POSITION STATEMENT

GREENING THE ELECTRIC POWER SUPPLY

Addendum to IEEE-USA’s
National Energy Policy Recommendations

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Prepared by the
IEEE-USA Energy Policy Committee
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Contents

INTRODUCTION AND SUMMARY ................................................................. 4

EXPANDING THE USE OF RENEWABLE ELECTRIC GENERATION ................. 8
  Evolution of Renewable Mix ........................................................................... 8
  Operating Implications of Integrating Renewables into the Bulk Power System .... 10
  Planning Implications of Integrating Renewables into the Bulk Power System...... 14
  Integrating Renewables into the Distribution System........................................ 18
  Further R&D Needs ....................................................................................... 19
  Recommendations ......................................................................................... 20
  Appendix: R&D Needs for Selected Renewable Technologies ................................ 21

REDUCING CARBON EMISSIONS FROM FOSSIL POWER PLANTS.................. 31

REVITALIZING NUCLEAR POWER GENERATION ........................................ 36
INTRODUCTION AND SUMMARY

Electricity and electrification continue to be engines of progress worldwide, as central station and distributed electricity generation displaces direct combustion and engine drives, reducing environmental impact at the point of use and increasing energy efficiency. The way electricity is generated at central or distributed facilities creates environmental impacts. Greening the electric power supply is the process of continuously reducing the environmental impact of electricity generation.

As of 2014, coal generated about 39% of U.S. electricity—traditionally the fossil resource with the largest proven reserves. As coal combustion produces roughly twice the carbon dioxide emission than natural gas, the reliance on coal is largely responsible for the electric utility sector accounting for 31% of U.S. energy-related greenhouse gas emissions.

2013 CO₂ Emissions from Fossil Fuel Combustion

Historically, expanded use of electricity produced at central station power plants has greatly reduced emissions at the point where energy is used, enabled less costly control of emissions at the point of generation, and reduced the total environmental impact of energy use. To continue the positive effects of electrification, the United States needs to reduce the environmental footprint of electric power generation. The “greening” of generation would further decouple electricity use from greenhouse gases or criteria pollutants.

The greening of generation starts with improved power plant efficiency and increased control over emissions. Older power plants that are less efficient and produce more greenhouse gases, and other pollutants, can be retired. About 13 GW of coal-fired capacity is expected to retire in 2015 alone. The U.S. Energy Information Administration (EIA) also projects that about 60 GW of coal generation will have

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1 U.S. Energy Information Administration, May 2015
3 EPA regulated air pollutants, by developing human health-based and/or environmentally-based criteria for setting permissible levels.
retired between 2012 and 2020.\textsuperscript{5} Coal combustion will be mostly replaced by more efficient natural gas fueled power plants—which are not only more efficient, but also produce less greenhouse gas emissions-as natural gas has nearly half the carbon dioxide emissions of coal.

In addition to the opportunity for natural gas to displace coal— at least, in part, driven by the recent fall in natural gas prices—nuclear power generation can be continued and expanded, with economic improvements and new, safer designs.

Nuclear power is a well-established technology, but no new plants have been built in the United States for many years. It is only recently that Southern Company received approval for 2,000 MW of new capacity—the first since 1978. Another plant, an expansion on an existing site, has also since been approved. Nuclear plant retirements have been announced as well—driven by difficulties in competing with the lower cost and higher flexibility of natural gas generation. In addition, the nuclear industry will have to continue dealing with the questions and negative public sentiment arising from Japan’s Fukushima disaster, as well as with spent fuel disposal.

Part of the solution can come from several renewable generation technologies ready for deployment, including wind, geothermal, hydroelectric, photovoltaics, solar thermal, and some biopower applications. In fact, renewable energy accounted for 13% of electricity consumed in 2014\textsuperscript{6}. Of this, almost 50% was delivered by conventional hydropower, followed by wind at about 35%, and biomass at more than 10%. It should be noted that not all biomass fuels reduce carbon emissions; some applications may result in large increases of air emissions.\textsuperscript{7,8,9}

For renewables to have a growing share of electric power generation, the principal issues include the costs of the technology; the need for new electric transmission; the variability and uncertainty of the resource; and the need for increased planning and operating reserves to assure reliability. Some of these costs are partially offset by elimination of fuel costs when sun or wind is available. But the overall costs of most forms of renewable electricity still remain above that of more conventional resources, and require government policies and incentives to encourage implementation. Federal incentives and state Renewable Portfolio Standards (RPS) provide a significant impetus for the renewables market.

For coal-fired plants, new technologies could remove carbon dioxide before combustion, or capture the carbon dioxide after combustion. The carbon could then be sequestered on a geological time scale, or reused. However, carbon capture and sequestration have yet to be demonstrated on a commercial scale. In addition, since virtually no new coal plants are expected to be built over the next decades,

\textsuperscript{5} Annual Energy Outlook 2014, U.S. Energy Information Administration, March 2014
\textsuperscript{7} See, for example, May 8, 2015, letter to EPA from Massachusetts Senators Markey and Warren (http://www.biologicaldiversity.org/programs/climate_law_institute/pdfs/EPABioenergyCleanPowerPlan_05-08-15.pdf)
\textsuperscript{9} Think Wood Pellets are Green? Think Again. NRDC issue brief IB:15-05-a, May 2015

\textbf{Introduction and Summary}
these technologies must be retrofittable to existing plants to have an impact. Currently, the cost of carbon capture, including its energy efficiency penalty, is the principal barrier to large-scale applications of this technology.

Natural gas-fueled combustion turbines and combined cycle plants will likely provide much of the new generation capacity added over the next 10-15 years. Even with the anticipated increase in the very low current price of natural gas, these turbines may reduce the potential market for wind, solar and nuclear power by undercutting their cost effectiveness. On the other hand, the increased number of fast-response, gas-fired generators will ease the challenges of integrating variable and uncertain renewable generation into the power grid.

To a large extent, public policy will influence the pace of progress toward a green electricity supply. As illustrated in the figure below, the power-generating capacity installed in the United States has been gradually shifting toward cleaner technologies, partly in response to the changing regulatory emphasis.

Similarly, as seen in the figure below, the growth of renewable resources is currently dependent on federal tax credits and state Renewable Portfolio Standards. To avoid cost increases and reduce impediments to market development, renewable incentives and energy targets must remain stable and predictable, until the market has matured.

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In summary, no “silver bullet” currently exists to reduce environmental impacts, while keeping electricity costs affordable. The United States must pursue a balanced portfolio strategy, paying attention to understand fully the impacts of any policy-driven substitution of alternative energy sources for electricity generation.

One of the shortcomings of current approaches to managing greenhouse gas emissions is addressing the generation side only, without a full understanding of the demand-side of the equation; i.e., how customers use energy and electricity. For example, in the EPA Clean Power Plan, substituting electrified transportation for gasoline may be preferable to shuttering coal plants; it would reduce both greenhouse gas emissions and other air pollutants, including smog.

The details of technologies to be considered for greening the power system are provided in the sections that follow.
EXPANDING THE USE OF RENEWABLE ELECTRIC GENERATION

Expanding the use of renewable generation is a major element of greening the electric power supply. Using renewable energy sources plays an increasingly important role in keeping pace with the expected rise in U.S. electric demand, and reducing greenhouse gas (GHG) emissions. To meet these objectives, government and private industry must work together to develop new and expanded infrastructure that includes transmission, distribution, energy storage and generation, from a varied portfolio of renewable energy sources, and other technologies. This expanded infrastructure will accommodate newly developed and mature technologies needed to complement the existing mix of electric generation and varying consumer demands. It will provide added operational flexibility that will strengthen the electric system to make it more reliable, more secure, reduce environmental impacts, and increase customer satisfaction. These new approaches will also help the electric power industry facilitate new uses of electricity, achieve greater societal benefits, and provide customers information they can act on to save energy and money.

This section addresses four topics: (1) the evolution of the renewables industry over time; (2) systems operational issues; (3) planning implications; and (4) further R&D needed to reduce costs and improve “fit” into the electric system.

Evolution of Renewable Mix
Over the past decade, the mix of installed renewable generating technologies has changed drastically. Figure 1 graphs this change.

