Experts Agree: The U.S. Power Sector is Rapidly Decarbonizing as a Result of Market Trends

By Nicholas Bianco & Martha Roberts

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The power sector is in the midst of a steady move to a low carbon future. In recent years, new generation has been dominated by low-cost zero-carbon and lower-carbon resources. As a result, carbon dioxide pollution from the power sector declined by 21 percent from 2005 levels by 2015.[1] These trends are expected to continue. Data shows that emissions from the power sector further declined to 25 percent below 2005 levels over the last 12-month period for which data was available (October 2015-September 2016).[2] These rapid declines are being driven by a number of factors, including steadily falling renewable prices, sustained low natural gas prices, consumer preference, and Congress' extension of tax credits for renewable energy resources. As a result the power sector is achieving significant emissions reductions and is on its way to achieving the 2030 targets in the Clean Power Plan (CPP).

Our review of the literature finds that experts expect these trends to continue and that the power sector is already evolving consistent with the best system of emissions reductions contemplated by the U.S. Environmental Protection Agency (EPA) when the Agency developed the Clean Power Plan. Furthermore, there is general consensus that it will be even easier to meet the climate pollution reduction goals of the program than EPA previously predicted, and thus EPA's approach in calculating emission reduction goals was conservative.

While all of these trends are encouraging, it is clear that the Clean Power Plan has an essential role to play in ensuring that these reasonable reductions are achieved. It does so by establishing clear market and regulatory signals to power companies that encourage them to both think long-term and to deploy their generation in a manner that allows them to cost-effectively reduce climate pollution while maintaining affordable and reliable power supplies. It can also help protect against any shift in market conditions that might otherwise undermine the progress being made.

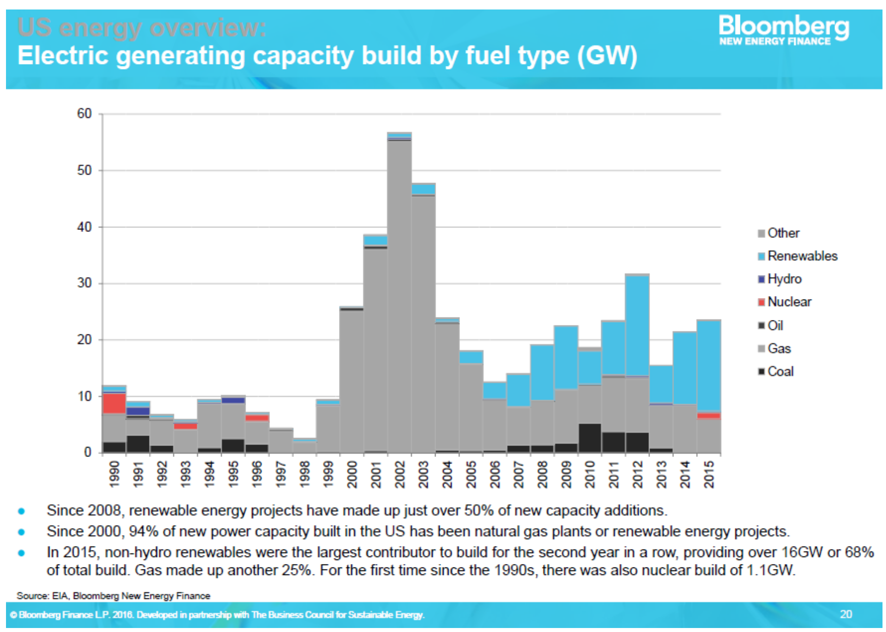
In this report, we review the literature showing that:

1. Emissions of climate pollution from the power sector are falling while states grow their economies;

[1] U.S. EIA, Carbon dioxide emissions from electricity generation in 2015 were lowest since 1993. May 2016. https://www.eia.gov/todayinenergy/detail.php?id=26232
[2] U.S. EIA, U.S. Carbon dioxide emissions from energy consumption. December 2016 Monthly Energy Review, http://www.eia.gov/environment/data.cfm#summary

2. Studies consistently show that the climate pollution goals established under the Clean Power Plan are readily achievable and consistent with current trends, and also that the Clean Power Plan is essential for realizing the sectors emission reduction targets;
3. These trends are equally apparent at the state and company level;
4. Underlying these developments is a surge in renewable development, which is largely driven by increasingly favorable economics;
5. Low natural gas prices continue to drive reductions in emissions of climate pollution as a result of a re-dispatch of the system away from the highest emitting plants; and
6. States and consumers continue to grow their investments in energy efficiency, lowering electric bills while creating jobs and reducing emissions of climate pollution; and,
7. Power generators also have important opportunities to reduce emissions through heat rate improvements and other improvements.

