Joint Institute for Strategic Energy Analysis

A Review of Sector and Regional Trends in U.S. Electricity Markets: Focus on Natural Gas

Natural Gas and the Evolving U.S. Power Sector Monograph Series: Number 1

Jeffrey Logan
National Renewable Energy Laboratory

Kenneth B. Medlock III, Ph.D.
Rice University

William C. Boyd, Ph.D.
University of Colorado – Boulder

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Technical Report
NREL/TP-6A50-64652
October 2015

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The Joint Institute for
Strategic Energy Analysis
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.jisea.org

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Foreword

Natural Gas and our Changing Energy Economy

Unconventional natural gas produced from shale is reshaping the U.S. energy sector. In 2011, the Joint Institute for Strategic Energy Analysis (JISEA) published its first major report in a series of studies on natural gas and the U.S. energy sector. *Natural Gas and the Transformation of the U.S. Energy Sector: Electricity* provides a new methodological approach to estimate natural gas-related greenhouse gas emissions, tracks trends in regulatory and voluntary industry practices, and explores various electricity futures.

Since then, our work has examined additional critical topics related to the role of natural gas in our energy economy, including potential synergies between natural gas and renewable energy in the power and transportation sectors; the state of knowledge about emissions of natural gas systems compared to other fuel sources; and the research required to better characterize the potential role that natural gas can play in a more environmentally sustainable energy economy. We've also convened panels of energy thought leaders on behalf of the White House. Our ongoing work in this space will explore economic, environmental, and systems impacts of natural gas development and use.

As the natural gas landscape continues to shift in the United States and globally, JISEA believes that bringing objective views and analytical expertise to bear on these issues can help move the discussion forward on a productive path. It is part of our mission to provide leading-edge, objective, high-impact research and analysis to guide global energy investment and policy decisions. JISEA has a growing portfolio of natural gas research that reflects our commitment to "getting gas right."

This report is the first in a three-part monograph series focusing on natural gas and the electricity sector. This opening piece provides a high-level view of recent trends in the U.S. electricity sector, and how natural gas is affecting policy, operational, and investment decisions therein. A second monograph will explore the question of natural gas as a bridge to a more sustainable electricity sector, and a third will consider the flexibility attributes that natural gas can offer to electric power sectors around the world.

We look forward to your feedback and thank you for your interest in the work of JISEA.

Doug Arent
Executive Director, Joint Institute for Strategic Energy Analysis

Acknowledgments

We would like to thank America's Natural Gas Alliance (ANGA), E.ON Climate & Renewables, Alstom, and Southern Company for making this work possible, and providing valuable feedback and perspective along the way. These sponsoring organizations may have different views on one or more matters addressed in the report. They were not asked individually or collectively to endorse the report findings nor should any implied endorsement by the sponsoring organizations be assumed.

We also thank David Hurlbut, Wesley Cole, Cara Marcy, and Owen Zinaman of the National Renewable Energy Laboratory (NREL) and Doug Arent of the Joint Institute for Strategic Energy Analysis for their input. We are especially grateful to Kate Larson (Rhodium Group), Yingxia Yang (The Brattle Group), and Paul Hibbard (The Analysis Group) for review comments that improved the quality of this monograph. Finally, we thank Karin Haas of NREL for editorial and layout assistance that greatly improved readability. Findings, content, and conclusions of this study are the sole responsibility of the JISEA study team.

Executive Summary

The U.S. electricity generation mix is undergoing unprecedented change. According to data from the U.S. Energy Information Administration (EIA), monthly generation from natural gas plants exceeded that from coal for the first time ever in April 2015, and then again in July 2015 (Figure ES-1). This study explores dynamics related to natural gas use at the national, sectoral, and regional levels, with an emphasis on the power sector. It relies on a dataset from SNL Financial to analyze recent trends in the U.S. power sector at the regional level. The research aims to provide decision and policy makers with objective and credible information, data, and analysis that informs their discussions of a rapidly changing energy system landscape.

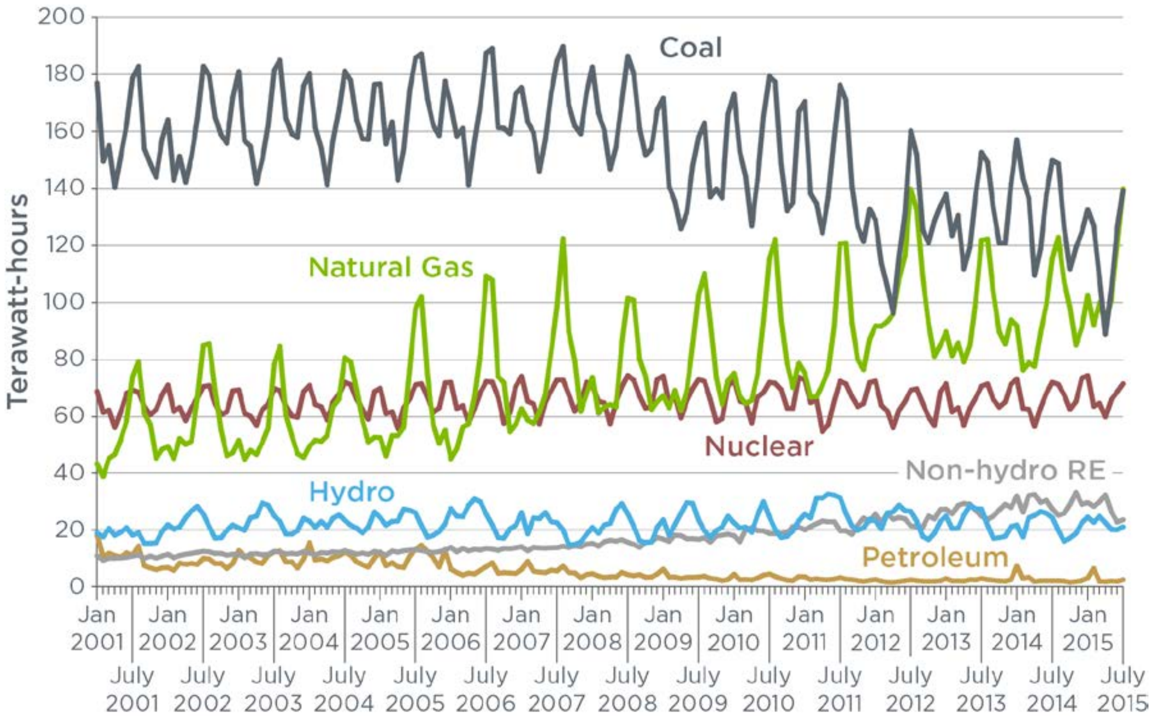

Figure ES-1. Monthly net U.S. electricity generation by source

Source: JISEA, derived from EIA (2015a) data through June 2015

Starting in mid-2008, U.S. electricity generation from coal began to decline substantially for the first time. By early 2015, coal-fired electricity output was down 25% compared to its peak. Natural gas generation, in contrast, has been growing strongly since about 1990, a trend that predates the shale gas revolution.[1] Renewable electricity—primarily wind and solar—is also driving change in the power sector, with notable cost and performance improvements occurring over the past 5 years. In the first quarter of 2015, solar photovoltaic (PV) technology was the single largest source of new capacity installed in the U.S. power sector (SEIA 2015), and both wind and PV power purchase agreements

[1] The shale gas revolution refers to technological breakthroughs in hydraulic fracturing, directional drilling, and other processes that have allowed large scale production of methane-rich gases at low cost. See MIT (2012) for additional background.

are now routinely being executed at prices of $50/MWh or lower (Trabish 2015; Wiser and Bolinger 2015). These changes, along with improvements in energy efficiency, are allowing the United States to reduce its greenhouse gas emissions significantly while maintaining a reliable and affordable power supply. Inexpensive and abundant U.S. natural gas supply is one reason the U.S. has been able to declare a national carbon mitigation target that exceeds any previous declaration.

Not all end-use sectors for natural gas are growing strongly, nor are all regions of the country experiencing rapid change in natural gas-fired electric power demand. Currently, the power sector is experiencing the strongest demand growth for natural gas, followed by industry and transportation. Power sector gas demand is likely to remain strong over the next 5-10 years as prices are expected to stay relatively low and new environmental regulations continue to favor less carbon-intensive generation. But exports of liquefied natural gas are expected to start growing robustly within the next several years. This growth could affect domestic natural gas prices, and alter investment and operational decisions in the power sector, although there is also plentiful supply set to enter the market if and when prices begin to rise.

This study also summarizes regional changes in natural gas demand within the power sector. The transition from coal to natural gas is occurring rapidly along the entire eastern portion of the country, but is relatively stagnant in the central and western regions. This uneven shift is occurring due to differences in fuel price costs, renewable energy targets, infrastructure constraints, historical approach to regulation, and other factors across states. Growth in renewable electricity generation largely supplements the shift from coal to natural gas: renewables are growing fastest in regions where natural gas power generation growth is slowest. Table ES-1 below summarizes select metrics for these regional changes, which are discussed in more detail in section 3 of the report.

Table ES-1. Summary of Selected Changes in Regional Power Markets

Region	% Change in Power Demand (2005-2014)	% Change in Natural Gas Generation (2005-2014)	% Change in Coal Generation (2005-2014)	% Change in Non-hydro Renewable Generation (2005-2014)	2014 Fleet-wide Capacity Factor for NGCC (%)	2014 Fleet-wide Capacity Factor for Steam Turbines (%)
NPCC	-20	0	-75	5	45	19
RFC	-11	111	-29	199	47	53
SERC	-2	84	-25	16	49	51
FRCC	3	60	-23	-39	53	43
MRO	3	-23	-10	430	18	64
SPP	0	-5	-8	417	40	48
TRE	10	3	-1	751	47	46
WECC	-5	8	-17	115	45	54

Source: JISEA, derived from SNL (2015) data. See Figure 12 for a map of these regions.

Regional Definitions: NPCC=Northeast Power Coordinating Council; RFC=Reliability First Corporation; SERC=Southeast Reliability Corporation; FRCC=Florida Reliability Coordinating Council; MRO=Midwest Reliability Organization; SPP=Southwest Power Pool; TRE=Texas Reliability Entity; WECC=Western Electricity Coordinating Council.

The U.S. natural gas sector faces ongoing challenges and opportunities. While overall growth opportunities appear strong over the coming decade, there remain several complex problems that could affect the evolution of natural gas usage by the power sector specifically.

Social opposition to natural gas development continues in some regions of the country, especially where residents are not accustomed to drilling. In addition to the real and perceived concerns about water, air and general environmental contamination, induced earthquakes (likely associated with reinjection of wastewater after hydraulic fracturing occurs) have garnered increasing attention over the past few years (Weingarten et al. 2015). Additionally, scientific uncertainty persists regarding the full life cycle greenhouse gas emissions of natural gas given the incomplete data and limited analysis of fugitive emissions.

While the shale gas revolution may have helped build positive momentum leading up to the 2015 Paris climate meetings, longer-term climate benefits may be more difficult to achieve. If very aggressive cuts in greenhouse gas emissions are to be achieved—say 80% from 1990 levels by 2050—then natural gas demand in the power sector will likely need to peak around 2030 if that sector is to contribute substantially to reach such a goal. Carbon capture and sequestration may be the only option that offers opportunity for a growing natural gas sector beyond 2030, but it remains, to date, commercially unproven at scale. Investors and policymakers may need to consider the potential for stranded assets if new gas infrastructure investments continue and carbon mitigation needs become more urgent.

Finally, some regions, such as New England or Florida, may become over-exposed to natural gas generation if coal and nuclear power sources are retired without addressing limitations in pipeline and transmission infrastructure. This, in turn, carries a longer-term risk of potential economic and/or reliability concerns if natural gas prices rise unexpectedly or supply is disrupted.

How the natural gas industry responds to these and other challenges will impact not only the evolution of the U.S. power sector, but a host of global environmental, security, and economic development issues as well.

Acronyms

BCF	billions of cubic feet
BCF/D	billions of cubic feet per day
BTU	British thermal unit
CSAPR	Cross States Air Pollution Rule
CPP	Clean Power Plan
EIA	Energy Information Administration
FRCC	Florida Reliability Coordinating Council
GHG	Greenhouse gas
INDC	Intended Nationally Determined Contribution
ISO-NE	Independent System Operator – New England
kWh	kilowatt-hour
LCOE	levelized cost of electricity
LNG	liquefied natural gas
MATS	mercury and air toxics standard
MCF	thousands of cubic feet
MW	megawatt
MWh	megawatt-hour
MRO	Midwest Reliability Organization
NERC	North American Electric Reliability Corporation
NGCC	natural gas combined-cycle
NPCC	Northeast Power Coordinating Council
RFC	Reliability First Corporation
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewable Portfolio Standard
SERC	Southeast Reliability Council
SPP	Southwest Power Pool
TWh	terawatt-hour
TRE	Texas Reliability Entity
WECC	Western Electricity Coordinating Council

Table of Contents

List of Figures

1 The Changing Generation Mix

The U.S. electricity generation mix is currently undergoing unprecedented change. According to data from the U.S. Energy Information Administration, monthly generation from natural gas plants exceeded that from coal for the first time ever in April 2015, and then again in July (Figure 1). Here, we explore dynamics related to natural gas usage in the United States at the national, sectoral, and regional levels, with an emphasis on power generation. This section reviews recent changes at the national level as context for sectoral and regional analysis that follows in sections 2 and 3, respectively.

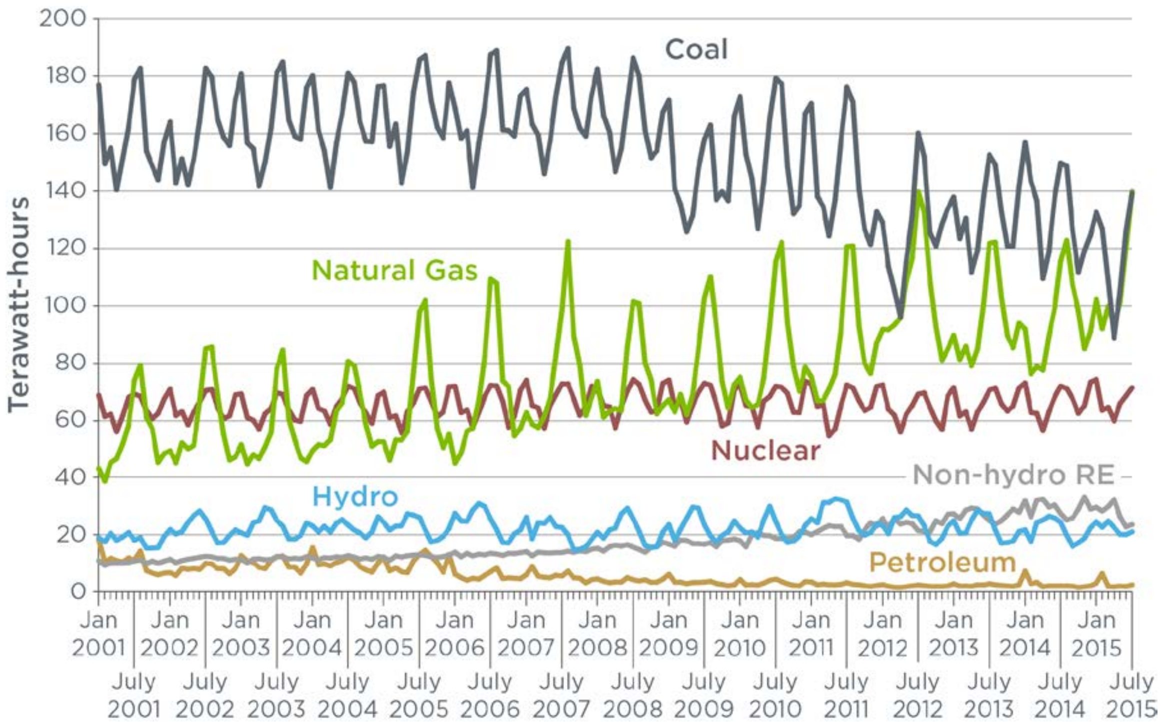

Figure 1. Monthly net U.S. electricity generation by source

Source: EIA (2015a) data through June 2015

The current period of rapid change in the U.S. power sector is unprecedented by historical standards. As Figure 2 below indicates, the long-term trend in the power sector between the 1950s and the 2000s has been of sustained growth in the amount of coal-fired generation.

