Chapter 1
Keeping the Lights on in the New World

1.1 Introduction

Reliable electricity is something that Americans expect from the bulk power supply system. It ensures that homes remain at comfortable temperatures; it enables timely, accurate response to emergencies; it keeps industry moving and powers the millions of transactions made daily in the U.S. marketplace. An adequate, reliable, and affordable supply of electricity is critical to maintaining and improving the nation's security, standard of living, and competitive edge in a world where electricity serves as the cornerstone of a modern economy.

The U.S. electric power grid comprises thousands of individual entities that produce and deliver electricity to end-use consumers, usually without interruption. These entities are responsible for ensuring a continuous balance between electricity supply and demand, coordinating the reliable exchange of electricity between buyers and sellers over thousands of miles of high-voltage transmission lines, and maintaining the operational integrity of the current and future interconnected grid.

Currently, electricity is difficult to store so it must be generated at the instant that it is used. It flows simultaneously over many paths in the transmission networks and cannot typically be routed over selected lines, except in the case of direct current facilities. As a result, the operation of the generators and transmission lines that make up the bulk power system must be constantly monitored and controlled to ensure that they are operating within safe limits, and that adequate, consistent, and reasonably priced electricity will remain available.

This report addresses the current trends of electricity generation and transmission, the use of demand-side resources, and future electricity needs. Through analysis of these components, the Electricity Advisory Committee (EAC or Committee), representing industry, academia, and state government, recommends policies to the U.S. Department of Energy (DOE) to consider when addressing issues related to maintaining a strong and reliable electric power service in the future.

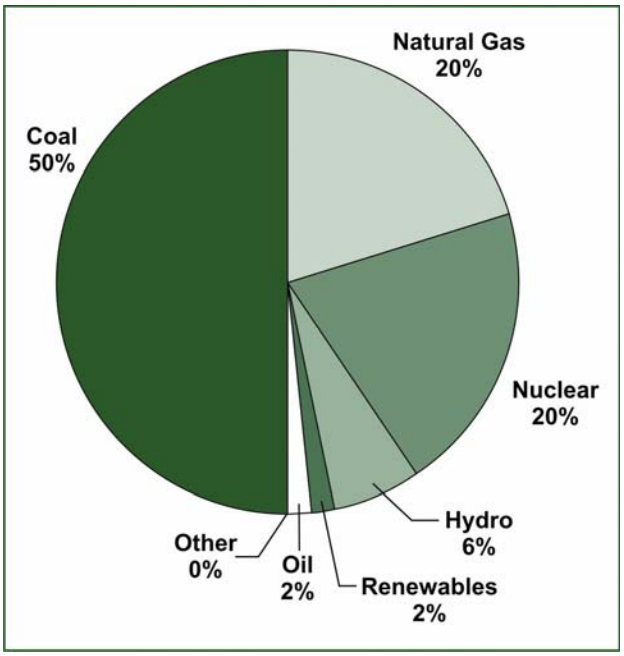
The overall purpose of this report is to ensure the smooth transition of the electric power system infrastructure in the coming years as the infrastructure addresses a "new world" of increasing demand for low-carbon resources and higher levels of reliability and complexity. The following chapter provides an overview of the major elements of the bulk electricity supply and delivery system and the challenges that need to be addressed over the next two to three decades to ensure the continued reliability and efficiency of U.S. electric power service. Chapters 2–4 discuss the challenges of generation adequacy, demand-side resources, and transmission adequacy in greater detail while putting forth specific recommendations to address the electricity challenges of the new world.

1.2 U.S. ELECTRICITY GENERATION RESOURCES

Currently in the United States, there is a mix of generation and demand-side resource technologies available to meet demand requirements. These electricity-producing technologies vary in their availability to serve load at times of high demand, their costs, and their average capacity.

In 2007, the mix of generation resources in the United States reflected a heavy dependence on generation technologies that burn fossil fuels or use nuclear technology to produce electricity (Figure 1-1).

Figure 1-1. Electricity Resource Mix in the United States, 2007



Source: Energy Information Administration 2007.[1]

Note: Some of the relevant data used in this figure was obtained at the national level, while some was obtained from region-specific reports.

Renewable energy resources, including wind, geothermal, and solar photovoltaics, are generally higher in cost than fossil fuel-burning resources, with costs that range from as low as $70 per megawatt hour (MWh) for the best wind power resources to as high as $400 per MWh for solar photovoltaics. None of these costs reflects the cost of transmission needed for reliable integration of the resource into the bulk power system or the impact of subsidies (such as production tax credits) that may reduce the apparent cost of a given resource. In comparison, low-cost resources tend to include natural gas, coal, and biogas, which range from $60–120 per MWh, depending on the cost of fuel and the location and size of the facilities. Figure 1-2 shows the levelized costs of a variety of generating technologies and fuels in the western United States. (The comparable costs for the eastern United States are assumed to be similar.) These costs reflect the expenses of owning, operating, and purchasing fuel for these resources.

The average on-peak capacity/utilization factors of resource technologies are important for determining the adequacy of total resources because they reflect each technology's dependability during peak demand periods. Average capacity factors represent the fraction of the year during which an average plant of that type is producing electricity. Figure 1-3 depicts these factors for the different resource technologies currently in use today, As the figure shows, the existing fossil fuel burning resources (natural gas and coal) and nuclear resources have very high capacity factors, which correspond to the ability to provide peak capacity as well as a flexible, dispatchable form of energy. On the other hand, wind power, the most abundant and lowest cost renewable resource, may have an average capacity factor of 30–40% depending on the type and location of the turbine. On-peak capacity factors of this technology, however, are typically lower.

1.3 CHARACTERISTICS OF RESOURCES TO MEET ELECTRICITY NEEDS

Traditional Resources

Coal, natural gas, nuclear, and hydroelectricity resources made up 96% of electricity generation in the United States in 2007,[2] though these shares are slowly declining due to increased development of renewable energy generation. The following section discusses the characteristics of each of these resources.

Coal

Coal has been a dominant resource in the domestic electric industry due to its relatively low cost and widespread availability, providing nearly half of the

