program to increase the global confidence in uranium resource assessment. No such program has been initiated.

Since the 2003 MIT report, the OECD/IAEA has published its most recent (2007) "Red Book" update[16] on uranium resources, production and demand. Also noteworthy is the 2006 publication of a retrospective review[17] of the last forty years of Red Book issues. In brief, resources are rising faster than consumption. Table 2 shows Red Book identified resources, undiscovered resources, and the number of reactor years of fuel provided by those resources. Based on the total projected Red Book resources recoverable at a cost less than $130/kg (2006$) of about 13 million metric tons (hence about an 80 year supply for 800 reactors), most commentators conclude that a half century of unimpeded growth is possible, especially since resources costing several hundred dollars per kilogram (not estimated in the Red Book) would also be economically usable. Using a probabilistic resources versus cost model to extend Red Book data, we estimate an order of magnitude larger resources at a tolerable doubling of prices. Since 2003, the spot price for natural uranium spiked due to a variety of factors, including the temporary shutdown of major producing mines and the management of uranium inventories. However, this does not appear to reflect the underlying resource economic reality indicated above.

This reinforces the observation in the 2003 MIT study that "We believe that the world-wide supply of uranium ore is sufficient to fuel the deployment of 1000 reactors over the next half century."

[14] U.S. Department of Energy, National Uranium Resource Evaluation (NURE) Program Final Report, GJBX-42(83), (1983).

[15] OECD, Nuclear Energy Agency, International Atomic Energy Agency, *World Uranium Geology and Resource Potential, International Uranium Resources Evaluation*, Miller Freeman, San Francisco, CA (1980).

[16] Uranium 2007: Resources, Production and Demand, OECD NEA No. 6345, 2008 (Red Book)

[17] Forty Years of Uranium Resources, Production and Demand in Perspective, 2006, "The Red Book Retrospective," OECD, NEA No. 6096, 2006

| Table 2. World Uranium "Red Book" Resources and Implied reactor years of operation[1] | | |
|---|---|---|
| **Resource Class** | **United States** | **World** |
| **Identified Resources** | | |
| Metric tons | 339,000 | 5,469,000 |
| Number of 1-GWe Reactor Years @ 200 MT/GWe-yr | 1,700 | 27,000 |
| **Undiscovered Resources** | | |
| Metric tons | 2,131,000 | 7,567,000 |
| Number of 1-GWe Reactor Years @ 200 MT/GWe-yr | 10,700 | 37,800 |

[1] Cumulative resources extractable at costs <130 $/kg U. For about 30 years resource estimates have remained constant or grown at <$130/kg U in current dollars without adjusting for inflation. In effect, the resource base in inflation adjusted dollars has grown.

Uranium enrichment

Since 2003 there have been major changes in uranium enrichment with gas centrifuge technology now replacing gaseous diffusion technology in the U.S. and Europe. In the United States one gas-centrifuge plant is starting up, two other centrifuge plants are being planned, and work is underway for an advanced laser enrichment plant. Enrichment capacity is not a constraint on a larger nuclear enterprise.[18]

Reprocessing and recycle

A decision to adopt a closed fuel cycle, with reprocessing SNF and recycling the fissile plutonium and uranium into reactors for power and transmutation of long-lived actinides, depends on three factors (1) economics, (2) impact on waste management, and (3) nonproliferation considerations.[19]

[18] Louisiana Enrichment Services centrifuge plant in New Mexico is in startup. Areva and U.S. Enrichment Corporation have announced plans for centrifuge enrichment plants respectively in Idaho and Ohio. General Electric-Hitachi is operating a pilot laser enrichment plant and plans for a commercial plant in North Carolina

[19] The 2003 study unfortunately did not point out that decisions on adopting a closed fuel cycle or a once-through fuel cycle would vary from country to country and that there is a significant difference between continuing with a specific program and committing to a new program. In addition to reprocessing facilities in Russia and China, there are three large facilities to reprocess commercial SNF plus smaller facilities in India. Since 2003, the La Hague facility in France continues its record of reliable operations and processes SNF for several other countries. There have been operational difficulties at the British Sellafield plant. The Japanese are in the process of starting up their reprocessing plant at Rokkasho-Mura, which appears to have cost over $25B for an 800 tonne/year reprocessing capability, a high cost relative to the costs of earlier facilities.