Background on the Clean Power Plan



The Clean Power Plan establishes the nation's first ever climate pollution standards for the power sector, which is the largest source of climate pollution in the United States and one of the largest sources in the world. (According to EPA, electricity generation accounted for nearly 30 percent of all U.S. climate pollution in 2014.[3]) As a result, the Clean Power Plan is one of the most important measures the United States has ever taken to combat the threat of climate change. The Clean Power Plan is expected to ensure that carbon dioxide emissions from the power sector decline **32 percent** below 2005 levels by 2030.

Power plants are also major sources of emissions for a range of pollutants that contribute to ground-level ozone, better known as smog, and dangerous particulate pollution, better known as soot—as well as for pollutants that have neurotoxic or carcinogenic (cancer-causing) effects. It is anticipated that steps taken to reduce climate pollution under the Clean Power Plan will have

[3] U.S. EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2014

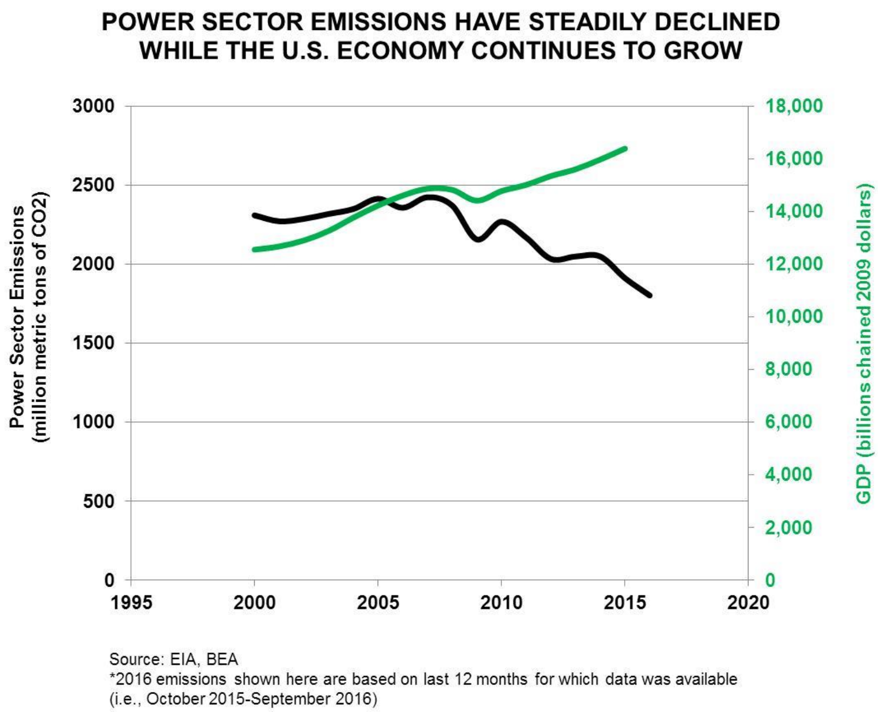
the additional benefit of reducing emissions of these and other harmful air pollutants, in addition to helping mitigate climate change.

As a result, when the program is fully implemented it will yield up to **$54 billion** in annual climate and health benefits and save up to **3,600 lives** each year.

Emissions of Climate Pollution from the Power Sector Are Falling While States Grow Their Economies