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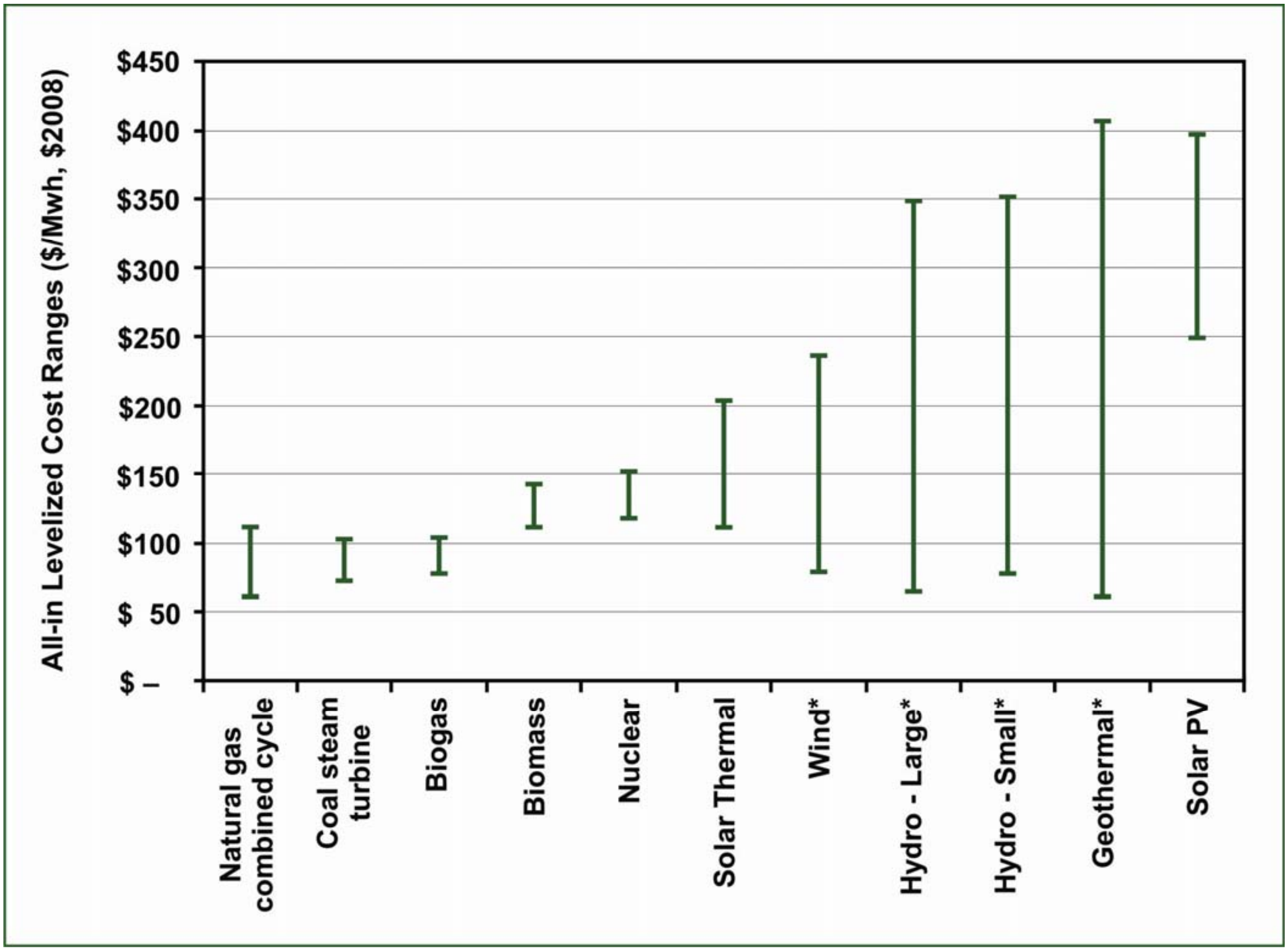
[1] Energy Information Administration, *Annual Energy Review* (Washington, DC: Energy Information Administration, 2007), table 8.2b, http://www.eia.doe.gov/emeu/aer/elect.html.
[2] See Figure 1-1.

Figure 1-2. Relative Cost of Conventional and Renewable Energy Resources in the Western Electricity Coordinating Council (WECC), Dollars Per Megawatt Hour (MWh), in 2008 Dollars



** The costs of resources denoted with an asterisk are highly site-specific and have wide ranges in cost depending on the project location.*

Source: Energy Information Administration 2007.[4]

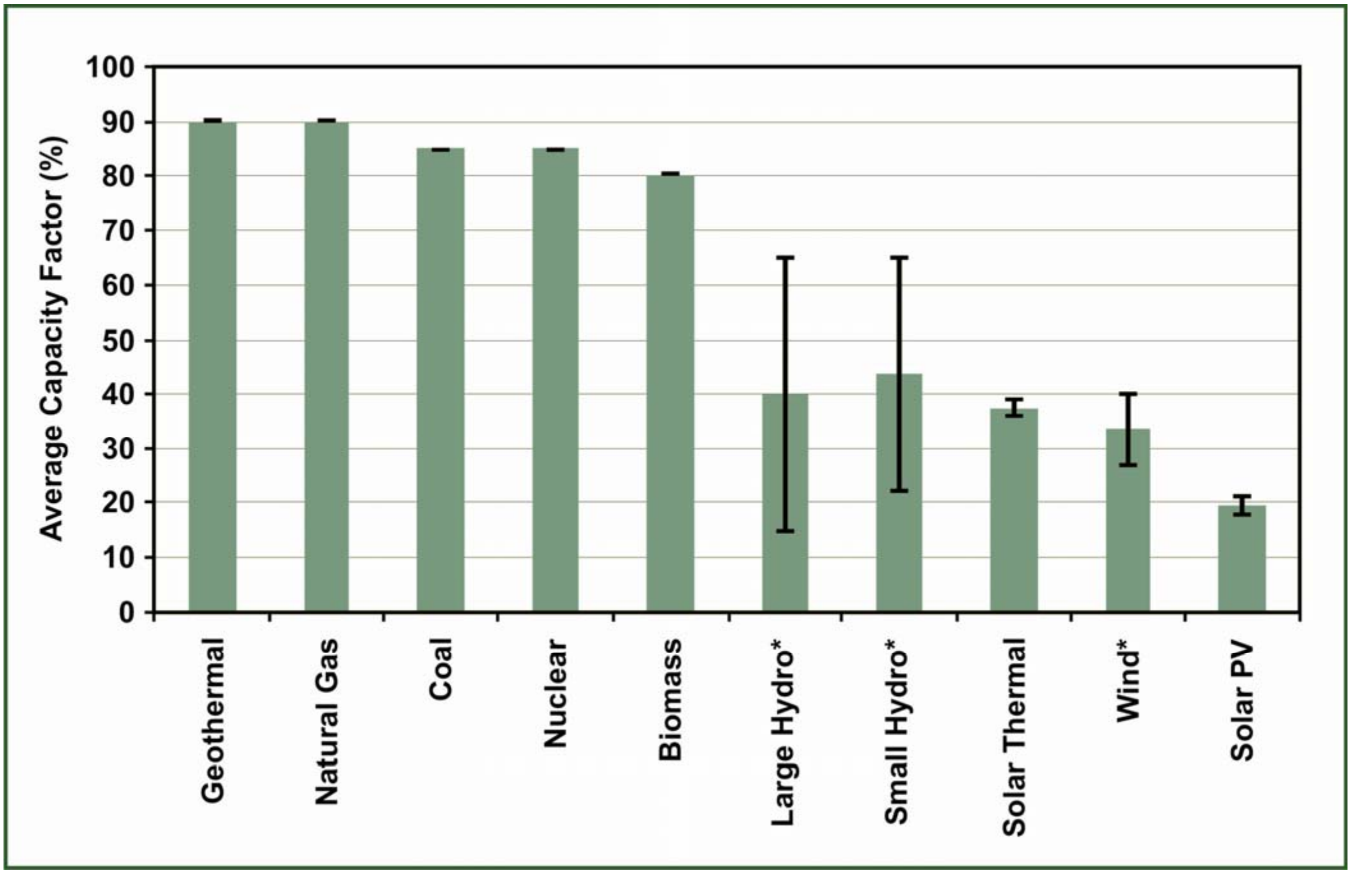
nation's electricity in 2007. U.S. coal plants are used as baseload generation due to both the historically inexpensive fuel costs and the difficulties of starting up and shutting down the units quickly, leading to a relatively high average capacity factor of 72.6% in 2006.[3]

Although it remains one of the most widely utilized electricity-producing resources in the United States, the environmental impact of coal is high on both a local and global level and at every level of the production chain. Coal mining can lead to significant landscape changes and issues with water runoff, while coal power plants have a large footprint. Generation from coal releases significant amounts of both local pollutants (particulates, sulfur oxides [SO_x], nitrogen oxides [NO_x], and mercury) and global pollutants such as carbon dioxide (CO_2).[5] Cooling water for coal plants can also cause environmental damage if improperly discharged into lakes or streams. Coal plants, whether they employ once-through cooling or closed-loop cooling (cooling towers), also consume water; this can be an issue where water use is a constraint. Furthermore, since coal plants are hard to

[3] Energy Information Administration, Office of Coal, Nuclear, Electric and Alternative Fuels, *Electric Power Annual 2006* (Washington, DC: Energy Information Administration, 2007), 5, http://www.eia.doe.gov/cneaf/electricity/epa/epa.pdf.
[4] Energy Information Administration, *Annual Energy Review* (Washington, DC: Energy Information Administration, 2007), table 8.2b, http://www.eia.doe.gov/emeu/aer/elect.html.