Starting in mid-2008, however, coal generation began to decline substantially for the first time, and by early 2015, it was providing 25% less than its peak level in 2007. Natural gas generation, in contrast, has been growing strongly since about 1990, well before the emergence of low-priced gas associated with the shale gas revolution that began in 2007–2008. Petroleum used as a fuel source for electricity generation has been on a steady decline since the late 1970s, and today accounts for only a small, but often critical, piece of the supply puzzle in several regions as shown in section 3. On the surface, nuclear generation has been stable since the mid-1990s, although low-priced natural gas is threatening the continued operation of at least a handful of U.S. nuclear plants (Vine and

Juliani 2014). Hydroelectric output has been relatively stable since the late 1970s, and non-hydro renewable generation has grown strongly since 2005. Wind has been the primary source of growth in non-hydro renewable generation, but solar output (only part of which is represented in the EIA data used here[2]) has been growing very strongly in the past few years. In the first quarter of 2015, solar photovoltaic installations accounted for 51% of all new capacity additions to the power sector (SEIA 2015).

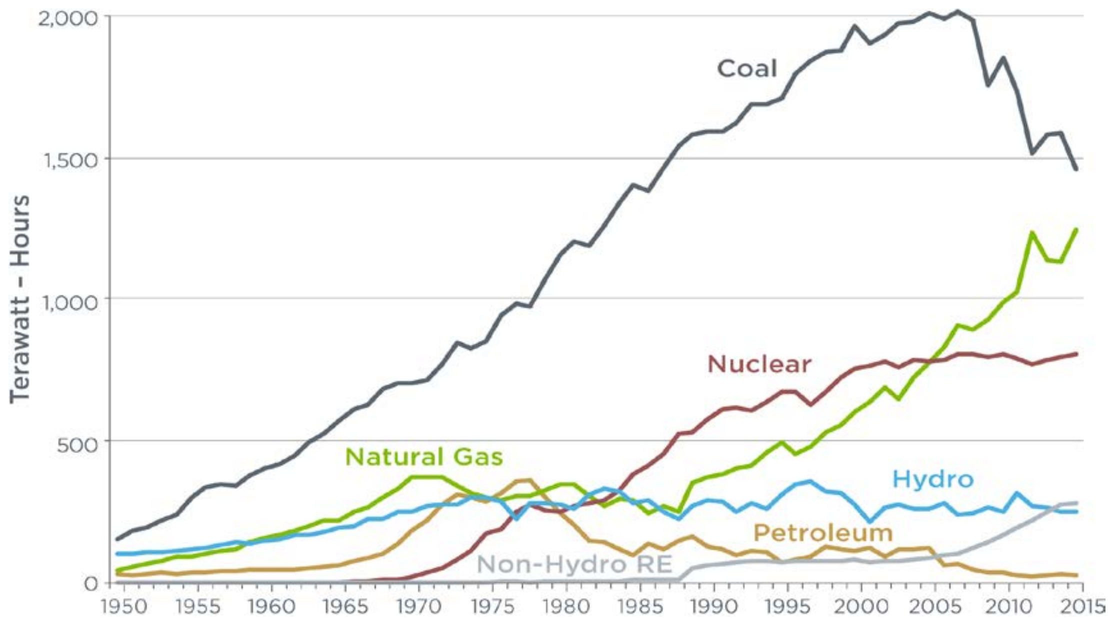

Figure 2. Annual net U.S. electricity generation by source

Source: EIA (2015a) data
Note: Data for 2015 are based on a rolling 12-month total ending in July 2015. Solar data excludes behind-the-meter installations less than 1 MW.

The annual percentage shares of U.S. net generation tell a similar story (Figure 3). Coal currently accounts for about 37% of total U.S. net generation, down from a peak of approximately 57% in 1987–1988. Natural gas generation briefly exceeded 30% share in 2012 when natural gas prices dropped precipitously due to oversupply, and its share is now climbing again. Hydroelectric power has lost market share since the end of World War II, even though its output has remained relatively stable over time. Its share has stabilized over the past 10 years as generation has remained fairly flat, with variations driven by differences in annual precipitation that affect hydro generation availability. Petroleum has declined from about 18% in 1977 to less than 1% in 2015. Finally, non-hydro renewables are approaching 7% of total U.S. net generation. These recent changes have been remarkably abrupt given the normally slow-moving changes that mark electric utility systems (Girouard 2015).

[2] EIA solar data used in this analysis capture grid-connected sources over 1-MW in size. Distributed sources, including residential rooftop installations, are a significant share of total annual and cumulative solar generating capacity. EIA will reportedly begin estimating distributed generation output soon in mainstream publications.

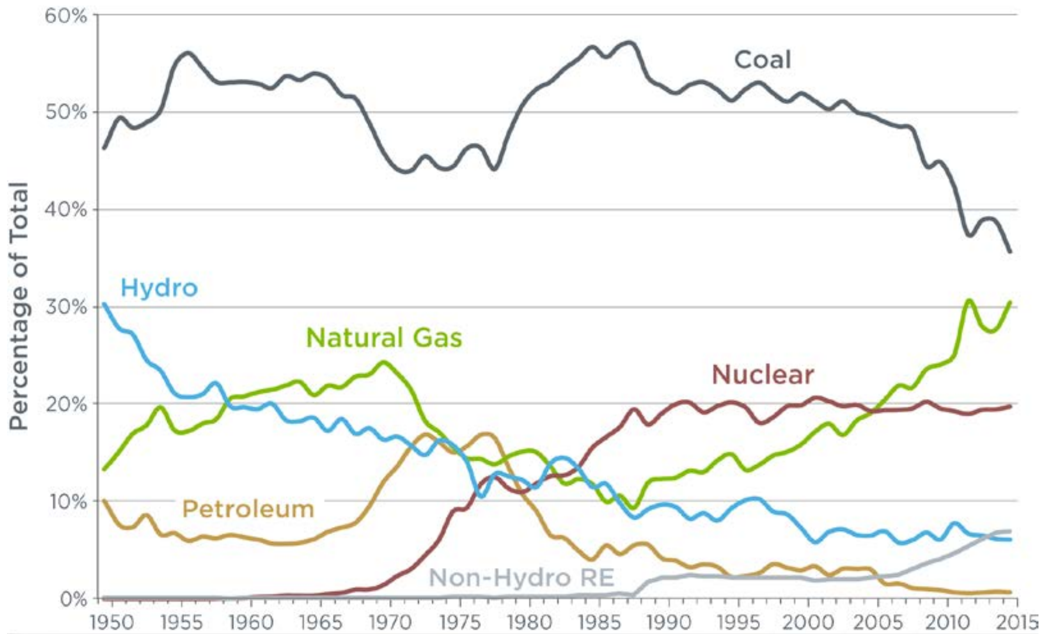

Figure 3. Annual market share of U.S. power generation by source

Source: EIA (2015a) data
Note: Data for 2015 are based on a rolling 12-month total ending in July 2015. Solar data excludes behind-the-meter installations less than 1 MW.

Greenhouse Gas Implications

Recent analyses provide multiple perspectives on the impact of the shale gas revolution on U.S. and global greenhouse gas (GHG) emissions. In the simplest approach, greater natural gas use in the U.S. power sector in place of coal has resulted in a 13–23% reduction in burner-tip[3] carbon dioxide emissions through 2012, depending on the starting point of measurement (De Gouw et al. 2014; Logan et al. 2013). In April 2015, burner-tip carbon dioxide emissions in the U.S. power sector reached their lowest monthly level since April 1988 (EIA 2015i). But when the life cycle emissions of hydraulically fractured gas are fully accounted, some studies indicate that the GHG emission savings between coal and natural gas can change significantly (Howarth et al. 2011; Petron et al. 2012). One study by the National Energy Technology Laboratory found that LNG exported from the Gulf Coast and used to displace local coal generation in Europe and Asia would lead to lower greenhouse gas emissions on a life cycle basis (Skone et al. 2014). Other analyses find that additional research and new analytical approaches are needed to resolve the disparity between different methane leakage measurement techniques and arrive at a more accurate understanding of the life cycle GHG emissions of natural gas (Brandt et al. 2014; Arent et al. 2015). Without strong national limits on GHG emissions, some analysts conclude that natural gas will slow the process of decarbonization by delaying the deployment of renewable energy (Shearer et al. 2014). At least one analysis finds that the displacement of coal generation by natural gas could result in greater climate forcing by reducing the output of sulfur dioxide and

[3] Burner-tip refers to the combustion stage only, and ignores the elements upstream (i.e., fugitive methane emissions) and downstream (i.e., plant decommissioning) of the power plant.

other carbonaceous aerosols that reflect incoming solar radiation (Wigley 2011). Finally, the question of how long natural gas can serve as a "bridge" to a more sustainable energy future is highly dependent on the carbon dioxide stabilization target—a topic of vigorous debate among stakeholders across the globe (Levi 2013). The second monograph in this series will address the topic of natural gas serving as a bridge to a low-carbon electricity future.

While the role of natural gas as a bridge fuel may be interpreted in multiple ways, natural gas has played an important role in reducing reported carbon dioxide emissions in the U.S. power sector over at least the short term, providing an important basis for the United States' Intended Nationally Determined Contribution (INDC) submission to the UN Climate Convention Secretariat, which includes a 26-28% reduction in GHG emissions below 2005 levels by 2025 (WRI 2015). The U.S. INDC targets have in turn helped to encourage China and other large emitters to submit their own INDC's that include substantial reductions targets compared to previous actions (TCRP 2015). Thus, the U.S. shale revolution has, at least temporarily, helped leverage greater global action to mitigate GHGs.

1.1 Drivers of Change

Three major factors currently drive change in the U.S. power sector:

1. Low cost, abundant natural gas
2. Continued improvements in renewable electricity cost and performance
3. Increasingly stringent environmental regulations.

Low cost, abundant natural gas

Abundant domestic natural gas supply has resulted in lower prices and allowed natural gas to compete directly with coal in many regions of the country. Prices paid by natural gas generators peaked in 2008 and have been relatively low since then with the exception of a brief period in the winter of 2013–2014 (Figure 4).[4] Coal prices continued to rise slowly through 2012, but the competitive pressures of natural gas have contributed to coal prices stabilizing or slightly declining since.[5] Indeed, U.S. coal markets are now generally oversupplied, but exports to Europe and Asia have helped to prevent prices from collapsing further.[6] Other attributes of natural gas generators, including their ability to ramp output up and down quickly (flexibility) and relatively low capital costs, emissions, and water use also contribute to their greater use. The third monograph in this series will address the subject of flexibility among electricity generators.

[4] Although coal prices are lower than gas per unit of energy in Figure 4, the higher efficiency of natural gas combined-cycle units often results in lower overall electricity prices than coal-fired steam turbines.
[5] A relatively low economic growth rate in the U.S. has also played an important role insomuch as electricity demand growth and growth in other uses of natural gas have also been relatively low.
[6] U.S. steam and metallurgical coal exports grew significantly from early 2009 to early 2012 before falling. While the price of exported metallurgical coal has fallen significantly, prices for steam coal used in power generation have remained stable (EIA 2015b).

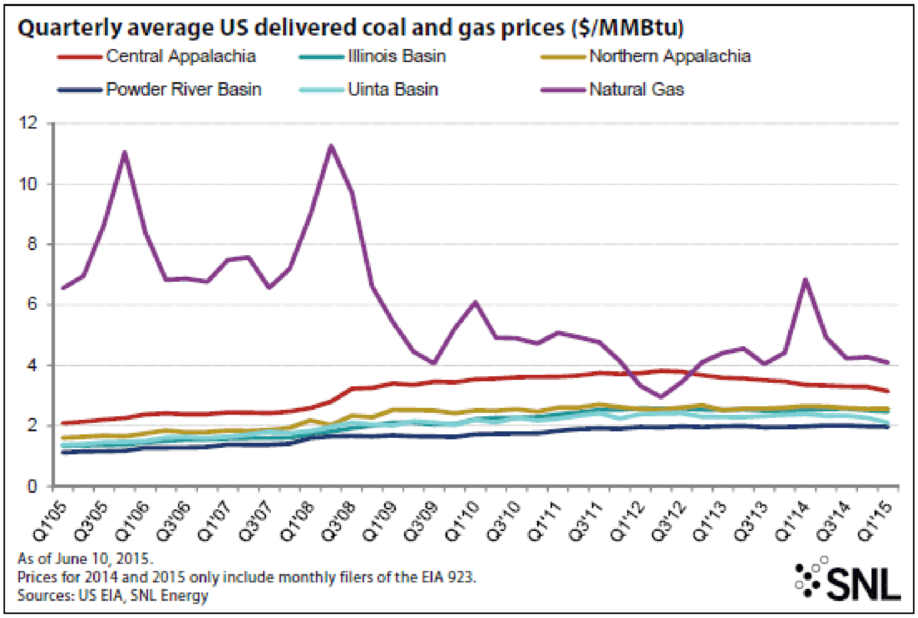

Figure 4. Prices paid by power generators for natural gas and coal

Source: Christian and Fawad (2015)

Since 2008, almost all of the new natural gas supply in the U.S. has come from shale basins as a result of improvements in hydraulic fracturing, directional drilling, and other technological advances (MIT 2011). Shale gas now accounts for over 55% of total U.S. natural gas output, as shown in Figure 5, and shale plays like the Marcellus provide enormous quantities of natural gas very close to areas of high demand (EIA 2015c). Despite the jump in output from shale gas close to population centers, lack of infrastructure and misaligned market operations between the natural gas and electricity sectors can still result in shortages during key times of the year (MIT 2014). New England, for example, has experienced natural gas shortages due to constraints on regional deliverability during exceptionally cold winters in 2012–2013 and 2013–2014 (see Section 3). While production has declined in largely "dry" shale plays (Haynesville and Fayetteville) over the past few years, it has continued to increase in "wet" plays as the associated gas and petroleum liquids have helped overall project economics.

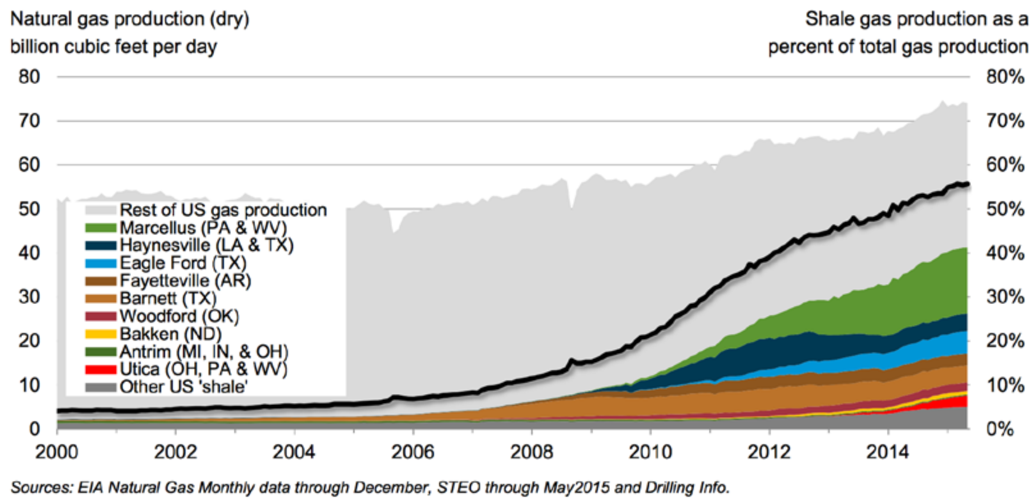

Figure 5. Sources of U.S. natural gas production

Source: EIA (2015c)
Note: Black line in figure indicates shale as a percentage of total gas production.

Natural gas prices, while notoriously difficult to predict, are projected by the EIA to stay low over the next few years (EIA 2015d), rising slowly to over $7.80/MMBtu at the Henry Hub by 2040 as measured in 2013 dollars (EIA 2015e). Gas producers have defied expectations by continuing to drive down the cost of producing shale gas (BNEF 2015). Almost all of current production activity is occurring through hydraulically fractured, horizontal wells, as seen in Figure 6. Even though the number of drilling rigs has declined four-fold from its peak in 2008, total output continues to rise with prices remaining relatively low and stable.

