6. Increase Generation from Low-Emissions Resources

1. Profile

More than two-thirds of the electricity generated in the United States is produced from fossil-fueled generators that emit substantial amounts of carbon dioxide (CO_2) and other greenhouse gases (GHGs), as well as many criteria and hazardous air pollutants. However, nearly all of the non-fossil fuel technologies used to generate electricity produce far fewer emissions[1] of most pollutants, or produce no emissions at all. Hydroelectric (a.k.a. hydro) and nuclear power technologies are the most mature and widely deployed of the zero-emissions technologies. Wind turbines and utility-scale and distributed solar photovoltaics (PV) currently produce considerably less electricity than hydro and nuclear, but are experiencing rapid, sustained growth in the United States and worldwide. Other relevant technologies include geothermal and concentrating solar power generators. Biomass, landfill gas, and biogas[2] technologies clearly result in emissions of some air pollutants, but are considered by many to be net-zero GHG emissions technologies on a lifecycle basis.[3] Table 6-1 exhibits the major zero- and low-emissions technologies that are covered in this chapter and their proportionate contribution to total US generation in 2012.

Table 6-1

Contribution of Zero- and Low-Emissions Technologies to Total US Generation (2012)[4]

Technology	kWh	Percentage of Total US Generation (2012)
Nuclear	769,331,249	19.0%
Hydroelectric	276,240,223	6.8%
Biomass[5]	57,622,166	1.4%
Wind	140,821,703	3.5%
Geothermal	15,562,426	0.4%
Solar	4,326,675	0.1%
Total	**4,047,765,259**	**31.4%**

Increasing the proportion of these zero- and low-emissions technologies in the electricity supply portfolio can be a cost-effective way to reduce carbon emissions from the levels currently produced by a fossil fuel-heavy portfolio. This chapter therefore focuses on the inherent potential of these technologies to reduce GHG and other air pollutant emissions, and the costs and cost-effectiveness of the technologies themselves. Public policy measures that may be used to accelerate deployment of these technologies are covered separately in Chapters 16 and 17, and complementary policies that are necessary or helpful to integrate higher levels of renewable resources into the power system are addressed in Chapter 20.

Although the net energy contribution from wind, solar, and other renewable technologies today is relatively low, these technologies may offer the most promising sources of

1 Throughout this chapter, references to "emissions" or "pollution" generally refer to GHG emissions, unless the context for the specific discussion is tailored to criteria or hazardous air pollutants or pollution in other media.

2 Biogas systems use anaerobic digestion to turn organic waste into a gas (primarily methane) and useable liquid and solid products. Sources of organic waste include manure from dairy and livestock operations, sludge filtered from wastewater, municipal solid waste, food waste, yard clippings, crop residues, and so on. For additional information, see: www.americanbiogascouncil.org or www.biogas-renewable-energy.info

3 The regulatory treatment of emissions from these technologies is explored in greater detail later in this chapter.

4 Based on US Energy Information Administration data available at: http://www.eia.gov/electricity/

5 Includes wood, wood-derived fuels, landfill methane, biogas, municipal waste, and other biomass waste.

carbon emissions reduction in coming years. There are at least three key reasons for this.

First, the main alternative to the introduction of zero- and low-emissions technologies is the application of carbon capture and sequestration to support the continued use of higher-emitting, predominantly fossil-fueled generation. However, to achieve GHG emissions reductions from fossil-fueled generators comparable to those that could be achieved with zero- and low-emissions alternatives would likely require carbon capture and sequestration to be used on a massive scale. But sequestration is very expensive today; major breakthroughs are required to match the economics that wind and solar already exhibit.[6]

Second, the economics of many of these zero- and low-emissions technologies are improving. Their life-cycle costs are declining, making them increasingly cost-competitive with the fossil fuel alternatives. Depending on available weather-related resources and grid connections, wind now competes favorably with fossil-fueled generation in most regions of the United States and internationally. Solar compares favorably with utility service at retail price levels in some regions of the United States, and it is increasingly competitive[7] with fossil-fueled generation and market resources.[8]

Third, the potential scale of renewable resources is large. This is fortunate, as a large amount of generation will be needed to replace the energy produced by an aging fleet of fossil-fueled generators, many of which are scheduled for retirement even in the absence of GHG regulations. Wind resources are now widespread, and utility-scale and distributed solar resources represent the fastest-growing category of generation (in terms of percentage growth rate) across all categories of generation, including fossil fuels. Between 2011 and 2012, solar energy grew by 138 percent in the United States. Its economics continue to show significant improvement.

Figures for the United States suggest that the technical resource potential for wind in the United States at 80 meters (wind turbine hub height) is between 10,000 and 12,000 gigawatts (GW), more than enough to match all energy requirements of US retail consumers.[9,10] Although geothermal only provides a material contribution to the current resource mix in a few states (and 0.4 percent of total generation nationally), the National Renewable Energy Laboratory estimates that existing and emergent geothermal technologies (especially deep enhanced geothermal) may offer a resource potential comparable to onshore wind potential (i.e., a multiple of total US retail requirements).[11] However, the potential based on existing geothermal technologies is much more limited, and according to Bloomberg New Energy Finance, the United States has already realized a 34-percent share of its 9-GW potential

6 The topic of carbon capture and sequestration is covered separately in Chapter 7.

7 As used here and throughout this chapter, "competitive" means that the resource can compete favorably (i.e., the levelized costs are near or below the reference market basis – or, in context, the retail rate) with comparable market-based resources free of either tax incentives, ratepayer-based incentives, or other policy-based encouragements unless specified.

8 See, for example: Rocky Mountain Institute. (2014, February). *The Economics of Grid Defection.* Available at: http://www.rmi.org/electricity_grid_defection

9 Refer to: http://www.windpoweringamerica.gov/windmaps/resource_potential.asp. Even at a low 30-percent capacity factor, this suggests that the resource potential of wind alone is many times the retail load in the United States of roughly 4,000,000 megawatt-hours.

10 There are multiple ways to assess the potential deployment of renewable resources. Technical potential represents "the achievable energy generation of a particular technology given system performance, topographic limitations, environmental, and land-use constraints. The primary benefit of assessing technical potential is that it establishes an upper-boundary estimate of development potential." Lopez, A., Roberts, B., Heimiller, D., Blair, N., & Porro, G. (2013, July). U.S. *Renewable Energy Technical Potentials: A GIS-Based Analysis.* National Renewable Energy Laboratory. Available at: http://www.nrel.gov/docs/fy12osti/51946.pdf

11 Traditional geothermal technologies pipe pockets of steam from modest depths below the surface to generate electricity in turbines. Deep enhanced geothermal systems extract energy from deep within the Earth's crust. This is achieved by fracturing hot dry rock between three and ten kilometers below the earth's surface using a hydroshearing method similar to the hydrofracturing methods now commonly used for gas and oil extraction. Fluid is pumped through the rock and absorbs the earth's heat before it is pumped back to the surface to generate electricity. Lopez, et al, at supra footnote 10. Enhanced geothermal systems technology is new and uncertain. The first US project to rely on this technology was connected to the grid in early 2013.

from identified geothermal systems.[12] The potential for emerging geothermal technologies may take considerable time to realize.[13] Finally, the potential for solar generation is many times that of either wind, biomass, or geothermal in the United States. Table 6-2 summarizes the technical potential of various renewable energy technologies as reviewed by the National Renewable Energy Laboratory in 2012. Nuclear energy is not considered to be a renewable resource and is not shown in this table, although it is a zero-emissions technology covered elsewhere in this chapter.

Table 6-2

Total Estimated US Technical Potential by Technology[14]

Technology	Generation Potential (TWh)[a]	Capacity Potential (GW)[a]
Urban utility-scale PV	2,200	1,200
Rural utility-scale PV	280,600	153,000
Rooftop PV	800	664
Concentrating solar power	116,100	38,000
Onshore wind power	32,700	11,000
Offshore wind power	17,000	4,200
Biopower[b]	500	62
Hydrothermal power systems	300	38
Enhanced geothermal systems	31,300	4,000
Hydropower	300	60

a Non-excluded land was assumed to be available to support development of more than one technology.

b All biomass feedstock resources considered were assumed to be available for biopower use; competing uses, such as biofuels production, were not considered.

TWh - terawatt-hours

In contrast to most of the emerging renewable energy technologies, nuclear and hydro are mature technologies and are expected to continue to provide a material contribution to the generation mix for years to come, reducing the carbon footprint of the power sector. Even under current baseline projections, the International Energy Agency and the US Energy Information Administration both recognize a 24-percent expected contribution from nuclear and hydro in the United States in 2035, roughly comparable to their 26-percent share in 2011.[15,16] Nuclear and hydro resources typically have high construction costs, but once built operate at high capacity factors because they have relatively low operating costs. All nuclear generators and some of the larger hydro plants typically operate as base load, that is, they operate at higher capacity factors not just on average but across all or most hours of the day, on all or most days of the year.[17]

After a period of nearly two decades when no new nuclear power plants were built in the United States, some new nuclear generation is currently under construction in three states: South Carolina, Georgia, and Tennessee. However, the relatively high capital costs, longer planning and construction periods, and additional investor protections that are necessary (federal loan guarantees, regulatory assurances of cost recovery, and protections from

12 Bloomberg New Energy Finance. (2013, February). *Geothermal – Research Note,* Appendix A; Williams, C. F., Reed, M. J., & Mariner, R. H. (2008). *A Review of Methods Applied by the US Geological Survey in the Assessment of Identified Geothermal Resources.* US Geological Survey Open-File Report 2008-1296. Available at: http://pubs.usgs.gov/of/2008/1296/pdf/of2008-1296.pdf

13 One government-sponsored MIT report concluded that a "cumulative capacity of more than 100,000 MWe (megawatts of energy) from enhanced geothermal systems can be achieved in the United States within 50 years with a modest, multiyear federal investment for RD&D in several field projects in the United States." Massachusetts Institute of Technology. (2006). *The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century.* pp. 1-6.MIT-led Interdisciplinary Panel for US Department of Energy. Available at: http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

14 Supra footnote 10.

15 International Energy Agency. (2013, November). *World Energy Outlook.* Available at: http://www.worldenergyoutlook.org/publications/weo-2013/

16 US Energy Information Administration. (2014, May). *Annual Energy Outlook 2014, with Wind Projections to 2040.* Available at: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf

17 The need for baseload generation and the economics of operating in that fashion have changed considerably in recent years in ways that have contributed to the early retirement of a few nuclear units. This is especially true in areas where wholesale electricity markets exist. Low natural gas prices have reduced wholesale energy costs, which translates into less revenue for nuclear units. The widespread deployment of wind turbines (which have near-zero operating costs) has similarly reduced wholesale prices and nuclear revenues.

liability) remain a deterrent to widespread development of new nuclear capacity in much of the United States.[18] Given the risks and capital requirements, it seems unlikely that the private sector can manage these investments without significant state-sponsored support. The federal government role therefore seems essential to maintaining an ongoing viable role for nuclear generation.

The promise of increased hydro capacity appears to be similarly constrained, but for different reasons. In the United States, most of the potential for large-scale hydro generation was tapped decades ago. Looking ahead, most of the potential for increased hydro capacity consists of imports from new, large projects in Canada, uprates of existing US hydro projects, and new, small community-scale projects. Major new hydro projects are underway in at least two Canadian provinces, and at least one regional transmission organization (ISO New England) is reviewing the ability of the current system to accommodate more imports from northern neighbors.[19]

Some forms of biomass power generation, principally those involving combustion of biomass in a steam generating unit, are also quite mature. Many states also classify generation from municipal waste combustors (i.e., waste-to-energy facilities), another mature technology, as renewable for regulatory purposes.[20] Waste-to-energy generation can provide additional benefits by reducing the volume of waste sent to landfills and the associated methane emissions. Although the technical potential to increase biomass generating capacity is promising, the availability and costs of this resource can be extremely location-dependent. Also, the regulatory treatment of emissions from some forms of biomass combustion is currently a subject of considerable debate (discussed below).

Although the technical potential for deploying zero- and low-emissions technologies is vast, far in excess of actual US electricity needs, the economic potential is of course more limited. Assessments of technical potential do not take into consideration the costs or cost-effectiveness of building and operating the resources. Zero- and low-emissions technologies are frequently more capital-intensive than fossil fuel technologies. But even though they may be more expensive to construct, once built they tend to have lower operating costs relative to thermal and fossil fuel resources. For that reason, where they are available, these resources tend to be the first resources used to serve load.[21]

2. Regulatory Backdrop

This section explains some of the air pollution regulations applicable to low-emissions resources, summarizes other types of regulations unique to nuclear and hydro generators, and then turns to some of the

18 Nuclear energy in the United States has also confronted ongoing challenges associated with project delays, higher than planned costs of construction, high decommissioning costs, and uncertain and high costs of spent fuel handling and disposal. For more details, refer to Chapter 4 of: Sovacool, B. (2011, May). *Contesting the Future of Nuclear Power: A Critical Global Assessment of Atomic Energy.* Singapore: World Scientific Publishing. An abbreviated discussion of these issues can be found at: Union of Concerned Scientists. (2009, May). *Fact Sheet: A Resurgence of Nuclear Power Poses Significant Challenges.* Available at: http://www.ucsusa.org/assets/documents/nuclear_power/nuclear-resurgence.pdf

19 See, for example: ISO New England. (2013). *Regional System Plan.* p. 126. Available at: http://www.iso-ne.com/trans/rsp/index.html. See also: http://www.hydroquebec.com/about-hydro-quebec/who-are-we/hydro-quebec-glance.html and http://www.gov.nl.ca/lowerchurchillproject/backgrounder_7.htm.