[5] Environmental Protection Agency, "Coal-Clean Energy," http://www.epa.gov/cleanenergy/energy-and-you/affect/coal.html.

Figure 1-3. Average Capacity Factor of Conventional and Renewable Energy Resources in the Western Electricity Coordinating Council



** The capacity factors of resources denoted with an asterisk are highly site-specific and have wide ranges in performance depending on the project location.*

Source: California Public Utilities Commission 2006.[7]

site near areas that are densely populated, they often require significant transmission development, which can have environmental impacts of its own.

Natural Gas

Generation from natural gas has increased its market share in recent years, growing at a rate of about 6.8% annually over the last 10 years.[6] Natural gas-fired units are typically used during periods of intermediate to high demand, since these units are able to quickly increase or decrease their power production.

Natural gas-fired generation has a reduced environmental impact compared to coal, releasing approximately one-half of the CO_2, one-third the NO_x, and negligible amounts of SO_x and mercury. Combined-cycle natural gas turbines also consume water and require water for cooling purposes, which can lead to environmental damage if improperly discharged into lakes or streams. Combustion turbines do not require any water for cooling, but they are far less fuel-efficient than the combined-cycle units.

[6] Environmental Protection Agency, "Natural Gas- Clean Energy," http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html.

[7] California Public Utilities Commission, Order Instituting Rulemaking to Implement the Commission's Procurement Incentive Framework and to Examine the Integration of Greenhouse Gas Emissions Standards Into Procurement Policies, Docket No. R.06.04.009, April 13, 2006. Capacity factors for hydroelectric generation and wind power resources are highly site specific. The capacity factor for solar thermal technologies depends on the technology type and vintage. Documentation of the assumptions underlying the all-in levelized cost estimates are documented on the Energy and Environmental Economics, Inc. (E3) website at: http://www.ethree.com/cpuc_ghg_model.html.
The natural gas capacity factor in Figure 1-3 is based on high-efficiency combined-cycle generation.

Nuclear

Nuclear generators make up 11% of the net summer generating capability in the United States, despite the fact that there has not been construction started on a single nuclear reactor since the River Bend reactor in 1977.[8] Nuclear generation has a high capacity factor (nearly 90%) and is used exclusively for baseload power generation due to the long time frames required to start up and shut down generation.

Though nuclear energy does not have any emissions associated with its generation, there are still significant environmental concerns surrounding further development. Foremost among these concerns is the disposal of spent nuclear fuel and irradiated plant materials that will remain radioactive for thousands of years. Nuclear power also has issues similar to other technologies in regard to using water for producing steam and cooling.[9]

Hydro

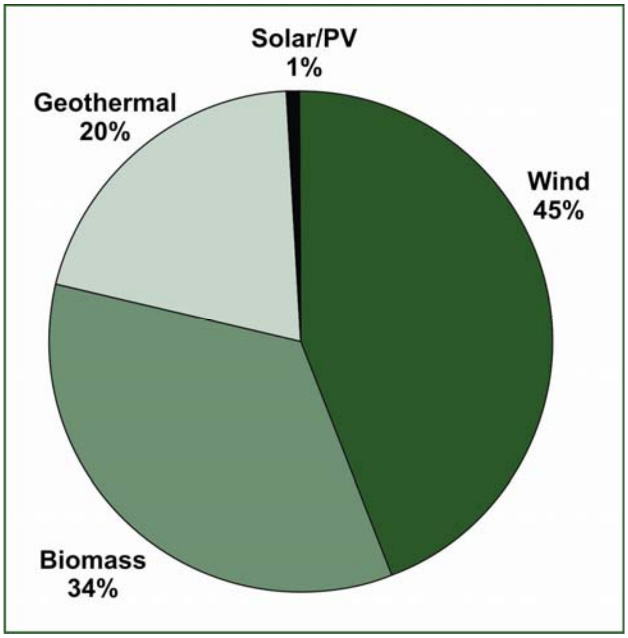
Hydroelectric resources are currently the most significant source of renewable power in the United States, generating about 6-8% of the electricity in 2006–2007. Hydroelectric power is generally used as baseload generation, but its availability is subject to variations in water levels and the use of water for other purposes, such as recreation and support of fish reproduction. During times of drought, hydropower often cannot produce at full capacity.

When discussing the environmental impacts of hydropower, a distinction must be made between run-of-the-river hydropower and dam hydropower. Run-of-the-river installations are typically much smaller and have a significantly lower impact, while large dams flood large strips of the landscape and disturb fish migration routes, among other impacts. While hydropower does not generate any CO_2, decomposing biological materials in the inundated areas behind the dam release methane (CH_4), which has much more radiative forcing potential than CO_2. These emissions are difficult to measure and are highly site-specific, although CH_4 emissions are typically worse from dams sited in warm climates, especially tropical ecosystems.

Renewable Energy Resources

Renewable energy's share of overall generation in the United States is small but increasing. Figure 1-4 shows the share of the overall sum for each of the renewable technologies.

Figure 1-4. Non-Hydro Renewable Generation by Resource



Source: Energy Information Administration 2007.[10]

Renewable energy, including wind power, biomass, geothermal, and solar generation, composed 2% of total electricity generation in the United States in 2007. However, this percentage is expected to increase as many states make progress towards achieving local renewable portfolio standards (RPS). Such standards typically mandate that a specific percentage of electric power supplied at retail be obtained from qualifying renewable energy technologies. As of July 2008, 27 U.S. states had adopted some form of state RPS requirements.[11]

Renewable energy's contribution to resource adequacy and on-peak capacity varies by technology type and resource location. For example, while wind and solar technologies currently operate with fairly low on-peak capacity factors (averaging 24% and 14%), geothermal and biomass provide higher on-

[8] Energy Information Administration, "U.S. Nuclear Reactor List-Operational," (Washington DC: Energy Information Administration, November 2004), http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/operational.xls.

[9] Environmental Protection Agency, "Nuclear Energy- Clean Energy," http://www.epa.gov/cleanenergy/energy-and-you/affect/nuclear.html.

[10] EIA 2007, Form EIA-860

[11] See the Database of State Incentives for Renewables and Efficiency (DSIRE) available at http://www.dsireusa.org.

peak capacity (with capacity factors averaging 74% and 28%).[12]

Wind Power

Wind power resources vary in quality across the United States, ranging from very high-quality Class 7 wind, often found in the midwestern high plains, to low-quality Class 1 and Class 2 wind, which are not commercially viable with existing technologies.

The capacity factor of wind also varies widely, ranging from 5–40% of rated wind power plant capacity. DOE's *20% Wind Energy by 2030* study assumed the capacity factors shown in the table below for 2005:

Table 1-1. DOE Assumed Capacity Factors

Wind power Resource Power Class at 50 Meters	Wind power Capacity Factor (%) in 2005
3	32
4	36
5	40
6	44
7	47

Source: U.S. Department of Energy 2008.[13]

Utilities, transmission operators, and regulators in the United States are generally less confident in the availability of wind power resources than the capacity factors used in the DOE study would suggest. The California Energy Commission; Pennsylvania, New Jersey, Maryland Interconnection LLC (PJM); PacifiCorp; Puget Sound Energy (PSE); Avista; and Rocky Mountain Area Transmission Study (RMATS) all use values close to 20% for wind power capacity factors, while other utilities apply capacity factors closer to 10% or lower.[14]

The low on-peak availability of wind power indicates that this resource is less useful for resource adequacy purposes than as an energy resource. Likewise, although wind power forecasting capabilities are improving, intermittent and unpredictable wind power remains problematic for resource planning purposes in many regions of the country.