Figure 1: Renewable Additions by Type (Nameplate MW)

The period from 1990 to the early 2000s shows small amounts of annual installations made up primarily of a geothermal, municipal solid waste, and forest biomass mix. Beginning about year 2000, wind
technologies began to dominate capacity additions. In the mid-2000s, solar generating technologies began to appear, and have now become a substantial share of additions. The accelerating introduction of new wind and solar technologies is important, because of the intermittency of these two technologies, in contrast to the baseload, dispatchable features of the principal technologies in the earlier period.\textsuperscript{11}

The great increase in renewable capacity installations, beginning about 2005, is primarily due to four factors. First, renewable alternatives are rapidly becoming cost competitive with conventional generating resources in many parts of the country. Technological improvements in performance and manufacturing cost reductions have narrowed the gap. Figure 2 shows the reductions in installed prices of several specific, utility-scale solar PV technologies in recent years. Investment banking firms are now advising their clients of continuing cost reductions that may make customer PV installations even more cost-effective in the future.\textsuperscript{12}

FIGURE 2: HISTORIC REDUCTION IN SOLAR PV INSTALLED PRICES

![Figure 2: Historic Reduction in Solar PV Installed Prices](image)


Second, state-level renewable portfolio standards established by public service commissions and legislatures have created mandates for utility procurement of renewables. For example, California has a legislative mandate that all load-serving entities procure renewable energy equivalent to 33 percent of retail electricity sales by 2020, using a specified list of renewable technologies; and in February 2015, the California State Senate introduced legislation to increase this requirement to 50 percent by 2030.

Third, project developers have responded strongly to federal production tax credits and investment tax credits for specific technologies. The on-again, off-again nature of federal production tax credits for

\textsuperscript{11} Dispatchability refers to the ability of the generating machine to alter its electrical output, in response to market price signals, or directly from real-time operating instructions from the system operator.
wind, and investment tax credits for other technologies, is reflected in the variation in capacity additions from one year to the next in Figure 1. Not only do these tax uncertainties affect project investment decisions, but the unpredictability has also adversely affected manufacturing facilities for the renewable equipment.

Finally, a general sense of environmental stewardship exists in some regions of the country, inducing limited introduction of renewables, even if not financially cost-effective. Until the U.S. EPA-proposed rules on carbon emissions from existing power plants issued in 2014 (finalized in early August 2015), the federal government had not yet acted directly to reduce GHG emissions in the utility sector.

**Operating Implications of Integrating Renewables into the Bulk Power System**

Baseload renewable technologies (geothermal, landfill gas, and others) or dispatchable renewable technologies (municipal solid waste, biomass, and others) create few, if any, operational issues. Such technologies have operational features within the range of traditional generating equipment. However, unlike these technologies, the timing and amount of electric output from wind and solar resources is dependent upon natural meteorological phenomena, at any moment in time. For this reason, these resources are often called “intermittent,” or “variable and uncertain.” For example, wind blowing with varying speeds, and clouds drifting by in front of the sun, will reduce electricity production from these renewable resources. Further, these resources are generally non-dispatchable, without large scale storage capability at the project site.

At low levels of penetration, variable and uncertain renewable resources can be readily integrated into the system, with some changes in operating practices. At this level, the challenges of variable and uncertain power production are not greater than those caused by normal customer load variability and uncertainty. However, as renewable energy production reaches about 30 percent of annual energy consumption, traditional planning and operation approaches must be adapted to address the characteristics of intermittent technologies.13

Figures 3 and 4 illustrate the seasonal and daily variability of wind and solar—the two dominant variable and uncertain renewable technologies. Figure 3 provides aggregated hourly production of wind and solar generating facilities online in the California Independent System Operator (CAISO) balancing authority area, in December 2014.

In electrical systems, total generation output must be matched with customer demand at each moment in time, because storage has been impractical. Historically, this goal is achieved by adjusting the output of generators on line. The variability and uncertainty of renewable technologies adds complexity to this process. A different mix of generating resources may be needed in the future, to accommodate the added variability coming from wind and solar generation. Supplemental resources may be needed that are both flexible and reasonably efficient. Combinations of responsive and quick-start, natural gas-fired peaking, and combined cycle generation matched to the mix of renewable resources, may be desirable options for consideration in resource planning processes. Changes in system operating practices and

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procedures may also be required. To the extent bulk storage becomes feasible and economical, another option can be added to the resource mix.

Substantial penetration of variable and uncertain renewables may induce changes in voltage and reactive power management, and transient behavior of the system, in addition to the obvious challenges of balancing load and resources to maintain frequency. Each of these issues must be addressed in ways that allow for compliance with mandatory North American Electric Reliability Corporation (NERC) reliability standards for the Bulk Power System (BPS).

**Figure 3: Variable Production on Three Consecutive Days in December 2014**

![Graph showing hourly solar energy production on three consecutive days in December 2014](image)

**Source: CAISO, Renewables Watch**

Figure 4 examines another issue—the minute-by-minute variability in wind and solar production commonly hidden, when data is presented as hourly averages. In this figure, minute-by-minute wind and solar production data are shown for the aggregate of all such resources in the CAISO system, for a segment of a day in early January 2013. This four-hour period encompasses the morning solar ramp up period. During hour nine, little variation occurs around the hourly average for wind, but considerable variation for solar. During hour 10, wind production is increasing steadily, so the hourly value overstates actual production in the early portions of this hour; while the hourly value understates production, in the latter period. At some points, both wind and solar have significant changes within five-minute periods (below the scheduling time increment in the CAISO system), so responsive regulation resources would have to compensate for this minute-to-minute variability, to maintain the required balance between generation and load demand.
For voltage control, reactive power management, frequency regulation, and other grid management services, monetary incentives do not universally exist to encourage renewable projects to provide the services that conventional generators have provided for many years. Some organized wholesale electric markets—PJM is a good example—have created market rules that allow any supplier to participate.\(^\text{14}\) However, legal challenges have created uncertainty for demand resources in wholesale markets.\(^\text{15}\) By contrast, areas of the country still organized as integrated utilities, with few independent generators, rarely provide such incentives to the renewable projects located there. As the system mix has evolved toward greater reliance upon renewable generation, fewer generators have the necessary technical capabilities and/or contractual incentives to provide these required reliability services. Several different paths need exploration: (1) requiring renewables to provide these services; (2) paying other generators to explicitly provide them, separate and apart from other services; or (3) augmenting the transmission system with reactive power, or energy storage devices, to substitute for lack of these capabilities in the generating fleet. The approach taken in any region may depend, to a large extent, on whether or not an organized wholesale market exists there. The issues provoke the institutional challenges of balancing authority,\(^\text{16}\) consolidation, or cooperation in some regions; integration of sometimes separate generation and transmission planning domains, jurisdictional authority, cost allocation, and adequate revenues for conventional generation, as well as a plethora of market design challenges and regulatory and government policies.

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\(^{14}\) PJM operates a regulation market that includes demand response, storage and generation resources that meet the technical requirements. See [https://www.pjm.com/~/media/documents/manuals/m18.ashx](https://www.pjm.com/~/media/documents/manuals/m18.ashx)


\(^{16}\) An entity responsible to maintain load-resource balance within an area consisting of generation, transmission and loads within a metered boundary.
Although a renewable project’s output is frequently described as “must take,” accepting the output of variable and uncertain resources cannot be done blindly. Efforts to anticipate production patterns can be undertaken with more intensive use of meteorological forecasts and seasonal patterns. Developing a body of historical data about specific resources under the control of the operator, whether in an integrated utility setting; or a broader electricity market, for an independent system operator, can be helpful. System operators currently have authority to shut down transmission connected renewables, in situations where NERC criteria are violated, such as high frequency or equipment overloads, but they may be reluctant to do so. Instead, they attempt to use the curtailment provisions in many intermittent project contracts.

Another approach that can address renewable variability and its consequences is to require renewable projects in organized markets to follow the normal rules for all generators, and rely upon the economic incentive of hourly, or sub-hourly, market prices to influence project dispatch decisions. As an example, in PJM, grid-connected wind and solar power are already integrated with normal market rules, including Locational Marginal Pricing (LMP) for energy. However, with a zero fuel cost, and without dispatchability, the renewable resource is always a price-taker. With production tax credits linked to output, renewable generators can even make money when the market price is negative. A negative price is a signal for most generators to shut down. In this setting, the incentives of production tax credits and effective market outcomes may work in opposite directions. In another example, Midwest Independent System Operator (MISO) has created an option for renewable facilities to be dispatchable. Special tariffs provisions, telemetry requirements, and dispatch response protocols apply to such facilities.17

Those resources that are dispatchable may be called upon to operate in a supplemental manner—ramping output up or down to accommodate renewable production patterns. Such activity has numerous implications, for both existing conventional resources, as well as shaping the desired characteristics of gas-fired resource additions.18 To address the need to operate existing units in more flexible manners, it may be appropriate to reduce the freedom of load-serving entities to self-schedule the operating output level of these generating resources—increasing the share of resources responsive to hourly, or sub-hourly, market prices, or system operator dispatch instructions.