## 7. NON-PROLIFERATION

It is widely agreed that expansion of commercial nuclear power must occur with an acceptable low risk of transfer of nuclear material or technology that could move a nation to, or close to, acquiring a nuclear weapons capability or of making weapons-usable fissionable material available to subnational groups. The most sensitive elements of the fuel cycle are enrichment and reprocessing. In the case of enrichment, fuel enriched from natural abundance 0.7% U-235 to the commercial level of 4 to 5% must undergo further isotope separation to reach the "highly enriched level," normally taken to be >20% for U-235, necessary for nuclear devices. On the other hand, reprocessing, as practiced today in the PUREX (Plutonium and Uranium Recovery by Extraction) process, chemically separates plutonium from irradiated fuel and the separated plutonium (at the isotopic mixtures obtained from conversion of U-238 in normal reactor burn-up) is readily usable in weapons. Today, there are about 270 tonnes of separated plutonium from reprocessing of commercial nuclear fuel around the world.

The 2003 study emphasized that the expansion in global nuclear deployment envisioned in the mid-century scenario could include a significant number of emerging countries (where electricity growth is expected to be most rapid) becoming users of nuclear power. Forty countries have expressed interest in nuclear power in recent years and over 20 countries are actively considering nuclear power programs.[20] Many of these countries are located in regions of political instability, thus underlining the importance of separating potentially sensitive fuel cycle technology – front-end enrichment and back-end spent fuel management – from power reactor operations.

The 2003 study proposed that nuclear supplier states, roughly the G-8,[21] offer fuel cycle services to new user states on attractive terms in order to slow the process of additional states, especially new users with only a few reactors, building enrichment and reprocessing facilities. Other groups have made similar proposals and, since 2003, the Bush Administration took a leadership role in advancing this approach, leading, for example, to the Nonproliferation statement at the G-8 Gleneagles, Scotland summit on July 8, 2005.[22] This is a significant advance in international nonproliferation policy since the 2003 study.

Another positive development is the initiative taken by the International Atomic Energy Agency, supported by private organizations such as the Nuclear Threat Initiative and then by several countries (including the United States and the Persian Gulf states), to establish a nuclear fuel bank. The fuel bank is intended to provide security of nuclear fuel supply, so that countries have less reason to pursue enrichment or reprocessing facilities.

[20] http://www.iaea.org/Publications/Booklets/NuclearPower/np08.pdf

[21] The G-8 countries are Canada, France, Germany, Italy, Japan, Russia, the United Kingdom, and the United States.

[22] Available at: http://www.g7.utoronto.ca/summit/2005gleneagles/nonprolif.pdf

However, the G-8 initiative on providing fuel cycle services remains untried. Since 2003 there have been three unrealized opportunities where the G-8 nuclear fuel cycle initiative could have been helpful: (1) Russia leasing fuel to Iran for the Bushehr reactors now under construction, (2) United States convincing Brazil to abandon its plans for its new Resende enrichment plant, and (3) Using the U.S.-India agreement to encourage India to scale back its plans for PUREX fuel reprocessing. Iran's enrichment program is the centerpiece for international concern about use of the nuclear power fuel cycle to reach nuclear weapons "threshold" status.

*"The G-8 initiative on providing fuel cycle services remains untried."*

Since 2004, the DOE developed the Global Nuclear Energy Partnership (GNEP), a framework that encompasses its domestic and international R&D activities on advanced fuel cycles. Internationally, the purpose was to limit the spread of enrichment and reprocessing technologies through an arrangement of supplier and user countries. Domestically the purpose was to develop technology for a closed fuel cycle: the ultimate vision includes separation of spent nuclear fuel into multiple streams, fabrication of advanced fuel containing uranium, plutonium, and minor actinides, production of electricity, and destruction of the actinides in fast reactors. The objective is to achieve a closed fuel cycle that extends uranium resources, reduces long-lived isotopes in waste, and is proliferation resistant.

Whatever the merits of this closed-fuel cycle vision, it will be more expensive than today's once through fuel cycle, and involve a multi-billion dollar federal R&D and demonstration effort over several decades. Initially DOE undertook an R&D program to explore fuel cycle options. DOE then launched the GNEP program that included deployment of closed fuel cycle facilities. The unfortunate feature of GNEP is a premature move to reprocessing commercial reactor spent fuel, signaling exactly the opposite to the restraint on reprocessing being urged for new nuclear power users. Congressional doubts about the wisdom of quick deployment of reprocessing technology led to a reassessment of the GNEP effort. A key objective of the ongoing MIT Nuclear Fuel Cycle study is to provide analysis to assess the cost, benefits, and timing of different fuel cycles.