Wind power energy generates no direct greenhouse gas (GHG) emissions, other air pollutants, or particulate matter. However, the full environmental impact of wind power generation on migratory birds, bats, and other wildlife has yet to be determined. Specifically, some wind power projects have generated concern that the rotating turbine blades can negatively impact migratory birds' flight paths and lead to bird and bat mortality.[15] Some wind power projects are more prone to harming wildlife than others, depending on the specific location of the project, just as some wind turbine technologies are more wildlife-friendly than others.[16] Large wind power development projects face other siting issues, including concerns about the terrestrial footprint or the impact on marine life in the case of offshore wind power projects, or potential interference with some radar installations and low-level military flight training routes.[17]

Solar Photovoltaic

There are two principal forms of solar photovoltaic (PV) installations: distributed PV and utility-scale PV. Distributed PV installations are typically small in size (only a few kilowatts [kW] in capacity) and are often "behind-the-meter," meaning that from the utility perspective they are considered a demand reduction rather than a source of supply. Distributed PV makes up the vast majority of current PV installations. Utility-scale PV is typically larger in size (closer to 1 MW or larger in capacity), and is ground-mounted as opposed to being located on rooftops as typically is the case with distributed PV. The United States is beginning to develop utility-scale PV, though it is still in its infancy as a large-scale generation technology. Both distributed and utility-scale solar PV installations have a capacity factor in

[12] Implied on-peak capacity factors of renewable energy technology types are from EIA Form 860 using 2007 data. http://www.eia.doe.gov/cneaf/electricity/page/eia860.html.

[13] U.S. Department of Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, (Washington, DC: U.S. Department of Energy, 2008), http://www.20percentwind.org/20percent_wind_energy_report_revOct08.pdf.

[14] EIA 2007, Form EIA-860.

[15] Altamont Pass Avian Monitoring Team, *Altamont Pass Wind Power Resource Area Bird Mortality Study*, Prepared for Alameda County Community Development Agency (Portland, OR: Altamont Pass Avian Monitoring Team, July 2008), http://www.altamontsrc.org/alt_doc/m21_2008_altamont_bird_fatality_report.pdf.

[16] U.S Government Accountability Office, *Wind Power: Impacts on Wildlife and Government Responsibilities for Regulating Development and Protecting Wildlife*, (Washington DC: GAO, 2005), GAO-05-906, http://www.gao.gov/new.items/d05906.pdf.

[17] U.S. Department of Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, (Washington, DC: U.S. Department of Energy, 2008), http://www.20percentwind.org/20percent_wind_energy_report_revOct08.pdf.

the range of 18–21% because they are limited to only producing power when the sun is shining.
Solar PV produces no direct air pollution or GHG emissions and requires no water for cooling unlike geothermal, solar thermal, and biomass resources. The principal environmental concern with solar PV is that the chemicals required to produce the panels and often utilized in the panels themselves can be harmful pollutants such as cadmium telluride, which is used extensively to make some of the lower cost thin-film resources. This effect can be mitigated somewhat by the proper care for and disposal of the units. Utility-scale solar PV raises additional concerns about the impacts on wildlife and local ecosystems when large land areas are required for ground-mounted solar PV facilities.

Concentrating Solar Thermal

As a solar-powered technology, concentrating solar thermal energy is only available during daylight hours, with availability varying by region and weather patterns. Unlike solar photovoltaic, most solar thermal technologies require direct solar rays known as direct normal insolation (DNI), which means that performance declines significantly under cloudy conditions. Some solar thermal technologies can store thermal energy for a few hours by transferring it to silicon oil or molten salt. Thermal storage capabilities may be available for up to six hours, increasing the capacity value of solar thermal as an energy source from 10% up to 40%.[18]

While solar thermal energy produces no direct GHG emissions or air pollutants, solar thermal projects require relatively large land areas to generate energy at the utility scale. The terrestrial footprint of solar thermal technologies can interfere with natural patterns of sunlight, rainfall, drainage, or other existing land uses, such as grazing. Water availability is another concern, as the optimum solar resources rely on water for cooling, yet are typically located in the Desert Southwest.

Geothermal

Geothermal power uses the heat contained in subterranean geologic strata to generate electricity. The heat driving the generation process typically comes from subterranean hot water or brine trapped in porous rock that is brought to the surface in a well. Geothermal is a baseload resource, is available during all hours of the day, is independent of weather conditions, and has no associated fuel costs. The Energy Information Administration's (EIA) *Annual Energy Outlook 2008* estimates geothermal's capacity factor to be 90%.

The primary environmental impact of generation from geothermal resources is water use. Water is typically used as the cooling agent in geothermal energy production, though at a rate of approximately 5 gallons per MWh, compared to nearly 360 gallons per MWh consumed by natural gas-fired generators.[19] No fossil fuels are burned in the process, although geothermal generation can result in a small amount of fugitive GHG emissions.[20]

Biomass

Biomass encompasses a number of different technologies and fuel sources, including wood, forestry waste, crop waste, dedicated biomass crops (e.g., switchgrass), municipal solid waste (MSW), landfill gas (LFG), and gases produced from dairy wastes and municipal wastewater treatment. More specifically, biomass refers to technologies that burn biomass fuels and use the heat to operate a steam turbine. Biogas refers to technologies that burn gaseous biomass fuels in a combustion turbine or reciprocating engine.[21]

Biomass combustion turbines can operate at capacity factors competitive with traditional turbines, estimated at 80–85%. The limiting constraint on biomass is feedstock availability, which has traditionally been limited by the price of coal as a fuel substitute. In 2001, the EIA estimated that with coal prices at $1.23 per million British thermal units (Btu), economically available biomass feedstock could generate up to about three gigawatts (GW) of capacity in the United States. Higher demand for renewable energy resources and/or higher coal prices could generate more economically attractive biomass feedstock.

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[18] L. Stoddard, J. Abiecunas, and R. O'Connell, Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California, NREL/SR-550-39291 (Kansas: Black & Veatch, April 2006), http://www.nrel.gov/csp/pdfs/39291.pdf.

[19] Alyssa Kagel, Diana Bates, and Karl Gawell, *A Guide to Geothermal Energy and the Environment* (Washington, DC: Geothermal Energy Association, 2007), http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf.

[20]

[21] Biomass-derived liquids such as ethanol, biodiesel, and Fischer-Tropsch liquids have high-value competing uses such as transportation fuels and chemical feedstocks and are not treated here as fuel for electricity generation.

Despite the fact that biomass combustion produces GHG emissions, there are no net CO_2 emissions from biomass generation when the entire biomass fuel cycle (carbon cycle) is taken into account. Thus, biomass is generally considered to be a zero-carbon fuel. Biomass combustion produces particulate matter as well as other air pollutants such as SO_x and NO_x; however, it is generally less polluting when compared to coal-fired generation.[22]

Demand-Side Resources

While the above technologies all constitute sources of electricity generation that can be developed to serve load, demand-side resources can serve adequacy needs by reducing load, thus reducing the need for new generation. "Demand-side resources" typically refers to one of two methods of reducing load: energy efficiency or demand response / load management.