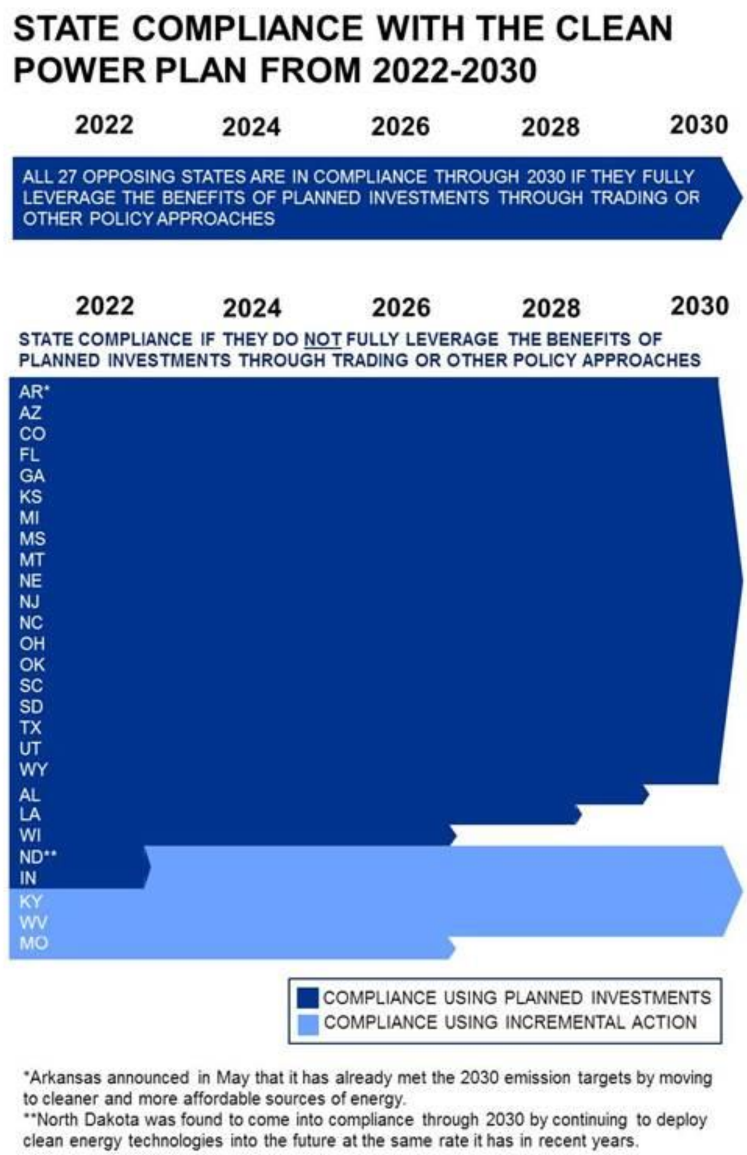
The power sector is in the midst of a steady move to a low-carbon future. In recent years, new generation has been dominated by low-cost zero-carbon and lower-carbon resources, with natural gas and renewables accounting for 94 percent of all new generation built from 2000 to 2015 (see Figure 1).[4] Carbon-free energy accounted for 70 percent of all new generation brought online last year.[5] Recent estimates suggest that through the end of 2016, the nation will have built more than 21 gigawatts (GW) of wind[6] and solar[7] combined and at least 8 GW of natural gas.[8] These trends are expected to continue as these resources remain consistently more cost effective.[9]

These trends have helped drive a steady decline in climate pollution from the power sector. The Energy Information Administration (EIA) reports that emissions had already fallen 21 percent below 2005 levels in 2015.[10] These trends have continued through 2016. Using the most recent 12 month period (October 2015-September 2016), we found that emissions from the power sector



[4] Sustainable Energy in America Factbook. Bloomberg New Energy Finance. 2016 www.bcse.org/sustainableenergyfactbook/
[5] Sustainable Energy in America Factbook. Bloomberg New Energy Finance. 2016 http://www.bcse.org/sustainableenergyfactbook/
[6] https://www.snl.com/web/client?auth=inherit#news/article?id=38605862&KPLT=6&s_data=si%3D7%26kpa%3Dundefined%26sa%3D
[7] http://www.seia.org/research-resources/solar-market-insight-report-2016-q4
[8] https://www.ferc.gov/legal/staff-reports/2016/oct-energy-infrastructure.pdf
[9] www.wri.org/publication/seeing-believing-creating-new-climate-economy-united-states
[10] https://www.eia.gov/todayinenergy/detail.php?id=26232

had declined to 25 percent below 2005 levels.[11] As a result, the power sector is clearly in a position to be able to cost-effectively achieve the 2030 targets established by EPA under the Clean Power Plan.