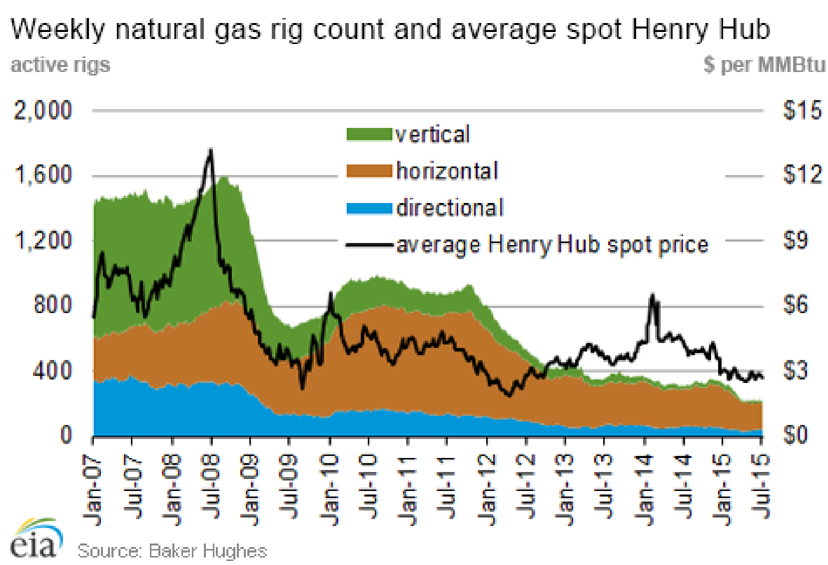

Figure 6. Weekly natural gas rig counts and price

Source: EIA (2015g)

Natural gas storage levels provide one indicator of near-term price behavior. Storage levels typically reach their low point in late winter after stock drawdowns occur and they tend to peak in late fall just before the winter heating season begins. Natural gas storage levels had been exceptionally low through the early fall of 2014, leading some to believe that prices would once again spike in the winter of 2014–2015 (EIA 2015g). However, stocks built strongly during the last half of the year and continued to do so through the first half of 2015 (Figure 7). Currently stocks are equivalent to the 5-year average. This, coupled with a growing number of completed but non-producing wells (BNEF 2015), suggest that low prices are likely to continue over the near- to mid-term.

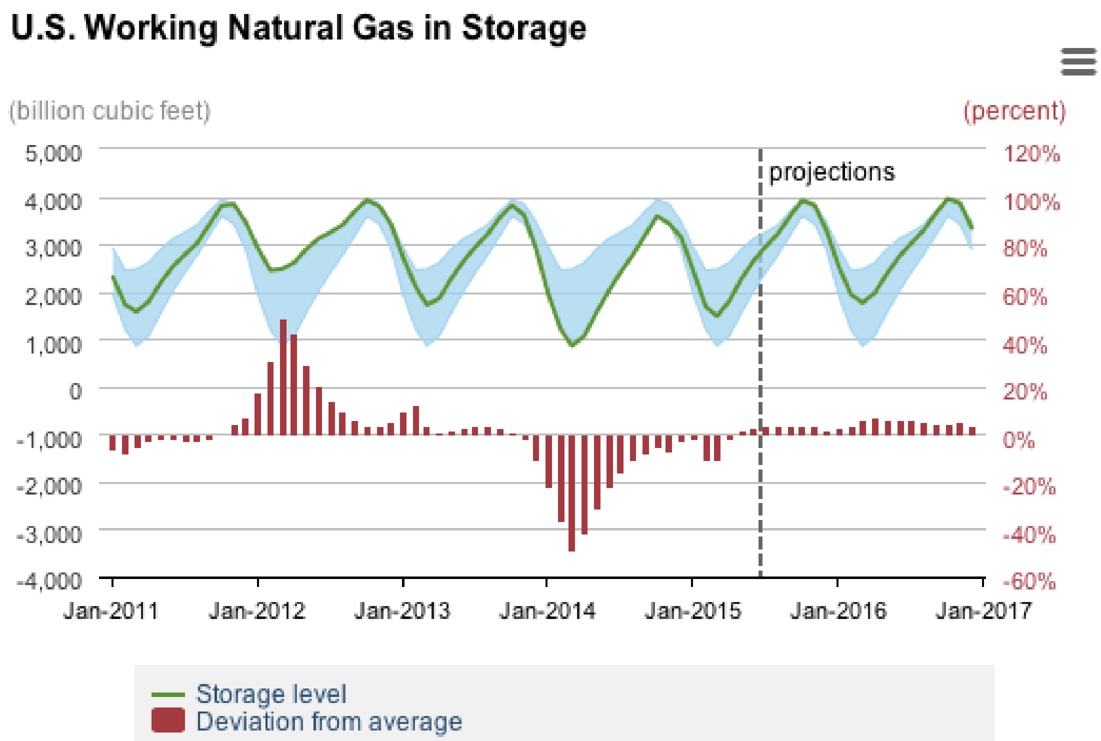

Figure 7. Levels of working gas in storage

Source: EIA (2015g)

Note: Blue band around storage level represents the range between the minimum and maximum from January 2010 to December 2014.

Continued improvements in renewable electricity cost and performance

Advances in renewable electricity generation technologies, particularly wind and solar, have contributed to their fast growth. The unsubsidized levelized costs of electricity (LCOE) for wind and solar have declined by a reported 58% and 78%, respectively, over the past five years (Lazard 2014) (Figure 8). In a recent request for proposal, Austin Energy received an offer to contract for solar electricity at less than \$40/MWh (Trabish 2015), while Nevada Power Company received a power purchase agreement proposal from First Solar and Sunpower with a first-year price of \$38.70/MWh (Martin 2015).

Wind power purchase agreements routinely come in even lower (Wiser and Bolinger 2015). These PPA prices include incentives, as discussed below. All costs and prices for both wind and solar are expected to continue declining (Lazard 2014; Lacey 2015; NREL 2015a). Some regions of the country face increasing challenges of integrating larger amounts of variable renewable electricity into the grid, although more experience and "lessons learned" are available to understand integration options (NREL 2015b).

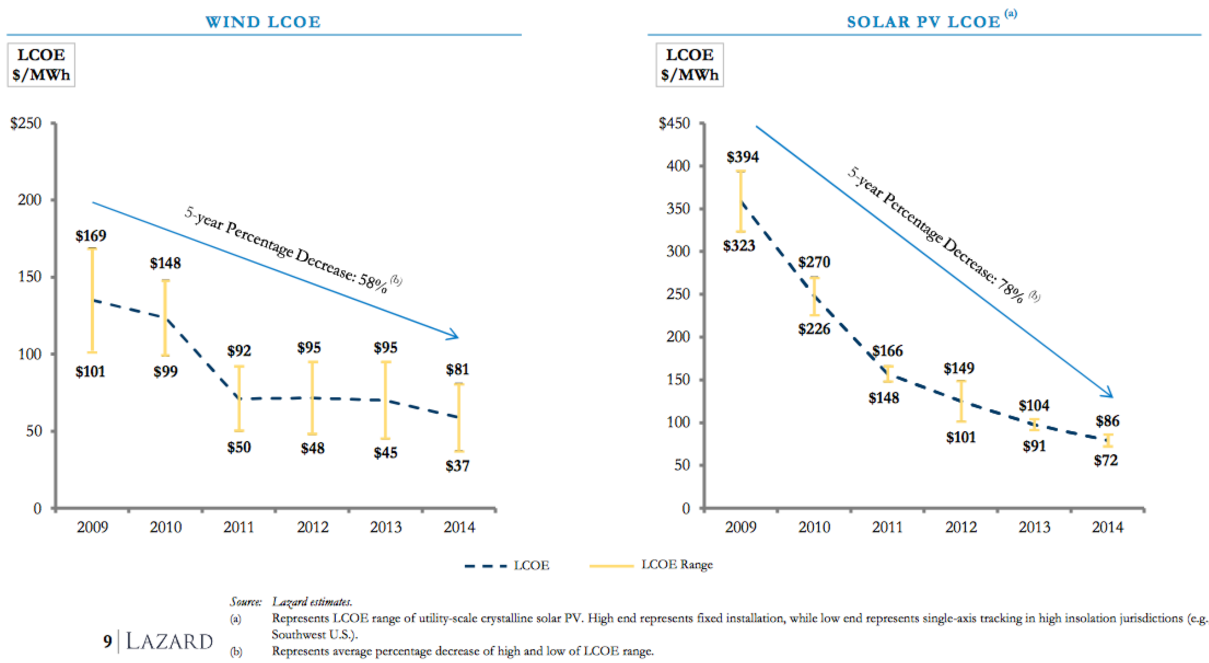

Figure 8. Evolution of wind and solar costs over time

Source: Lazard (2014)

In addition to falling costs, deployment of renewable electricity technologies benefits from a variety of federal, state, and local incentives. These include federal production and investment tax credits, the former lapsing at the end of 2014 and the latter scheduled to decline significantly at the end of 2016; state renewable portfolio standards that require load serving entities to procure a certain percentage of renewable electricity; and other policies such as net energy metering that allow consumers to sell excess solar-generated electricity back to the grid, often at retail rates. Growth in variable renewable electricity may be impacted by the expiration in tax credits, but some analysts believe the expenses involved in "monetizing" the credits make them less valuable than they appear (Bolinger 2014). Growth in zero marginal cost variable renewable generation, combined with greater affordability of battery storage, continues to raise debate about the viability of the traditional business model of utilities in some states, particularly Hawaii and California, but that subject is beyond the scope of this study (Kind 2013; Costello 2015).

Increasingly stringent environmental regulations

Environmental regulations are impacting the deployment of new fossil fuel generators and the operation of existing plants. In particular, the Mercury and Air Toxics Standard

(MATS) and the Cross States Air Pollution Rule (CSAPR) have resulted in an acceleration of fossil plant retirements, mainly coal plants without flue gas desulfurization and other emission mitigation technology.[7] While the aggregate capacity of these retirements has been large, the actual generation represented by these plants is less due to their limited use. To date, much of the lost generation is being replaced by greater operation of the existing fleet of natural gas combined-cycle (NGCC) units and by increased deployment of renewable technologies.

Other regulations, including the Clean Power Plan[8] (CPP), will further impact decisions to build and operate fossil fuel power generation plants. The CPP is anticipated to result in a 32% reduction in U.S. power sector carbon dioxide emissions from 2005 levels by 2030, and offers states different options in how they go about lowering emissions. Many states are likely to accelerate the use of energy efficiency, coal-to-natural gas redispatch, and renewable energy to comply with the CPP targets for emission mitigation.

In addition to the three drivers noted above, demand growth for new electricity has been very modest over the past decade, limiting the growth opportunities for all new generation sources. Total electricity demand peaked in 2007 and has not exceeded that level through mid-2015. As noted in section 3, power demand in many regions has declined significantly over the past decade, due to the economic recession as well as successful energy efficiency policies at the state and federal level. Other factors contributing on the margin to changes in the U.S. generation mix include the nuclear accident at Fukushima in 2011, energy insecurity among nations that have historically imported natural gas from Russia, and economic slowdown in China.

[7] The U.S. Supreme Court remanded MATS on June 29, 2015, although most utilities had already moved to comply with the rule by either installing pollution control equipment or retiring plants that would be uneconomic. At the time of this writing, the ultimate fate of the MATS rule remains uncertain.
[8] For more information on the Clean Power Plan, see http://www2.epa.gov/cleanpowerplan/clean-power-plan-existing-power-plants.

2 Natural Gas Sectoral Dynamics

Any significant change in natural gas demand from non-power sectors could affect natural gas usage in the electricity sector. While the previous section explored dynamics of how and why the aggregate generation mix for electricity is changing in the United States, this section briefly reviews natural gas supply and demand dynamics in other sectors. The goal is to develop insights on how these changes might influence the electricity sector going forward.

2.1 Natural Gas Supply

Natural gas production in the continental United States continues to grow strongly, despite the recent decline in oil-directed drilling that also produces associated natural gas. Productivity gains in the Appalachian Basin have been particularly strong, especially in the Marcellus and Utica plays (Figure 5), offsetting the decline in associated gas output (BNEF 2015). The most recent Short Term Energy Outlook from the EIA projects dry natural gas output to climb 5.5% in 2015 from 2014 levels, and another 2% in 2016 (EIA 2015d).

Accordingly, many projections call for continued downward pressure on prices as supply remains robust (BNEF 2015; EIA 2015d). Of course, as will be noted in Section 3, there may be periods of high regional prices, especially in New England where infrastructure and operational bottlenecks can occur, but these are generally short-lived and weather-dependent. Upward price pressure may begin to return as the United States starts exporting more liquefied natural gas (LNG), and then again as states take steps to comply with the CPP by possibly substituting natural gas for coal in power generation (Platts 2014; Gelman et al. 2013). The ultimate outcome will be a function of overall demand, which is uncertain at the moment, but it will also reflect the pace of productivity improvements in shale-directed drilling activity. If drilling/production efficiency does not continue to improve, natural gas output could begin to fall as per-unit costs would become prohibitive. This would, in turn, cause prices to rise more quickly, and present commercial impediments to LNG exports and domestic demand growth more generally.

2.2 Natural Gas Demand by Sector

Figure 9 illustrates how natural gas use by sector has evolved historically. Very little growth is observed in residential, commercial, and lease/plant fuel[9] natural gas demand over the past 40 years. While commercial sector natural gas demand has grown over the past few years, the changes are modest. Recent growth seen in the pipeline and distribution use is attributable to the growth in production and sales associated with the growth in domestic production. Residential demand has not grown much, nor is it

[9] Lease and Plant Fuel includes natural gas used in well, field, and lease operations, such as gas used in drilling operations, heaters, dehydrators, field compressors, and natural gas processing plants.

generally expected to grow in the coming years.[10] Natural gas vehicle demand has tripled over the past 15 years, but total demand in that sector is only about 3 billion cubic feet (BCF) per year (EIA 2015g).

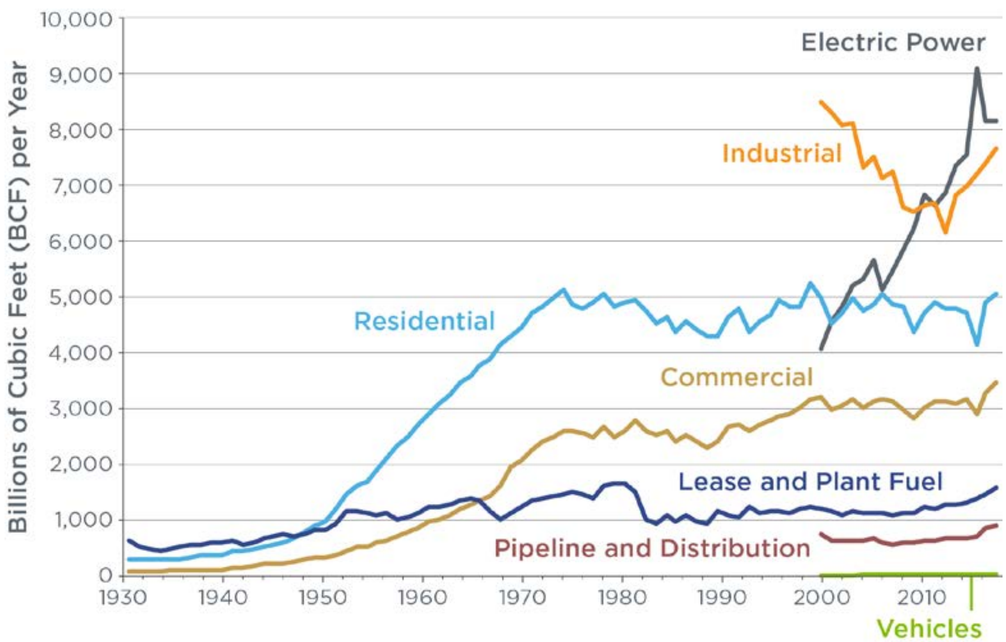

Figure 9. Natural gas demand by sector

Source: Created by JISEA using EIA (2015h) data

The most significant areas of growth, especially in the last few years, are the industrial and power generation sectors. The shale gas revolution has been accompanied by growing enthusiasm for a rejuvenated U.S. manufacturing sector, as plentiful gas supply translates into relatively low and stable prices for the industrial sector (ACC 2013; PwC 2014). Indeed, industrial natural gas demand was in steep decline during the late 1990s and early 2000s, but it began growing lockstep with the dramatic decline in U.S. natural gas prices triggered by abundant domestic supply as hundreds of new petrochemical projects have come on-line over the past few years. Nevertheless, future growth in the industrial sector is expected to be relatively modest, especially when compared to that in the power sector (CEE 2015; BNEF 2015). Figure 10 from a 2015 Texas Bureau of Economic Geology forecast—which is considered one of the more bullish forecasts—anticipates fairly strong near term growth in petrochemicals (ethylenes and chlor-alkalis) and nitrogen fertilizers, although annual aggregate industrial demand growth is only from 1–4% of total demand through 2018.