Energy Efficiency

Energy efficiency is the concept of designing and deploying improved technologies that can perform the same function as existing electricity end-uses while reducing electricity use. Relatively efficient alternatives exist for a widespread array of products and applications, including refrigerators; lighting; and heating, ventilation, and air conditioning (HVAC) systems. However, products do not have to use electricity in order to be able to promote energy efficiency. Building materials and designs can reduce electricity use as well.

Market barriers to energy efficiency reduce its penetration rates, despite the fact that many energy efficiency measures are cost effective (i.e., produce net benefits relative to cost) over their lifetimes. One market barrier is the typically higher up-front cost of energy-efficient appliances and measures, which may discourage consumers from purchasing them. This issue is typically addressed by an energy efficiency program that provides incentives (e.g., rebates or free appliance replacement) to consumers who purchase or use energy-efficient products, or through local, state, or national regulation that requires the use of energy-efficient products. Many of these codes and statutes apply to buildings, setting a baseline for the appliances and materials they use to promote a minimum level of efficiency.

The cost of energy efficiency varies widely. In some cases, the incremental cost of installing or purchasing a more efficient product is less than the cost of the energy that it would take to run the less efficient product. For example, a 2004 study by Resources for the Future found that the development of efficiency standards for appliances provided energy savings at a cost of approximately 3.8¢ per kWh,[23] compared to the average nationwide electricity price of 7.6¢ per kWh at that time.[24]

While energy efficiency is typically promoted as a way to reduce energy usage, it can also serve to substantially reduce peak electricity demand. Many of the appliances commonly targeted by energy efficiency programs are the same appliances that contribute to a utility's demand. Air conditioning units are a prime example of this, as peak demand is usually correlated with the hottest days of the summer, when air conditioners are running at full capacity. EIA estimates that energy efficiency programs reduced peak demand by 15,959 MW in 2006, or the equivalent of 32 typical power plants (500 MW generators). Throughout 2006, energy efficiency was estimated to reduce total energy usage by an estimated 62,591 gigawatt hours (GWh). However, it is difficult to estimate the impact that energy efficiency programs will have on peak loads and energy usage in the future, as it is highly dependent on the technologies deployed and the level of deployment.

The environmental benefits of energy efficiency are vast, as it reduces the need for more generation. This in turn, eliminates the environmental impacts of the displaced generation. As different geographic areas around the United States rely on highly varied generation portfolios, efficiency can have a greater or lesser environmental benefit, depending on where it is deployed.

Demand Response / Load Management

Demand response, also referred to as load management, consists of encouraging consumers to reduce their electricity consumption during times of

[22] Zia Haq, Energy Information Administration, "Biomass for Electricity Generation," http://www.eia.doe.gov/oiaf/analysispaper/biomass/pdf/biomass.pdf.

[23] Kenneth Gillingham, Richard G. Newell, and Karen Palmer, Resources for the Future, *Retrospective Examination of Demand-Side Energy Efficiency Policies* (Washington, DC: Resources for the Future, 2004), http://www.rff.org/Documents/RFF-DP-04-19rev.pdf.

[24] Energy Information Administration, *Electric Power Annual* (Washington, DC: Energy Information Administration, 2008) table 9.2, http://www.eia.doe.gov/cneaf/electricity/epa/epat9p2.html.

especially high demand. This encouragement is typically done by enrolling consumers in utility-sponsored demand response / load management programs. Historically, the peak reduction caused by demand response / load management has been hard to predict because it depends on individual decisions made at the consumer level. However, recent inclusion of demand response / load management resources in capacity markets, such as Independent System Operator-New England's (ISO-NE) Forward Capacity Market and PJM Interconnection's Reliability Pricing Model, is resulting in an increased reliance on long-term contracted demand response / load management which can be compared more easily with generation resources.

The cost of demand response / load management, like energy efficiency, is highly variable to the point where each consumer can receive a different payment to reduce his or her load. However, the recent forward capacity auctions mentioned above have provided some information as to the amount of demand response / load management consumers are willing to provide at the clearing price of the auction. In PJM's auction for the 2011–2012 delivery year, 1,365 MW of demand response / load management cleared at a price of $110/MW per day, or the equivalent of about $4.58/MWh.[25] In ISO-NE's recent auction for the same time period, 2,554 MW of demand response / load management resources cleared when the auction reached its price floor of $4.50/kW per month, or roughly $6.25/MWh per month (for a 30-day month).[26]

While demand response / load management has the environmental benefit of reducing the need to build additional power plants to serve the system peak, it does not necessarily reduce the amount of electricity generated in a given year. Demand response / load management often serves to simply shift electricity consumption to a different time period. The EIA estimates that load management reduced the peak load in 2006 by 11,281 MW but only reduced energy usage that year by 865 GWh. This represents a peak load savings of 71% of the size of energy efficiency's estimated peak savings but only 1.4% the size of energy efficiency's estimated energy savings.[27] With the introduction of sizeable intermittent renewable energy resources, the evolution of smarter devices at the demand side, and the increasing attention to the Smart Grid concept, demand response could play a major role in reshaping the historical demand curve every day of the year, rather than only on peak days, in a manner that reduces reliance on traditional generation facilities.

Combined Heat and Power

Combined heat and power (CHP) systems are located at consumer facilities (primarily industrial and very large commercial facilities) and generate both power and steam. The steam is used on site (or nearby) for process heat or space conditioning, and the power may be used on site or sold to the grid. These plants can have very high efficiency (45–80%) because much of the heat is used and not wasted. According to EIA, in 2006, CHP systems generated about 322 terawatt hours (TWh) of electricity, accounting for 7.9% of net generation that year.[28] Several studies have estimated that the amount of power from CHP could be increased by more than 50%.[29] On the other hand, realizing this potential will require the overcoming of a variety of barriers, ranging from host-site reluctance to get into the power business, fluctuations in gas and electricity prices over time, and problems with environmental regulations and interconnection requirements in some service areas and jurisdictions.

1.4 Transmission Resources

The U.S. electric grid infrastructure consists of about 3,000 consumer-serving entities and 500 transmission owners. This makes the U.S. grid system unique compared to the rest of the world. It also presents a distinct set of challenges in transmission planning, operating, siting, investment, regulatory oversight, and access. The development and deployment of a national strategy on transmission that meets the needs

[25] Pennsylvania, New Jersey, Maryland Interconnection LLC, "2011/2012 Base Residual Auction Results," May 2008, http://www.pjm.com/markets/rpm/downloads/20080515-2011-2012-bra-results-spreadsheet.xls.

[26] Independent System Operator-New England, "ISO New England Inc., Docket No. ER08-___-000 Forward Capacity Auction Results Filing," (Washington, DC: Schiff Hardin, March 2008), http://www.iso-ne.com/regulatory/ferc/filings/2008/mar/er08-633-000_03-03-08_fca_results_filing.pdf.

[27] Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, *Electric Power Annual* (Washington, DC: Energy Information Administration, 2008), table 9.2, http://www.eia.doe.gov/cneaf/electricity/epa/epa.pdf.

[28] Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, *Electric Power Annual* (Washington, DC: Energy Information Administration, 2008), table 1.1, http://www.eia.doe.gov/cneaf/electricity/epa/epa.pdf.

[29] Cites to be added, 50% figure checked and maybe modified.

of all market participants and consumers is extremely complex; yet, it is desperately needed.

The high-voltage transmission network in the United States comprises nearly 164,000 circuit miles of transmission lines at voltages 230 kilovolts (kV) and above. The total number of transmission miles is projected to increase by 9.5% (15,700 circuit miles) over the next 10 years. This figure represents 1,700 more circuit miles projected to be added over the coming 10-year period, when compared to projections one year ago.[30] Other reinforcements to the bulk power system, like new transformers and reactive power sources, are also planned and will further strengthen the system.