20 *DSIRE Quantitative RPS Data Project.* (2011, April 15). Available at: http://www.dsireusa.org

21 As a general rule, electricity resources are dispatched (signaled to deliver energy) based on merit order. *Merit order* reflects the dispatch or operation of available generators based on economic merit that is dictated by the short-run operating costs of each generator relative to others available to the system. Resources with zero or low operating costs are dispatched before higher operating cost resources. The practical effect of building low-carbon resources is that they displace operation of higher-carbon emission sources. An additional megawatt of wind, solar, or nuclear capacity will typically operate first in merit order and displace generation from a higher operating-cost resource, typically a fossil-fueled generator. However, it is also worth noting that some renewable generation technologies, wind and solar PV in particular, are generally considered to be "non-dispatchable," because these technologies either do or do not generate electricity based on factors (weather, time of day) that are beyond the control of the system operator. Instead of dispatching these resources, the system operator anticipates the amount of generation from them and then dispatches other resources in merit order to meet the "net demand" (i.e., the total demand minus the amount served by non-dispatchable resources).

financial incentives that have been used to reduce the effective costs of zero- and low-emissions resources.

Air Pollution Regulations

From an air pollution regulator's perspective, zero-emissions generation resources are unregulated.[22] This is the case for nuclear and hydro generators, as well as wind and solar and most other renewable resources. There are some low-emissions resources, however, that are subject to a variety of air pollution regulatory requirements. The low-emissions resources considered in this chapter include generators fueled by solid biomass, landfill gas, and biogas.[23] Although they are not zero-emissions resources, they are included in this chapter because they are often considered to be net-zero GHG emissions sources on a lifecycle basis.

The combustion of *solid biomass* fuels (typically derived from trees, wood wastes, certain types of woody plants, or municipal waste) can produce stack emissions that are greater than or less than those from fossil fuel combustion. To begin with, the emissions from solid biomass combustion can be highly variable depending on details about the biomass fuel and the combustion unit. In general, on a comparable input basis (i.e., pounds of pollutant per million British Thermal Units [MMBTU] of heat input), biomass fuels will produce higher emissions of almost all pollutants than natural gas does. Compared to coal or oil combustion, the results tend to vary by pollutant. For these reasons, solid biomass combustion is covered under a wide range of air pollution regulations, and larger sources are subject to permit requirements. Case-by-case assessments of potential emissions and control requirements are often necessary.

Landfill gas is produced in landfills when waste is anaerobically digested by microorganisms. The produced gas consists primarily of methane, an extremely potent GHG. Over the course of time, landfill gas is slowly emitted to the atmosphere as a fugitive emission unless the gas is captured. To address this problem, the US Environmental Protection Agency (EPA) promulgated an existing source performance standard for municipal solid waste landfills under its Clean Air Act Section 111(d) authority in 1996. That standard requires large landfills to install systems for capturing, and then flaring or controlling, landfill gas. One of the options available for compliance is to use the captured landfill gas to generate electricity. Landfill gas is similar in composition to natural gas and produces similar air pollutants when combusted. Thus, when landfill gas is used to produce electricity, it is regulated in a manner similar to a generator combusting natural gas.

Biogas is a broad term referring to gases produced from biological sources, most commonly from the anaerobic digestion of animal waste, wastewater, or food waste. Methane comprises the largest portion of biogas, just as it comprises the largest portion of natural gas or landfill gas. When biogas is combusted to produce electricity, it is used in the same manner that natural gas or landfill gas is used and produces similar air pollutants. With respect to most air pollutants, biogas combustion is therefore regulated in a manner similar to natural gas combustion.

Combustion of biomass, landfill gas, or biogas will produce CO_2 at the stack. However, the regulatory treatment of CO_2 emissions (or more generically, GHG emissions) from biomass, landfill gas, and biogas generators is a topic of considerable ongoing debate and controversy. At issue is the question of whether and to what extent to treat such fuels as "carbon neutral" (i.e., attribute no net CO_2 emissions to these fuels). In particular, details about solid biomass resources, including harvest management practices, accounting frameworks, and regulatory oversight, can be complex and influential in determining the actual carbon reduction potential and the appropriate calculation of that potential.[24] Although the scientific arguments in this debate are generally beyond the scope of this document, the salient point is that the regulatory treatment of GHG emissions from combustion of these fuels – particularly

22 Many zero-emissions generators are located at facilities that have other regulated sources of air emissions, such as fossil-fueled backup generators, but the zero-emissions generator itself is not regulated.

23 It should be noted that many publications, data sources, and regulations use the term "biomass" to encompass all solid or gaseous fuels derived from biological sources. A distinction is drawn in this chapter between solid biomass and biogas, because these two types of resources can have significantly different emissions profiles and different applicable regulations.

24 For an extensive discussion of the challenges associated with carbon accounting for solid biomass combustion, see: Fisher, J., Jackson, S., & Biewald, B. (2012, June). *The Carbon Footprint of Electricity from Biomass: A Review of the Current State of Science and Policy.* Synapse Energy Economics. Available at: http://www.synapse-energy.com/sites/default/files/SynapseReport.2012-06.0.Biomass-CO2-Report.11-056.pdf

biomass – remains uncertain at this time and could strongly influence the demand for generation from these sources.[25] Furthermore, state regulations may differ from federal regulations with respect to this topic.[26]

In the emissions guidelines for GHG emissions from existing power plants that the EPA proposed on June 2, 2014 (a.k.a. the Clean Power Plan), the EPA determined that increasing generation from renewable resources is an adequately demonstrated and cost-effective measure for reducing power sector CO_2 emissions. With respect to nuclear power, the EPA concluded that constructing new generators is generally not cost-effective, but completing construction of units that are already underway and preserving the availability of existing units that might otherwise be retired is a cost-effective way to reduce GHG emissions. Although the proposed Clean Power Plan regulation would not require states to include increased renewables and nuclear power in their compliance plans, the emissions targets that the EPA proposed for each state are based on assumed levels of zero-emissions resource deployment.

Regulations Unique to Nuclear and Hydro Generators

The nuclear energy industry is subject to a broad and unique regime of federal licensing, safety, and waste disposal regulations. These federal requirements, which are enforced by the Nuclear Regulatory Commission (NRC), add to the inherent cost and complexity of nuclear power, and make it very expensive and time-consuming to build new reactors.

To begin with, new sources must obtain a combined construction and operating license from the NRC prior to construction. The NRC must approve reactor design (or the project developer can choose among previously approved designs) prior to construction to ensure that necessary and appropriate safety and security features are included. The current licensing and construction process, shown in Figure 6-1, can take nine years to complete. Once obtained, an initial nuclear license spans a period of 40 years.

Most of the regulatory issues associated with nuclear power plant safety are beyond the scope of this chapter. What is relevant here is the fact that the NRC has sole authority and responsibility to monitor plant performance on an ongoing basis, with an eye toward reactor safety, radiation safety, and security. In doing so, the NRC serves as the implementing and enforcement authority for radiological emissions regulations, specifically the Environmental Radiation Protection Standards for Nuclear Power Operations promulgated by the EPA under 40 C.F.R. Part 190.

Spent nuclear fuel is an extremely dangerous material requiring special handling and disposal. Spent fuel is usually stored onsite at the power plant in steel-lined concrete pools filled with water, or in airtight steel or concrete-and-steel containers. According to federal law, the US Department of Energy (DOE) has responsibility for developing a permanent nuclear waste storage facility and transferring spent fuel from reactor sites to that facility. Since 1983, nuclear power plant owners have been required to pay into a nuclear waste fund for building such a facility. More than $20 billion has been paid into the fund, but a permanent storage site still does not exist.[27] In addition, every nuclear power plant in the United States is required by the NRC to set aside sufficient funds to decommission the entire plant when it reaches the end of its useful life.

Against this backdrop of regulations, most of the activity

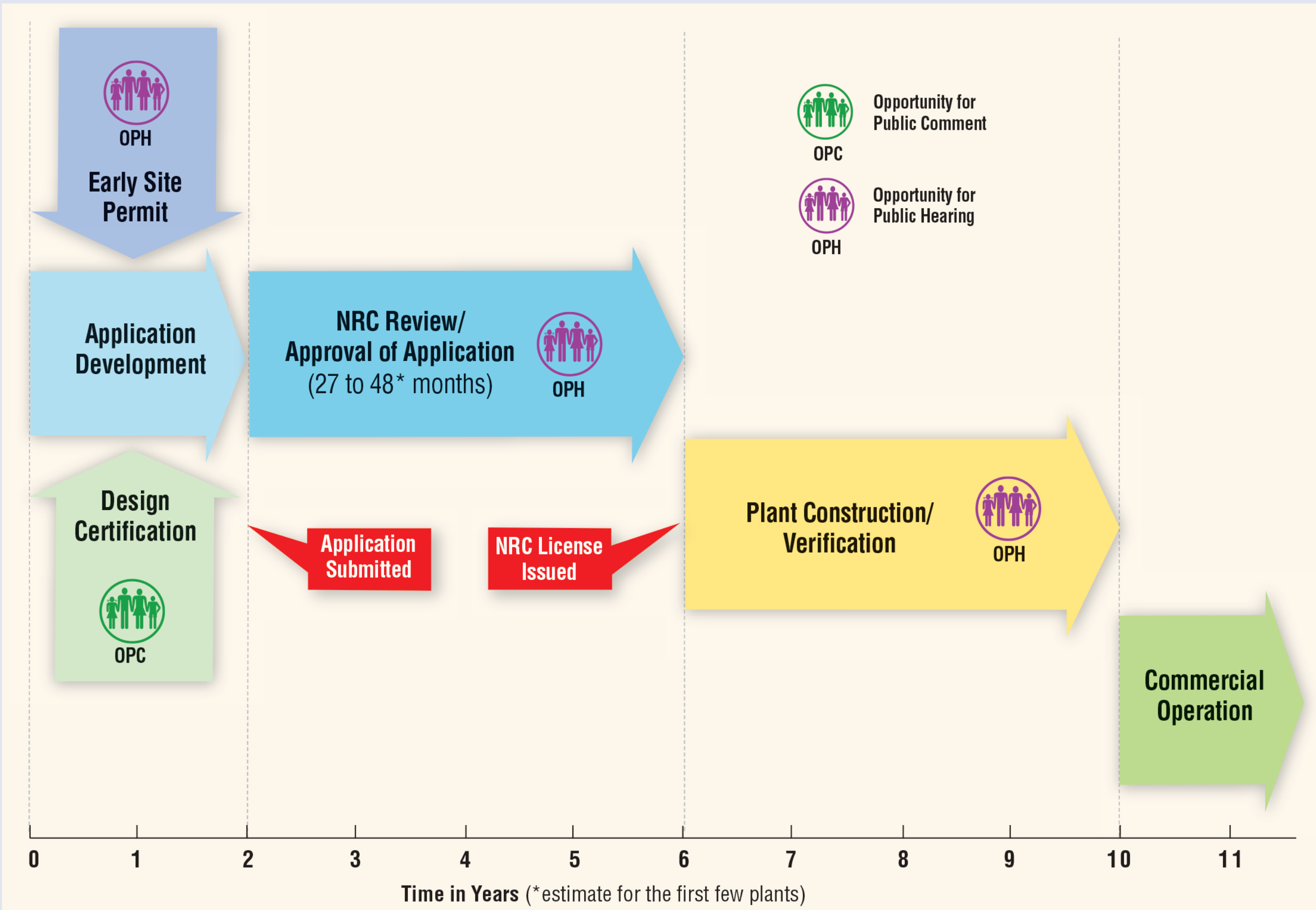
25 In July 2011, the EPA decided to temporarily defer the application of Prevention of Significant Deterioration and Title V permitting requirements to CO_2 emissions from biogenically fueled stationary sources while it studied whether and how to regulate such emissions. However, that decision was vacated by the US Court of Appeals for the District of Columbia Circuit in July 2013, *Center for Biological Diversity v. EPA,* 722 F.3d 421 (D.C. Cir. 2013), and the temporary deferral expired by its own terms in July 2014. In November 2014, the EPA released a revised *Framework for Assessing Biogenic Carbon Dioxide Emissions* from Stationary Sources (available at: http://www.epa.gov/climatechange/ghgemissions/biogenic-emissions.html); that document continues to undergo technical review. From a regulatory standpoint, the GHG reductions that may be achievable by switching to these fuels are thus uncertain.