Deployment of storage technologies may reduce the need for supplemental generating facilities, by smoothing out power production; partially mitigating natural intermittency. Until recently, consideration of energy storage technologies was framed as an economic question. Historically, for utility scale storage projects to be considered viable, the marginal price of electricity must be greater

18 In the California ISO, the system with the greatest current penetration of renewables, a substantial share of gas-fired additions, in recent years, are projects with multiple combustion turbines. Although the inherent energy efficiency of combined cycles is sacrificed, the improved flexibility to quickly ramp up or down to satisfy “net load” has become part of the solution to the renewable intermittency problem.
than the costs to store and retrieve energy, plus the value of the energy lost in the process. The development of battery storage, pumped storage, or other storage technology projects that can provide capacity value or ancillary services (such as regulation with extremely fast response times) expands this framework. A broader analysis of the value of all services a storage project can provide is appropriate. For any of the existing or proposed storage technologies to be utilized, limitations on these technologies must be rectified.

**Planning Implications of Integrating Renewables into the Bulk Power System**

The operational characteristics of renewable resources give rise to a number of planning concerns. These concerns may become more pronounced as renewables become a larger proportion of the utility fleet through time. Figure 5 (the famous “duck curve,” developed by the CAISO) illustrates this issue. Figure 5 depicts for a single day, the net load curve that dispatchable resources will have to satisfy. A net load curve is created by subtracting contemporaneous production from wind and solar power from gross load to produce “net load.” Since solar production is limited to daytime hours, and peaks in the middle of the day, this net load is the set of hours most affected, as solar capacity increases through time.

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20 The adoption of D.13-10-040 by the California Public Utilities Commission directing the three major IOUs to install 1325MW of storage nameplate capacity by year 2024 should be seen as an explicit effort to force technological and marketplace innovation, even if such projects are not fully cost-effective by conventional analytic standards.
21 On any given day, the specific pattern of wind and solar production can create different visual patterns—many do not look like the famous “duck curve.”
Two specific issues are worth noting. First, the decreasing net load during the middle of the day, as additional solar production capacity is added each future year, may encounter minimum generation constraints--from those generators that will be needed later in the day--when solar production disappears. Second, as solar production decreases rapidly in the later afternoon and evening, a steep ramp up in output is needed from other resources. These phenomenon are collectively leading toward the need for more a flexible generation fleet that can be ramped up and down rapidly.

Resource planners have developed a variety of methods to forecast renewable performance and provide a capacity value for specific renewable technologies to address the variability characteristics of the resources for their system. This enables better integration of variable resources with planning of conventional ones when assessing provision of adequate reserve capacity, as required by mandatory reliability standards of the North American Electric Reliability Corporation (NERC). The California Public Utilities Commission uses a method in its resource adequacy program relying on historic data on a rolling, three-year average, to provide capacity value for individual wind projects on a monthly basis. Figure 6 shows the average value for Southern California wind projects for the three-year period, 2011 to 2013. The values for each month are based on the average output during the hours immediately surrounding the time of the monthly peak demand. Although the general pattern of highest values in the spring months, and lowest values for months late in the year, is common for all three years--the specific values for each month vary considerably over the three years.
In Figure 6, the substantial variations in production for a given month, over the three years, mean that substantial supplemental energy capability must be available from other resources to generate the energy needed to serve the load. As wind resources with such performance variability increase, as a percentage of system resource mix, the challenge of adapting the balance of system resources to complement such performance variability also increases.

Planning to address system peak load requirements is a fundamental element of system planning, but renewables complicate this process, because their production patterns cannot be forecast as reliably as can traditional generating technologies. Figure 7 uses an aggregate renewable production day, on the peak days of the CAISO balancing authority area, to illustrate this challenge. Not only is the amount of energy increasing over these years, but the hourly pattern is quite different. The wind production patterns are more variable than those of solar for renewables, within the CAISO system.
Demand response is frequently identified as one of the possible solutions to match supply and demand in a high renewable future. It is unclear to what extent end-user load is willing to engage in load reduction, or load shifting, under the much wider set of conditions characterizing renewable-induced supply/demand imbalances. The frequency of utilization of demand resources may be much higher than customers expect, compared to the traditional focus of most demand response efforts to date on load reduction during summer peaks. Demand response and load management programs that currently exist may need refinement. And other programs, including redesign of rate and price incentives, may be developed to help encourage end-users to curtail demand during peak energy usage periods, in response to system reliability, or market conditions.22

Energy storage is also a potential solution for matching supply and demand, and must be similarly integrated into the planning process. As noted earlier, developing battery storage may be very helpful to the short interval regulation and daily balancing issues associated with uncertain production variability. Only hydroelectric plants with large reservoirs are currently capable of providing the large amounts of energy needed for multi-day and seasonal variations in renewable production. The opportunities for new hydroelectric facilities are few and far between, so repurposing existing facilities may be necessary, to address long-term energy storage needs.

Renewable generating technologies also imply changes in transmission planning practices. As a general rule, central station renewables must be located in places where the production potential is greatest. Such locations are often remote from load centers, requiring transmission assessments to determine whether upgrades are necessary. FERC Order 1000 has been implemented to improve coordination of transmission planning across the boundaries of separate systems. In addition to considering new or upgraded transmission to support the remote location of most renewables, providing sufficient transmission capacity for such projects means that the transmission system may have to accommodate the highest output expected from the project. For example, a 100MW wind project may only be counted upon as 15MW from a generation planning perspective, but the transmission system may have to be capable of absorbing the full 100MW rating of the project. Planning for less than full output is also possible, but doing so implies that the full capacity value cannot be relied upon for energy or capacity valuation purposes. It may also imply that the actual output of a project will be curtailed under high output conditions, if the transmission system is fully loaded, to accommodate projects that have paid for full capacity rights. These resource valuations versus transmission tradeoffs have necessitated closer integration of supply resource and transmission planning.

**Integrating Renewables into the Distribution System**

Some renewable energy resources, mainly photovoltaic technology, have entered the distributed generation (DG) market.\(^\text{23}\) For example, California has more than 4,000 MW of installed rooftop photovoltaic systems configured to serve customer loads.\(^\text{24}\) Large scale solar projects (5–20MW), are connected to the grid at distribution voltages, and are also being heavily promoted. After a long period of subsidized development, the customer side of this market’s meter portion has become cost competitive with numerous solar development companies offering long-term leasing arrangements. Such arrangements are predicated on end-user cost reduction in utility bills paying for the solar installation costs. Some customers derive value from environmental considerations that are not readily monetized. Today, the utility distribution system side of the market has a wider range of technologies, and penetration is considerably lower—since such systems are more likely to be installed when traditional marketplace economics show them to be cost-effective. The end-user and utility-side of the meter domains also differ in the use of photovoltaic inverter systems. End-user PV installations commonly lack any kind of control. Distribution-side PV installations are more likely to have inverters with some degree of response to reactive power conditions, but still generally do not have real-time telemetry to the system operator that would enable shifts in real power, when problems are anticipated.

Although many of the natural variability and uncertainty characteristics of renewable technologies are the same—whether interconnected as small scale projects at the distribution level, or as utility-scale projects at the transmission level—high-penetration levels of intermittent renewable distributed generation create a different set of challenges than at transmission-system level. Distribution is

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generally designed to be operated in a radial fashion, with one-way power flow to customers, and DG (including PV and wind technologies) interconnection violates this fundamental assumption. Impacts caused by high-penetration levels of variable and uncertain renewable DG can be complex and severe; and may include: voltage increase, voltage fluctuation, interaction with voltage regulation and control equipment, reverse power flows, temporary overvoltage, power quality and protection concerns, and current and voltage unbalance, among others. These impacts may be mitigated using a combination of conventional and advanced solutions. Distributed energy storage, particularly battery storage systems, advanced power electronics-based technologies, such as distribution-class FACTS devices, and increased real-time monitoring, control and automation can play an important role in alleviating these issues and facilitating integration. Moreover, updated modeling, analysis, design, engineering, planning and operations practices are required to facilitate integration, and ensure reliable and secure operation of increasingly active and dynamic modern power distribution systems.

**Further R&D Needs**
While there have been continual advancements in renewable energy technologies R&D, it is essential to aggressively support further R&D efforts aimed at making renewable energy more economical and technologically realistic. Renewable power sources have common limitations, which must be rectified through R&D efforts; specifically, R&D must focus on improving efficiency, increasing competitiveness with traditional energy sources, and addressing the intermittent and variable nature of renewable energy through effective energy storage. Given energy supply and demand’s seasonal, weekly, daily, hourly and transient variability, it is imperative to develop the technology to achieve a balance between generated power and demand on a large scale. An enhanced capacity for the transmission and storage of renewable energy should be matched by improvements in individual energy technologies. Each renewable energy source has unique limitations. Evaluating the current state of technology, including source-specific economic and technological feasibility, will identify the specific areas requiring further R&D.