More transmission resources and investments will be needed, however, to maintain reliability and integrate new resources as aging infrastructure is replaced and changes are needed to the transmission system topology. New generation supply is projected to outpace transmission development by nearly two times. Further, many new supply resources are likely to be located remote from demand centers (e.g., wind power generation) and constrained to those areas. The amount of transmission required to integrate these resources is significant.

From 1974 to 1983, annual investment in transmission infrastructure averaged about $5 billion in 2005 dollars. In the next 10-year period, average annual investment fell to $3.7 billion and by 1993–1994 hit a low of $2.5 billion. Since that time, annual investments have begun to climb, reaching $5.8 billion annually in 2005, with projections to exceed $8 billion in 2009. This remains a very small component of an industry with $800 billion of capital that is projecting a need for $200 billion in the next three years.

Lagging investment in transmission resources has been an ongoing concern for a number of years. More investment is required as each peak season puts more and more strain on the transmission system, especially in constrained areas such as California and the Desert Southwest.

The process to site new transmission continues to be difficult, time-consuming, and expensive due to local opposition, environmental concerns, insufficient information provided by project proponents, land-agency staffing constraints, and the need for state and federal planning and permitting coordination, especially for proposed lines that would cross state borders. Such factors delay and, in some cases, stop projects from being built. As a result, transmission permitting, siting, and construction frequently take significantly longer (i.e., 7–10 years) than the permitting, siting, and construction of generation.

Transmission lines are the critical link between the point of electricity generation and consumers. As demand grows and generation is built in areas remote from the demand, more capacity on the transmission system is needed to meet demand. Under-investment in transmission puts additional strain on existing resources, raising the risk of system disturbances, lengthening restoration time when outages do occur, and limiting access to remote generation.

1.5 Control Centers

Control centers are the nerve center of any large-scale electric power system. There are several levels of control centers, each defined by the magnitude and number of loads served, generation coordinated, and transmission operated. An Independent System Operator (ISO) or Regional Transmission Organization (RTO) uses its control center to manage and operate the assets under its purview in order to accomplish its various tasks. The primary function of a control center is as an interface between the power system and the system operators responsible for operating it. Data acquisition allows system operators to monitor the condition of the system and implement supervisory (manual) controls, such as opening and closing circuit breakers to engage or disengage transmission lines in the network or switching in and out shunt capacitors or reactors to control voltage levels throughout the network. A Supervisory Control and Data Acquisition (SCADA) system uses a communication system to gather system-wide data sequentially at a rate in range of 2–10 second (s) per measurement. The fastest scan rates (2–4 s) are used to collect the data needed for Automatic Generation Control (AGC), which controls tie-line power flows and generator outputs. This system is the main wide-area control in use today. It can effectively act on a slow time scale and therefore does not require high bandwidth communication. The energy management system (EMS) software in most control centers provides a number of computational tools to assist the operators in reaching their decisions, but very little, if

[30] North American Electric Reliability Corporation, "2008 Long-Term Reliability Assessment: 2008-2017," (Princeton, NJ: North American Electric Reliability Corporation, October 2008), http://www.nerc.com/files/LTRA2008.pdf.

any, of this is implemented as a closed-loop or automatic control.

Some control centers also perform the important task of scheduling power transactions that are managed by the system operators. A principal role for such a control center is to facilitate markets (i.e., to support as many transactions as the various market players require to conduct their businesses.) This role is discharged under the constraint of maintaining the reliability and security of the interconnected system. The system operator also has the obligation to provide transmission service to all consumers through open, non-discriminatory access to available transmission capacity and to have reliable supply to maintain reliable and efficient electricity. The system operator has the responsibility to acquire and supply all necessary services, such as ancillary services, to fulfill this obligation. Finally, as defined by the Federal Regulatory Energy Commission (FERC), the ISO/RTO is independent of all market participants, having no ownership/financial interests in any of these entities and vice versa.

In addition to operating under normal conditions, control centers are designed to operate when there are emergencies that cause system stress and during restoration when there are widespread outages of equipment that have left all or portions of load unserved. The loss of a control center poses a serious threat to the operations of an electricity system. For this reason, emergency planning dictates the existence of a backup control center that can assume the appropriate functions of the primary center at any time it is needed.

The effectiveness of a control center's capability to enable the system operators to do their job depends on the tools and technology available. The complexity of the planning and operation tasks performed under the severe reliability and security constraints imposed during an emergency is an enormous challenge both technically and institutionally.

1.6 Human Resources

The United States has become a technological society fully dependent on certain critical infrastructures like the bulk power system. This system has been cited as the greatest engineering achievement of the twentieth century by the National Academy of Engineering. The engineers who created it were educated mostly at universities in the United States. The engineering faculties and graduate students at those universities have conducted much of the research needed to support the continuing evolution of the system. This group of industry and academic experts is as important an asset to the safe, reliable, and economical operation of the bulk power system as any generator, transmission line, or control center. It is also an asset that is at risk.

More than 50% or about 200,000 current utility workers are eligible for retirement by the year 2010. The electric power industry's engineering workforce is aging and engineering work is increasingly being outsourced. According to the DOE report prepared in response to Section 1101 of the U.S. Energy Policy Act of 2005 on current trends in the workforce,[31] "in 2004, there were 10,280 electrical engineers working in the electric power generation, transmission, and distribution industry. By 2014, the Bureau of Labor Statistics projects demand will grow to 11,113."

In 2007, the North American Electric Reliability Corporation (NERC), the organization responsible for setting the rules and monitoring the reliability of the bulk electric system, listed the manpower deficit as one of three major threats to maintaining the future reliability of the bulk power system.[32] NERC updated the DOE statistics of 2005 by noting that 40% of senior electrical engineers and shift supervisors will be eligible for retirement in 2009, and that there will be an increase of 25% in demand for industry workers by 2015.

At the same time, the undergraduate student enrollment in power systems engineering programs in the United States has been diminishing and is not improving, primarily because the number of power system programs at universities is declining. Graduate student enrollment has been steadier because of the large percentage of foreign students in the Master of Science (M.S.) and doctorate (Ph.D.) programs. The power engineering faculty in the United States are growing older, with the average age of the professoriate creeping upward and the number of

[31] U.S. Department of Energy, *Workforce Trends in the Electric Industry: A report to the United States Congress pursuant to Section 1101 of the Energy Policy Act of 2005* (Washington, DC: Department of Energy, August 2006), http://www.oe.energy.gov/DocumentsandMedia/Workforce_Trends_Report_090706_FINAL.pdf.

[32] North American Electric Reliability Corporation, "2008 Long-Term Reliability Assessment: 2008-2017," (Princeton, NJ: North American Electric Reliability Corporation, October 2008), http://www.nerc.com/files/LTRA2008.pdf.

years remaining in their professional lives rapidly decreasing. The number of faculty retirements is outpacing the number of faculty additions, and the trend is not showing signs of reversal.

1.7 Electric Service Institutions

The policy challenges facing DOE and the nation to ensure a reliable and efficient electricity service are further complicated by the fragmented structure of the electric industry. The industry includes a large and complex array of participants with varying business models and objectives, and is governed by a complex scheme of state, federal, and self-regulation. These complexities must be understood and taken into consideration as DOE works to meet its electricity policy goals.