26 Vermont, for example, has adopted regulatory requirements for sustainable biomass harvesting and forest management practices that reduce the lifecycle GHG emissions associated with biomass fuels. For further information, refer to Vermont Public Service Board, Docket 7380, 2/28/2008 and certification proceedings and orders. Available at: http://www.state.vt.us/psb/orders/2008/files/7380amendedcpg.pdf

27 In 2013, a federal court ordered the DOE to stop collecting payments for the nuclear waste fund until the department makes provisions for actually collecting and storing nuclear waste.

Figure 6-1

Nuclear Power Plant Licensing and Construction Process [28]



in the nuclear power industry in recent decades has been associated with existing units rather than new units. This is largely a result of federal initiatives to enable both the relicensing of existing units and increases in the generating capacity of those units (i.e., "uprates"), which can generally be accomplished at a lower cost, with less lead time, and with lower financial risk than construction of an entirely new reactor. NRC approval is required for both relicensing and power uprates; license extensions typically add 20 years to the life of a unit. Since the 1970s, the NRC has granted 134 uprates, adding capacity roughly equal to that of six new nuclear facilities.[29] But by way of comparison, the last entirely new nuclear reactor built in the United States began operation in 1996, and there are just five new nuclear power stations under construction today.

Finally, it is worth noting that several states have adopted laws concerning the construction of new nuclear reactors. Minnesota has banned new nuclear facilities, while 12 other states have imposed preconditions on any new construction. Three states (Maine, Massachusetts, and Oregon) require voter approval of any new reactors, and five states require approval by the state legislature (Hawaii, Illinois, Massachusetts, Rhode Island, and Vermont). California, Connecticut, Illinois, Kentucky, Maine, Oregon, West Virginia, and Wisconsin require the identification of a demonstrable technology or a means for high-level waste disposal or reprocessing. Two states, West Virginia and

28 Nuclear Energy Institute. Available at: http://www.nei.org/corporatesite/media/filefolder/Key_Licensing_Steps.pdf

29 For more information on uprates, refer to: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/power-uprates.html

Wisconsin, further require a finding that the construction of a nuclear facility will be economically feasible for ratepayers.[30]

With few exceptions, licensing requirements for hydroelectric generating facilities are similarly vested in federal rather than state hands. The Federal Energy Regulatory Commission (FERC) is responsible for licensing and relicensing almost all hydro projects and overseeing ongoing project operations, including dam safety inspections and environmental monitoring. Licenses are issued to new projects for a 30- to 50-year term. The traditional licensing process is a lengthy one, requiring up to seven years to license or relicense a large project. The FERC is currently testing a new two-year licensing process for certain types of hydro projects. Other matters concerning FERC regulation of hydro projects are beyond the scope of this chapter.

Financial Incentives

The remainder of this section presents a summary of public policies that have been used to advance and accelerate deployment of zero- or low-emissions technologies specifically by *lowering the effective cost of these technologies*. These types of public policies represent only one of several ways to increase deployment of cleaner technologies; some of the other ways are addressed separately in different chapters of this document.[31]

Financial incentives supporting nuclear and hydro generation have largely come from the federal government rather than state governments. This is because all nuclear and most hydro projects are very large and require huge investments to complete. The scale of economic support needed to make a difference has generally been beyond what states are able or willing to support. In addition, nuclear and hydro generators have benefitted in most cases from cost recovery guarantees that have traditionally been granted to large capital investments by rate-regulated utilities and public power entities.

Beginning nearly a century ago, early efforts by the federal government focused on creating large hydro projects through government-owned entities such as the Tennessee Valley Authority and the Bonneville Power Administration. These federal entities were large enough to raise the capital necessary to take advantage of scale economics, and they were able to justify projects not merely based on the economics of electricity generation but also based on co-benefits for agricultural water needs.

Early barriers to the development of nuclear energy in the United States were associated in large part with catastrophic failure liability. These barriers were addressed through the passage in 1957 of the federal Price-Anderson Act, which largely socialized those risks by pooling the liability across the entire industry. That Act also capped the amount of liability that could be due from the industry. Because private liability insurance was not available for new nuclear investments, federal liability insurance was necessary to make nuclear investments possible. The federal government thus provided an essential economic service (at taxpayer expense) that the private sector was unable or unwilling to provide.

In contrast to the large investments in nuclear and hydro power that have mostly been made by rate-regulated utilities and public power entities with an assurance of cost recovery from utility customers, renewable power projects tend to be smaller, owned by independent power producers or by utility customers, and financed by private capital with no assurance of cost recovery. Recognizing those differences, the federal government and many state governments have adopted financial incentives specifically for some types of renewable resources that lower the effective cost or price of these technologies. These economic policies come in the form of tax credits, incentives, and exemptions; rebates and grants; favorable loan terms; and support for renewable manufacturing industries. The states' experiences with financial incentives are summarized in the following section of this chapter.

30 Based on information compiled by the National Conference of State Legislatures. Available at: http://www.ncsl.org/research/environment-and-natural-resources/states-restrictions-on-new-nuclear-power-facility.aspx

31 Chapter 16 addresses legislative and regulatory frameworks (e.g., renewable portfolio standards) that have been used to require utilities to procure power from renewable resources, thus increasing the market share of these resources regardless of their effective costs. Chapter 19 addresses another set of public policies specifically related to the promotion of distributed generation resources (i.e., generally speaking, resources that are owned by a customer of a utility rather than the utility itself). And finally, a number of other chapters describe complementary policies that are necessary or helpful to integrate higher levels of zero- or low-emissions resources into the power system while ensuring system reliability and controlling costs. Several policies are mentioned briefly in this chapter and then addressed more expansively in those other chapters.

Table 6-3

Generation Mix by State for the Year 2012[32]

State	Coal	Natural Gas	Oil	Nuclear	Hydro	Biomass	Geothermal	Wind	Solar	Other
AK	10%	52%	15%	0%	23%	0%	0%	1%	0%	0%
AL	30%	36%	0%	27%	5%	2%	0%	0%	0%	0%
AR	44%	26%	0%	24%	3%	3%	0%	0%	0%	0%
AZ	36%	27%	0%	29%	6%	0%	0%	0%	1%	0%
CA	1%	60%	0%	9%	14%	3%	6%	5%	1%	1%
CO	66%	20%	0%	0%	2%	0%	0%	11%	0%	0%
CT	2%	46%	0%	47%	1%	2%	0%	0%	0%	2%
DC	0%	87%	13%	0%	0%	0%	0%	0%	0%	0%
DE	16%	79%	0%	0%	0%	1%	0%	0%	0%	3%
FL	20%	68%	1%	8%	0%	2%	0%	0%	0%	1%
GA	33%	35%	0%	28%	1%	3%	0%	0%	0%	0%
HI	15%	0%	71%	0%	1%	3%	2%	4%	0%	4%
IA	62%	3%	0%	8%	1%	0%	0%	25%	0%	0%
ID	0%	12%	0%	0%	71%	4%	0%	12%	0%	0%
IL	41%	6%	0%	49%	0%	0%	0%	4%	0%	0%
IN	81%	13%	1%	0%	0%	0%	0%	3%	0%	2%
KS	63%	6%	0%	19%	0%	0%	0%	12%	0%	0%
KY	92%	3%	2%	0%	3%	0%	0%	0%	0%	0%
LA	21%	57%	3%	15%	1%	2%	0%	0%	0%	2%
MA	6%	68%	0%	16%	2%	5%	0%	0%	0%	3%
MD	43%	13%	0%	36%	4%	1%	0%	1%	0%	1%
ME	0%	42%	1%	0%	26%	22%	0%	6%	0%	3%
MI	49%	20%	0%	26%	0%	2%	0%	1%	0%	1%
MN	44%	14%	0%	23%	1%	4%	0%	15%	0%	1%
MO	79%	7%	0%	12%	1%	0%	0%	1%	0%	0%
MS	13%	71%	0%	13%	0%	3%	0%	0%	0%	0%
MT	50%	2%	2%	0%	41%	0%	0%	5%	0%	1%
NC	44%	17%	0%	34%	3%	2%	0%	0%	0%	0%
ND	78%	0%	0%	0%	7%	0%	0%	15%	0%	0%
NE	73%	2%	0%	17%	4%	0%	0%	4%	0%	0%
NH	7%	37%	0%	43%	7%	6%	0%	1%	0%	0%
NJ	3%	43%	0%	51%	0%	1%	0%	0%	0%	1%
NM	68%	24%	0%	0%	1%	0%	0%	6%	1%	0%
NV	12%	73%	0%	0%	7%	0%	7%	0%	1%	0%
NY	3%	44%	0%	30%	18%	2%	0%	2%	0%	1%
OH	66%	17%	1%	13%	0%	1%	0%	1%	0%	1%
OK	38%	50%	0%	0%	1%	0%	0%	10%	0%	0%
OR	4%	19%	0%	0%	65%	1%	0%	10%	0%	0%
PA	39%	24%	0%	34%	1%	1%	0%	1%	0%	1%
RI	0%	99%	0%	0%	0%	1%	0%	0%	0%	0%
SC	29%	15%	0%	53%	1%	2%	0%	0%	0%	0%
SD	24%	2%	0%	0%	50%	0%	0%	24%	0%	0%
TN	46%	10%	0%	32%	10%	1%	0%	0%	0%	0%
TX	32%	50%	0%	9%	0%	0%	0%	7%	0%	1%
UT	78%	17%	0%	0%	2%	0%	1%	2%	0%	0%
VA	20%	35%	1%	41%	0%	3%	0%	0%	0%	1%
VT	0%	0%	0%	76%	17%	5%	0%	2%	0%	0%
WA	3%	5%	0%	8%	77%	1%	0%	6%	0%	0%
WI	51%	18%	0%	22%	2%	3%	0%	2%	0%	0%
WV	96%	0%	0%	0%	2%	0%	0%	2%	0%	0%
WY	88%	1%	0%	0%	2%	0%	0%	9%	0%	1%
US Overall	**37%**	**30%**	**1%**	**19%**	**7%**	**1%**	**0%**	**3%**	**0%**	**1%**

3. State and Local Implementation Experiences

Current deployment levels for zero- and low-emissions technologies vary geographically based on a number of factors, including the local availability of renewable resources, state financial incentives, state procurement requirements such as those explained in Chapter 16, and underlying regional energy market fundamentals.[33] Table 6-3 details the approximate contribution of each resource to the generation mix of each state in 2012 based on data collected by the US Energy Information Administration.[34]

Throughout the twentieth century, the federal government took actions that spurred the development and deployment of large-scale nuclear and hydro generators. State policies played only a small role in this deployment. As noted in Tables 6-1 and 6-3, those technologies currently provide about 26 percent of total US generation. That number has changed very little over the past two decades. No new nuclear plants have been built since 1996 and, after allowing for variable weather conditions, the amount of electricity generated by hydroelectric facilities has remained fairly constant since 1969.[35]

In contrast, emerging technologies like wind and utility-scale and distributed solar are seeing rapid growth spurred by a combination of federal, state, and local policies as well as global economic forces. At the national level, in 2010 wind and solar represented just 2.3 percent and 0.03 percent of total generation, respectively. By 2012, their contributions had increased more than 50 percent, to 3.5 percent and 0.1 percent of total generation, respectively. Recent data on the installed capacity of wind and solar generators are summarized in Table 6-4.

Table 6-4

Installed Capacity of Wind and Solar Power, 2014[36]

Technology	Installed Capacity
Utility-scale wind	Greater than 65 GW
Residential solar PV	3.47 GW_{dc}
Non-residential solar PV	5.09 GW_{dc}
Utility-scale solar PV	9.74 GW_{dc}
Concentrating solar power	1.69 GW_{ac}

These values currently represent a small portion of the overall generation mix. However, wind power represented 2012's second-largest category of growth in generation, after natural gas, and the largest in terms of capacity additions. And in some states, wind is already providing sizable portions of total generation (25 percent or more in two states, and between 12 percent and 24 percent in seven states).[37] Wind remains the largest source of investment in the US electricity sector.[38] Solar PV is seeing the highest growth trajectory in the United States of any resource

32 Specifically, this is based on US Energy Information Administration summaries of Form 923 data. Facilities with generators having a nameplate capacity of 1 MW or greater and that are connected to the grid are required to submit Form 923. Because smaller facilities are not required to report, these data are only an approximation of total generation. Most PV sites, for example, have a rated capacity of less than 1 MW and thus are omitted from the totals. Source data are available at: http://www.eia.gov/electricity/data/state/annual_generation_state.xls

33 It should be noted that utilities facing state procurement requirements will in many cases procure renewable energy from facilities in other states. For this reason, the geographic deployment of renewable generators does not always align closely with state procurement requirements. For example, according to a legislative committee report, approximately 62 percent of the wind power generated in Montana is used to meet renewable energy procurement requirements of California utilities. Report available at: http://leg.mt.gov/content/Committees/Interim/2013-2014/Energy-and-Telecommunications/Meetings/September-2013/other-state-rps.pdf

34 Supra footnote 32.

35 Refer to: http://www.eia.gov/beta/MER/index.cfm?tbl=T10.01#/?f=A&start=1949&end=2013&charted=15-6

36 American Wind Energy Association. (2015, January 28). *US Wind Industry Fourth Quarter 2014 Market Report.* Available at: http://awea.files.cms-plus.com/4Q2014%20AWEA%20Market%20Report%20Public%20Version.pdf; Solar Energy Industries Association. (2015, March). Solar Market Insight Report 2014 Q4. Available at: http://www.seia.org/research-resources/solar-market-insight-report-2014-q4; Solar Energy Industries Association. (2015, March). Personal communication.