[10] A caveat here is the emergence of new technologies. One such potential technology is the gas-fired microturbine. Another is the gas-fired fuel cell. Each of these could provide both heat and electricity to residential consumers. Some observers believe that microturbine and fuel cell deployment could expand in certain residential applications as consumers seek greater reliability and resilience, especially after Hurricane Sandy disrupted power for consumers in the Northeast (Johnson 2015). Prices would need to decline, however, for either to be significantly valued over traditional natural gas or diesel generators (Riverview Consulting 2013).

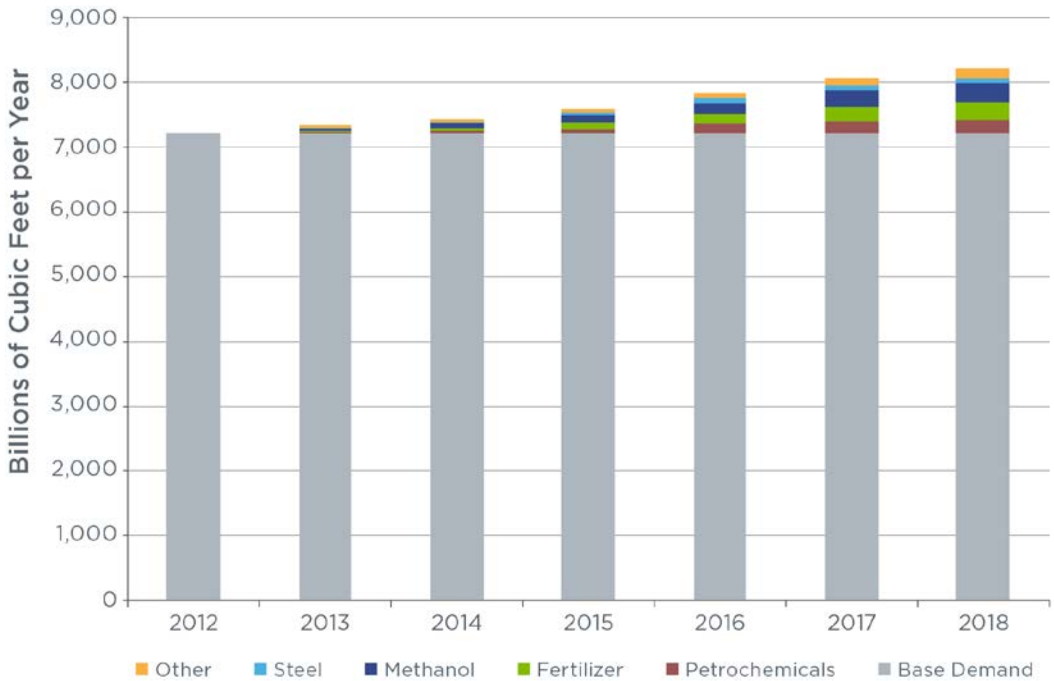

Figure 10. Forecasted growth in industrial natural gas demand

Source: Created by JISEA using CEE (2015) data

A sector that is expected to experience strong growth is foreign demand for U.S. natural gas, meaning exports of natural gas via pipelines and LNG. The United States is currently the largest producer of natural gas in the world, but remains a net importer of natural gas, primarily from Canada, albeit imports are small. This is expected to change in the next year or two as LNG export terminals come on-line and pipeline exports to Mexico grow, while imports from Canada continue to shrink (EIA 2015d).

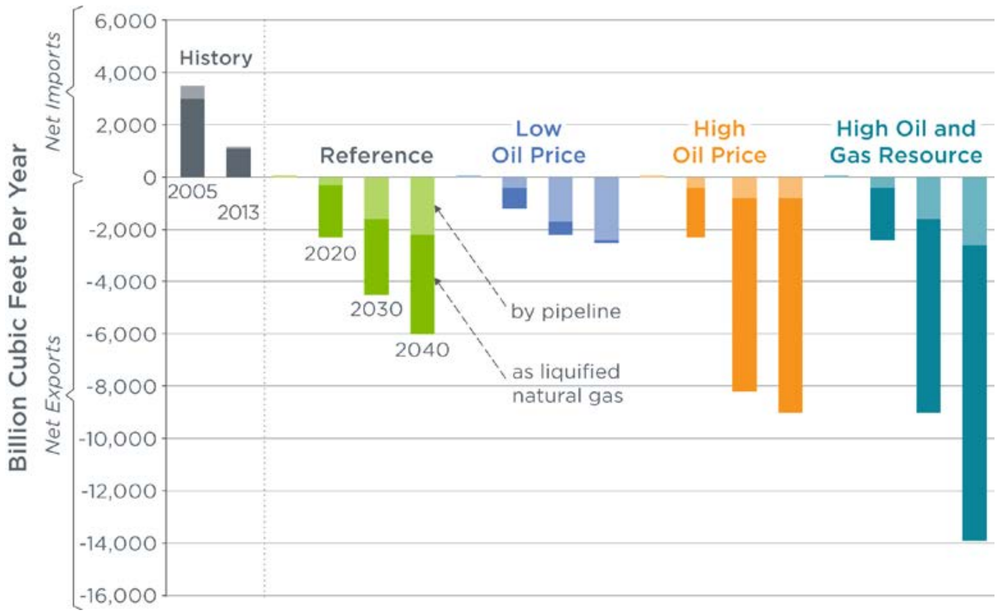

Figure 11. U.S. net natural gas trade in four scenarios

Source: Created by JISEA using EIA (2015e) data

Figure 11 details the most recent analysis from the EIA on U.S. natural gas trade. In its Annual Energy Outlook 2015 reference case, the EIA sees net natural gas exports climbing to over 2,100 bcf (5.8 bcf/d) in 2020, mostly in the form of LNG. By 2030, net exports are projected to double again to over 4,200 bcf (11.5 bcf/d), with much of the additional growth occurring via pipeline exports.

Several studies have attempted to determine the impact on domestic prices under a variety of natural gas export scenarios (EIA 2014a; CRA 2013; NERA 2012; NERA 2014).[11] A 2014 EIA study estimates that producer prices would increase between 4 and 11% in scenarios where LNG exports reach 12 bcf/d and 20 bcf/d, respectively. At face value, these would seem to be very modest impacts. Additional study and experience is likely to help determine the actual impact of exports on domestic prices, especially given recent changes in regional pricing in Asia and Europe associated with the decline in oil prices.

[11] A study by Charles River Associates for the Dow Chemical Company (an industrial natural gas user that opposes large-scale LNG exports) showed larger price impacts if high levels of exports are achieved (CRA 2013). An opposing study by NERA Economic Consulting for Cheniere Energy (a developer of LNG export projects) found more positive macroeconomic impacts and lower impact on domestic natural gas prices (NERA 2014).

3 Regional Natural Gas Dynamics and Outlook in U.S. Power Markets

This section considers regional changes in natural gas use and discusses issues associated with changing generation mixes. While the national topics discussed above help us understand aggregate trends, some regions are changing much more quickly than others, and this regional focus will help shed light on the future evolution of natural gas in the power sector.

Each of the following regional discussions presents three charts: 1) the changing mix of electricity generation as a function of fuel type; 2) the change in utilization of select existing fleets of plants, as measured by capacity factors,[12] focusing primarily on steam turbines (mainly coal) and combined-cycle (mainly natural gas), but also considering other technologies when they might influence the overall generation mix (wind); and 3) the expectations of future changes in generation capacity based on announced projects or those under construction.[13] In some cases, additional graphics of natural gas prices in specific regions are included to illustrate important trends. Table 1 at the end of this section summarizes selected metrics in regional power markets.

Figure 12 below defines the regions used in this analysis. Although three of these regions include large sections of Canada, and one includes part of Mexico, we restrict the discussion below mainly to the continental United States.

[12] Capacity factor, also referred to as utilization rate, is a measure of how much electricity a plant generates compared to its theoretical maximum over a defined period of time. For example, if a plant has a capacity factor of 0.5, it generated half as much electricity in a period as is actually possible.
[13] Projected changes in this series of figures after 2014 may be considered conservative because only mature project announcements and those already under construction are included. These are not forecasts and do not include speculative new builds.

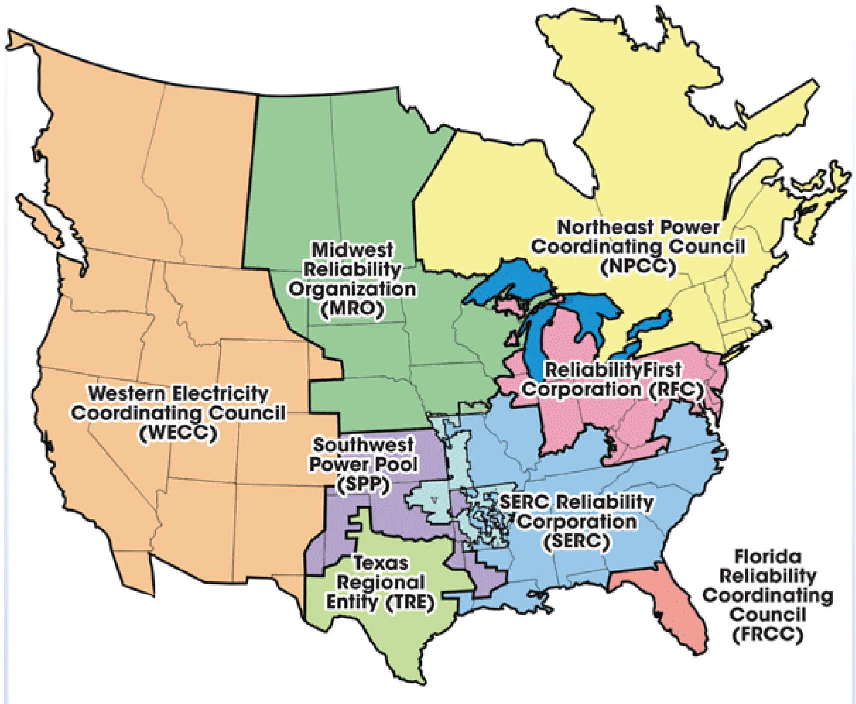

Figure 12. Regional definitions in NERC

Figure 13 below summarizes the annual generation mix in each region for the year 2014. Significant diversity exists between many of the regions, with MRO and SPP dominated by coal; NPCC, FRCC, TRE and WECC dominated by natural gas; and RFC, and SERC dependent on coal but diversified.

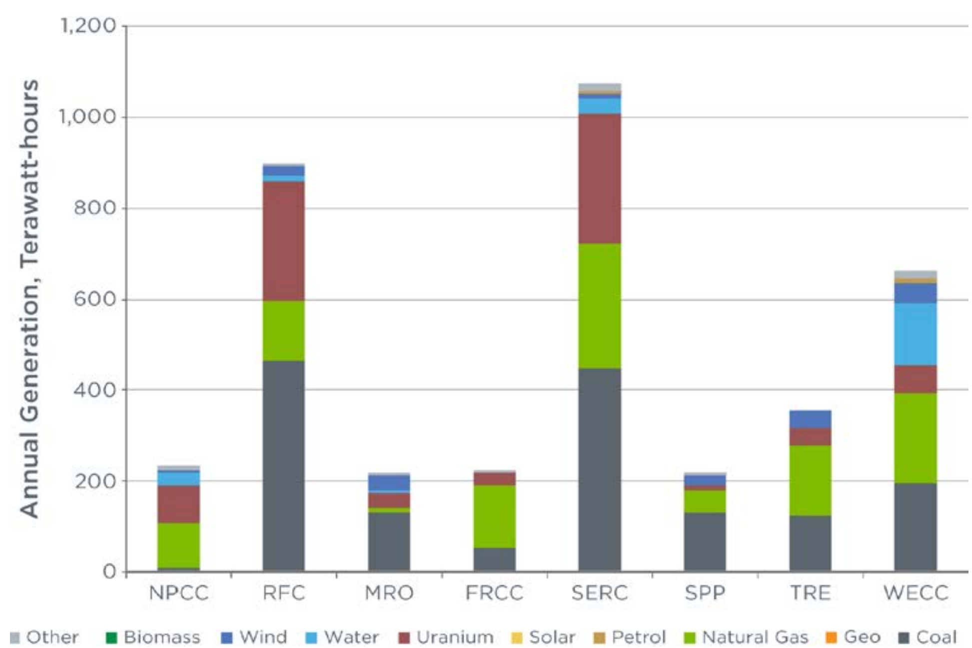

Figure 13. Annual generation mix for each region in 2014

Source: Created by JISEA using SNL (2015) data

3.1 Northeast Power Coordinating Council

Perhaps no other region has been impacted as greatly as New England from the recent changes in natural gas and electricity markets. The independent system operator, ISO-NE, has struggled with notable natural gas shortages over the past three winters, leading to power and natural gas price spikes. Spot prices at the Algonquin Citygate surged past \$30/MMBtu in winter of 2013–2014, and exceeded \$10/MMBtu in the winters of 2012–2013 and 2014–2015 (NGI 2015). Surprisingly, the winter of 2014–2015 experienced colder temperatures and higher natural gas demand than either of the two previous winters, yet markets functioned fairly well and price spikes remained more muted (FERC 2015). As discussed further below, several of the recent changes instituted in New England may be starting to have an impact.

Ironically, perhaps, New England natural gas prices during the non-winter seasons have been significantly below those quoted at the Henry Hub, fueling debate about whether New England really needs new gas transmission capacity to help balance supply and demand over a relatively short period of the year, or whether other options (e.g., relying on more imported LNG, energy efficiency, gas storage, dual fuel capability and renewables) might be cheaper (Sullivan 2015).

New England's changing generation mix shows a continued reduction in coal use, growing reliance on natural gas, accelerated use of non-hydro renewables since 2012, and an increase in liquid petroleum-fired generation in 2013 and 2014. Figure 14 presents generation data for key fuels in the Northeast Power Coordinating Council (NPCC). Additionally, electricity demand continues to decline from its peak in 2005 and was approximately 20% below that level in 2014 (Table 1). While natural gas generation has remained stable over the period, declining overall demand for power has resulted in a larger market share for natural gas and non-hydro renewables (Table 1). Many states in the region have engaged in substantial efforts to promote energy efficiency and conservation, helping avoid difficulties resulting from limited infrastructure, weak electricity-natural gas coordination, and the rising demand for natural gas (Acadia 2015).