Notably, these reductions have occurred while the U.S. economy has grown by more than 15 percent (2005-2015).[12] The United States is hardly alone in decoupling economic growth from emissions of climate pollution. Analysis by WRI shows that the United States and 20 other countries have successfully decoupled economic growth over the period from 2000 to 2014, as measured by Gross Domestic Product (GDP), and emissions of climate pollution from energy-related activities. Leveraging modeling by EIA, WRI further concluded that these trends will continue here in the United States in the years ahead. [13]

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[11] http://www.eia.gov/environment/data.cfm#summary. EIA publishes monthly emissions data for the power sector, with September 2016 the latest month for which data was available at the time of this report.
[12] Figure based on real GDP in chained 2009 dollars. From: "Current-dollar and "real" GDP. Bureau of Economic Analysis, last accessed December 30, 2016. Available at: https://www.bea.gov/national/xls/gdplev.xls
[13] http://www.wri.org/blog/2016/04/roads-decoupling-21-countries-are-reducing-carbon-emissions-while-growing-gdp

Studies consistently show that the climate pollution goals established under the Clean Power Plan are readily achievable and consistent with current trends, and also that the Clean Power Plan is essential for realizing the sectors emission reduction targets

An array of analyses have assessed future power sector emissions and concluded that strong existing trends towards low-cost, low-carbon generation resources are already driving the power sector towards lower emissions, consistent with EPA's identified best system of emission reduction. They consistently find that these trends mean that natural gas and renewable energy generation will continue to expand substantially in future years.

As a result, these analyses generally conclude that the business-as-usual baseline level of carbon emissions from the power sector will be lower than EPA projected in its Clean Power Plan analysis, and that reaching the Clean Power Plan targets will be even more readily achievable than originally anticipated. These studies correspondingly reinforce that achievement of the Clean Power Plan targets is eminently affordable, with minimal impacts on electricity rates—and the potential for substantial overall bill *savings* for consumers where energy efficiency investments are used to help achieve emission reduction targets. Further, these analyses show that the Clean Power Plan ensures that cost-effective measures will be implemented in all states and drives the deployment of these measures throughout the nation—while providing certainty to guide optimal investment decisions.

Appendix 1 provides a detailed summary of seven analyses that each reach these conclusions. These analyses reflect the work of a wide range of organizations, from consulting firms to academic policy institutes, including: the Bipartisan Policy Center (BPC)[14], the Center for Climate and Energy Solutions (C2ES)[15], the Energy Information Administration (EIA),[16] M.J. Bradley & Associates [17], the Nicholas Institute for Environmental Policy Solutions at Duke University (Nicholas Institute)[18], and Resources for the Future.[19] Their results are robust across

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[14] "The Bipartisan Policy Center is a non-profit organization that combines the best ideas from both parties to promote health, security, and opportunity for all Americans. BPC drives principled and politically viable policy solutions through the power of rigorous analysis, painstaking negotiation, and aggressive advocacy. As the only Washington, DC-based think tank that actively promotes bipartisanship, BPC works to address the key challenges facing the nation. Our policy solutions are the product of informed deliberations by former elected and appointed officials, business and labor leaders, and academics and advocates who represent both ends of the political spectrum. We are currently focused on health, energy, national and homeland security, the economy, housing, immigration, infrastructure, and governance." BPC website, http://bipartisanpolicy.org/about/who-we-are/

[15] C2ES is "an independent, nonpartisan, nonprofit organization working to forge practical solutions to climate change." Center for Climate and Energy Solutions, About the Center for Climate and Energy Solutions, http://www.c2es.org/about.

[16] "The U.S. Energy Information Administration (EIA) collects, analyzes, and disseminates independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding of energy and its interaction with the economy and the environment." U.S. Energy Information Administration, About EIA, http://www.eia.gov/about/.

[17] "M.J. Bradley & Associates LLC (MJB&A) provides strategic and technical advisory services to address critical energy and environmental matters including: energy policy, regulatory compliance, emission markets, energy efficiency, renewable energy, and advanced technologies. Our multi-national client base includes electric and natural gas utilities, major transportation fleet operators, clean technology firms, environmental groups and government agencies." M.J. Bradley and Associations, About Us, http://www.mjbradley.com/about-us.

[18] "The Nicholas Institute for Environmental Policy Solutions at Duke University improves environmental policymaking worldwide through objective, fact-based research to confront the climate crisis, clarify the economics of limiting carbon pollution, harness emerging environmental markets, put the value of nature's benefits on the balance sheet, develop adaptive water management approaches, and identify other strategies to attain community resilience.

the several different power sector modeling platforms and modeling assumptions employed, including IPM, NEMS, Haiku, ReEDS, and DIEM.

Remarkably, this suite of analytic efforts demonstrated resoundingly consistent conclusions. The robustness of these findings across multiple different sources underscores the achievability of the Clean Power Plan targets.

These trends are equally apparent at the state and company level

Evaluations that focused on state and power company pathways to reach Clean Power Plan targets tell a similar story. These analyses also find that, thanks to underlying power market trends, individual states and companies are very well positioned to achieve the Clean Power Plan targets.