37 American Wind Energy Association. (2013). *State Capacity and Generation.* From *US Wind Industry Annual Market Report: Year Ending 2013.* Available at: http://www.awea.org/AnnualMarketReport.aspx?ItemNumber=6308&RDtoken=61755&userID

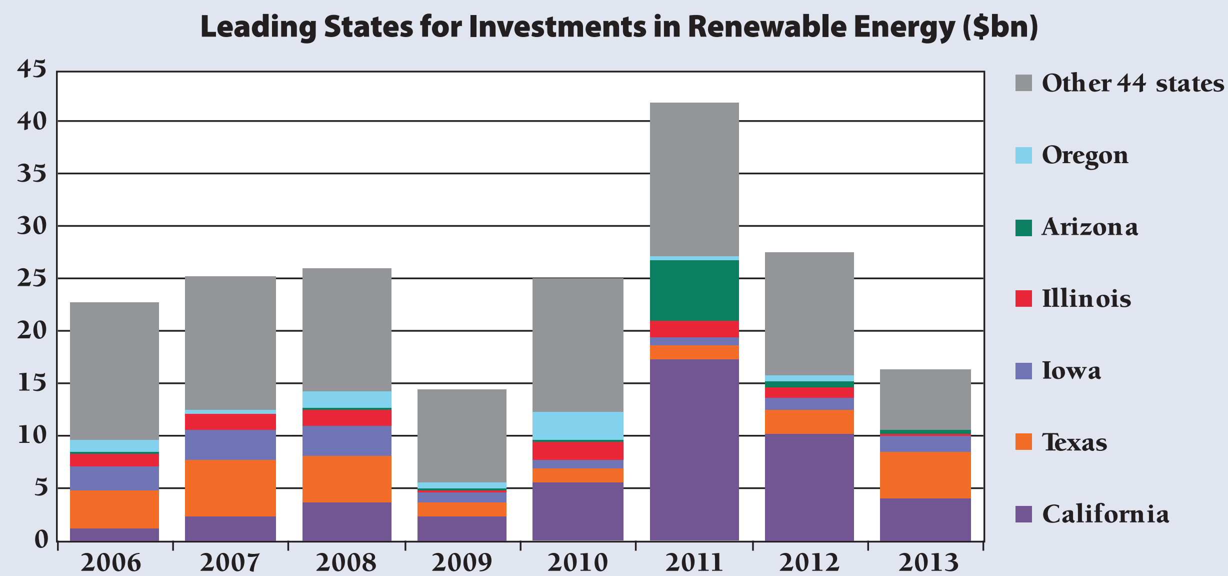
38 Wiser, R., & Bolinger, M. (2013, August). *2012 Wind Technologies Market Report.* Lawrence Berkeley National Laboratory for the US Department of Energy. Available at: http://emp.lbl.gov/sites/all/files/lbnl-6356e.pdf

(138 percent growth in energy generation from 2011 to 2012). Between 2010 and 2013, solar PV installations grew by roughly 940 megawatts $(MW)_{dc}$ to 1470 MW_{dc} per year.[39] This is consistent with larger global trends: solar generating capacity increased globally by 26 percent in 2013, from 31 GW in 2012 to 39 GW in 2013.[40] In the United States currently, distributed PV provides roughly 40 percent of installed solar capacity, whereas utility-scale PV provides most of the rest of the capacity and concentrating solar power provides a small percentage.[41] Utilities are already relying on solar and wind to meet an increasing portion of their electric load.

As shown in Figure 6-2, the states that have seen the greatest investment in renewable energy include six states that represented 54 percent of total US investment from 2008 through 2013. California alone accounted for 23 percent of US investment. California's contribution is rooted in a combination of factors that include a large economy, progressive clean energy policies, high-quality resources, and relatively high electricity prices. The next three states that are large investors in renewables simply exist in a region that is rich in renewable energy. Illinois, Iowa, and Texas are part of an American "wind corridor" where the wind resource is abundant, land is relatively cheap, and population density is low (making siting of wind turbines easier).

State policies are certainly one of the drivers for deployment of renewables. A summary of financial incentives adopted by state governments is presented in Table 6-5, with each type of incentive explained in more detail following the table. Information cited below and additional details about each state policy can be obtained

Figure 6-2



Source: Bloomberg New Energy Finance Note: This captures new build asset finance (ie, project investment) and VC/PE transactions for renewable energy deals. Asset finance excludes small distributed capacity. VC/PE excludes PE buy-outs as these are not new investment. In cases where a particular deal had more than one applicable state, the investment amount was allocated equally across each of the recipient states. For asset finance, the recipient state(s) are determined according to the location of the project(s) being financed. For VC/PE, the recipient state is determined according to the location of the organization raising the funds. The values shown here do not correspond to investment numbers shown in Figure 12 as this chart only includes two of the asset classes (AF and VC/PE), only includes renewable energy (and not other forms of clean energy), and only includes transactions with specified location.

39 Compiled from Solar Energy Industries Association and GTM Research. (2012 and 2013). *US Solar Market Insight;* Interstate Renewable Energy Council. (2012 and 2013). *US Solar Market Trends.*

40 United Nations Environment Programme. (2014, April). *Global Trends in Renewable Energy Investment.* Available at: http://www.unep.org/energy/Publications/Publication/tabid/131188/language/en-US/Default.aspx?p=843151a8-8975-41d2-be27-07554800b702

41 Solar Energy Industries Association and GTM Research. (2014, Quarter 2). *US Solar Market Insight.* Available at: http://www.seia.org/research-resources/solar-market-insight-report-2014-q2

Table 6-5

Financial Incentives for Lowering Effective Cost of Zero- and Low-Emissions Technologies[42]

Mechanism	Incentive	Number of States Implementing	Examples[43]
Personal Tax	Investment Tax Credit	22	Kentucky Federal Government Montana
Corporate Tax	Investment Tax Credit Production Tax Credit Accelerated Depreciation	24	Federal Government Arizona Hawaii
Sales Tax	Sales Exemption Exemption From Generation Tax	28	Indiana Connecticut
Property Tax	Discounted Basis on Renewables Qualifying Renewables Exclusion	40	Arizona Florida
Rebates	Investment Rebate Incentive Purchase Payment	47	Idaho Arizona
Grants	Community Grants Low-Income Support Competitive Grants	21	Connecticut Colorado Vermont
Loans	Revolving Loan for Renewables Loan Loss Reserve Fund	49	Alabama Hawaii
Industry Support	Manufacturer Tax Credit	24	South Carolina Utah Oklahoma

through the Database of State Incentives for Renewables & Efficiency website at: http://www.dsireusa.org/.

Personal Investment Tax Credit

The federal government and many states have established some form of personal investment tax credit for eligible renewable energy projects. At the federal level, the tax credit extends through 2016 and can be applied to 30 percent of the cost of the initial investment. In addition to the federal tax credit, 22 states have implemented their own personal tax credits against state income tax obligations. States like North Carolina have applied the tax credit to a long list of eligible technologies. The credit available in North Carolina is equal to 35 percent of the eligible investment and applies through 2015.

Corporate Tax Incentives

In 1992, the federal government initiated a renewable energy production tax credit program. This program currently offers a tax credit equal to 2.3 cents per kilowatt-hour (kWh) of generation for a short list of qualifying technologies, including wind. Other technologies are eligible for a tax credit equal to 1.1 cents per kWh. The production tax credits generally apply only to the first ten years of operation for each eligible generator. This tax credit expired at the end of 2013, but projects that began construction prior to 2014 remain eligible and eligible

42 Database of State Incentives for Renewables & Efficiency. Available at: http://www.dsireusa.org/

43 A complete list of the types of incentives adopted by each state is available from the Database of State Incentives for Renewables & Efficiency website at: http://www.dsireusa.org/summarytables/finee.cfm

projects will continue to receive the tax credits.

The federal government also offers a business investment tax credit equal to 30 percent of expenditures for solar, fuel cells, and small wind, and a credit of ten percent for other technologies, including geothermal. The federal government also offers accelerated depreciation (often five years) on qualifying investments. Similarly, 24 states offer an investment tax credit for qualifying technologies. For example, in the case of Arizona the focus is on various solar technology investments and the investment tax credit is equal to ten percent. Arizona also offers production tax credits for qualifying wind and solar investments.

Sales Tax Exemptions

Twenty-eight states offer some form of sales tax exemption on qualifying renewable equipment. New Jersey, as an example, offers a sales tax exemption on qualifying solar investments that applies to residential and commercial customers. The amount of the exemption in New Jersey is 100 percent.

Property Tax Exemption

Forty states offer some form of exemption on property taxes associated with qualifying renewables technology. Connecticut, for example, offers a 100-percent exemption on what it deems "Class I" renewables (including wind and solar), which applies to both the commercial and residential sectors.

Rebate Programs

Forty-seven states offer some form of rebate program for qualifying clean energy investments. An advantage of rebates is that they offer value to both for-profit and non-profit (tax exempt) entities. States like Illinois offer rebates for solar and wind technologies. In the case of Illinois, the solar rebate offered to for-profit entities is equal to 25 percent of the project cost, or $1.50/watt for residential projects and $1.25/watt for commercial projects. Nonprofits and the public sector are eligible for rebates equal to 40 percent of solar project costs or $2.50/watt. A similar framework is applied for wind.

Grants

Twenty-one states offer some form of grant program. States like Wisconsin offer grants for qualifying energy projects. Wisconsin had a program budget equal to $9 million in 2013. Grants are awarded for 10 percent to 40 percent of project costs, with a minimum award of $5000. Maximum incentives of $100,000 apply to wind and PV projects.

Loans

Forty-nine states and the District of Columbia have some form of loan program for renewable generation investments. Iowa, for example has established a revolving loan fund for a variety of qualifying technologies. The loans are offered at zero percent interest for a period of up to 20 years. The maximum incentive offered is up to 50 percent of project cost and $1 million. Iowa also has the Iowa Energy Bank, offering low-interest loans to non-profits, schools, hospitals, and municipalities, as well as state government. Loan programs also exist at the municipal level, as in Florida, where they are widespread.

Manufacturing Industry Support

Twenty-four states offer some form of industry support through mechanisms like manufacturing tax credits. States such as South Carolina offer manufacturing tax credits to renewable energy operations. In the case of South Carolina, the credits are offered for the manufacture of a number of qualifying renewables, including wind and solar. The credits are available up to $500,000 for any year and $5 million total for operations that begin during the period between 2010 and 2015.