Although most R&D is specific to each generating technology, the electric transmission grid, customer loads and generators must operate seamlessly across each interconnection zone. R&D must be continued to further enable the grid to accept supply from existing and new power plants of all fuel types, including renewable resources and end-use technologies, such as plug-in, hybrid electric vehicles. It must deliver the electricity to users in a manner that meets all applicable reliability standards and enables federal and state environmental policy goals implementation. Customers expect uninterrupted service at all times. R&D resources must be expended to support using advanced information technologies that create opportunities to enhance grid operation and improve efficiency, while maintaining appropriate security.

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25 See the *IEEE Report for the Quadrennial Energy Review*, September 2014; http://www.ieee-pes.org/qer
26 Flexible Alternating Current Transmission System (FACTS) refers to a family of power electronics-based devices able to enhance alternating current system controllability and stability, and to increase power transfer capability.
**Recommendations**

In summary, IEEE-USA recommends the following actions to expand the use of renewable resources for electricity generation:

**R&D:** Congress should focus more aggressively on funding R&D aimed at accelerating technology advancements, and reducing the total cost of energy delivered by a broad range of renewable electric generation options.

**Grid-Scale Energy Storage:** The U.S. DOE should further study the potential value and opportunities of energy storage in grid-level applications; and how distributed storage can effectively be integrated into the bulk-power system.

**Market Transformation:** Congress and the states should promote renewable energy because of its supply security, distributed and modular nature, and reduced greenhouse gas emissions. Portfolio standards and other mechanisms should also be considered by all states and Congress.

**Stable Incentives:** Financial incentives for renewables should assure that these technologies don’t get displaced in the long-run by the short-term availability of inexpensive natural gas. Incentives should be stable, and sufficiently predictable to allow long-term planning by renewable power purchasers, project developers and equipment manufacturers.

**Regional Planning:** The U.S. DOE and FERC should continue supporting regional and interconnection-wide transmission planning practices and system operating procedures, integrating variable renewable generation, and the developing measures to ensure adequate contribution to planning and operating reserves from conventional generators, dispatchable renewable generators and storage, and demand-side technologies.

**Market Design:** FERC and system operators should revise market designs to recognize the diversity of renewable resources, to develop market mechanisms enabling emerging flexible technology solutions and mitigating risks for stakeholders, and to accommodate institutional and/or operational constraints to the electric power supply system.

The Appendix provides further details for the more prominent renewable technologies.
Appendix: R&D Needs for Selected Renewable Technologies

The following describes the current state of technology for wind, solar (photovoltaic and thermal), Space Solar Power, geothermal, wave, and tidal power. Although this paper does not address other renewable resources, ocean thermal and various biomass options (such as composted agricultural wastes, municipal wastes, landfill gas, etc.), these technologies also warrant R&D efforts. For the sake of brevity, these topics were not included, and may be referred to in other sections.

Wind Power

Research continues to benefit wind power generation, producing more efficient and reliable wind towers and improving electric generation costs. A recent U.S. DOE statement noted that wind power has the capability to contribute twenty percent of U.S. energy requirements by 2030. (U.S. Department of Energy, 20% Wind Energy by 2030, Increasing Wind Energy’s Contribution to the U.S. Electricity Supply, July 2008.) Currently, deploying wind power technologies is limited by its location, with respect to the existing transmission system, poor capacity factors and the economics of other generation technologies. The future transmission system needs to be properly planned, designed and developed to integrate future wind generation. Wind has the potential to provide clean energy, but it is also limited by wind speed, location, and other factors, such as visual appeal.

Land-based wind power plants cannot be dispatched, meaning they cannot produce a desired energy output quickly to meet impending demand; however, modern commercial wind power plants are fairly reliable, and do not require frequent maintenance or repairs. Wind towers require specific operating speeds to produce energy without damaging components, making location a key factor in wind power. Individual wind towers also suffer from low power generation and have to work in groups, or “farms,” to contribute electricity to a power grid. Visual appeal can become less impactful through appropriate siting, such as offshore wind farms. Offshore wind farms also provide more consistent power generation because of a more stable wind supply; however, offshore wind farms afford potential maintenance concerns, due to logistics, exposure to salt spray and/or humid environments, and connection to the transmission grid.

Key attributes, issues and development needs for wind power include the following:

1. Output is dependent upon weather conditions, seasonal variations, and other short- and long-term variability.
2. Wind turbines have a low visual appeal.
3. High capital costs are associated with constructing wind turbines.
4. Large plots of land are required for commercial applications.
5. Land can be leased for other use after construction is completed.
6. Location of wind farms follows wind availability and suitability for generation.
7. Lower power prices can be achieved through improvements in turbine efficiency and component fatigue.
8. Research on wildlife impact is ongoing.
9. Operating costs are low after construction.
10. Competitive prices for wind power are reaching the market.
**Photovoltaics**

Photovoltaic power has continued to improve technologically, through advanced research in solar cell development to attain higher efficiency and lower costs. As a result of the modularity of solar cells, they can be utilized in a variety of applications ranging from residential use to commercial power generation. Power output occurs as direct current, which must be inverted to alternating current for integration into home wiring or the bulk power grid. Growth within the photovoltaic sector has been significant, with 2007 recording a fifty percent increase in production from 2006, to a total of 12,400 megawatts worldwide. The global solar photovoltaic market is expected to grow with a compound annual growth rate of 12.5 percent during 2009 - 2014 to reach $38.1 billion in 2014 (EE Times News and Analysis, November 24, 2009; http://www.eetimes.com/electronics-news/4198437/Report-predicts-global-concentrated-photovoltaic-market-to-be-worth-266m-by-2014). In terms of commercial power applications, photovoltaics remain nominally more costly than current fossil fuels. Thin film photovoltaic cells, a new technology with great potential in the field of solar energy, can achieve efficiencies up to twenty percent, and use less semiconductor material than traditional photovoltaic cells, making production more cost-effective.

With the introduction of thin film cells, cost reductions and size reductions, the range of feasible applications of small-scale power generation continues to increase. Large-scale production is still a limitation, as maintaining stable manufacturing conditions needed to produce thin film cells are difficult to achieve. For all intents and purposes, solar power is an infinite power source--and new solar cells are durable, reliable, and have an estimated service life of twenty-five years. However, solar power is variable and uncertain (for example, no energy is produced at night), as is the case with many other renewable energy resources. It depends on the availability of sunlight, limiting the amount of power that photovoltaics can produce (capacity factor). In addition, photovoltaic plants still require large capital investments and land area to construct and operate.

Key attributes, issues and development needs for photovoltaic power include the following:

1. Photovoltaics have to be price and efficiency competitive to sustain a healthy and growing market share.
2. Industrial applications require large dedicated land areas to be feasible as power sources for the power grid.
3. Output from solar power is affected by weather, seasonal variations, and other factors that inhibit the availability of sunlight.
4. Further research is needed to develop inverters that can improve system stability and power quality.
5. Solar cells allow for a range of commercial and residential applications, because of their modular configuration.
6. Semiconductors in solar panels create hazardous waste that must be disposed of after the life of the solar cell has expired.
**Thermal Solar Power**

Thermal solar power, like photovoltaics, continues to see increases in improved reliability and efficiency. Thermal solar panels are modular in nature, and can be used in a variety of applications, ranging from residential use to industrial power generation. The four main methods of thermal solar heating are thermal solar panels, parabolic troughs, power towers and dish systems. Flat thermal panels, mainly used in residential applications to heat water directly, require minimal maintenance and operating costs. Heated water can be used in place of, or to supplement, boilers to lower domestic heating costs, heat for swimming pools, or applied to space heating. Parabolic troughs direct sunlight to collector tubes positioned above the troughs to heat fluid inside the tubes; the heated fluid inside the tubes can be stored to generate electricity, in the absence of sunlight. These systems benefit from a simple design but do not reach high temperatures, like more sophisticated solar systems.

For a large-scale application, the heat absorbed by the fluid is used to generate steam, which is used to run a steam turbine--just like the conventional technology that utilities use. Power towers use arrays of mirrors to concentrate sunlight on a collection tower and generate heat. The generated heat is absorbed by the fluid in tubes that are directed to a steam generator. The generated steam is routed to run a steam turbine that is coupled to an electric generator to produce electricity. High temperatures may be achieved in this design, but relatively high maintenance is required, due to moving components. In the dish design, mirrors are used to create a large parabolic dish to focus solar heat on a point above the dish. A Stirling engine can be placed at the focal point allowing heat from the dish to run the engine. The highest heat is generated from this design, but frequent maintenance is required, and size is limited, because the rotating dish must support the engine. Unlike photovoltaic solar electric systems, thermal solar replicates all of the properties of any other generating technology using turbine/generator sets.