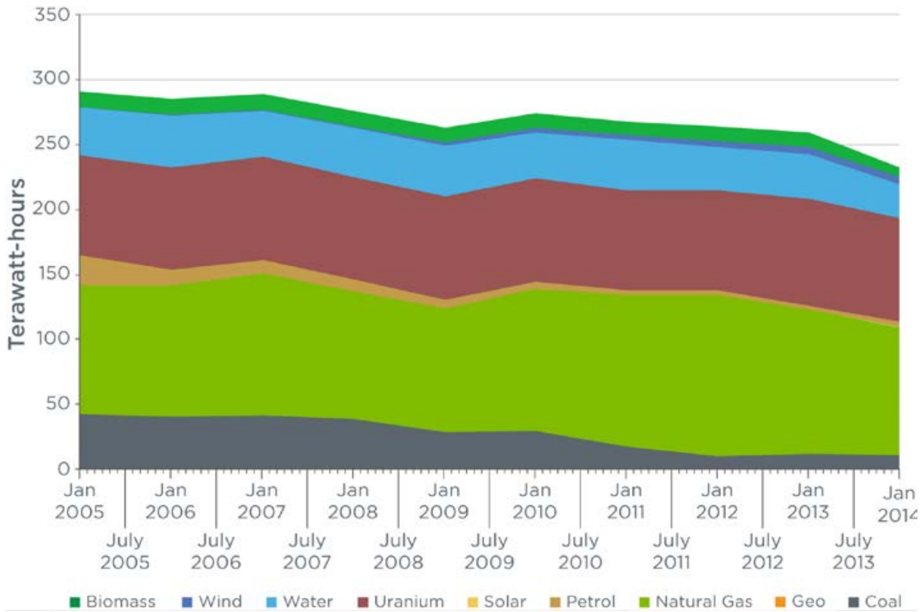

Figure 14. The changing generation mix in the NPCC region

Source: Created by JISEA using SNL (2015) data

Capacity factor trends for select generation technologies in NPCC are provided in Figure 15. Utilization of coal plants is declining swiftly—partly to comply with the Regional Greenhouse Gas Initiative (RGGI) and MATS, and party due to competition from low-priced natural gas. In 2014, the average fleet-wide capacity factor for coal plants was only 19% (Table 1). Use of the existing fleet of combined-cycle plants, mainly fired by natural gas, but occasionally switching to light petroleum in the winter, is rising steadily. As noted, combustion turbine utilization is fairly high in the NPCC, averaging about 10% a year.

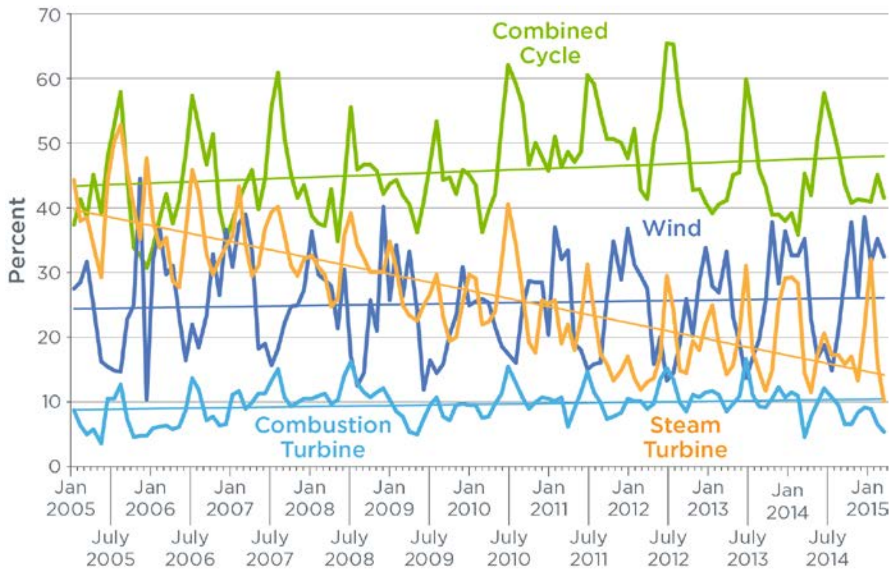

Figure 15. Changing capacity factors for select technologies in NPCC

Source: Created by JISEA using SNL (2015) data

Historic and expected capacity additions are shown in Figure 16. Projected changes after 2014 may be considered conservative because only mature project announcements and those already under construction are included. Moderate growth in natural gas, wind, and solar plant capacity is expected.

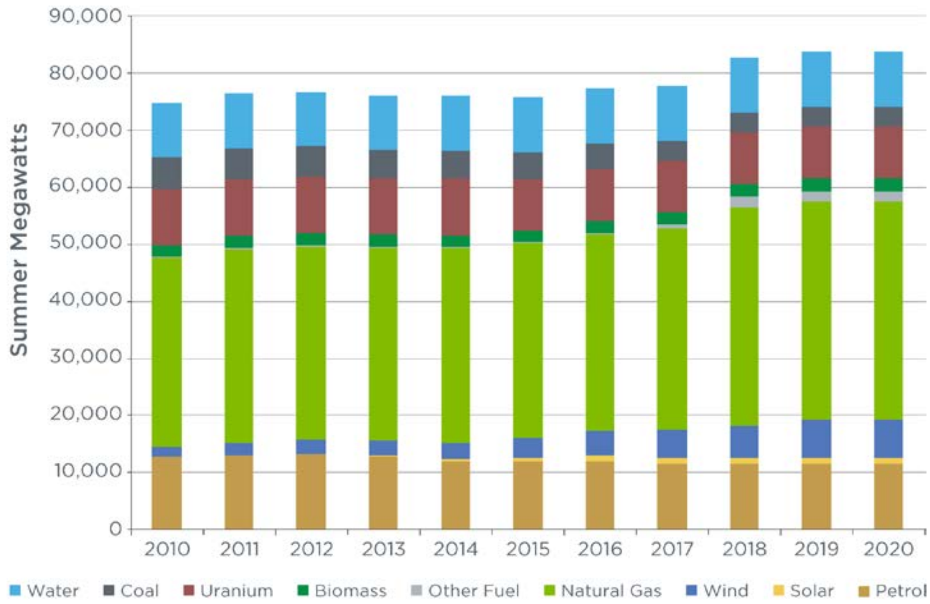

Figure 16. Historic (pre-2015) and expected capacity in NPCC

Source: Created by JISEA using SNL (2015) data
Note: Future capacity is based on actual planned/under construction projects, and not based on any projections of unreported new developments or retirements.

As previously noted, natural gas prices in many parts of New England surged over the past three winters due to gas shortages, some of which were due to limitations in gas infrastructure and some due to misalignments in electricity and natural gas markets. While winter gas prices in Massachusetts and Connecticut far exceeded the average U.S. price, as shown in Figure 17, impacts over the past winter were generally less severe than some had expected.

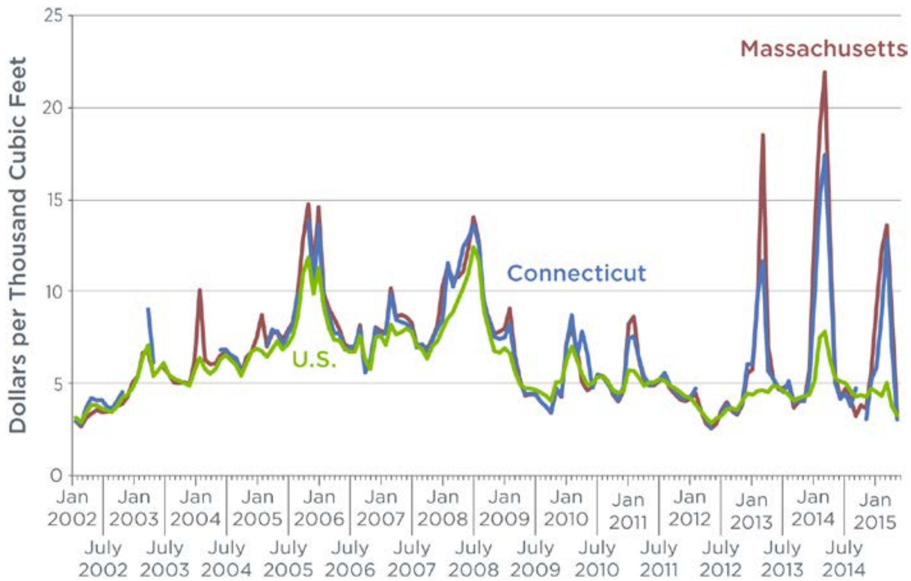

Figure 17. Delivered monthly natural gas prices for generators in the United States, Massachusetts, and Connecticut

Source: EIA (2015f)

Expectations for future prices at the Algonquin Gate, a major trading hub in Massachusetts, are provided in Figure 18. Winter price spikes are expected to continue, while non-winter prices below that of the Henry Hub indicate oversupplied markets.

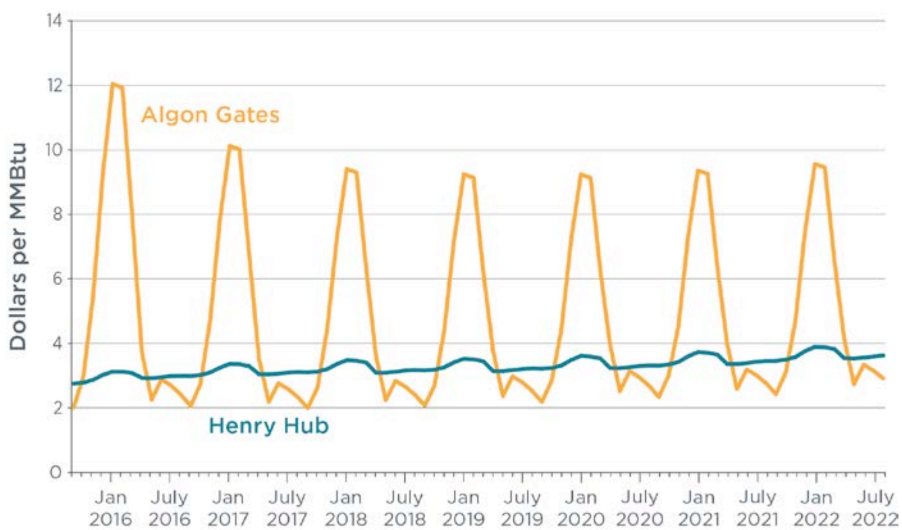

Figure 18. Natural gas price futures for the Algonquin and Henry Hubs

Source: Created by JISEA using SNL Forwards and Futures (2015) data

Some of the steps that ISO-NE and others have taken to better coordinate natural gas and electricity markets, and continue to meet the goals of clean, reliable, and affordable electricity include:

- Working with FERC and other stakeholders on better coordination of natural gas and electricity market scheduling and other gas purchase contracting issues (MIT 2014)
- Instituting a Winter Reliability Program that includes special demand response, and oil and dual-fuel generator measures (ISO-NE 2015)
- Enacting stronger energy efficiency and conservation measures
- Expanding reliance on liquid petroleum and LNG shipments during winter
- Enacting capacity markets to reward availability and flexibility of generators
- Planning and executing expansion of infrastructure (NG pipelines and electricity transmission).

3.2 Reliability First Corporation

The Reliability First Corporation (RFC) region, which covers several mid-Atlantic and mid-western states, comprises many of the states that have experienced the sharpest expansion in shale gas output. Coal has been negatively impacted the most in the face of low-priced gas (Figure 19). Natural gas generation has more than doubled since 2001, while coal has declined by approximately 30% (Table 1). Most of the other generating sources in the region have remained stable, with the exception of petroleum-fired power, which is now almost non-existent, and non-hydro renewables, which started from a very low base. As in New England, petroleum has continued to serve an important role in the winters of 2012–2013 and 2013–2014 given the exceptionally cold weather and natural gas constraints in some parts of the region. As in NPCC, overall electricity demand in RFC has been on a downward trend.

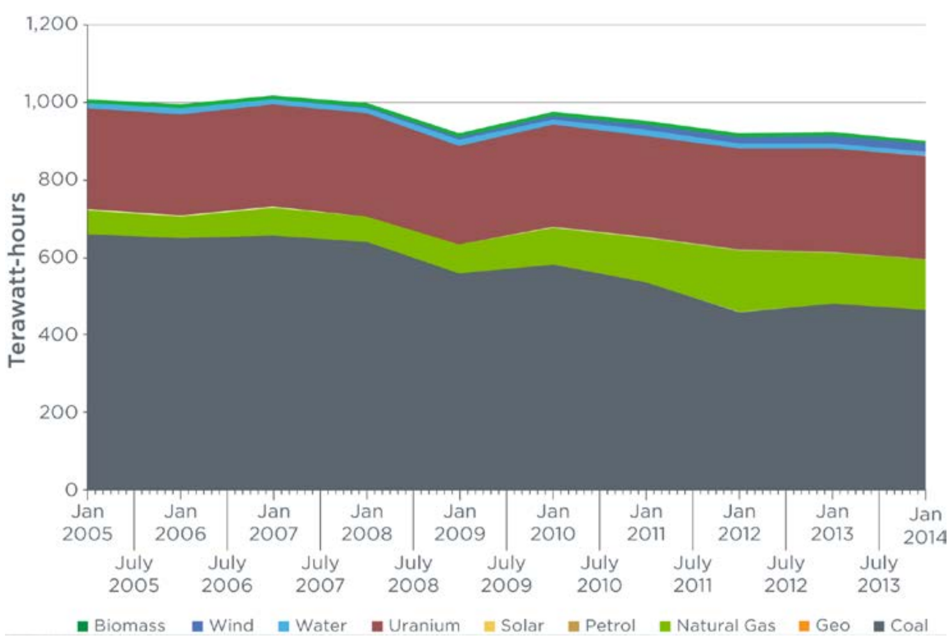

Figure 19. The changing generation mix in the RFC region

Source: Created by JISEA using SNL (2015) data

The changing generation mix is reflected in the capacity factor trends presented in Figure 20. Coal capacity factors have declined from an average in the high 60% range in 2005 to just over 50% in 2014. Combined-cycle utilization is growing faster than in any other part of the country, rising from an average of about 10% in 2005 to nearly 50% in 2014. Average wind capacity factors have climbed as well throughout the period.

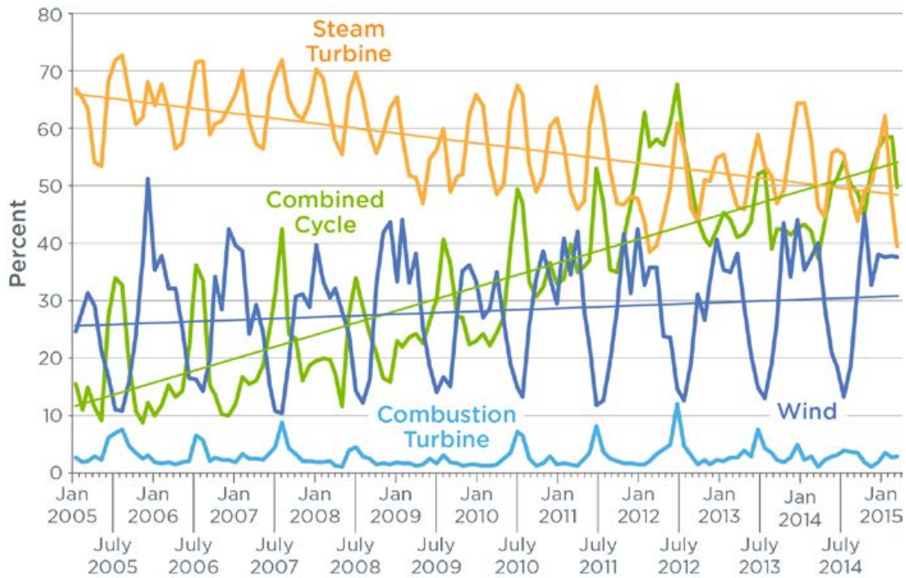

Figure 20. Changing capacity factors for select technologies in RFC

Source: Created by JISEA using SNL (2015) data

Figure 21 indicates a continued expected decline in coal-fired capacity and an increase in natural gas capacity. Most other sources are expected to remain fairly stable, although wind capacity may nearly double by 2020 from the 2010 level.