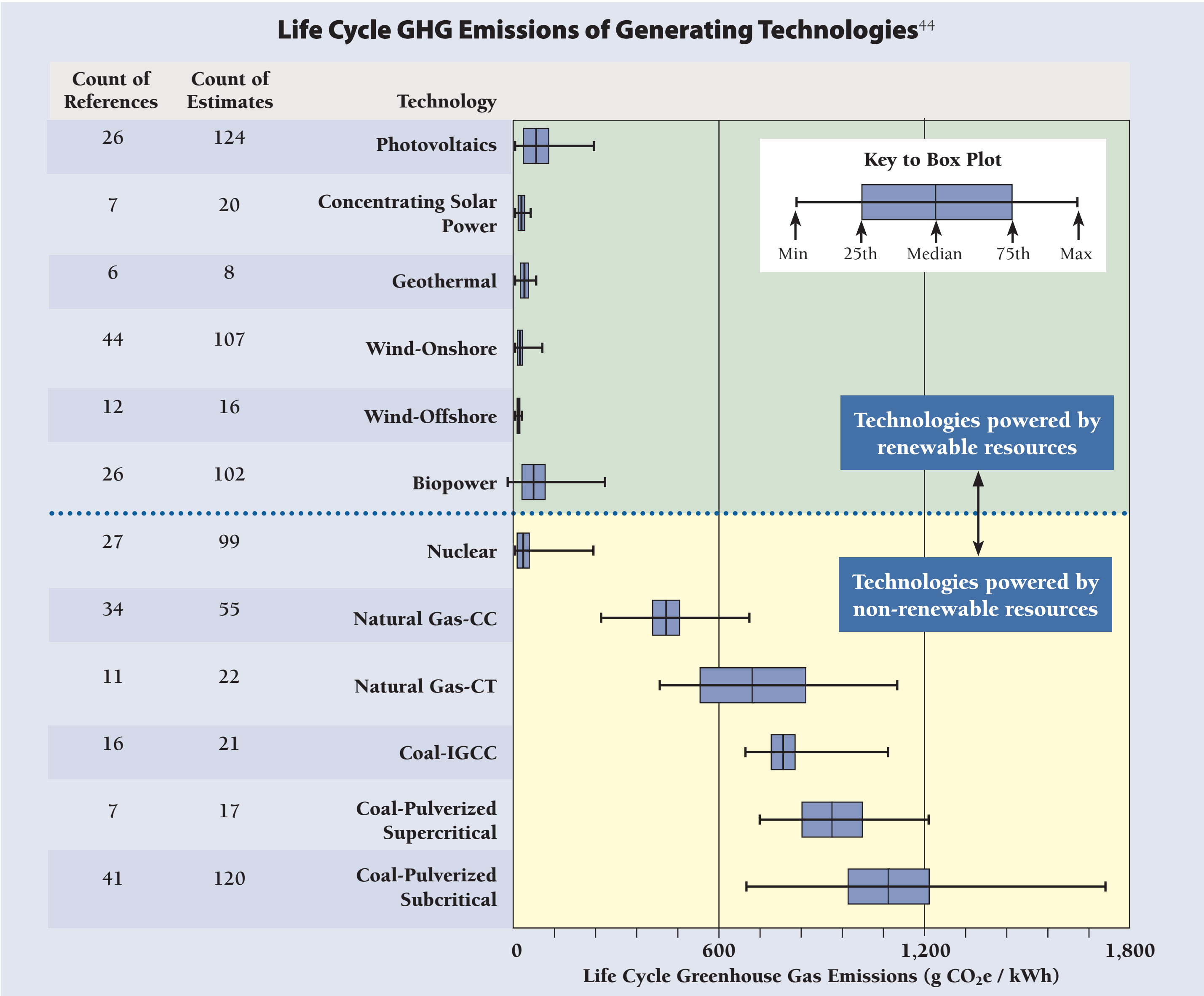
In summary, there is a wide variety of strategies used by both the federal government and by individual states that have the effect of lowering the effective cost observed in the market and typically borne by ratepayers. The federal tax credits that apply to solar and wind, among other categories of clean energy technologies, are substantial. State initiatives have further driven down the costs of manufacturing, owning, and purchasing electricity from qualifying renewable generation technologies.

4. Greenhouse Gas Emissions Reductions

The GHG emissions reduction potential of zero- and low-emissions technologies is potentially substantial. Several variables and viewpoints factor into the quantification of that potential.

One of the viewpoints that factors into quantification is whether to consider the "lifecycle" GHG emissions of different resources or only the stack emissions. This question is particularly important with respect to solid biomass, landfill gas, and biogas generators, because they are the only resources discussed in this chapter that have

Figure 6-3



stack emissions. A lifecycle perspective on emissions requires that consideration be given to GHG emissions that occur in every stage of the production and operation of both a generating technology and any fuels that it uses. Biogenic fuels come from plants and trees that absorb CO_2 as they grow, and release CO_2 when they are combusted. Thus, the lifecycle emissions of such fuels tend to be lower than the stack emissions. In contrast, the lifecycle emissions of most other resources are somewhat higher than their stack emissions, because some amount of GHG emissions occurs in the process of building the generator or producing and delivering its fuel. Figure 6-3 summarizes the results of numerous assessments of the lifecycle GHG emissions profile of different generation technologies, based on a review of literature and surveys conducted.

Regardless of whether one accounts for lifecycle emissions or only stack emissions, another viewpoint that factors into quantification is the time scale under consideration. When viewed over an immediate or short-term time scale, the way that renewable energy deployment decreases emissions is by reducing the need for generation

44 Hand, M. M., Reilly, J. M., Porro, G., Baldwin, S., Mai, T., Meshek, M., DeMeo, E., Arent, D., & Sandor, D., eds. (2012). *Renewable Electricity Futures Study.* Volume 1 of 4, at A-51. NREL/TP-6A20-52409. National Renewable Energy Laboratory. Available at: http://www.nrel.gov/analysis/re_futures/

from existing fossil-fueled generating units. For example, each MWh generated by a geothermal power plant means one less MWh needs to be generated by some other unit that already exists and is connected to the grid. Over a longer time frame, however, the deployment of new zero- and low-emissions resources reduces the need for future deployment of other higher-emitting resources.

As previously noted, zero-emissions resources may in some cases have high construction costs, but once built tend to have low operating costs and for that reason tend to be the first resources used to serve load. So in the immediate and near-term time scale, deployment of these resources tends to displace generation from resources with higher operating costs, most commonly the fuel costs associated with fossil-fueled generators. However, coal-fired generators typically emit about twice as much CO_2 per unit of net generation as gas-fired generators. Therefore, the amount of GHG emissions reduction attributable in the short-term to the deployment of zero-emissions resources depends on which generators serving the same grid operator operate "on the margin," that is, which generators would have been dispatched but for the availability of zero-emissions resources. The answer to that question varies by location, time of day, and season.[45] Detailed discussions of the topic of avoided emissions are available from several sources.[46]

The EPA has created a tool called AVERT (AVoided Emissions and geneRation Tool) to help air pollution regulators assess the short-term avoided emissions that result from renewable generation or energy efficiency programs.[47] The American Wind Energy Association used AVERT to make its own assessment of the emissions avoided in each state in 2013 owing to the deployment of wind energy. The assessment estimated that wind energy reduced power sector emissions by more than five percent in 2013.[48] The American Wind Energy Association's results for CO_2 emissions are presented in Figure 6-4 for illustrative purposes, to demonstrate the approximate magnitude of the impact from just this one zero-emissions technology.[49]

Historically, electricity demand has grown over time and new generating capacity has been built to meet demand. Although growth rates are projected to be lower over the next few decades than they were over the past few decades, there is still an expectation that additional generating capacity (incremental to what exists today) will be needed to meet future demand. Also, the capacity lost when power plants retire needs to be replaced. So, from this longer-term perspective, the addition of zero- and low-emissions capacity displaces not just the need to dispatch existing fossil-fueled generators but also the need to add new fossil fuel capacity in the future. The GHG reduction potential of zero- and low-emissions resources over this longer time scale thus depends on the type of new capacity that is displaced, and virtually all recent assessments assume that the type of capacity displaced will be natural gas generators.

Putting all of this together, the immediate and short-term GHG emissions reduction of zero- and low-emissions resources depends on which existing units (usually fossil-fueled generators) operate on the margin, and the answer depends on local conditions, time of day, and season. If an average coal-fired unit is displaced, the emissions reductions could be on the order of 2250 pounds of CO_2

45 For example, CO_2 emissions of the marginal generators in the Northeast region (principally gas- and oil-fired units) were calculated to be roughly 900 pounds per MWh. ISO New England. (2013, December). *2012 ISO New England Electric Generator Air Emissions Report.* Available at: http://www.iso-ne.com/committees/comm_wkgrps/prtcpnts_comm/eag/mtrls/2013/dec202013/draft_2012_emissions.pdf

46 See, for example: Shenot, J. (2013, August). *Quantifying the Air Quality Impacts of Energy Efficiency Policies and Programs.* Montpelier, VT: The Regulatory Assistance Project. Available at: www.raponline.org/document/download/id/6680. The methodologies are virtually the same for any MWh of generation from a zero-emissions resource or MWh of energy savings from an energy efficiency measure.

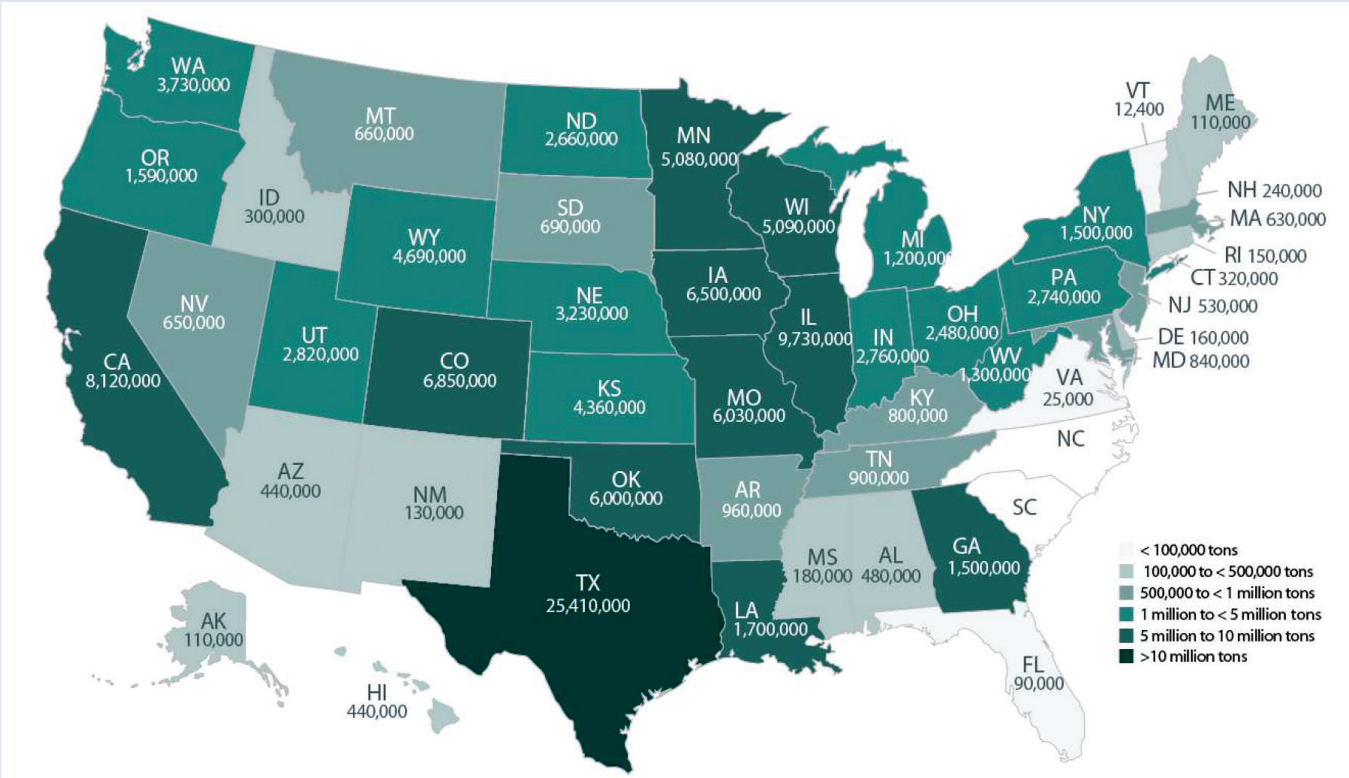
47 The EPA's AVERT is available at: http://www.epa.gov/avert/

48 Personal communication from Tom Vinson, Vice President of Federal Regulatory Affairs, American Wind Energy Association, February 9, 2015.

49 AVERT is designed to provide more accurate estimates in most cases than would be expected from using the regional average emissions factors included in the EPA's Emissions & Generation Resource Integrated Database (eGRID), with only a little extra effort. However, AVERT is also designed to be simple to use, and it cannot be expected to produce extremely precise or accurate results. Dispatch models and other sophisticated methods of assessing avoided emissions (which require much greater effort to use) offer more precision and accuracy and may be more appropriate for regulatory purposes.

Figure 6-4

Avoided CO_2 Emissions From Wind Energy in 2013[50]



per MWh or more. If an average gas-fired unit is displaced, the value could be about half that amount.[51] But over a longer time scale, the GHG emissions reduction potential of zero-emissions resources will probably trend toward the emissions rates for new gas-fired power plants, on the order of 800 to 1000 pounds of CO_2 per MWh.

Before moving on to other topics, it is worth noting that the regulatory treatment of GHG emissions reductions might differ from a scientific or analytical assessment of emissions reductions. For example, in the proposed Clean Power Plan emissions guidelines, the EPA has proposed that states using a rate-based approach to compliance develop plans whereby the adjusted emissions rate of covered fossil-fueled generators must meet specified (pounds per MWh) targets. In calculating an adjusted emissions rate, the EPA has proposed that states would be allowed to add MWh of generation from "preserved" nuclear and renewable resources to the MWh of generation from covered fossil-fueled generators. This would have the effect of treating those resources as zero-emissions resources for regulatory purposes, rather than forcing states to make the kinds of "avoided emissions" calculations discussed previously.[52]

5. Co-Benefits

Zero- and low-emissions technologies can provide a wide range of co-benefits in addition to GHG emissions reductions. Benefits relating to other air pollutants, water consumption, and electric system operations are briefly discussed here before presenting a summary of all co-benefits.