Key attributes, issues and development needs for thermal solar power include the following:

1. Output depends on the weather, seasonal variations, and other factors that impede sunlight availability, as thermal solar power relies on direct sunlight to convert heat into electricity.
2. Current power generating designs are not economically competitive in the power industry.
3. Large plots of land are needed for solar plants, and solar plants work best in desert-type climates.
4. Thermal solar generating facilities should be constructed away from residential areas, due to aesthetic concerns.
5. Use of flat thermal solar panels is increasing, as an alternative heating source in residential units and commercial establishments.
6. Some solar applications will require provisions to keep mirror or cell surfaces clear of dust or contaminants.
Space Solar Power
Since the 1960s, many researchers have been excited by the promise of space solar power (SSP), which entails deploying large solar farms in earth’s orbit, and beaming energy down to power grids on earth by way of microwaves. NASA research in the 1990s found solutions to most of the glaring problems in earlier SSP designs, but cost and flexibility issues remained. SSP would provide electricity 24 hours per day, available even in areas without other steady renewable energy resources. It should be seen as an alternative to nuclear fission, especially for developing nations, rather than an alternative to earth-based solar farms, (which are especially useful in meeting daytime peak demand).

There was a substantial revival of interest in SSP in 2014, due to new designs and technological innovations. The most definitive primary source of new information on SSP is the 2014 book, The Case for Space Solar Power, by John Mankins, director of the NASA SSP work in the 1990s; co-director of the last U.S. funding opportunity on SSP; and recipient of a recent NASA grant to integrate the outcomes of the recent U.S. research with outcomes of the ongoing efforts funded by Japan’s government. China has also begun funding the SSP area, and Abdul Kalam, former president of India, has called for a new international effort in SSP, with or without U.S. participation.

Mankins proposes a low-cost, modular path to develop and demonstrate key SSP technologies. He estimates a cost of 9 cents per kWh for electricity anywhere on earth, and a switching capability to move that electricity to receiving antennas all over the earth--to track variations in demand and emergency needs. The biggest technical obstacle to attaining this low cost is the lack of access to earth orbit at $500/kilogram, a key assumption in his cost estimates. IEEE-USA has concluded that $500/kilogram is a credible and worthwhile near-term target, but none of the existing space activities, private or public, U.S. or abroad, address the key technical requirements in enough detail to offer much hope of getting costs that low.

SSP proponents have also argued for new price guarantees, on a level playing field, with large earth-based solar farms--to enable private-sector development of SSP, after more of the R&D is complete and low-cost launch becomes available. It has also been suggested that SSP assembly could be an important test bed for inclusion in the National Robotics Initiative.

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27 National Academy of Sciences (http://www.nap.edu/catalog/10202.html)
29 IEEE-USA (http://www.ieeeusa.org/policy/positions/SpaceAccess0214.pdf)
30 National Space Society (http://nss.org/EU)
Key attributes, issues, and development needs for space solar power include the following:

1. Greater investment in R&D is required to reach the $500/kilogram launch cost target.

2. Securing an appropriation of competitive funding is required to validate and improve on the Solar Power Satellite via Arbitrarily Large Phased Array (SPS-ALPHA) modular building block design presented by John Mankins and other potential design concepts.

3. Development of simulation software is required which automatically performs, among other things, ray tracing, and mechanical stability and heat flow analyses demonstrating that modular systems can effectively be constructed to provide large functional power stations.

4. Modular construction in high earth orbit will require a cooperative arrangement of human controllers and robots, following an approach such as teleautonomous systems that was pioneered by the Canadian mining industry. This kind of construction challenge could be an excellent testbed for inclusion in the National Robotics Initiative (NRI), providing both a new application and a testbed for more direct competition between the many research teams interested in NRI.

**Geothermal Power**

Geothermal power currently provides 3,100 megawatts of power capacity in the United States. Geothermal generating facilities were the first to be developed at a major scale, but in the past decade, that early development has not kept pace with wind and solar developments. Unlike other renewable technologies, geothermal power plants are usually “base load” units operating continuously throughout the year. By using steam or hot water from the earth (instead of using fossil fuels to heat water), geothermal plants are able to utilize the same processes of power generation, without harmful emissions from combustion. While common air pollutants are avoided, noxious gases like hydrogen sulfide may be released from some reservoirs. Because some of the same generating components are used in conventional power plants, geothermal facilities require annual downtime for maintenance. Unlike a wind farm, or a solar photovoltaic facility, with components that can undergo maintenance one item at a time, geothermal plants must be offline for some annual maintenance. Geothermal power plants must be sited in locations with appropriate thermal activity—frequently requiring a lengthy intertie to connect to the bulk power system. Thermal activity locations may also dissipate after years of use, and may even reach exhaustion from overuse. The DOE has set a goal for the next decade to expand the capacity of geothermal power by 15,000 megawatts. (U.S. Department of Energy; http://www1.eere.energy.gov/geothermal/powerplants.html).

To expand geothermal output capacity, new sites for geothermal plants must be investigated. Methods to reduce the very significant costs associated with assessing and developing geothermal reservoirs is one element of R&D that would greatly assist in achieving the DOE goal. Currently, approximately one-half of resource assessment costs are spent prior to drilling a pilot well, as a result of relatively inefficient methods utilized to understand the shape, depth and nature of a reservoir. R&D funding to improve reservoir characterization allowing pilot wells to prove out a resource more effectively, would both reduce the cost and accelerate the
development of geothermal generating facilities. Methods to improve output, water and steam extraction techniques, and thermal reservoir management must also be further developed. By improving thermal efficiency of geothermal plants, existing and future facilities will gain a higher output capacity. Horizontal drilling techniques popularized in the natural gas industry could also reduce the emission of noxious gases, especially if closed loop systems were developed to inject and withdraw using two different wells. These concerns could be reduced through time with increased R&D attention.

Key attributes, issues, and development needs for geothermal power include the following:
   1. Geothermal facilities have been limited to areas with naturally heated groundwater or steam, predominately located in the western section of the United States.
   2. The process of scouting for geothermal sites with a reservoir suitable for construction of a plant needs to be improved, and accomplished more cost effectively.
   3. Currently geothermal power can be competitive with coal, and has been proven as a viable energy source, without some of the limitations of coal.
   4. Small amounts of greenhouse gases are released from geothermal wells--but at about 50 times less than that produced by a fossil fuel plant.
   5. R&D spending has the potential to substantially reduce some of the barriers to geothermal development, especially for geologic formations that have traditionally been considered to be marginal.

Tidal Power
Two primary tidal energy technologies exist: tidal stream generators, which function as underwater turbines; and barrage systems, which exploit the cyclic rise and fall of the sea level, due to tidal forces. Instead of damming water on one side, like a conventional dam, a tidal barrage first allows water to flow into a bay or river during high tide; and then, releases the water back, during low tide. This flow and release is done by measuring the tidal flow and controlling sluice gates at key times of the tidal cycle. Turbines then capture the energy as the water flows in and out the sluice gates. The general development and deployment of tidal power plants has been limited by the high capital costs involved with construction. The technology for barrage systems has been largely developed; however, deployment of the system to commercial-scale facilities has been thwarted by high capital costs. In addition, large barrage systems extensively affect ecosystems--by altering the flow of saltwater in and out of estuaries; this alteration changes the hydrology, salinity, turbidity, and other ecosystem characteristics.

Tidal stream generators are a relatively new technology, and currently, no commercial-scale production facilities routinely supply power. In general, tidal stream generators mimic wind energy technologies. While a standard tidal energy technology has not taken precedence, several tidal power designs have been experimented with. Specifically, in 2006, Verdant Power began running a prototype project, using a free-flow kinetic hydropower system in the East
River, near New York City. Over the first two-year period, Verdant Power operated six full-scale turbines, delivering 70 megawatt hours of energy to two end users in the New York City area. (Verdant Power, LLC, http://verdantpower.com/what-initiative/). The turbines installed have had a relatively small effect on the ecosystem, in comparison to barrage systems.

Key attributes, issues, and development needs for tidal power include the following:

1. Constructing tidal power plants is costly, but operation costs are low; overall, the cost per kilowatt-hour is not competitive with conventional fossil fuel power.
2. Tidal power is intermittent, providing power for approximately 10 hours each day, when the tide is moving in or out. Although tidal power is an intermittent energy source, it is also a precisely predictable source of energy.
3. Large barrage systems extensively affect ecosystems.
4. Siting of tidal systems is limited to regions where substantial energy fluxes are present.