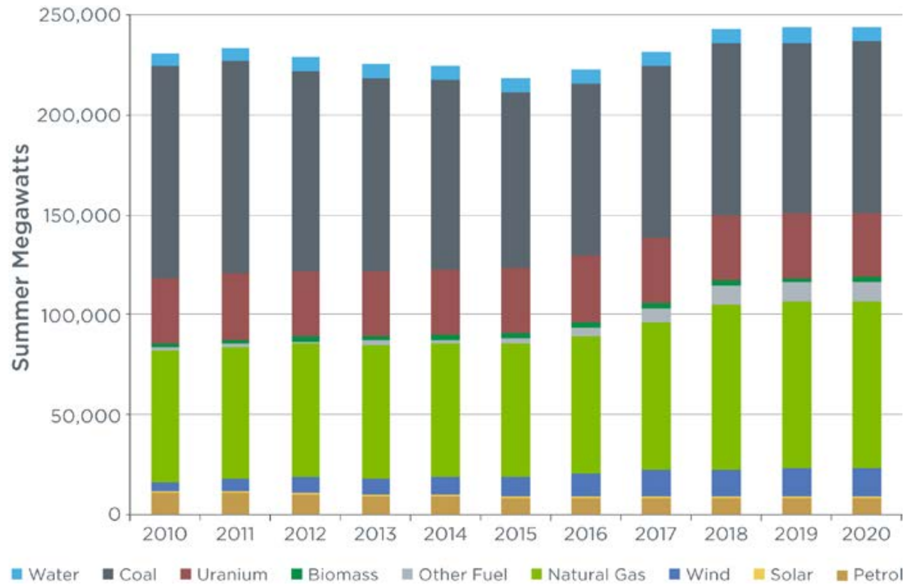

Figure 21. Historic (pre-2015) and expected capacity in RFC

Source: Created by JISEA using SNL (2015) data
Note: Future capacity is based on actual planned/under construction projects, and not based on any projections of unreported new developments or retirements.

As in New England, the price that generators pay for natural gas in the RFC region has surged over the past few winters due to infrastructure constraints (Figure 22). Again the irony here is that supply in this region far exceeds demand and prices are normally below those of the Henry Hub during the non-winter months (EIA 2014b).

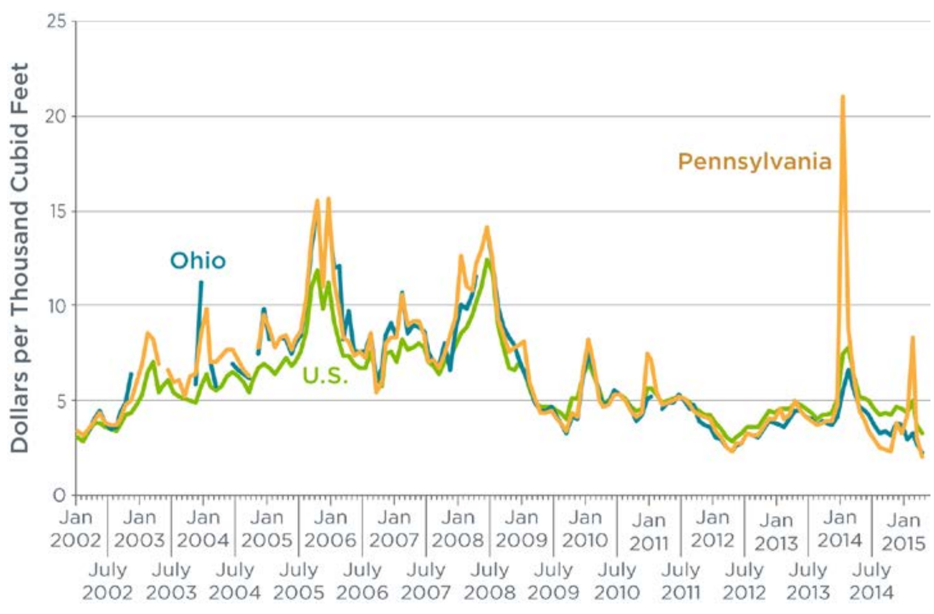

Figure 22. Delivered monthly natural gas prices for generators in the United States, Ohio, and Pennsylvania

Source: Created by JISEA using EIA (2015f) data

3.3 Midwest Reliability Organization

Unlike other regions, Midwest Reliability Organization (MRO) has maintained a heavy reliance on coal and has seen very little expansion in natural gas generation (Figure 23). The most dynamic sector in this region is non-hydro renewables, particularly wind. Electricity demand has not declined in MRO as it has in NPCC and RFC, but has instead remained stable since 2005.

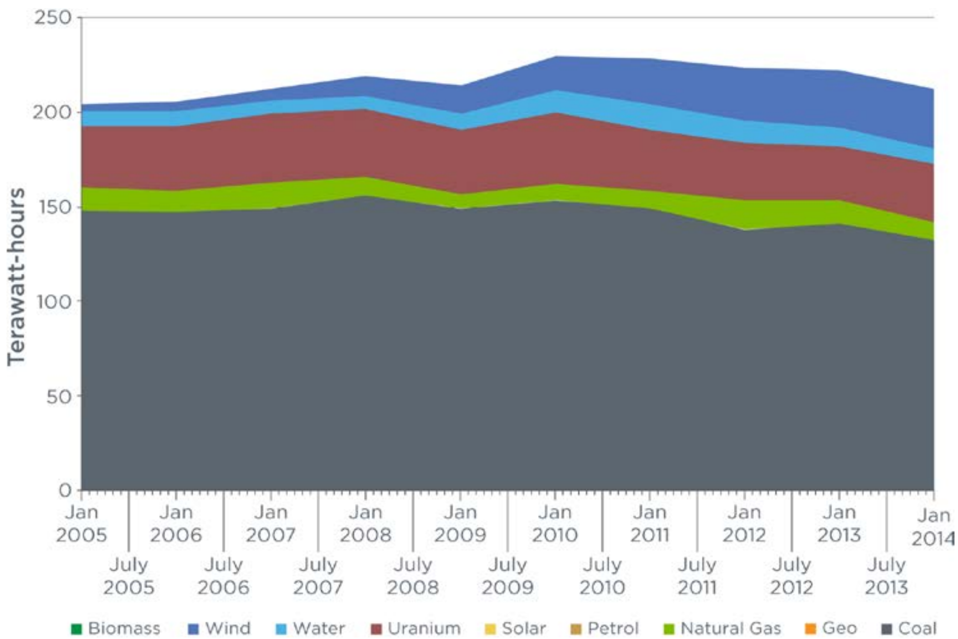

Figure 23. The changing generation mix in the MRO region

Source: Created by JISEA using SNL (2015) data

Utilization of steam turbine plants (largely coal) in the MRO has declined slowly but steadily since 2005, but still stood at a 64% fleet-wide average in 2014 (Table 1). Combined-cycle capacity factors have been rising, but still stood at less than 20% in 2014 (Figure 24 and Table 1). Of note, average utilization of wind plants is higher than that of combined-cycle plants. Given the high coal and low gas plant usage, this region appears to have potential to make greater use of combined-cycle generators as a means to comply with the CPP, but additional analysis is required to verify that existing infrastructure is compatible with the redispatch.

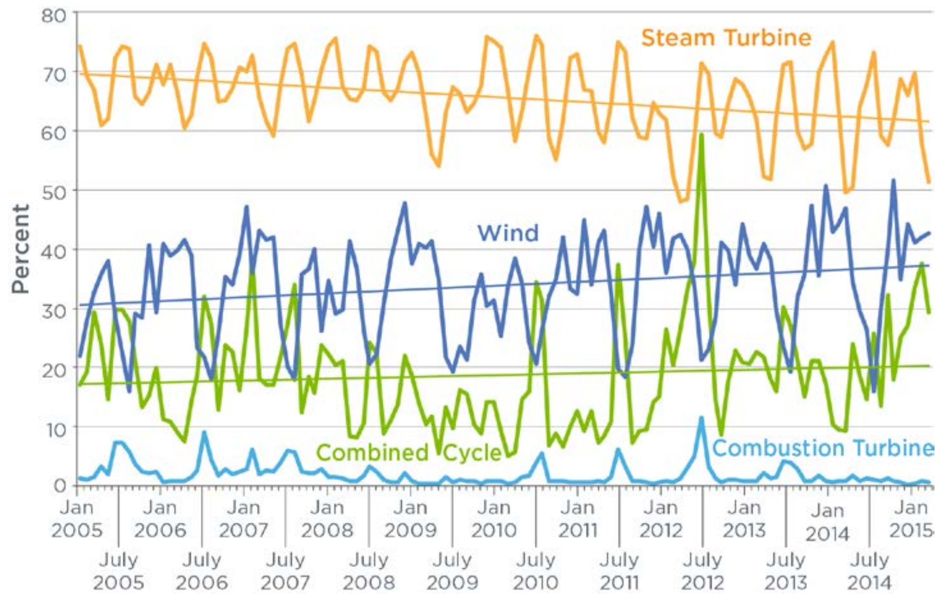

Figure 24. Changing capacity factors for select technologies in MRO

Source: Created by JISEA using SNL (2015) data

The outlook for new capacity in MRO indicates modest overall growth through 2020 (Figure 25). The largest source of expected new generating capacity is wind, followed by natural gas. Significant coal plant retirement is also expected, keeping overall net expansion in check.

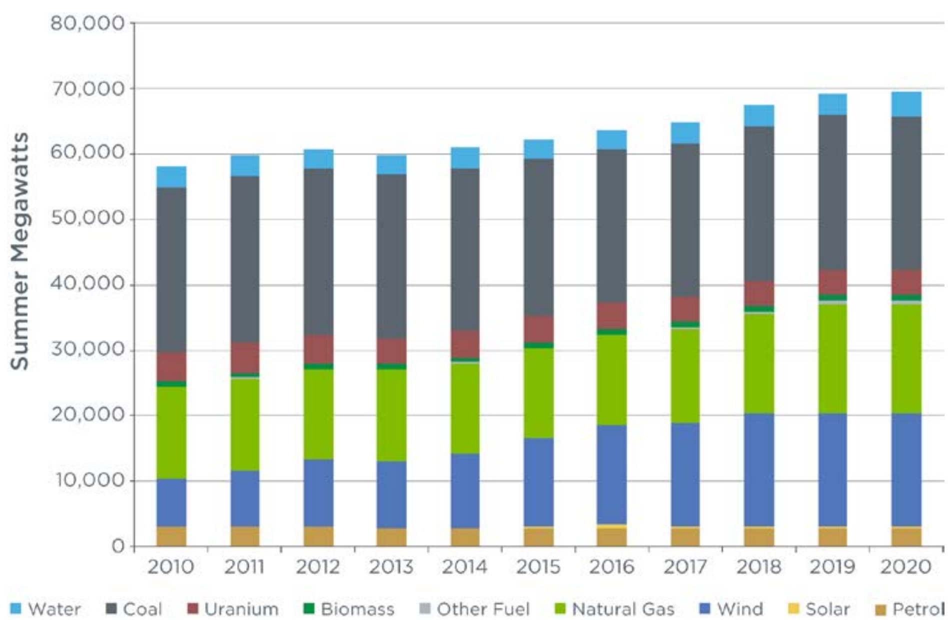

Figure 25. Historic (pre-2015) and expected capacity in the MRO region

Source: Created by JISEA using SNL (2015) data

Note: Future capacity is based on actual planned/under construction projects, and not based on any projections of unreported new developments or retirements.

3.4 Florida Reliability Coordinating Council

The Florida Reliability Coordinating Council (FRCC) region, like many others, has seen a steady erosion in coal generation that has been replaced largely with natural gas (Figure 26). The region is heavily dependent on natural gas generation. Petroleum-fired electricity has now largely disappeared in the FRCC, although other sources of power remain fairly stable. Overall demand is relatively steady, but has declined slightly compared to historic levels. Unique to this region is the decline in non-hydro renewable generation, mainly due to a drop in biomass-fired power (Table 1).

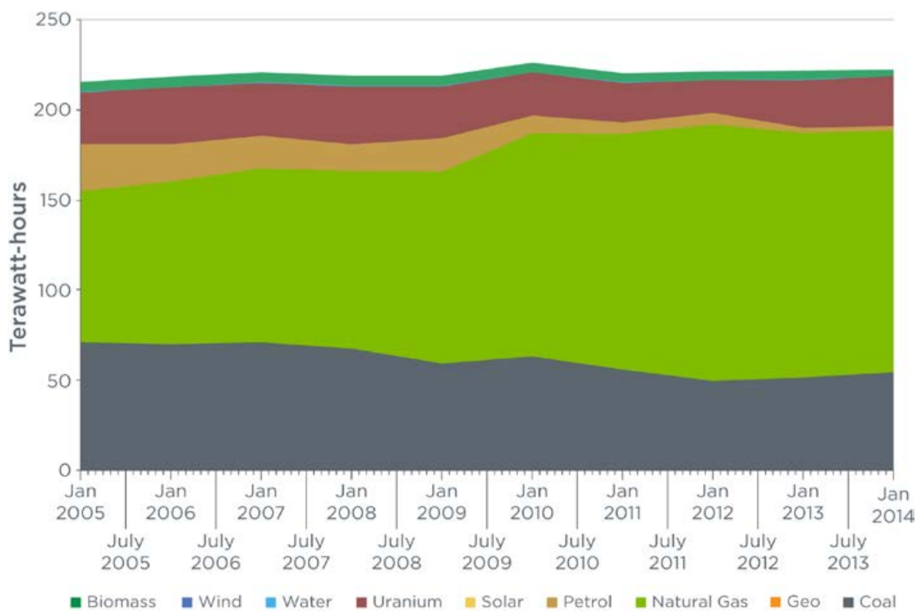

Figure 26. The changing generation mix in the FRCC region

Source: Created by JISEA using SNL (2015) data

Plant utilization in the FRCC has fallen rapidly for steam turbines (coal) while rising more modestly for combined-cycles (Figure 27). The capacity factor profile for nuclear plants is normally steady with the exception of scheduled maintenance outages every year or two. Although Florida has only two nuclear power plants, they seem to exhibit a deeper fluctuation in utilization compared to, at least, the Southeast Reliability Council region (Figure 30).

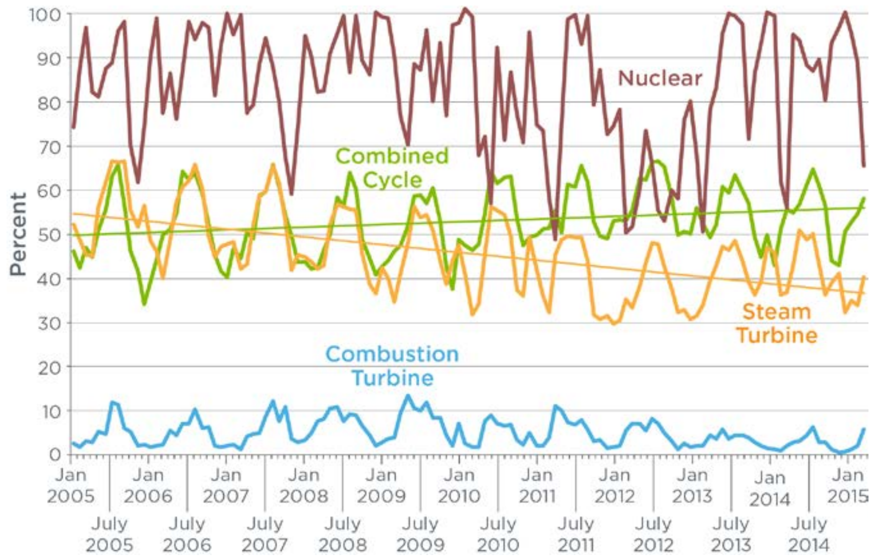

Figure 27. Changing capacity factors for select technologies in FRCC

Source: Created by JISEA using SNL (2015) data

Expected capacity changes in FRCC include a reduction in coal and petrol, an increase in natural gas, and modest increases in biomass and solar (Figure 28). Like NPCC, the FRCC region appears to be increasingly reliant on NGCC for a large portion of its generating mix. Any disruption in natural gas supply or increase in prices could thus have significant impacts on the region compared to others.