Types of Electric Utilities

There are three types of electric utilities providing electric service to the nation's residential, commercial, and industrial consumers:

- **Investor-owned utilities (IOUs)** – Approximately 220 IOUs provide service to 96 million consumers (approximately 68.6% of all consumers).[33] These electric utilities are owned by shareholders and operate using a for-profit business model. IOUs' retail electric services are regulated at the state level by state public utility commissions (PUCs), while their wholesale sales and interstate transmission services are regulated by FERC.[34]
- **Rural electric cooperatives (co-ops)** – Approximately 930 rural electric cooperatives (co-ops) provide service to 17.5 million consumers (approximately 12.4% of all consumers). They are privately owned by their end-use consumers and provide service using a not-for-profit model. They are generally self-regulated by their boards of directors, although some are also subject to state, or in a few cases federal, regulation. Many co-ops borrow money from the Rural Utilities Service (RUS), a program of the U.S. Department of Agriculture (USDA), and thus must comply with RUS regulations in providing electric service.
- **Public power systems** – Approximately 2,000 public power systems provide electric service to approximately 20 million consumers (14.5% of all consumers). They are owned and operated by units of state and local governments and also operate under a not-for-profit model. They are generally self-regulated by their city councils, utility boards, or other governing bodies.

There is a broad diversity in size and sophistication among these utilities. The largest utilities serve consumers numbering in the millions, while the smallest serve only a few hundred consumers. Most of the smaller public power and co-op utilities do not participate directly in the wholesale electric market; rather, they rely on associated wholesale suppliers (generation and transmission cooperatives or joint action agencies) to obtain their wholesale power supplies and transmission service, or they contract these functions out to unaffiliated third-party suppliers. Together, IOUs, co-ops, and public power systems have 557,275 MW of nameplate generation capacity (51.8% of the industry total).

Non-Utility Power Suppliers

The restructuring of the electric power industry, which began with the passage of the Public Utilities Regulatory Policies Act of 1978, gives rise to a class of power suppliers known as "non-utility generators." These organizations may be fully independent or may be affiliates of traditional utilities. A substantial percentage of electric generation is now owned and operated by non-utility power suppliers: as of 2006, non-utility power suppliers held 445,476 MW of nameplate capacity, which is 41.4% of the industry total. They generally hold market-based rate authority granted by FERC that allows them to sell their power in wholesale markets.[35]

Federal Suppliers

In certain regions of the country, federal utilities are a major presence. The Tennessee Valley Authority (TVA) provides wholesale transmission and power

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[33] Statistics are for 2006, the latest year for which EIA data is available, unless otherwise noted.

[34] Because the bulk of the state of Texas is served by a separate electrical interconnection, the Electric Reliability Council of Texas which does not operate in interstate commerce, the Texas Public Utility Commission is the sole economic regulator of electric service there.

[35] See FERC's standards for granting market-based rate authority which are set out in Order No. 697, *Market-Based Rates for Wholesale Sales of Electric Energy, Capacity and Ancillary Services by Public Utilities*, 72 Fed. Reg. 39,904 (July 20, 2007), [2006-2007 Regs. Preambles] FERC Stat. & Regs. ¶ 31,252 , and Order No. 697-A, 73 Fed. Reg. 25,832 (May 7, 2008), III FERC Stat. & Regs. ¶ 31,268.

supply service in a seven-state area in the Southeast to a substantial number of public power systems and co-ops, who in turn serve 4.5 million consumers. The Bonneville Power Administration (BPA) has a strong presence in the Pacific Northwest, marketing wholesale power from an extensive system of hydroelectric facilities on the Columbia River and operating a regional transmission system. Other federal utilities include the Western Area Power Administration (WAPA), the Southeastern Power Administration (SEPA), and the Southwestern Power Administration (SWPA). All of these entities market wholesale power from federal hydroelectric projects on a cost-of-service basis, primarily to not-for-profit public power systems and co-ops. BPA, WAPA, SEPA, and SWPA are power-marketing administrations (PMAs), which are distinct and self-contained entities within DOE; TVA, however, is not operated under DOE auspices. Together, federal utilities have 72,826 MW of nameplate generation capacity (6.85 % of the industry total).

1.8 MARKET STRUCTURES

Wholesale Open Access Transmission/Restructuring

Starting with the passage of the Energy Policy Act of 1992 and continuing with its Order Nos. 888 and 890, FERC has required electric utilities subject to its regulation to offer "open access" interstate transmission service on their transmission systems. These utilities have accordingly implemented Open Access Transmission Tariffs (OATTs), under which they must offer transmission service on a non-discriminatory basis to third parties (including competing power suppliers) using common rates, terms, and conditions.

Regional Transmission Organizations

Taking the concept of open access transmission service a step further, certain regions of the country have formed RTOs as FERC strongly encouraged in its Order No. 2000. There are currently six FERC-regulated ISOs operating as RTOs: ISO-NE; the New York ISO (NYISO); the PJM Interconnection, L.L.C., which covers the Mid-Atlantic and some parts of the Midwest; the Midwest ISO (MISO), which covers other parts of the Midwest; the California ISO (CAISO); and the Southwest Power Pool (SPP), which covers parts of Texas, Louisiana, Arkansas, Missouri, Kansas, and Oklahoma. While not FERC regulated, the Electricity Reliability Council of Texas (ERCOT) is operating as an ISO that covers most of Texas.[36] However, other regions of the country, including the Pacific Northwest, the Desert Southwest, and the Southeast, have not formed RTOs.

RTOs direct the operation of the transmission systems in their regions that are still owned by the individual member utilities. RTOs provide non-discriminatory regional transmission service under a single OATT with a unified regional rate structure. They also operate a variety of centralized markets for various wholesale power supply products, but they act solely as a market-maker and do not profit from transactions conducted in their markets.

Retail Access

Many IOUs, and virtually all co-ops and public power utilities, still provide electric service under a traditional vertically-integrated business model, owning and operating generation, transmission, and distribution facilities and measures while selling "bundled" retail service to their end-use consumers. These utilities provide retail service under a "cost-of-service" model; thus, their rates reflect their costs of providing service plus a reasonable return (or in the case of not-for-profit co-ops and public power systems, a financial reserve). State public utility commissioners regulate the retail rates of IOUs and some electric cooperative utilities.

This traditional utility service model, however, has given way to unbundled or disaggregated business models in many regions of the country. Approximately 15 states and the District of Columbia have implemented full retail access for their IOUs, unbundling the electric distribution function from the retail power supply function.[37] Hence, these retail electric utilities now primarily provide only

[36] Since ERCOT does not operate in interstate commerce, it is regulated by the Texas Public Utility Commission and not the FERC.

[37] Kenneth Rose, *Status of Retail Competition in the U.S. Electric Supply Industry*, Testimony before the House Public Utilities Committee, The Ohio House of Representatives (February 5, 2008), http://www.ohiochamber.com/governmental/ pdfs/Kenneth%20Rose-2_020508.pdf.; As Dr. Rose relates in some detail, 15 states and the District of Columbia allowed retail access for all consumer classes. Twenty-six states never implemented retail access; four states repealed or did not implement their retail access regimes; three states have limited access to large consumers only; and two have suspended or delayed their retail access regimes. Even in states with retail access regimes, cooperatives and public power systems have generally continued to operate under the traditional retail service model, using cost-based rates.

unbundled transmission and distribution services. Power supply service to retail consumers is handled by other suppliers at market-based rates or provided by the utility under an unbundled provider of last resort (POLR) or default supply service.

In moving to retail access, many states required their IOUs to divest their generation facilities to third parties, either affiliated or independent. The divestitures of utility generation facilities that occurred during the implementation of retail access gave the non-utility generator sector a substantial boost, greatly increasing the generation assets subject to wholesale market-based rate authority, rather than traditional retail cost-of-service regulation.