**Wave Power**

Compared to the other renewable energy technologies described, wave power is still in its infancy; but in general, the prospect of wave power shows promise. It is projected that in the Pacific Northwest alone, wave energy has the potential to produce 40–70 kWh per meter of western coastline. Experts believe that enough energy exists in ocean waves to provide up to 2,000,000 MW of power capacity. (U.S. Department of Energy; http://www.eere.energy.gov/basics/renewable_energy/wave_energy.html). Like tidal power systems, wave power systems require high capital costs—but have low operation and maintenance costs. Wave power is normally available as low-speed, high forces, and the flow is not steady or constant. By contrast, most electric generators operate at higher speeds and require a steady, constant flow. Wave power devices must also be able to withstand weather conditions and saltwater corrosion. In addition, wave farms have the potential to displace commercial and recreational fishermen from productive fishing regions—and may present navigation hazards.

Key attributes, issues and development needs for wave power include the following:

1. Wave power systems cannot currently compete economically with traditional power sources; however, operation and maintenance costs are very low.
2. Waves are an intermittent source of energy.
3. Siting of wave power plants is difficult; wave power systems must be in an area where waves are consistently strong, environmental impacts are minimal, and scenic shorefronts are aesthetically unaffected.
4. Wave power technologies must be able to withstand all weather conditions.
Biomass Power
The use of biological materials to produce power is not a new technology; use of wood as a fuel is of ancient origin, and has been shown to have been used when homo sapiens were primarily nomadic—as well as in established communities and regions, tens of thousands of years ago. Use of other materials has been institutional in certain societies—dung, straw, peat, and, of course, coal, have been used in various locations. The remainder of this section will deal only with non-fossil biomaterials, and does not consider municipal or industrial waste streams.

Biological materials can be used to recover energy in one of two ways: They can be combusted (used as fuels); or they may be fermented (biologically or chemically reduced), to produce heat and/or products that may be used as fuels. Both systems have merit in specific situations. Most processes using biomass have to address air pollution concerns, which can be exacerbated by variation in the fuel quality. Biological materials inherently contain carbon in some form; however, because most such carbon is removed from the environment in the growth process, it is usually considered that any carbon released during use of such materials does not add to the atmospheric burden.

1. Fuels
Wood is a scarce resource throughout the world today, and IEEE-USA does not recommend its use, except in those instances where wood may be a byproduct. For example, burning wood chips, bark and sawdust from forest products industries in properly designed boilers has not only recovered useful energy, but also eliminated a source of potentially dangerous air emissions. Current interest is increasing, however, in crops selected for high-energy value and rapid growth potential. Various grasses have been proposed as energy crops, and exploration of other materials such as oils from tobacco, soybeans and algae continue to show promise. Particular note should be taken of other waste products: Bagasse from sugar production, for example, can be utilized in the same fashion as wood wastes.

A common problem in most biomass fuels is relatively high moisture content. In many cases, high moisture content requires firing supplemental fuel; or pre-processing, such as oven-drying, air-drying, or sun-drying. While dried wood, bark, bagasse, and similar materials have heating values typically around 8000 BTU/lb.; as-received materials often contain as much as 50% moisture, and effective as-received heating values may be 4000 BTU/lb., or even lower. Aggregation and transport may also pose significant challenges for fuel crops.
Considerations for biomass fuels may include the following:

a. Availability and cost, e.g., waste products versus cultivated crops  
b. Collection, transportation and preparatory processing, if needed  
c. Combustion and energy recovery technology for a particular application  
d. Preventive measures for air emissions from combustion  
e. Residue disposal

2. Fermentation / Chemical Processing
Fermentation processes have been applied to human and animal wastes, especially in small-scale applications, but processes suitable for vegetal products also exist. Fermentation processes produce heat, some of which may be recovered for other uses. And they may produce gases—such as methane, carbon monoxide and hydrogen, which may be used separately as fuels. (Liquid fuel products may be produced from certain processes, e.g., production of ethanol.) Fermentation may be accompanied by undesirable odors, in some cases; and emissions of harmful gases are also possible. Technology exists to control both of these issues, where they occur. Processes may be simple in nature, or may involve extensive additional chemical processing (e.g., methanation).

Considerations for fermentation include the following:

a. Scale, cost and nature of appropriate technology  
b. Transportation, feed arrangements (e.g., batch or flow-through), and feed materials and fuel byproducts storage, if necessary  
c. Emissions control, if necessary (includes emissions or odor from storage, as well as from processes)  
d. Additional materials necessary (e.g., chemical reagents or catalysts)  
e. Arrangements for heat recovery from fermentation, if appropriate  
f. Product fuel materials collection and application  
g. Residue disposal

Key attributes, issues, and development needs for biomass power include the following:
1. Biomass power is obtained from the energy in plants, and plant- or animal- derived materials, including residues from agriculture or forestry, or from organic components of municipal and industrial wastes.
2. Biomass can be used for direct heating, for generating electricity, or for conversion into other fuels, products and materials.
3. Biomass power production usually produces lesser amounts of pollutants per BTU than equivalent fossil fuel use, and is nearly carbon neutral.
4. Farm production of biomass crops can reduce biodiversity and negatively impact wildlife habitat. Biomass production may displace production of other crops.
5. The use of bio-engineered crops for fuel requires stakeholder acceptance.
6. Further collaboration among various industry sectors is required: (i.) to achieve a better understanding about effects of biomass use on resources and on the production of food, energy, products and materials; and (ii.) to determine the most efficient, cost-effective and sustainable ways to use biomass.
REDUCING CARBON EMISSIONS FROM FOSSIL POWER PLANTS

Continuing the R & D initiative to develop and demonstrate economical carbon capture and storage, or conversion, technologies that would make coal a viable energy resource in a carbon-emission-constrained world.

Combustion releases heat from fuels, and the combustion process is basic to utilization of fuel energy. Most fuels, including biomass fuels, contain carbon—which combines with oxygen from air supplied for combustion to produce carbon dioxide, known as a major greenhouse gas (GHG).

Biomass acquires its carbon in the growth process—most of it extracted from the air—so carbon dioxide from biomass is considered to be cyclical in the environment, and not contributory to the greenhouse effect. But combustion of the three fossil fuels—coal, petroleum and natural gas (including natural gas liquids and derivatives, such as propane) produces carbon dioxide from combustion of native carbon (which is not recycled), and which may increase atmospheric levels of carbon dioxide.

Coal combustion produces about twice the carbon dioxide per equivalent heat unit, as does combustion of petroleum products. Natural gas produces the least amount per unit of heat, but its emissions are not inconsequential. Put somewhat differently, carbon dioxide constitutes 18-20% of the flue gas from combustion of coal; 13-17% of flue gas from petroleum products; and 10-15% from natural gas combustion—assuming, in each case, that combustion occurs at exactly stoichiometric conditions (that is, no excess air).

As an aside, it should be noted that, in addition to carbon dioxide, some hydrocarbons also figure as GHG sources. In particular, methane is present in many coal seams; and because of the danger of inadvertent ignition, its exhaustion is a priority at operating mines. Mining of such coals thereby increases methane emissions significantly, and using coal for electricity generation releases methane as a secondary GHG. On a molecule-for-molecule basis, methane is a GHG with greater impact than carbon dioxide, although its contribution to the greenhouse effect is believed to be much less than carbon dioxide, due to smaller emissions.

Until the recent increase in natural gas production, coal has been the only fossil fuel of which the United States controls a very large supply. At current consumption rates, it could last for centuries. Coal is found in almost all states, although the principal production areas are primarily in the West (Montana, Wyoming, Colorado), Central (Illinois and West Kentucky), and East and Mid-Atlantic (West Virginia, Pennsylvania, Virginia and East Kentucky). Use of the lowest rank coal, lignite, is increasing in the Dakotas, Texas and Arkansas.
Coal quality varies enormously, and no two coals—even samples from the same mine—are exactly alike: Coal is a very complex mixture of elements, compounds and contaminants. The fuel value of coal lies in carbon, sulfur and hydrogen, but many other elements are present in small quantities. Carbon occurs in two forms in coal: As “fixed” carbon, it is the physical matrix in which most of the other constituents are held. Carbon is also chemically bound with hydrogen, and other elements in compound form, generally lumped as “volatiles.” The fixed carbon is usually the dominant form, and the relative quantities of fixed carbon and volatiles vary with the “rank” of coal. High ranks, such as anthracite, tend to have low volatiles, while low ranks such as sub-bituminous may have relatively large volatile fractions.