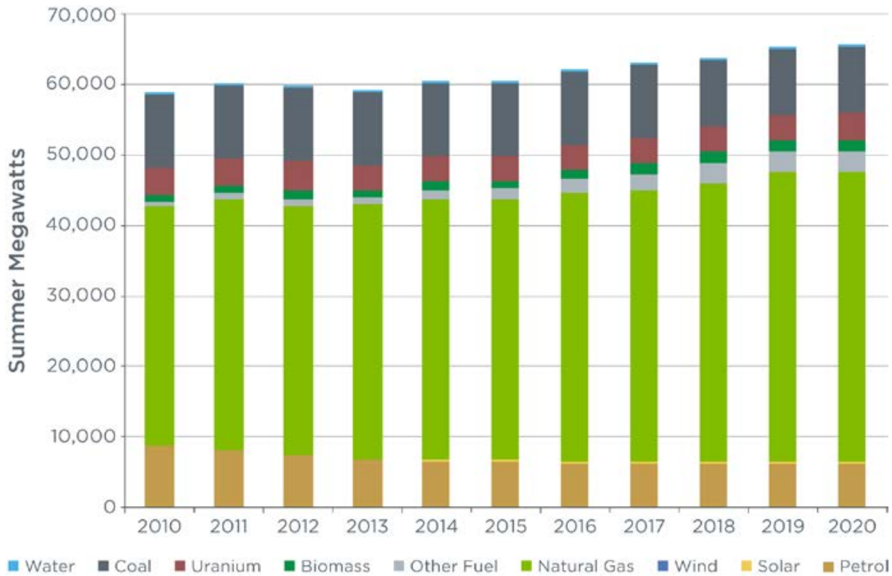

Figure 28. Historic (pre-2015) and expected capacity in the FRCC region

Source: Created by JISEA using SNL (2015) data
Note: Future capacity is based on actual planned/under construction projects, and not based on any projections of unreported new developments or retirements.

3.5 Southeast Reliability Council

The Southeast Reliability Council (SERC) region has seen a notable shift from coal to natural gas generation since 2005 (Figure 29). Other forms of generation are largely stable. Aggregate demand has declined slightly since 2005.

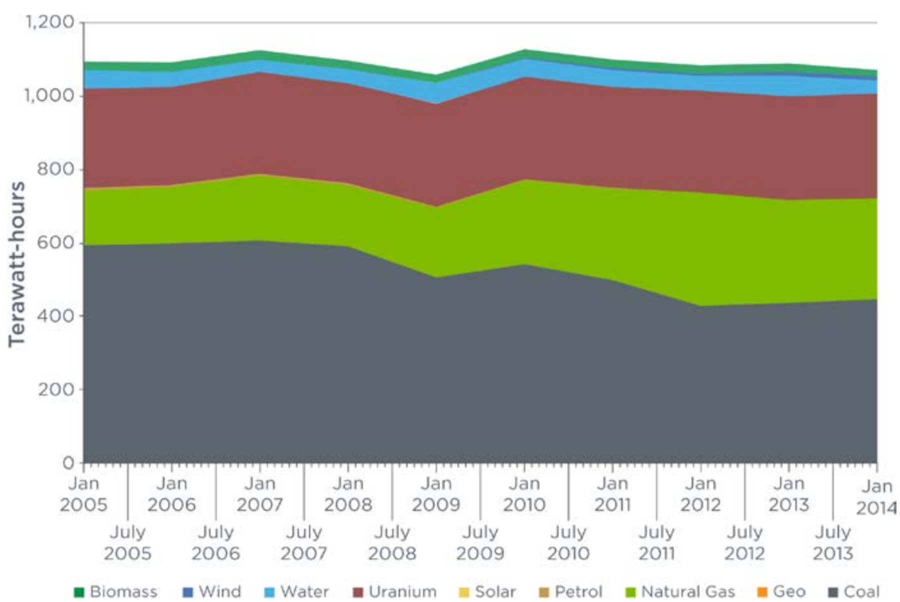

Figure 29. The changing generation mix in the SERC region

Source: Created by JISEA using SNL (2015) data

Utilization rates for steam turbines (coal) and combined-cycle plants are moving inversely, with the former down to 51% in 2014 (Figure 30 and Table 1). Wind capacity factors have risen steadily to nearly 40%, although from a limited base of projects, while nuclear and combustion turbines remain relatively stable at nearly 90 and 5%, respectively.

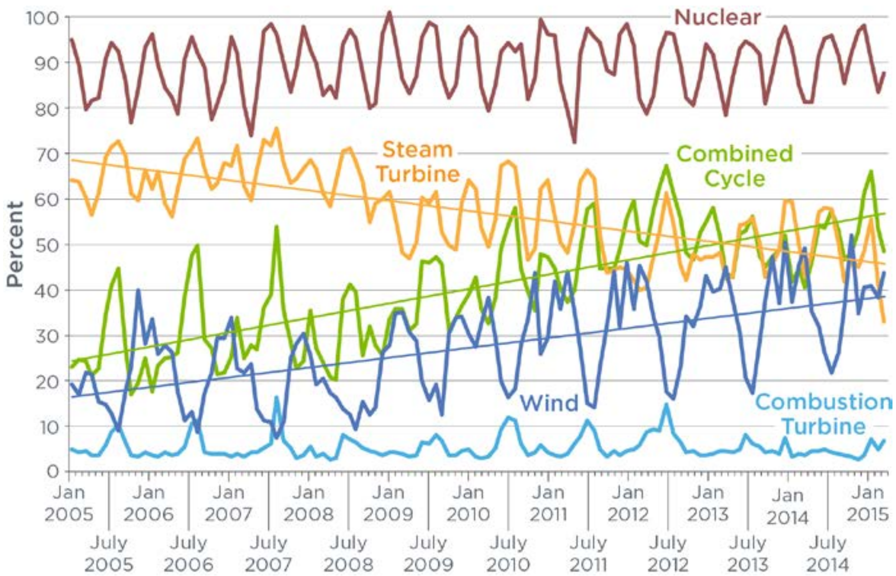

Figure 30. Changing capacity factors for select technologies in SERC

Source: Created by JISEA using SNL (2015) data

Expected changes in generation capacity in SERC include a decline in coal and slight upticks for natural gas, wind, and solar (Figure 31). Otherwise, the market is relatively stable given the lack of significant demand growth.

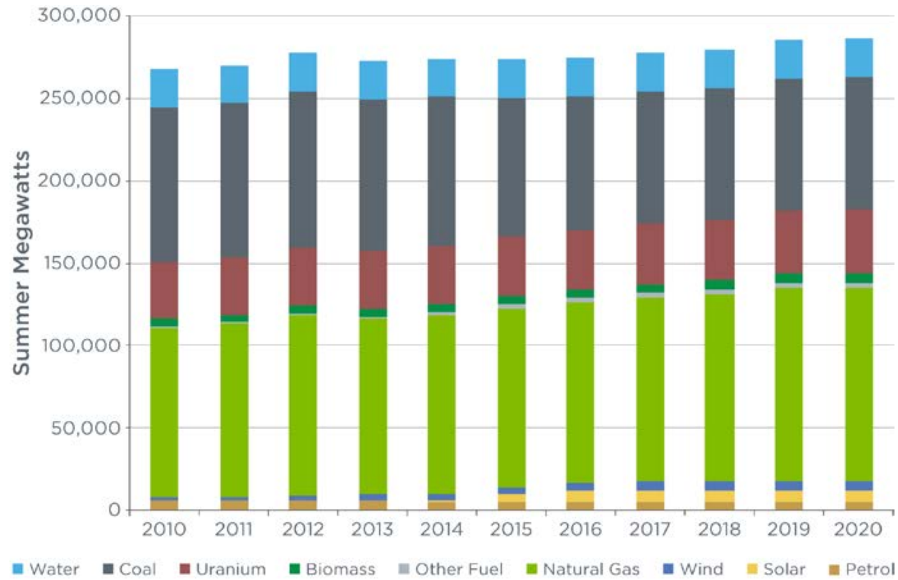

Figure 31. Historic (pre-2015) and expected capacity in the SERC region

Source: Created by JISEA using SNL (2015) data
Note: Future capacity is based on actual planned/under construction projects, and not based on any projections of unreported new developments or retirements.

3.6 Southwest Power Pool

The generation mix in the Southwest Power Pool (SPP) region has remained more stable than many other regions, with a continued heavy reliance on coal and modest drop in natural gas generation (Figure 32 and Table 1). Wind power has expanded significantly since 2010 in SPP.

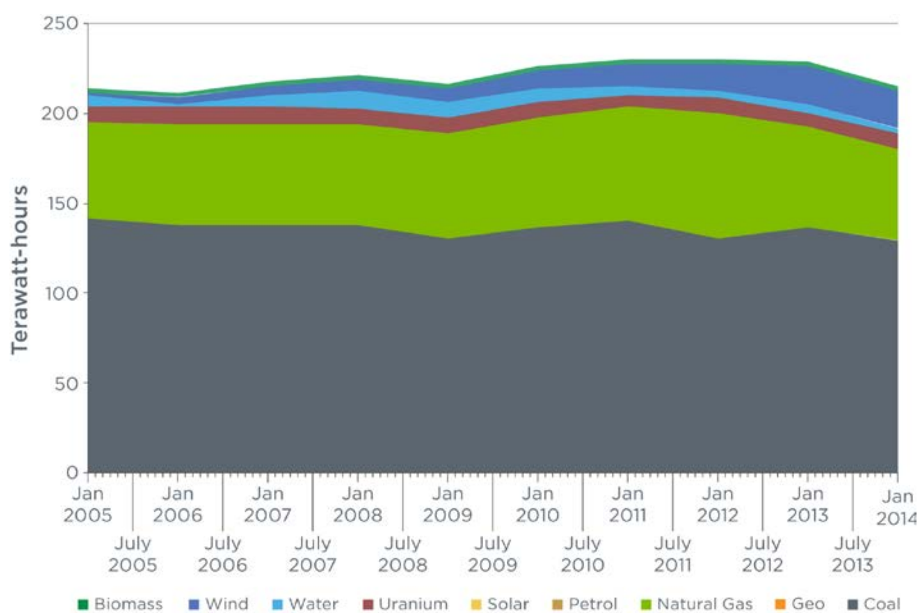

Figure 32. The changing generation mix in the SPP region

Source: Created by JISEA using SNL (2015) data

As in many other regions, the trend in utilization of steam turbines (mainly coal plants) in SPP is falling while that for combined-cycle plants is increasing (Figure 33).

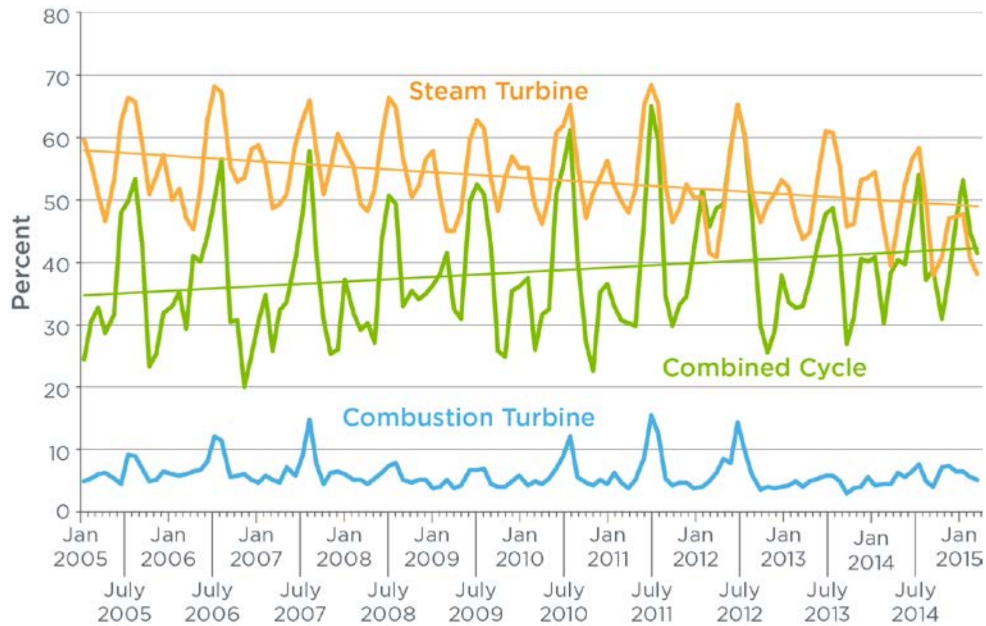

Figure 33. Changing capacity factors for select technologies in SPP

Source: Created by JISEA using SNL (2015) data

Announced new projects in SPP are fairly modest, with the exception of new wind builds. Figure 34 illustrates these expected changes in new generation capacity, and the strong historical growth in wind capacity.

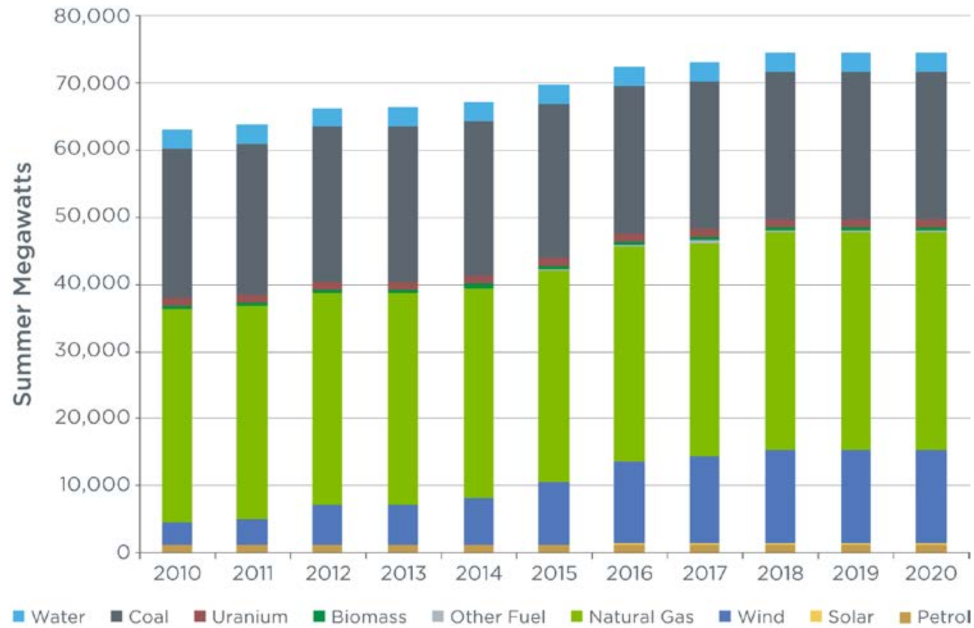

Figure 34. Historic (pre-2015) and expected capacity in the SPP region

Source: Created by JISEA using SNL (2015) data
Note: Future capacity is based on actual planned/under construction projects, and not based on any projections of unreported new developments or retirements.

3.7 Texas Reliability Entity

The Texas Reliability Entity (TRE) is one of the few NERC regions that is still witnessing growth in electricity demand (Table 1). Wind is the fastest growing source of new generation in TRE, with both coal and natural gas generation remaining relatively stable, with the exception of a forceful shift from coal to natural gas during the initial months of 2015 (Figure 35). TRE is heavily reliant on natural gas generation.

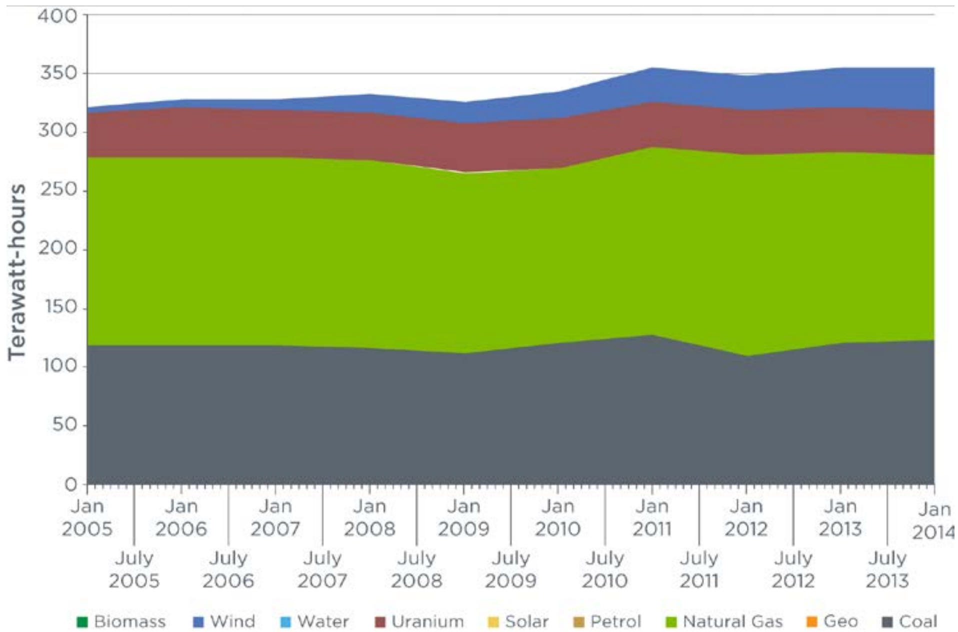

Figure 35. The changing generation mix in the TRE region

Source: Created by JISEA using SNL (2015) data

Unlike any other NERC region, the average utilization rates for steam turbines (mainly coal) in TRE has been increasing over the past decade, while that for combined-cycles has been slowly declining (Figure 36). Much of the decline in the latter is the result of new combined-cycle capacity being added each year, which can lead to lower average capacity factors if the rate of installations exceed the rate of growth in total electricity demand, all else being equal. Over the past year, steam turbine capacity factors and actual generation have fallen sharply, perhaps aligning trends in TRE with most other NERC regions. Interestingly, utilization of combustion turbines in TRE has been declining, but still remains relatively high compared to other regions.