The air emissions co-benefits for zero-emissions technologies depend on the same factors that were

50 American Wind Energy Association. (2014, May). *The Clean Air Benefits of Wind Energy.* Available at: http://awea.files.cms-plus.com/FileDownloads/pdfs/AWEA_Clean_Air_Benefits_WhitePaper%20Final.pdf

51 Based on data from the EPA clean energy website at: http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html

52 The EPA requested public comments on this approach, and it is of course possible that a different approach will be taken in the final rule. The treatment of renewable resources that emit GHG (e.g., biomass-fueled generators) as net zero-emissions resources is one area of considerable debate, as previously noted.

discussed with respect to GHG emissions reductions. It is important to understand the differences between immediate or short-term impacts caused by displacing generation from existing fossil-fueled units operating on the economic margin, and longer-term impacts caused by displacing the need for new fossil generation capacity.

Generators using solid biomass, landfill gas, or biogas are not zero-emissions resources; they will emit criteria and hazardous air pollutants. Regulators may need to carefully assess whether those emissions are less than or greater than what would be emitted from the displaced generation sources. In general, for these types of generators, uncontrolled emissions of most pollutants are equal to or higher than uncontrolled emissions from natural gas-fired units. Compared to coal- or oil-fired generators, some pollutants are emitted at higher levels and other pollutants (principally sulfur dioxide) are emitted at lower levels. An assessment by state and local agencies in the state of Washington, summarized in Table 6-6, offers one such comparison of uncontrolled emissions factors.[53] Controlled emissions factors would of course depend on the control devices used on each type of generator.

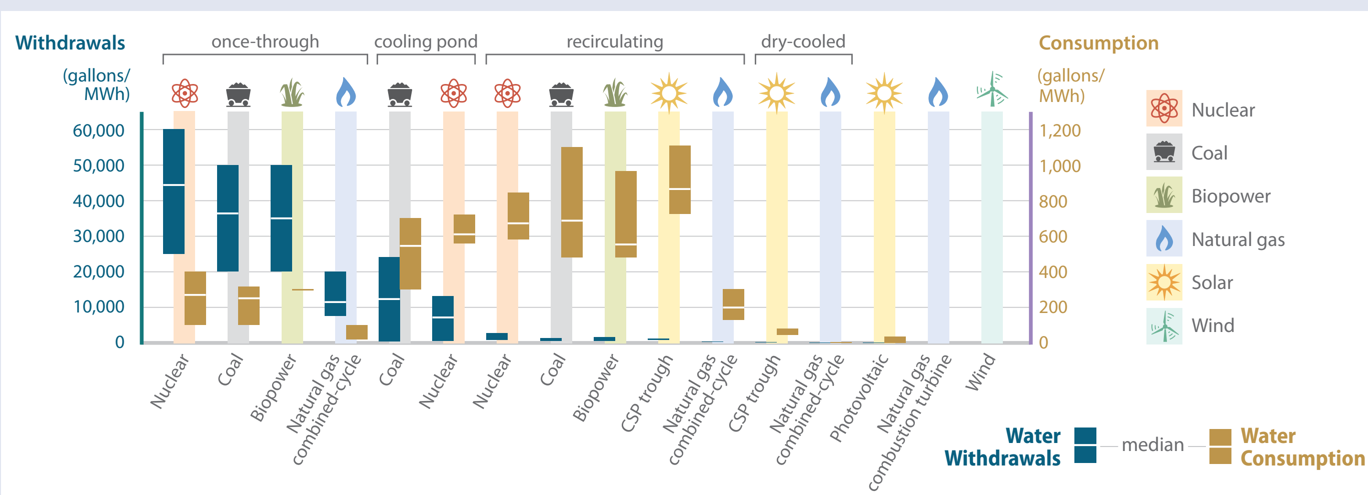
Table 6-6

Typical Uncontrolled Emissions From Biomass, Coal, and Natural Gas Generators[54]

Pollutant	Emissions (Pounds per MMBTU of Heat Input)		
	Forest Biomass	Coal	Natural Gas (Combined-Cycle)
Nitrogen Oxides	0.220	0.510	0.0371
Carbon Monoxide	0.600	0.025	0.0075
Sulfur Dioxide	0.025	0.890	0.0028
Volatile Organic Compounds	0.017	0.003	0.0043
Particulate Matter	0.570	0.460	0.0083
Hydrogen Chloride	1.9E-02	6.1E-02	0
Mercury	3.5E-06	1.6E-05	0
Manganese	1.6E-03	1.2E-03	0

Figure 6-5

Water Use by Fuel and Cooling Technology[55]



53 Washington State Department of Natural Resources. (Undated brochure citing 2010 reports). *Forest Biomass and Air Emissions.* Available at: http://www.dnr.wa.gov/Publications/em_forest_biomass_and_air_emissions_factsheet_8.pdf

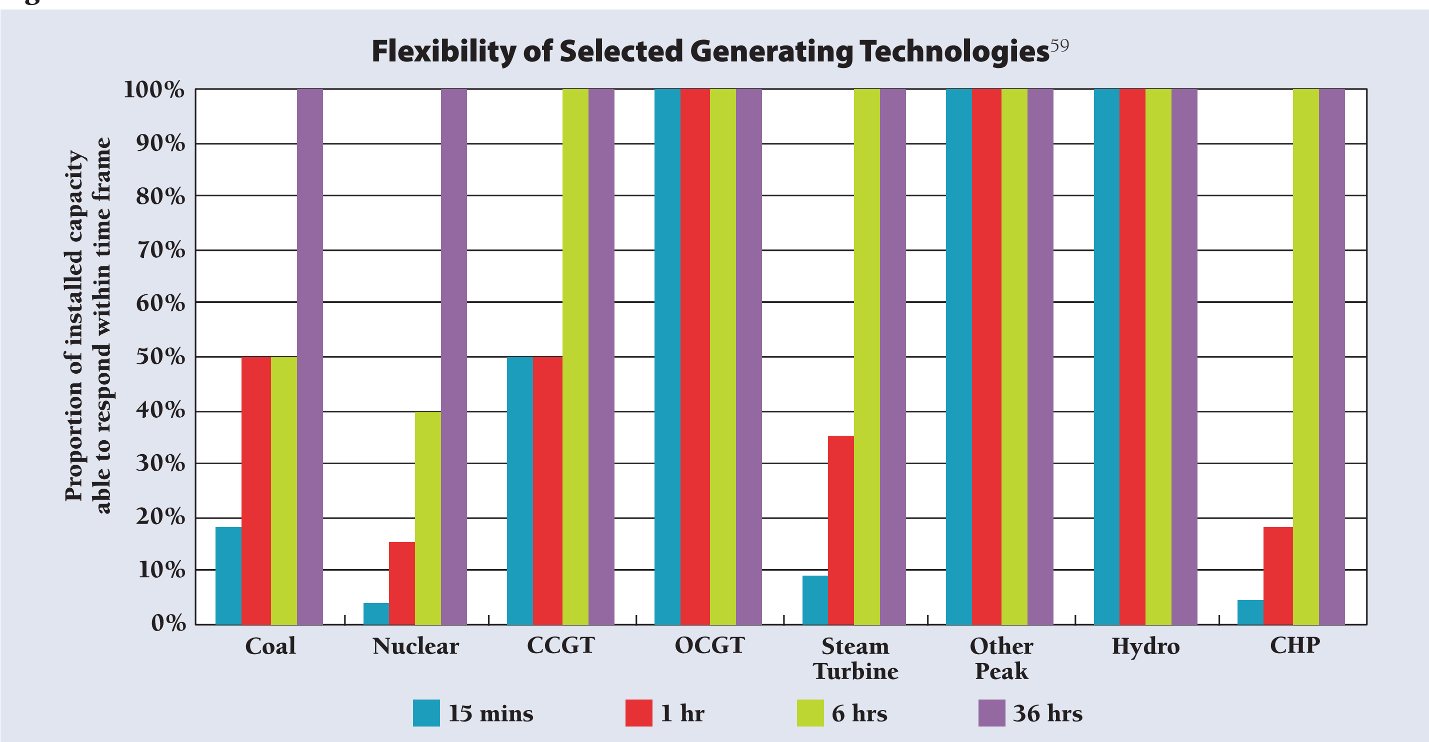
54 Ibid.

55 Averyt, K., Fisher, J., Huber-Lee, A., Lewis, A., Macknick, J., Madden, N., Rogers, J., & Tellinghuisen, S. (2011, November). *Freshwater Use by US Power Plants: Electricity's Thirst for a Precious Resource.* A report of the Energy and Water in a Warming World Initiative. Union of Concerned Scientists. Available at: http://www.ucsusa.org/assets/documents/clean_energy/ew3/ew3-freshwater-use-by-us-power-plants.pdf

For most generation technologies, there is a strong symbiotic relationship between electricity generation and water use. Water extraction and distribution practices place demands on the electric system, and conversely the generation of electricity places demands on water systems. Electricity generation in the United States accounts for 41 percent of overall US water requirements, mostly withdrawals associated with once-through cooling of thermal generation. The sector accounts for roughly three percent of US freshwater consumption. Categories of zero- and low-emissions technologies that do not require significant cooling (e.g., wind and solar) require little water. Figure 6-5 provides a summary graphic showing the different water requirements of various generating technologies.

Non-dispatchable generation will be an increasingly large and important component of the overall electricity mix going forward, but will also place new requirements on the broader system. A few zero- and low-emissions technologies enjoy the advantage of being both flexible and dispatchable technologies. Included among them are those combusted in traditional steam boilers or gasified for use in combined-cycle turbines.[56] As such, there is a solid understanding of how best to operate these resources and integrate them into the existing electricity grid. Use in traditional boilers and turbines renders biomass one of the few dispatchable renewable energy technologies. Unlike traditional wind and solar technologies, these boilers and turbines can be ramped as required for load, increasing their value for both capacity and energy purposes.[57] Hydro is another technology that can be extremely flexible. Nuclear generation units are comparatively inflexible.[58] Figure 6-6 provides a summary of

Figure 6-6



56 However, the flexibility of the generating technology may be limited in some cases by an inflexible fuel delivery system and lack of fuel storage capacity, meaning the generator must use all fuel as it is delivered. Generators firing landfill gas often fall into this category.

57 Supra footnote 24.

58 The currently operating nuclear units in the US fleet, all of which were built more than two decades ago, were designed specifically for baseload operation rather than flexible, load-following operation. This is not a purely physical limitation. Modern nuclear plants with light water reactors are designed to operate more flexibly. Some nuclear reactors in other countries (e.g., France and Germany) vary their output as customer demand increases or decreases. Refer to: Nuclear Energy Agency. (2011). *Technical and Economic Aspects of Load Following with Nuclear Power Plants.* Organisation for Economic Co-Operation and Development. Available at: http://www.oecd-nea.org/ndd/reports/2011/load-following-npp.pdf

59 International Energy Agency. (2011). *Harnessing Variable Renewables: A Guide to the Balancing Challenge.* Available at: https://www.iea.org/publications/freepublications/publication/Harnessing_Variable_Renewables2011.pdf

the typical response rate capabilities of different technologies over varying time frames as observed in the Nordic power area to highlight the opportunities and challenges.