Using coal for residential heating and cooking has declined substantially, and is probably not significant, except in some rural coal-producing areas. Certain coals are valued for metallurgical use (in the form of coke); however, the decline of the U.S. steel industry has reduced that use to a fraction of its former importance. Some coal is utilized for process and general heating, in certain industries; but the largest single use of coal is in electricity generation, where it fuels about 70% of the total kilowatt-hours. Sometimes coal is washed, or otherwise physically processed, before use—to reduce certain contaminants—unburnable materials (e.g., ash) and pyritic sulfur among them. Washing does not significantly reduce carbon content.
There is much interest in technological processes, that would preserve present coal markets, because of the large native reserves of coal; its present importance to electric power production; and its economic importance to certain areas of the United States, such as mining and rail transport. Various approaches are already being used to reduce sulfur emissions; and work is underway to see how carbon dioxide emissions might be reduced. There are several possible approaches:

1. **Removal of carbon prior to combustion**: Coal gasification, operated so that coal is heated in the absence of oxygen, drives off the volatiles, which can then be burned. The fixed carbon matrix (e.g., coke) remains and has limited noncombustion uses, such as asphalt production. Alternatively, the coke can be landfilled-- it is minimally leachable and generally nontoxic. This approach does not remove all of the carbon—hydrocarbon compounds are burned as part of the volatile fraction. But the fixed carbon is the dominant portion; and the reduction in emitted carbon dioxide is substantial.

Technology exists for such an approach, but the handling of large volumes of carbon byproduct will require additional engineering of gasifiers and plant auxiliaries. Such a system, of course, removes a substantial amount of fuel value from the coal, so the economics must be examined. Moreover, for equivalent heat outputs, the amount of coal supplied must be increased very substantially, which may require large increases in mining and transport capacity. Alternatively, liquefaction processes may offer other possibilities.

2. **Removal of carbon dioxide, post-combustion**: Various systems have been proposed, including utilizing carbon dioxide as a nutrient for certain plants (e.g., algae); reaction with other substances to form stable byproducts; and selective adsorption, or direct injection into underground formations. It must be noted that separation of carbon dioxide from flue gas is not a trivial step: A furnace using air to support combustion will produce flue gas dominated by nitrogen and nitrogen compounds, if operated at stoichiometric conditions. Various steps have
been proposed to provide separation. One option—using pure oxygen to support combustion, rather than air—can provide flue gas that approaches 100% carbon dioxide. In principle, post-combustion removal systems would sequester nearly all of the carbon dioxide produced. However, storage of the removed carbon poses its own difficulties: Underground storage technology for gaseous or liquefied carbon dioxide exists, but the economics, safety and security of such storage are unknown; and disposition of solid byproducts would depend upon whether they were marketable, or were substantially waste materials.

Experimental installations are just starting operation, and they face major hurdles, especially demonstrating the ability to handle the enormous volumes of flue gas produced by typical electric power generation plants. Such systems may have large power requirements: For some systems currently under development, it has been estimated that plant capacity would be reduced by about 30%; but this figure is likely to be quite sensitive to the disposal or storage option selected. The corresponding cost increase, and the attendant need to build additional capacity, make this option an unlikely choice—absent sufficient financial incentives.

3. In the short run, modest reductions in carbon emissions can be achieved by relatively simple modifications of existing technologies:

A. Improving performance of currently installed plants. As virtually no new coal plants are expected to be built in the foreseeable future, the United States will not benefit significantly from the technologies discussed in 1. and 2., above. However, additional efficiencies can be derived from existing plants. According to a NETL analysis, refurbishments and O&M practices that would bring underperforming units closer to “best-in-class,” along with retiring inefficient or pollution-prone plants, would improve the efficiency of the coal fleet by about 10%—from an average of 32.5% in 2008, to an average of about 36%.

B. Reconfiguring plants to use integrated gasification combined cycle (IGCC). While a few IGCC plants are in operation, the relatively small reduction of carbon emission, due to their higher efficiencies, compared to conventional pulverized coal firing, does not warrant a substantial increase in cost. Such plants are more complex than the typical coal plants, and reliability concerns are beginning to emerge.

C. Conversion of existing coal-fired furnaces to natural gas fuel. Since natural gas releases about half as much carbon dioxide as coal, per unit of heat obtained, it is to be expected that units with good lifetime prospects may be converted, if sufficient natural gas can be obtained. Coal requires a much larger furnace heat transfer surface than gas, so conversion of a coal furnace to natural gas firing is a relatively simple modification.
Carbon capture, and reuse or sequestration, may prove feasible, in some circumstances. A relatively new Canadian installation, for example, supplies carbon dioxide to a nearby oil field for “priming” (pressurization of such fields may be utilized for secondary recovery activities). The plant in question utilizes local coal, and is quite small; so, it is questionable whether this installation has much relevance to larger and more scattered U.S. plants.

In April 2014, The U.S. Department of Energy and Tampa Electric Company (TECO) had a successful spilotor project startup at the Polk Power Plant Unit-1 in Tampa, Florida, to demonstrate a warm gas cleanup carbon capture technology, in a coal gasification unit. The project included $168 million in American Recovery and Reinvestment Act funding.31

Overall, it is unlikely that much new coal-fired electric generation will be built; the Doe’s Energy Information Administration projects few new central-station, coal-fired power plants beyond those already under construction, or supported by “clean coal” incentives. Most electric capacity additions for the foreseeable future will be fueled by natural gas (offshore or obtained by fracking), and will represent only a small reduction in carbon emissions, compared to coal. Developing viable carbon capture technologies aimed at coal-plant retrofits and gas-fired plants must be a national R&D priority.

Significant engineering, environmental, socio-political and regulatory issues must be addressed, before geological sequestration becomes a viable option. We must develop a better understanding of the biomass cycle, and pursue a sustainable option for biomass sequestration, and co-firing for power generation.

31 By PennEnergy Editorial Staff, April 10, 2014 Source: U.S. Department of Energy
REVITALIZING NUCLEAR POWER GENERATION

Nuclear power is advantageous as a source of electrical energy, underpinning the U.S. infrastructure, because of the following characteristics:

- Abundant base-load electrical generation
- Large-scale electricity generation that is essentially carbon free
- Capability of production of high-temperature process heat suitable for large industrial uses, in place of fossil fuels
- Ample recyclable fuel supply that can reduce America’s dependence on fossil fuels
- Efficient generation technology that has a minimal footprint, compared to renewable technologies

Since commercial nuclear power is essentially carbon free, it has a positive impact on the environment by generating baseload electrical energy--without releasing carbon dioxide to the atmosphere (except for required periodic testing of emergency diesel generators). Additionally, because the nuclear fuel has high energy density, compared to coal, there is a significant reduction in carbon emissions from fuel delivery and waste removal from a nuclear plant, as compared to a coal-fueled plant.
Public opinion regarding nuclear power had grown more positive in recent years, but the 2011 tsunami damage at Fukushima Daiichi, and the resulting radioactive contamination, has caused some countries to freeze or abandon nuclear generation programs. In the United States, both industry and the Nuclear Regulatory Commission (NRC) undertook a variety of actions aimed at existing facilities, in the light of the Fukushima experience. Each plant underwent re-analysis of potential threats, considering, among other things:

- Potential for problems involving more than one unit, at the same site
- Potential for previously unanalyzed contingencies, or for contingencies beyond original design limits
- Adequacy of training and equipment for identification and control of newly identified contingencies

These analyses did identify numerous significant upgrades that might be needed in the event of such a contingency, and such upgrades are now in process at the affected plants; or in some cases, already complete. Among these changes are the staging at two U.S. sites, of portable safety equipment that may be necessary for plant emergencies, so that such equipment can be transported quickly to an affected plant. With particular respect to tsunamis, only two operating sites are currently exposed to the Pacific (which has the highest probability of such events). Plants on the Atlantic and Gulf of Mexico pose a much smaller risk. Those plants have been studied for such contingencies, nonetheless.

New reactors under design or construction have also been reviewed for such risks, but such reactors also incorporate significant design improvements that will enhance their safety. In particular, new designs are “passively safe.” That is, they are not dependent on human actions, or on externally powered safety systems, unlike the Fukushima reactors and most existing U.S. plants. Instead, they are dependent on natural physical principles, such as gravity, convection and conduction. Therefore, they should be much more resilient in crisis situations--because of(among other things), the innovative design and advanced safety features of these new reactors. As part of the administration’s commitment to jumpstarting the U.S. nuclear power industry, the DOE issued approximately $6.5 billion in loan guarantees in February 2014, for constructing two new reactors at the Alvin W. Vogtle Electric Generating Plant, in Georgia.