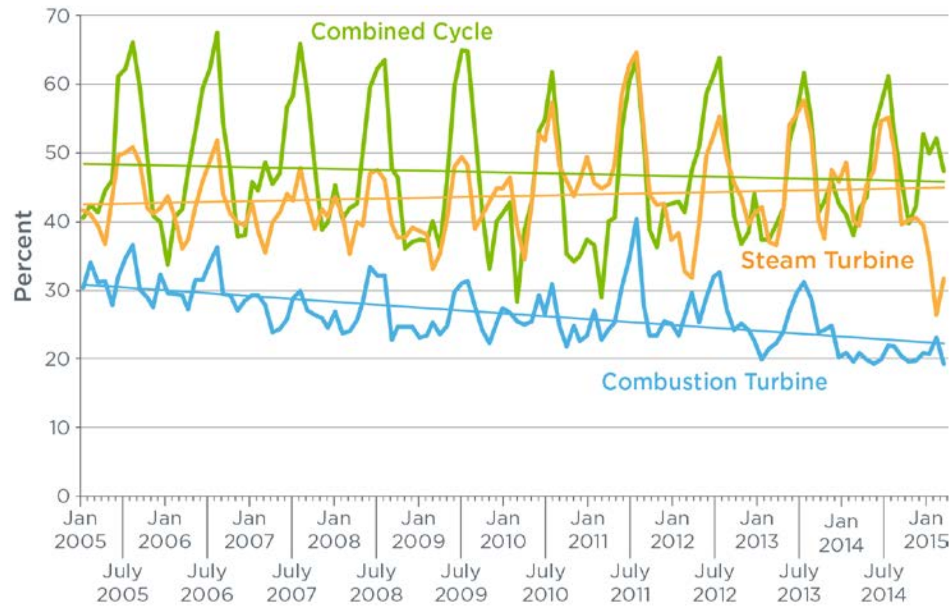

Figure 36. Changing capacity factors for select technologies in TRE

Source: Created by JISEA using SNL (2015) data

TRE expects continued growth in both natural gas and wind installations over the coming years, as shown in Figure 37. Note that there has been some modest retirements of old, natural gas-fired steam turbines in TRE over the past few years.

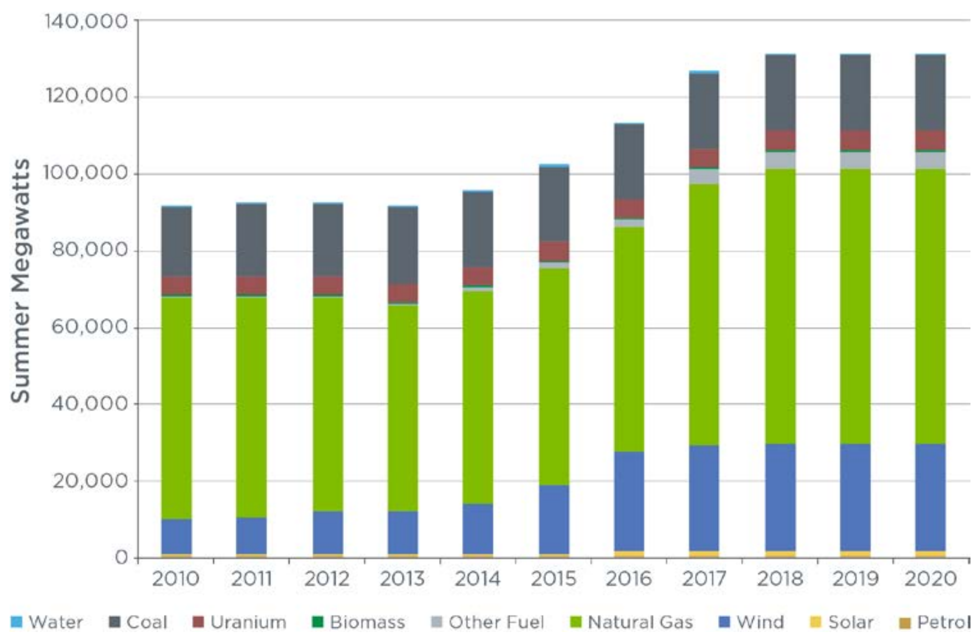

Figure 37. Historic (pre-2015) and expected capacity in the TRE region

Source: Created by JISEA using SNL (2015) data
Note: Future capacity is based on actual planned/under construction projects, and not based on any projections of unreported new developments or retirements.

3.8 Western Electric Coordinating Council

The WECC region is unique among all others for its high proportion of zero and low-carbon generation (Figure 38). Coal generation is relatively low in this region, and falling, while nuclear, hydro, wind, solar, and other renewables accounted for 39% of total generation in 2014. Natural gas generation in WECC has been relatively stable. Total demand for electricity has fallen by 5% since 2005.

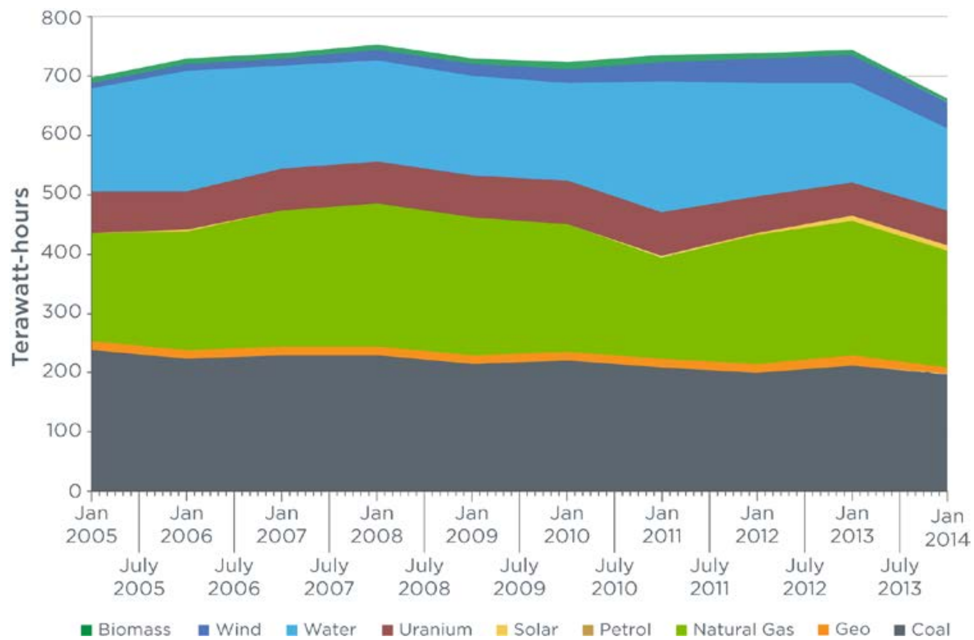

Figure 38. The changing generation mix in the WECC region

Source: Created by JISEA using SNL (2015) data

Plant utilization in WECC is similar to other regions in exhibiting falling coal plant capacity factors (Figure 39). Natural gas plant utilization in WECC is falling slowly for both combined-cycles and combustion turbines. Utilization of nuclear plants showed an unusual drop off for parts of 2012–2013 due to the idling of the San Onofre nuclear generating station after the discovery of extensive corrosion problems. Utilization rose again in late 2013 when it was announced that the plant would retire and its capacity was taken out of the calculation of capacity factor.

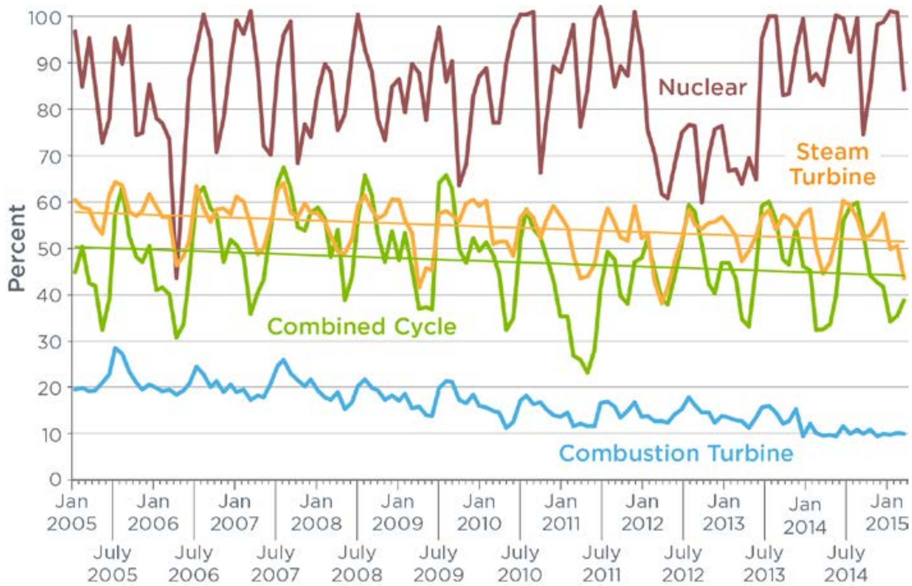

Figure 39. Changing capacity factors for select technologies in WECC

Source: Created by JISEA using SNL (2015) data

Most of the expected growth in new capacity in WECC is solar, wind, and natural gas (Figure 40). California's renewable portfolio standard (RPS) and other programs are driving much of the growth in renewables there (CEC 2015).

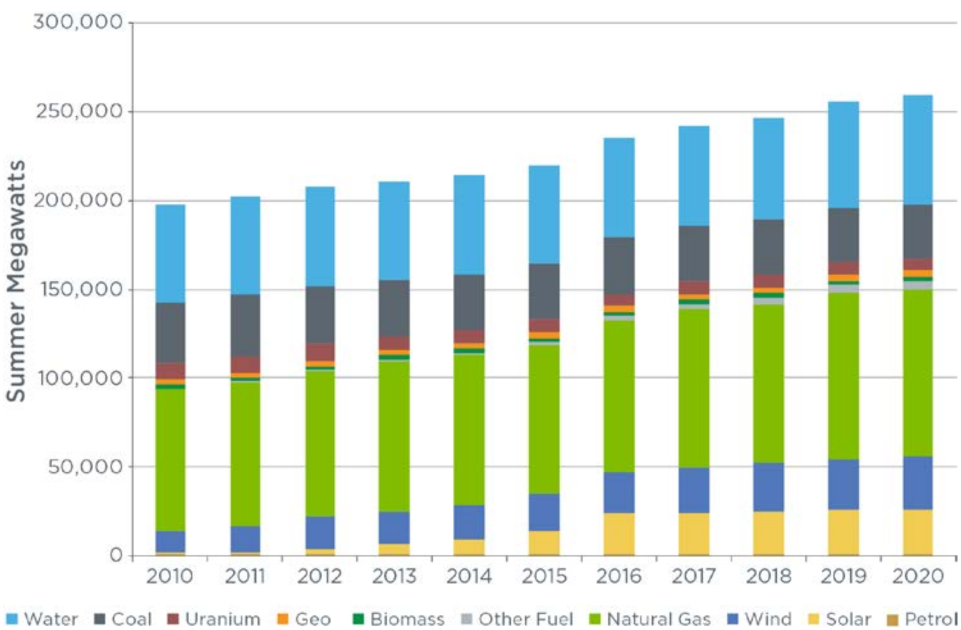

Figure 40. Historic (pre-2015) and expected capacity in the WECC region

Source: Created by JISEA using SNL (2015) data
Note: Future capacity is based on actual planned/under construction projects, and not based on any projections of unreported new developments or retirements.

Table 1. Summary of Selected Changes in Regional Power Markets

Region	% Change in Power Demand (2005–2014)	% Change in Natural Gas Generation (2005–2014)	% Change in Coal Generation (2005–2014)	% Change in Non-hydro RE Generation (2005–2014)	2014 Fleet-wide Capacity Factor for NGCC (%)	2014 Fleet-wide Capacity Factor for Coal (%)
NPCC	-20	0	-75	5	45	19
RFC	-11	111	-29	199	47	53
SERC	-2	84	-25	16	49	51
FRCC	3	60	-23	-39	53	43
MRO	3	-23	-10	430	18	64
SPP	0	-5	-8	417	40	48
TRE	10	3	-1	751	47	46
WECC	-5	8	-17	115	45	54

4 Synthesis and Conclusions

The U.S. electricity sector is undergoing a period of profound change due largely to developments in and supportive policies for natural gas and renewable energy technologies. Coal-fired generation has experienced the greatest impact from these developments and generation is down about 25% from 2008 levels. Natural gas and renewable electricity have largely made up the difference. Increased use of natural gas and renewables in place of coal has, *inter alia*, led to significant reductions in burner-tip carbon dioxide emissions.

Future growth in natural gas demand is likely to be strongest in the power sector and the industrial sector. Exports, particularly LNG, are also expected to grow strongly. Without significant technology breakthroughs or shifts in consumer behavior, residential and commercial gas demand is likely to remain stable. Growth in transportation sector natural gas demand remains strong, but is starting from a very low level.

The shift from coal to natural gas in the power sector is not happening uniformly throughout the country, but instead is occurring mainly in the eastern portion. That said, the central and western sections of the country may still be experiencing increases in power sector natural gas demand, especially in the first half of 2015, but these changes are relatively modest compared to the eastern regions (SERC, NPCC, FRCC, and RFC). Growth in renewable electricity generation is occurring fastest in the central and western portions of the country, supplementing the shift from coal to natural gas in the east.

The U.S. natural gas sector continues to experience opportunities and challenges. First, natural gas supply is expected to remain plentiful and continuous improvements in drilling and production efficiency will likely continue to put downward pressure on prices. This will likely lead to continued growth in gas consumption across most sectors. Second, environmental regulations, including the Clean Power Plan, could drive additional natural gas demand in the power sector.

The gas sector also faces complex barriers, including public opposition to drilling in some regions of the country and general concerns that hydraulic fracturing can threaten air and water resources, impact local communities, induce earthquakes, and result in higher greenhouse gas emissions if fugitive emissions are not controlled (Logan et al. 2013; Arent et al. 2015; Weingarten et al. 2015). More fundamentally, the natural gas sector could meet a "dead end" within a decade or two if the United States chooses to reduce greenhouse gas emissions by 80% from 1990 levels by the year 2050. Unless carbon capture and sequestration technologies are deployable by 2030 or soon thereafter, natural gas combustion in the power sector may need to peak, at least assuming that the power sector contributes substantially to move to such an emissions pathway (Logan et al. 2013). This uncertainty raises important questions about the length of the natural gas bridge to a more sustainable future, and introduces the possibility of stranded assets should the country need to mitigate emissions more rapidly than previously envisioned. Finally, the percentage of generation served by natural gas in some regions of the country is high enough to risk overexposure. Although it seems unlikely that the shale gas revolution will collapse, almost all analysts were similarly caught off guard when the revolution commenced. Prudent investors and regulators may benefit from keeping this in mind when planning future generation portfolios.

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