Safe, reliable electric service is an essential service. This of course means that all types of generation bring public benefits. Zero- and low-emissions generators bring the same electricity system benefits for each MWh of net generation delivered to end-users that other generating

Table 6-7

Types of Co-Benefits Potentially Associated With Zero- and Low-Emissions Technologies

Type of Co-Benefit	Provided by This Policy or Technology?
Benefits to Society	
Non-GHG Air Quality Impacts	Yes – biomass can vary depending on the category of pollutant and displaced alternative
Nitrogen Oxides	Yes
Sulfur Dioxide	Yes
Particulate Matter	Yes
Mercury	Yes
Other	Yes
Water Quantity and Quality Impacts	Yes – varies by technology
Coal Ash Ponds and Coal Combustion Residuals	Yes
Employment Impacts	Yes – varies at the local level
Economic Development	Yes – the economic development impacts will vary at the local and regional level and can be positive or negative[60]
Other Economic Considerations	Maybe
Societal Risk and Energy Security	Yes
Reduction of Effects of Termination of Service	Only for some customer-owned distributed generation
Avoidance of Uncollectible Bills for Utilities	Likely limited
Benefits to the Utility System	
Avoided Production Capacity Costs	No
Avoided Production Energy Costs	Yes – the primary technologies relied on (wind and solar) are typically capital intensive, with no energy and small operating costs
Avoided Costs of Existing Environmental Regulations	Yes
Avoided Costs of Future Environmental Regulations	Yes
Avoided Transmission Capacity Costs	Not generally – additional transmission capacity may be needed to reach resource-rich regions and to increase system flexibility to accommodate certain categories of variable energy resources
Avoided Distribution Capacity Costs	Generally applies for low to moderate levels of distributed generation and varies by technology
Avoided Line Losses	Generally applies for low to moderate levels of distributed generation and varies by technology
Avoided Reserves	No – the details matter, but the addition of variable energy resources, in isolation of other changes could increase the need for more system flexibility and capacity during periods of system stress
Avoided Risk	Yes, but specific risks are particular to the circumstances
Increased Reliability	Maybe
Displacement of Renewable Resource Obligation	No
Reduced Credit and Collection Costs	No
Demand Response-Induced Price Effect	The addition of variable energy renewables is typically associated with wholesale price reduction and stabilization effects[61]
Other	

60 One survey suggested an economic development benefit range of between $22 and $30 per MWh. Refer to: Heeter, J., Barbose, G., Bird, L., Weaver, S., Flores-Espino, F., Kuskova-Burns, K., & Wiser, R. (2014, May). *A Survey of State-Level Cost and Benefit Estimates of Renewable Portfolio Standards.* National Renewable Energy Laboratory and Lawrence Berkeley National Laboratory. Available at: http://emp.lbl.gov/sites/all/files/lbnl-6589e.pdf

61 One survey estimated the impacts at about $1 per MWh of total wholesale generation in specific markets. Refer to: Supra footnote 60.

resources do. In other words, nuclear, hydro, and other renewable generating resources shouldn't be considered simply as a pollution control cost, because they bring with them the value of an essential service: electricity. Besides the traditional energy and reliability benefits that extend to all categories of utility resources, whether directly owned or purchased through third parties, the addition of zero- and low-emissions resources – many of which do not burn any fuel – can bring diversity to the generation portfolio that potentially reduces the risk of fossil fuel price volatility. Many categories of zero- and low-emissions technologies (especially solar) are also well suited for placement close to loads, and can therefore provide transmission and distribution capacity benefits, reductions in operating reserve requirements, and reduced line losses. Those topics are covered in other chapters of this document.

The full range of co-benefits that can be realized through deployment of zero- and low-emissions technologies are summarized in Table 6-7.

Having mentioned all of the co-benefits of zero- and low-emissions resources, it bears mentioning that these resources, like all electric resources, can potentially have negative impacts as well. Nuclear power plants require vast quantities of water for cooling, and large hydro projects alter aquatic habitats on a vast scale. Wind turbines are sometimes opposed based on concerns about noise, ridgeline views, or avian impacts. Large-scale solar and wind projects may alter natural habitats across large tracts of land. The siting and permitting of zero- and low-emissions resources will sometimes generate significant public and political opposition, more so in some locations than others.

6. Costs and Cost-Effectiveness

The costs and cost-effectiveness of state efforts to rely on zero- and low-emissions resources vary by category of technology, geographic regions of the United States, and pre-existing state and federal support for these initiatives. They can also be quite variable and may depend in part on the perspective applied by any given economic screening tool.

Figure 6-7 shows the relative economics of different technologies based on estimates of the forward-looking levelized costs of energy (LCOE), a term explained in the following text box. The analysis in Figure 6-7 was prepared by Bloomberg New Energy Finance and has largely adopted the convention of excluding subsidies and incentives.[62]

Levelized costs provide a convenient reference point for the relative economics of different technologies on a roughly "apples-to-apples" basis. Nevertheless, there are also some important differences that are not captured in this type of cost comparison.[63]

As Figure 6-7 shows, there is overlap in the range of

Levelized Costs or LCOE

The LCOE reflect the average cost of producing the unit electricity over the life of its source. The LCOE estimates include consideration of all costs (including capital and fuel costs) and the amount of electricity produced from a particular type of generation.

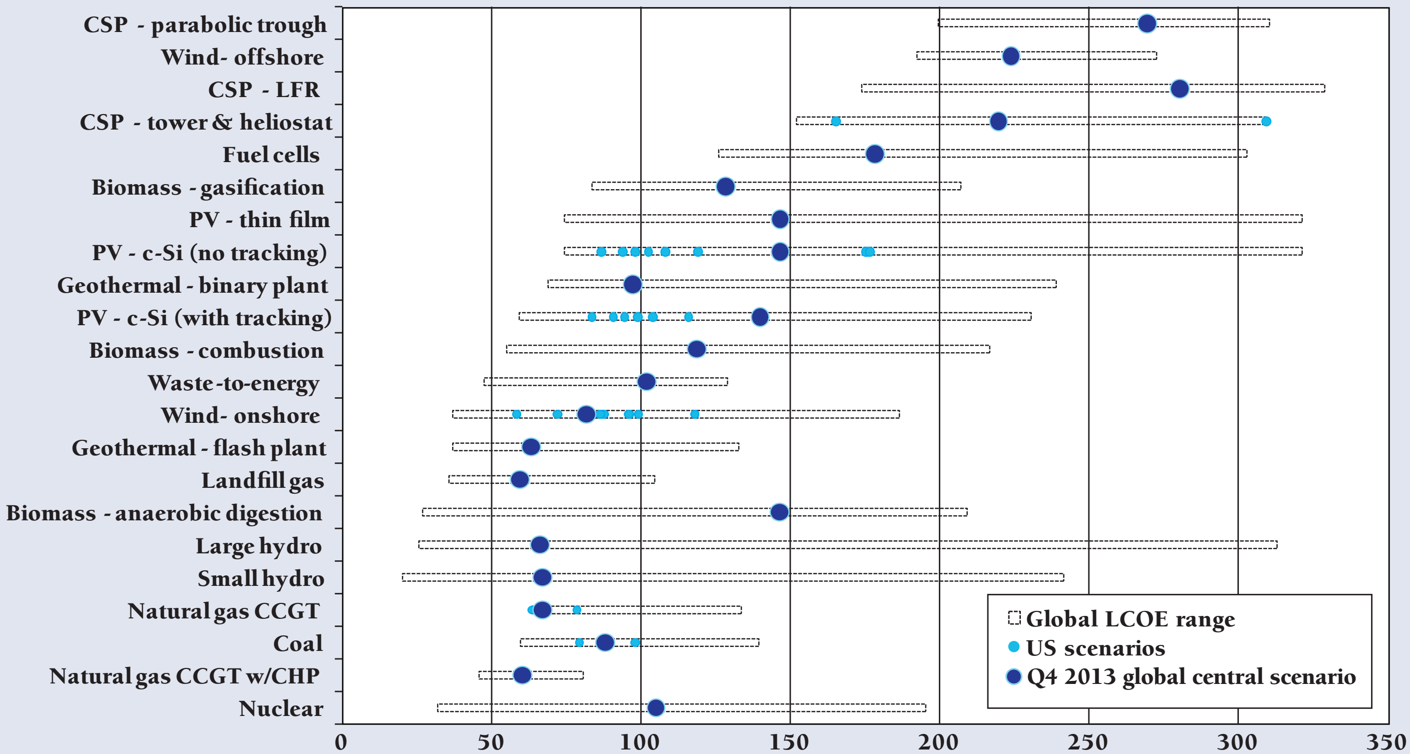
Levelized cost calculations also include the costs of financing a project.

62 Earlier estimates prepared by the DOE and presented in January 2013 found similar values. The Bloomberg New Energy Finance values are presented here because they reflect more recent cost data.

63 Levelized costs comparisons do not effectively account for significant changes in capital costs associated with technologies like wind and solar that have few operating costs. Capital costs, especially for solar PV, have declined significantly over the last several years. Levelized costs comparisons that are presented as a single value typically do not account for important regional differences associated with weather that may improve the value of some resources in regions that have supportive weather conditions. Levelized costs comparisons of this sort typically do not incorporate tax advantages that are associated with different technologies. In addition, the duration of the lifecycle of different technologies varies, and this can affect LCOE calculations. LCOE estimates are also calculated using an "overnight cost" for purposes of the cost comparison. This ignores important advantages of technologies like solar, wind, and even gas, that can be introduced over relatively short periods as compared with, for example, the addition of a large nuclear generator that may require eight to ten years. Also, LCOE estimates of this sort do not account for regional differences in the avoided costs or wholesale market differences between regions. Costs that are the same in two regions for a given technology may be cost-effective in one region but uneconomic in another, solely based on the comparative economics of the alternatives in that region.

Figure 6-7

Levelized Costs of Energy for Different Generating Technologies, Q4 2013 ($/MWh)



Source: *Bloomberg New Energy Finance, EIA Notes: LCOE is the per-MWh inflation-adjusted lifecycle cost of producing electricity from a technology assuming a certain hurdle rate (ie, after-tax, equity internal rate of return, or IRR). The target IRR used for this analysis is 10% across all technologies. All figures are derived from Bloomberg New Energy Finance analysis. Analysis is based on numbers derived from actual deals (for inputs pertaining to performance). Capital costs are based on evidence from actual deals, which may or may not have yielded a margin to the sellers of the equipment; the only 'margin' that is assumed for this analysis is 10% after-tax equity IRR for project sponsor. The dark-colored circles correspond to a global central scenario, with the exception of nuclear, gas, and coal – where the light blue circles correspond to US-specific scenarios; there are multiple light blue circles per technology, corresponding to different projects, with varying economics, that have been installed in the US across different regions. 'CHP' stands for combined heat and power; 'CCGT' stands for combined cycle gas turbine; 'c-Si' stands for crystalline silicon; 'CSP' stands for concentrated solar power; 'LFR' stands for linear Fresnel reflector.*

LCOE values observed for each resource. Considering the central scenarios for global LCOE, we see a cluster of technologies that are all roughly equal in cost. Those technologies include natural gas units, but also include hydro, geothermal, and landfill gas. Onshore wind projects cost somewhat more, but are competitive with coal-fired units. But it is also important to recognize that the costs of some of the less-mature renewable technologies have changed significantly in recent years and continue to decline. Wind generation, a prime example, is improving its performance with time as the industry's size and scale grows. Prices for new wind energy projects in the United States have fallen more than 40 percent in the past five years; in 2014, more than 3300 MW of new wind power purchase agreements were announced, building on the roughly 8000 MW of power purchase agreements signed during 2013.[64] Wind could be competitive with natural gas (even without tax and renewable energy incentives) if the delivered gas price rose above approximately $6 per MMBTU.[65] Solar PV module prices have dropped 80

64 Supra footnote 36.

65 Channell, J., Savvantidou, S., Jansen, H. R., Morse, E. L., Syme, A. R., & Yuen, A. (2013, October). *Energy Darwinism: The Evolution of the Energy Industry,* p. 53.Citi GPS: Global Perspectives and Solutions. Available at: https://ir.citi.com/Jb89SJMmf%2BsAVK2AKa3QE5EJwb4fvI5UUplD0ICiGOOk0NV2CqNI%2FPDLJqxidz2VAXXAXFB6fOY%3D

The Apples-to-Oranges of Levelized Costs Comparisons

LCOE provides a framework for apples-to-apples comparisons of different generating technologies, but it can also obscure important differences that may bias the results. Nuclear energy provides a good example. Not accounted for in these cost comparisons are costs that either go unaccounted for in commercial transactions or are undervalued. In the case of nuclear energy, this can be a relatively long list and includes both the undervalued cost of spent fuel disposal and the full insurance value of liability (or costs) in the face of a potential catastrophic accident. The high cost of decommissioning facilities at the end of their life provides yet a third category of undervalued costs.

Other areas that can differ between technologies include their flexibility in terms of planning, construction, and then operation. Wind and solar resources that are in close proximity to existing grid infrastructure can be planned and constructed over a relatively short period, and to a certain extent sized to meet specified needs. In contrast, nuclear reactors must be planned eight to ten years in advance of operation and currently are built only in very large-capacity increments. So hypothetically, if a jurisdiction needs 100 MW of capacity and nuclear reactors are only economical in a 500-MW size, the LCOE value of nuclear might be skewed. Also, if planning assumptions like needed capacity fail to materialize, there can be a sizeable liability for committed (but ultimately underutilized) investments. These investments are often shifted from prospective investors to ratepayers or taxpayers through regulatory pre-approvals or loan guarantees.

Another shortcoming of LCOE methodologies is that they fail to distinguish between the cost of resources and the *value* of what those resources can do, beyond simply generating MWh. Wholesale electricity prices are always higher during times of peak demand and lower off peak. Any resource that produces a disproportionate amount of its total generation on peak will be producing MWhs that have more value than a resource that disproportionately produces off peak. Also, nuclear generators and some types of renewables are inflexible and/or non-dispatchable. As the mix of resources available to system operators grows to include more and more inflexible and non-dispatchable resources, the *value* of flexible, dispatchable resources will increase. Value does not equal cost, and LCOE does not capture value.