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33 http://large.stanford.edu/courses/2012/ph241/schultz1/
The construction of these new reactors is also an important part of the administration’s *All-of-the-Above Energy Strategy* to deploy low-carbon energy technologies, enhance energy security, and support economic growth and job creation.\(^{35}\)

With a number of new units in the planning stages, shortages of critical components can present an obstacle.\(^{36}\) For example, the capability to fabricate large reactor vessels is limited, and all fabricators are located offshore, at this time. Potential U.S. suppliers of such services are waiting to see if demand materializes for such services; with enough orders, such capabilities could be located here, but the uncertain economic future has kept most such programs in the paper stage. Although energy from nuclear reactors is economical, compared to coal, or oil with carbon amelioration; the cost of natural gas is very low, at present, creating a dampening effect on nuclear commitments. Citing lower natural gas prices and stagnant growth in electric demand, the EIA reported in April 2014 that the United States will see a loss of approximately 10.5 gigawatts (GW) nuclear power generation by 2020.\(^{37}\)

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35[http://www.whitehouse.gov/sites/default/files/docs/aota_energy_strategy_as_a_path_to_sustainable_economic_growth.pdf](http://www.whitehouse.gov/sites/default/files/docs/aota_energy_strategy_as_a_path_to_sustainable_economic_growth.pdf)


The NRC has received license applications for about 30 new nuclear units,\textsuperscript{38} but only four are now under construction, and most of the rest are in abeyance. Three factors associated with the successful development of new nuclear units are utility scale, operations credibility of existing nuclear units, and the strength of the utility balance sheet. Nuclear plant costs include large capital expenditures over a number of years, during the construction phase; and most electric utilities are now unable to finance these projects on their own, with many of the proposed facilities having been planned for multiple-entity ownership. In addition, misalignment in the Regional Transmission Organizations (RTO) and Independent System Operators (ISO) markets, along with

\textsuperscript{38} http://www.nrc.gov/reactors/new-reactors/collection/new-reactor-map.html
distortions created by mandates and subsidies for other types of power generation, have severely undermined the competitiveness of nuclear power generation in those markets. Consequently, U.S. market conditions are such that utilities utilizing Integrated Resource Planning processes in long-term, bi-lateral, wholesale markets are currently developing all new nuclear units currently being constructed. Reforming the RTO and ISO wholesale electricity markets is important and necessary to revitalize nuclear power, and achieve an optimal mix of resources from a cost, environmental and reliability perspective.

The high front-end capital requirement has, however, provided incentive for developing small modular reactors (SMRs); which could be built, as needed, for additional base-load and load-following energy. In addition, nuclear hybrid energy systems utilizing SMRs have the potential to become more economical than traditional nuclear based solutions, by accommodating the integration of renewable energy. A large number of such designs are on drawing boards, and some are being explored with the NRC. Two SMR designs have received DOE cost-share support. One project has proposed to obtain NRC design certification, and achieve commercial operation, by 2025.39

An expansion of nuclear energy will also require increasing the supply of competent manpower, especially in the design and operational phases of new plants. The number of active nuclear engineering degree programs in U.S. universities has begun to rebound from historically low numbers—but government support for mathematics and science education, and for university programs, must be emphasized to meet the likely needs of a nuclear future.

Growing penetration levels of renewable energy sources, demand response, and other emerging technologies are transforming the power sector. In the absence of additional energy storage, nuclear power plants will need greater operational flexibility—to integrate with an evolving power sector, and respond to significant and irregular variations in the power supply.

Supporting a comprehensive spent nuclear fuel management program that would close the fuel cycle and develop a disposal facility, as mandated by the Nuclear Waste Policy Act of 1982 (Public Law 97-425).

The DOE submitted a license application to the NRC in 2008, for the construction of a deep geological nuclear waste repository at Yucca Mountain, Nevada, as mandated by
the Nuclear Waste Policy Act of 1987. The current administration has removed funding for this site, and its status is still uncertain.

The administration empaneled a Blue Ribbon Commission to make recommendations for the safe disposal of high-level nuclear waste. The report of that Commission emphasized a continued need for such a repository, but did not specify how that goal was to be achieved. The U.S. Court of Appeals for the District of Columbia Circuit decided in November 2013 that in view of the DOE's termination of the Yucca Mountain repository program, the DOE could not continue to collect the surcharge of one-tenth of a cent per kilowatt-hour on consumers of nuclear generated electricity. The fees totaled approximately $750 million a year industrywide, and since its inception, more than $20 billion has been paid into the fund by nuclear energy consumers. The fees could be re-instated, if either the Yucca Mountain project is revived, or because Congress enacts an alternative plan for the storage/disposal of nuclear waste.

During October 2014, the NRC published Volume 3 of its safety evaluation report for the Yucca Mountain repository license. The findings contained within Volume 3 concluded, among other things, that the DOE's repository design for Yucca Mountain meets the requirements that apply, after the permanent closure of the repository--including but not limited to the post-closure performance objectives contained in NRCs regulations. Approval of additional congressional funding for the DOE and NRC is necessary to complete the Yucca Mountain licensing review. Some thought has been given to other sites studied before Yucca Mountain was chosen, but as yet, there has been no consensus on what should be done to enable an alternative repository. In the interim, almost all existing plants, and all of the new installations, have already incorporated, or are planning, long-term storage of spent nuclear fuel on-site--at their respective locations.

Developing and deploying nuclear fuel reprocessing technologies to improve economics and reduce proliferation concerns.

Disposal is only one component of a complete, used fuel management program. Both technical and business cases can be made that nuclear fuel should be recycled, extracting the energy-related component and processing the resulting materials into

existing reactors; or into advanced, fast-spectrum reactors. Recycling technologies have been developed that could be implemented in connection with a disposal program, to minimize the disposal necessary for such materials. While such recycling appears expensive relative to purchase of fresh fuel at present—with static demand, fuel prices have remained quite low—avoiding substantial social costs, due to mining and processing fuel material, and in the long run, appears to be most beneficial for the environment. Although proliferation and security concerns were initially the rationale for avoiding fuel recycling, techniques now exist to make theft of such material unattractive. Moreover, it is possible to build reactors capable of utilizing discharged water reactor fuel, greatly reducing its content of long-lived isotopes, while simultaneously producing energy. Such systems would keep reactor fuel in such a form, that diversion of its contents would not be feasible, and would greatly ease requirements for long-term storage.

Supporting fundamental R & D in industry, academia and government to continue exercising world leadership in nuclear fission and fusion science.

As the demand for electricity continues to grow worldwide, concerns for energy supplies, rising energy prices, and the threat of greenhouse gas emissions will increase nuclear energy’s role in addressing those concerns, despite the moratoria in several countries. The OECD Nuclear Energy Agency’s 2008 report, The Outlook for Nuclear Energy, estimated 1,400 reactors would be in operation by 2050.\(^\text{43}\) Many of the new plants are expected to be constructed in developing countries. To accomplish such expansion, policymakers, academia, the nuclear industry and society must work together to increase public knowledge and confidence in the safety and non-proliferation of nuclear technology. More importantly, the technology holders, regulators and users, including those based in the United States, must work together to ensure appropriate safeguards are in place and safe operations are maintained.

The United States must continue to provide leadership and support to the Generation IV International Forum (GIF), and fusion energy research, to develop future generation nuclear energy systems that can be licensed, constructed and operated to provide reliable energy products—while satisfactorily addressing safety, waste, proliferation and public perception concerns.

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The commercial nuclear power industry has proceeded to develop standardized advanced reactor designs that enhance safety considerations, by incorporating passive design features and modular construction techniques that offer improved safety and better economics. Numerous applications have been submitted to the NRC for combined construction and operating licenses to build new plants with Generation III+ light-water reactors, using proven technologies. Working with private industry and international partners, the DOE is also pursuing R&D on Generation IV reactor technologies, including the Next Generation Nuclear Plant (NGNP), as authorized by the *Energy Policy Act of 2005*. Generation IV reactor concepts will offer safer, more economical and more reliable operation, with reduced waste production.

**Supporting the use of nuclear combined heat and power applications to other industries, such as chemical and petroleum, enhanced oil recovery, coal-to-liquid and production of hydrogen.**

With the capability of providing high-temperature steam and process heat, next-generation nuclear power is positioned to extend the range of nuclear applications beyond the advanced light-water reactors currently under construction. High-quality steam and process heat could be used in place of fossil fuels, in large industrial markets-preserving natural gas as a feedstock, and also reducing greenhouse gas emissions. Nuclear energy-based hybrid systems should be evaluated--to determine the best means to integrate various energy resources with the dynamics of the electric power grid.
ABOUT THIS IEEE-USA POSITION STATEMENT:

This statement, as approved by the IEEE-USA Board of Directors on 29 October 2015, was developed by IEEE-USA’s Energy Policy Committee, as an addendum to IEEE-USA’s Position Statement on the National Energy Policy Recommendations. It represents the considered judgment of a group of U.S. IEEE Members with expertise in the subject field. IEEE-USA advances the public good and promotes the careers and public policy interests of the 200,000 engineering, computing and technology professionals, who are U.S. members of IEEE. The positions taken by IEEE-USA do not necessarily reflect the views of IEEE, or its other organizational units.