Mandatory Reliability Standards

In addition to FERC's and/or the state PUCs' economic regulation, the owners, operators, and users of the bulk power system are now subject to mandatory reliability standards intended to maintain the reliability of the bulk power transmission system. The statutory authority requiring the development and enforcement of these reliability standards was enacted as part of the Energy Policy Act of 2005, in part as a response to the August 14, 2003 blackout in the Northeast.[38]

The statutory regime features a unique pairing of private and federal entities. FERC has designated a separate not-for-profit, self-regulating industry entity called the Electric Reliability Organization (ERO) to develop and enforce the mandatory reliability standards through an industry-driven collaborative process and to assess adequacy. The designated ERO in the United States responsible for such regulation is NERC.[39] The reliability standards that NERC develops with the help of industry participants must be approved by FERC before they become enforceable in the United States. Therefore, NERC and the eight regional entities to which it delegates certain authorities and for which it enforces standards are subject to FERC oversight within the United States.

The mandatory reliability standards went into effect in June 2007. Violations of the standards can trigger very substantial monetary penalties, as well as negative public attention for the violators. Hence, the users, owners, and operators of the bulk power system subject to these standards have undertaken very substantial compliance efforts within their respective organizations.

Consumer Benefits

While electric rates are bound to rise given the challenges facing the industry, failure to keep electricity rates affordable or to maintain the quality of service that supports the backbone of the world's largest economy would damage the quality of life for Americans. In order to prevent this possibility, the electric power delivery infrastructure will need to be expanded and/or upgraded. The costs of these new facilities, which are to be paid by consumers in their electric rates, must be commensurate with the benefits they will receive. New facilities that are put into operation must address both reliability and economic needs, and they must provide consumers and utilities with access to a well-balanced portfolio of generating resources, including renewable and demand-side resources, at reasonable costs. Failure of the transmission system to deliver energy reliably and economically to end-users would have a substantial negative impact on the price and quality of service.

The Implications and Planning Challenges of Industry Structure and Institutions

The complex and unique features of the nation's electric industry make it very difficult to define a simple set of policy prescriptions to ensure that the nation's future electricity needs will be served reliably and economically with due regard for the environment. Transmission and resource planning has become increasingly complex and dependent, at least in part, on market mechanisms. Different policy choices and implementation methods are necessary in different regions, since the North American electric power system is comprised of the Western, Eastern, and ERCOT Interconnections. The following discussion illustrates the attributes of the United States that present a challenge to the current and future state of the electricity system.

[38] This new statutory authority is set out in Section 215 of the Federal Power Act, 16 U.S.C. § 824o. NERC's reliability standards can be found at http://www.nerc.com/files/Reliability_Standards_Complete_Set_25Nov08.pdf.

[39] Since the North American electric transmission system does not stop at the United States' borders, Canada and Mexico are also partners in maintaining system reliability. The Canadian provincial regulators have also recognized NERC as the North American ERO.

Resource Adequacy

Approximately 55% of the U.S. peak demand is served by organized markets such as ERCOT, NYISO, ISO-NE, MISO, PJM, SPP, and CAISO. In organized markets and elsewhere, state rules on resource adequacy may be imposed on regulated load-serving entities. This system is vastly different from the historic monopoly service model where resources were reasonably defined many years in advance by source, location, type, and ownership. Even in non-RTO areas, some load-serving entities are opting to meet resource needs by competitive acquisition of resources via a mixed portfolio of long-, medium-, and short-term contracts. Although the approach to resource adequacy by providing a sufficient supply without excess and without time to spare may not be ideal, demand is generally met on a year-by-year basis. It is, however, a challenge to be confident that this market process will work for long-term resource adequacy, given the experience of many years of deterministic resource planning. NERC's resource adequacy assessments, for example, continue to be based on reported existing, planned, and proposed resources which can be reasonably expected to be available to meet forecast demand over the long term. However, in areas with centralized markets, including those with forward capacity markets, it is sometimes difficult to determine with a high degree of certainty that resources will be available when needed. As a result, NERC's traditional approach to resource adequacy assessments may understate future resource adequacy for areas with centralized markets.

Climate Change

Fossil and nuclear generation, which represents the vast majority of today's electric energy production, is facing significant economic and public relations challenges. Reliance on renewable technologies, like wind power and solar, is necessary and these resources are becoming more economically viable than they have been in the past. However, as intermittent resources, wind and solar are limited in their ability to meet capacity needs. Climate change initiatives are likely to impose restrictions on the operation of existing fossil generation resources, which produce at greater capacity. These limitations will affect resource adequacy on several fronts: maintaining existing resources, some of which may become uneconomic to operate in a carbon-constrained world, while adding sufficient new resources to meet demand growth; providing traditional, dispatchable resources necessary to support the use of increasing amounts of renewable energy resources; and tapping demand-side resources.

Understanding the inter-reliance between new variable generation, demand-side resources, and the support they will need from traditional resources is essential to sustaining a reliable and adequate electricity supply. However, the details of how this balance will be sustained technically, economically, and environmentally are still under debate. Further, it is not clear that planning assumptions based on the operational performance of traditional resources will be valid in an environment with a significant amount of intermittent resources. These assumptions need to be tested and revalidated to ensure that the planned system is one that operators will be able to control with the same degree of reliability as in the past.

Realizing the Potential of Demand Response / Load Management

Demand response / load management is a low-cost resource that should be maximized, but its full potential is currently unknown. The impact of demand response / load management on long-term planning may be significant, but experience with these programs is still limited. As demand response / load management programs begin to make up a larger fraction of total resources, the number of annual hours in which consumer service is interrupted will increase. At some point, the unwillingness of consumers to shift the timing of their energy use or be interrupted for more hours of the year may limit the contribution of this resource to the overall resource mix.

Transmission: The Critical Link

New long-distance transmission lines are needed to bring electricity from remote renewable energy resources to load centers. These transmission lines are likely to cross some combination of state boundaries, state parks, national forests, tribal lands, and agricultural and residential areas. The existing regulatory policies, procedures, and requirements regarding transmission siting are fragmented and time-consuming. This exposes the national grid to limitations that, if left unattended, could lead to serious problems. The situation has been characterized for many years as the need for more coordinated planning, as if lack of planning by itself is the source of the difficulty.

In fact, the transmission problem originates with debates about the need for a project, determining its beneficiaries, siting it, and allocating its costs. In the case of regional transmission facilities, these issues are proving extremely difficult to resolve. Even with good intentions, the mandate of state regulators is to protect the interests of the citizens of the particular state. Regulators in adjacent states may disagree about the merits of an interstate transmission project. While transmission represents a small portion of the average consumer's bill, identifying the probable beneficiaries of a specific transmission project for a specific period of time and allocating the costs among those potential beneficiaries continues to be a difficult process with uncertain, and, in some cases, unsatisfying results.

Application of New Technology

Technological innovation is leading to the development of many applications that have the potential to achieve a Smart Grid, which could help address some of the issues identified above. However, technology development is currently ahead of its practical application and the development of the policies needed to ensure its effective deployment. This new technology has the potential to benefit the entire electricity sector from wholesale to retail consumers and from transmission to distribution, regardless of where it is deployed. However, the potential widespread use of a Smart Grid creates a considerable challenge for traditional federal and state jurisdiction and necessitates flexible and innovative approaches to regulation, cost allocation, and cost recovery.

The cost/benefit analysis used to assess the value of new technologies must be expanded beyond the typical benefit/cost evaluation of retail electric consumers and take into account broader societal values, such as reducing CO_2 emissions.

The Human "Infrastructure" Challenge

Both the educational institutions and the trained workforce required to meet the challenge of keeping the lights on in the future are lacking. The education system serving the U.S. electricity sector has withered over the years, and the nation has a diminishing pool of high-caliber technical experts needed to develop and implement the necessary tools and technologies. If the nation does not find effective solutions to this problem, it is very hard to see how the United States will be able to provide a sustainable, reliable, and adequate electric service in the future.