Levelized costs comparisons can assume away one other critical feature of costs. Although not true for the levelized costs reflected previously by Bloomberg, levelized costs sometimes assume that the capital costs of investment can be made "overnight." Yet the differential costs of long construction periods and associated costs of financing are effectively ignored, even though those costs can be substantial and are typically borne by ratepayers in the form of capitalized financing costs.

percent since 2008.[66] The DOE recently announced that solar PV is 60 percent of the way toward the Department's goal of lowering costs to $0.06 per kWh by decade's end.[67] By the end of 2013, utility-scale solar averaged $0.11 per kWh; currently utilities in some areas are signing solar power purchase agreements for $50 to $60 per MWh over 20 to 25 years.[68] The learning curve (the rate of cost decline in relation to a doubling of capacity) is estimated to be between 20 and 40 percent.[69] Increasingly, zero- and low-emissions technologies are simply priced at or below

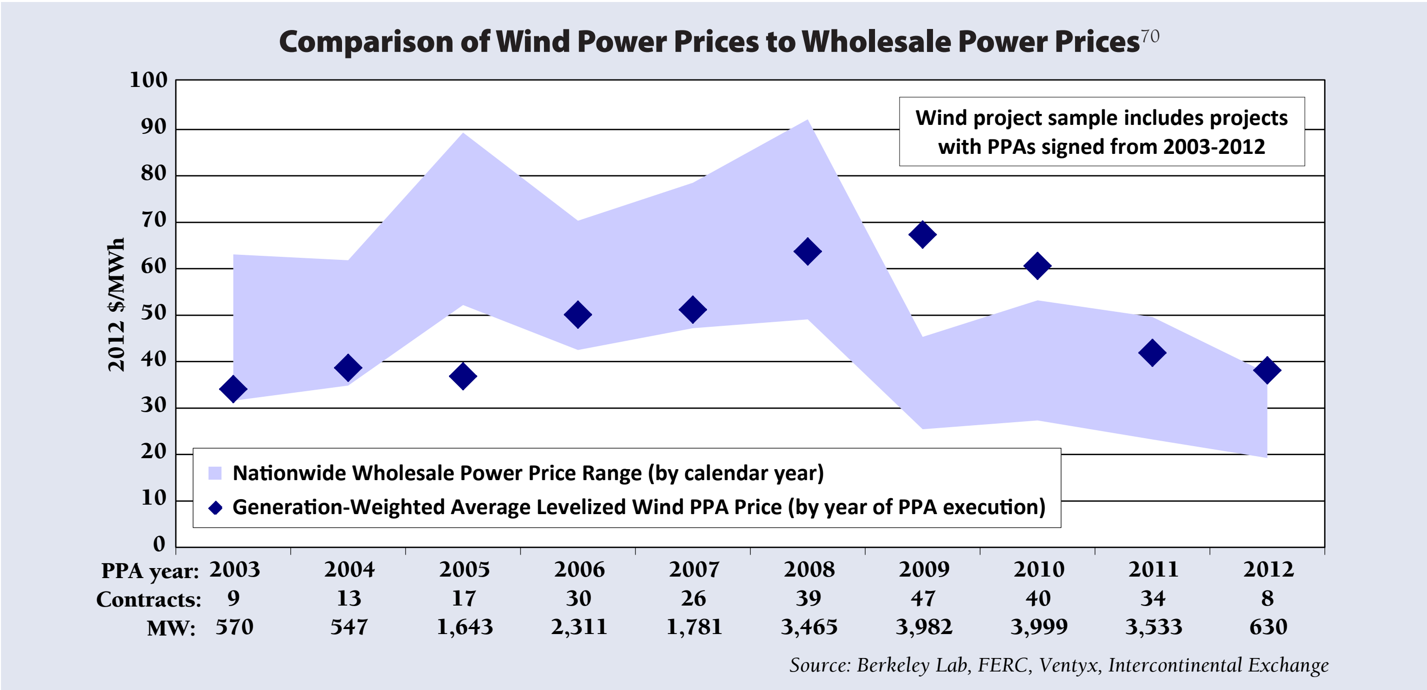
66 Bloomberg New Energy Finance. (2014, February). *2014 Sustainable Energy in America: Factbook.* Available at: http://about.bnef.com/white-papers/sustainable-energy-in-america-2014-factbook/

67 Available at: http://energy.gov/articles/us-utility-scale-solar-60-percent-towards-cost-competition-goal

68 See, for example: Case No. 12-0038-UT before the New Mexico Public Regulation Commission. Available at: http://www.epelectric.com/files/html/Macho_Springs/Macho_Springs_Notice_of_Proceeding_and_Hearing_12-00386-UT__2_.pdf. Also, in 2014 Austin Energy signed a 20-year power purchase agreement with Recurrent Energy for 150 MW of solar power. The terms of that agreement were not publicly reported but the cost was widely reported to be "less than $50 per MWh."

69 Supra footnote 65 at p. 48.

Figure 6-8



the fossil fuel alternatives. In Texas, for example, wind projects are coming in at $37 per MWh. At such levels they are competitive with any fossil fuel alternative.

LCOE values compare the long-term costs of different types of new resources. This provides useful information for assessing the cost-effectiveness of different options for building new resources to meet growing electricity demand or replace retiring generators. However, in the more immediate term, where existing generating capacity is sufficient to meet demand, the short-term *cost-effectiveness* of generation investments will depend critically on the relative price of wholesale electricity, which is highly dependent on the costs of operating *existing* generators. If it costs more to build a new generator than the unit can expect to recover in wholesale energy prices, it will not be cost-effective. Wholesale prices have declined in all regions of the United States over the last seven years, owing to low natural gas prices, surplus generating capacity, and a sluggish economy. Figure 6-8 shows how the economics of wind power have changed in the United States with the relative prices of wholesale electric energy. In some years, wind power prices were at the low end of the range of wholesale power prices and this type of generating resource was very cost-effective. In other years, wind prices have been higher than average wholesale prices, making it less cost-effective. Whether any resource is cost-effective over the lifetime of the investment will depend on how wholesale market prices change over the long-term.

7. Other Considerations

Many of the zero- and low-emissions technologies can pose challenges for system operators. On the one hand, large nuclear units are designed to run more or less at full capacity at all times. System operators have to essentially manage the system around the inflexibility of nuclear units. On the other hand, non-dispatchable resources like wind and solar PV vary their output based on weather conditions, and the system operator has to manage the system around the variability of their output. Both of these situations create challenges for the system operator, who must balance generation to meet end-user demand in real time, at all times.[71]

70 Wiser, R., & Bolinger, M. (2013, August). *2012 Wind Technologies Market Report.* Lawrence Berkeley National Laboratory for the US Department of Energy. Available at: http://emp.lbl.gov/sites/all/files/lbnl-6356e.pdf

71 Advancing technologies and markets, however, increasingly enable system operators to achieve this balance by adjusting electricity demand (through demand response and other programs), as well as through traditional generation supply resources. Chapter 23 provides additional information on this capability.

At low levels of deployment, the challenge of integrating inflexible and variable resources is not terribly difficult. But at higher levels of penetration, grid integration can be enormously challenging. Solutions, discussed in Chapter 20 of this document, are available and include an expanding array of options. But as a practical matter, the costs, cost-effectiveness, and emissions savings associated with zero- and low-emissions sources should account for the costs of those solutions and any incremental costs necessary to facilitate grid integration.[72] Most integration studies performed to date on renewable energy have focused on wind, as wind has been the predominant variable energy renewable technology to date. Many global studies suggest that the costs are between $1 and $7 per MWh for 10- to 20-percent penetration of variable energy renewable technologies.[73] Higher penetrations see higher costs, but actual experience with higher penetrations is limited, and time and experience with integration are likely to bring down integration costs.[74] State- and utility-specific studies in the United States show considerable variability in these integration costs, again based on the increasing wind penetration.

Additional issues could arise with the widespread adoption of customer-owned distributed generation, particularly distributed PV systems. Utilities may find it particularly challenging to maintain the electric grid if they can't control or reliably predict the output of customer-owned distributed generation. Reductions in retail sales could also make it difficult for utilities to maintain grid services unless significant changes are made to retail rates or rate designs. The unique opportunities and challenges associated with distributed generation are addressed in much greater detail in Chapter 17.

8. For More Information

Interested readers may wish to consult the following reference documents for more information on zero- and low-emissions technologies.

- American Wind Energy Association. (2014, May). *The Clean Air Benefits of Wind Energy.* Available at: http://awea.files.cms-plus.com/FileDownloads/pdfs/AWEA_Clean_Air_Benefits_WhitePaper%20Final.pdf
- Barbose, G., Darghouth, N., Weaver, S., & Wiser, R. (2013, July). *Tracking the Sun VI.* Lawrence Berkeley National Laboratory. Available at: http://emp.lbl.gov/sites/all/files/lbnl-6350e.pdf
- Bolinger, M. (2014, May). *An Analysis of the Costs, Benefits, and Implications of Different Approaches to Capturing the Value of Renewable Energy Tax Incentives.* Lawrence Berkeley National Laboratory. Available at: http://emp.lbl.gov/publications/analysis-costs-benefits-and-implications-different-approaches-capturing-value-renewable
- Bolinger, M., & Weaver, S. (2013, September). *Utility-Scale Solar 2012: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States.* Lawrence Berkeley National Laboratory. Available at: http://emp.lbl.gov/publications/utility-scale-solar-2012-empirical-analysis-project-cost-performance-and-pricing-trends
- Hand, M. M., Reilly, J. M., Porro, G., Baldwin, S., Mai, T., Meshek, M., DeMeo, E., Arent, D., & Sandor, D., eds. (2012). *Renewable Electricity Futures Study.* Volume 1 of 4, at A-51. NREL/TP-6A20-52409. National Renewable Energy Laboratory. Available at: http://www.nrel.gov/analysis/re_futures/

72 Integration costs are not unique to zero- and low-emissions resources; they are also an issue with more traditional forms of generation, which, because of size and inflexibility, may impose additional costs on the system.

73 Supra footnote 59.

74 Although actual experiences with high penetrations are limited, the National Renewable Energy Laboratory has extensively studied and modeled the potential implications of high penetrations. Refer to Chapter 20, and: Supra footnote 44.

- International Energy Agency. (2013, November). *World Energy Outlook.* Available at: http://www.worldenergyoutlook.org/publications/weo-2013/
- Lopez, A., Roberts, B., Heimiller, D., Blair, N. & Porro, G. (2013, July). *US Renewable Energy Technical Potentials: A GIS-Based Analysis.* National Renewable Energy Laboratory. Available at: http://www.nrel.gov/docs/fy12osti/51946.pdf
- National Renewable Energy Laboratory. (2013, November). *2012 Renewable Energy Data Book.* Available at: http://www.nrel.gov/docs/fy14osti/60197.pdf
- Rocky Mountain Institute. (2014, February). *The Economics of Grid Defection.* Available at: http://www.rmi.org/electricity_grid_defection
- Solar Energy Industries Association. (2014, September). *Solar Market Insight Report 2014 Q2.* Available at: http://www.seia.org/research-resources/solar-market-insight-report-2014-q2
- Union of Concerned Scientists. (2014, May). *Fact Sheet: Renewable Energy on Regional Power Grids Can Help States Meet Federal Carbon Standards.* Available at: www.ucsusa.org/renewablesandregionalgrids
- US Energy Information Administration. (2014, April). *Annual Energy Outlook 2014, with Projections to 2040.* Available at: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf
- Wiser, R., & Bolinger, M. (2013, August). *2012 Wind Technologies Market Report.* Lawrence Berkeley National Laboratory for the US Department of Energy. Available at: http://emp.lbl.gov/sites/all/files/lbnl-6356e.pdf

9. Summary

A wide range of zero- and low-emissions technologies are available to help displace higher-emitting sources of generation. Mature technologies like hydro and nuclear generation have limited room for expansion, largely owing to the best hydro locations having already been exploited, and the economics of nuclear technology in the United States being particularly disadvantaged. However, the potential for increased deployment of less-mature renewable technologies is extremely large. Policies adopted at the federal, state, and local levels have successfully led to cost reductions in certain categories of zero- and low-emissions technologies, especially wind and solar.

The GHG reduction benefits of zero-emissions generating resources is obvious and substantial, but will vary in the short-term depending on which higher-emitting resources are displaced (i.e., dispatched less often) owing to the availability of a zero-emissions alternative. Generating technologies that are low- but not zero-emissions at the stack require additional analysis to assess the GHG and other air pollutant benefits. Over time, ever-increasing deployment of zero- and low-emissions resources will reduce emissions by reducing not just the dispatch of existing fossil-fueled units but also the need to add new capacity from higher-emitting generators, most likely natural gas-fired units. It will also facilitate the retirement of fossil units of all types while maintaining adequate resources for system reliability.

The principal challenge associated with increased generation from zero- and low-emissions resources, aside from cost considerations, is likely to be the challenge of integrating inflexible or non-dispatchable resources into the grid and balancing generation with demand on a real-time basis. Solutions to address this challenge are presented in Chapter 20.