*"The unfortunate feature of GNEP is a premature move to reprocessing commercial reactor spent fuel, signaling exactly the opposite to the restraint on reprocessing being urged for new nuclear power users."*

## 8. TECHNOLOGY OPPORTUNITIES AND R&D NEEDS

The 2003 *Future of Nuclear Power* study included judgments about nuclear technology needs and recommendations for DOE's nuclear RD&D program. The 2003 study emphasized the importance of focusing on technologies relevant to near term nuclear power opportunities and avoiding large-scale demonstration and development projects for advanced fuel cycles and reactors that would not be commercialized for many decades. Comments on developments related to some technology findings and recommendations in the 2003 study follow:

(a) **Reactor technologies** The 2003 study recommended focusing on light water reactors and some R&D on the high temperature gas reactor (HTGR) because of its potential for greater safety and efficiency of operation. In contrast, the DOE has placed emphasis on fourth generation reactors (GenIV) suitable for breeding, transmutation, and production of hydrogen. The GenIV program does include HTGR R&D at a level of funding of $74 million as requested by the President for FY08. The focus is on demonstrating a high temperature reactor, suitable for providing electricity and high quality process heat for $CO_2$–free hydrogen production and other process heat applications. Significant progress has been made in fuel development which is the basis for HTGR enhanced safety, enhanced efficiency, and the high temperature capability. The changes in direction are a result of expressions of interest by the chemical and refinery industries; in contrast, the 2003 report emphasized the importance of demonstrating HTGR technology for commercial power applications. In the request for 2009, the DOE budget started an LWR Technology development program, which will partially examine issues of extending the life to 80 years and partially improve the power output of future LWRs. This program is expected to grow to a level of $50M per year.

(b) **Fuel cycle R&D** The 2003 study recommended lab-scale research on new separation technologies at a modest scale. Initially, the DOE program through the Advanced Fuel Cycle Initiative adopted this strategy. However, with the adoption of the GNEP program the emphasis was on near-term deployment that implied using near-term advances of existing technology and large-scale demonstration projects.

(c) **Modeling and simulation** The 2003 study emphasized the need for greater analytic capability to explore different nuclear fuel cycle scenarios based on realistic cost estimates and engineering data acquired at the process development unit scale. The DOE program has moved in this direction but much remains to be done.

(d) **International uranium resource assessment** Reliable estimates of the supply of natural uranium ore are important for estimating the economics of closed versus open fuel cycles and the timing when a transition to a closed fuel cycle might be desirable. As reported, the DOE has not launched such a project.

(e) **Waste management** The 2003 study urged that the DOE broaden its waste program beyond its almost exclusive focus on the Yucca Mountain Project to include a range of waste management alternatives. The 2003 study also emphasized the need for modeling to improve understanding of waste management and the entire fuel cycle life. The DOE has not moved significantly in this direction since 2003.

(f) **Fissile material protection, control, and accounting** (MPC&A) The 2003 study noted the need to develop MPC&A systems that would be suitable for use internationally so as to reduce the risk of material diversion from commercial fuel cycle facilities.

In total, the 2003 study recommended growing the annual nuclear R&D funding to approximately $450 million in the designated areas. The DOE nuclear budget has grown to that level but the distribution of new funds is not well aligned with the needs highlighted in the recommendations of the 2003 study.

## CONCLUSIONS

The central premise of the 2003 *MIT Study on the Future of Nuclear Power* was that the importance of reducing greenhouse gas emissions, in order to mitigate global warming, justified reevaluating the role of nuclear power in the country's energy future. The 2003 study identified the challenges to greater deployment and argued that the key need was to design, build, and operate a few first-of-a-kind nuclear plants with government assistance, to demonstrate to the public, political leaders, and investors the technical performance, cost, and environmental acceptability of the technology. After five years, no new plants are under construction in the United States and insufficient progress has been made on waste management. The current assistance program put into place by the 2005 EPACT has not yet been effective and needs to be improved. The sober warning is that if more is not done, nuclear power will diminish as a practical and timely option for deployment at a scale that would constitute a material contribution to climate change risk mitigation.


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