Analysis conducted for EDF by M.J. Bradley & Associates found that all 27 states opposing the Clean Power Plan could come into compliance with their emission reduction targets all the way through 2030 by fully harnessing the power of planned investments coupled with existing state laws.[20]

The analysis also considered conservative scenarios in which states do not take advantage of program flexibilities that allow them to capture cross-state abatement opportunities even if so doing would result in cost savings. When combined with subsequent announcements by Arkansas, they found that at least 22 of the states could comply through 2024 by fully leveraging planned investments, and that 19 states could comply through 2030. For the minority of states that were not found to meet their Clean Power Plan emission reduction targets through planned investments alone, this analysis indicates that states can reach their targets with cost-effective and available measures.

While the analysis shows that these states are well positioned for compliance, it also reaffirms the importance of the Clean Power Plan in delivering the needed reductions in climate pollution over the long term. This is because building new clean generation alone is not enough. It is also vital to ensure that the benefits of these investments are fully realized through optimal deployment. By establishing nationwide emission limits through 2030, the Clean Power Plan will provide clear market and regulatory signals to power companies to ensure generation shifting occurs in a manner that reduces climate pollution.

The Nicholas Institute is part of Duke University and its wider community of world-class scholars. This unique resource allows the Nicholas Institute's team of economists, scientists, lawyers and policy experts to not only deliver timely, credible analyses to a wide variety of decision makers, but also to convene these decision makers to reach a shared understanding regarding this century's most pressing environmental problems." The Nicholas Institute, About Us, https://nicholasinstitute.duke.edu/about.

[19] "Resources for the Future (RFF) is an independent, nonpartisan organization that conducts rigorous economic research and analysis to help leaders make better decisions and craft smarter policies about natural resources and the environment. RFF was the first think tank devoted exclusively to natural resource and environmental issues and helped create the field of environmental and natural resource economics." Resources for the Future, About RFF, http://www.rff.org/about.

[20] http://blogs.edf.org/climate411/files/2016/09/MJB-study-on-CPP-compliance.pdf

These findings are not unique. Similar results were obtained for Arizona by Pace Global,[21] which was contracted by the Arizona Utilities Group[22] to model Clean Power Plan compliance paths. Using Aurora, an hourly chronological dispatch model, and generation supply and load outlook assumptions provided by participating utilities, they found that the state can comply with the Clean Power Plan based on investments already planned under business-as-usual conditions.[23]

Similar results were also obtained for the states of Virginia,[24] Pennsylvania,[25] Michigan,[26] Missouri,[27] and Illinois[28] by the World Resources Institute[29] (WRI) when evaluating individual state-level compliance pathways using an in-house emissions modeling platform. Specifically, they found that the examined states could make considerable progress towards compliance, and in many cases come into compliance and even exceed the Clean Power Plan targets, through the combination of clean energy policies and targets on the books coupled with the more efficient use of existing infrastructure. The more efficient use of existing infrastructure includes better leveraging existing natural gas infrastructure and adopting low-cost operational improvements and best practices at coal plants, both of which are incentivized under the Clean Power Plan.

This progress can also be observed at the company level. Recent analysis by EDF found that even the companies that are litigating against the Clean Power Plan are making investments in low-cost, low-carbon technologies and strategies, and are well positioned to achieve the Clean Power Plan's emission targets, even though the companies are repeatedly claiming otherwise in court. Thus, these companies' own actions affirm the reasonableness of the Clean Power Plan targets.[30]

These studies are discussed in more detail in Appendix 2.

Finally, these findings are reinforced by numerous statements from state[31] and power sector officials[32] highlighting the achievability of the Clean Power Plan.

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[21] "Pace Global, A Siemens Business, is a leading provider of strategic energy consulting services. For nearly 40 years, Pace Global has provided innovative services to support the execution of business strategies, complex energy transactions, asset development, and operations focusing on select markets in the Americas." Pace Global, About, http://www.paceglobal.com/about/

[22] The Arizona Utilities Group consists of Arizona Electric Power Cooperative, Inc., Arizona Public Service Company, Salt River Project Agricultural Improvement and Power District, Tucson Electric Power Company, and UniSource Energy Services.

[23] Pace Global, CPP Rate-Mass Assessment, February 2016, Available at: http://legacy.azdeq.gov/environ/air/download/pace_cpp_rate.pdf

[24] http://www.wri.org/publication/how-virginia-can-meet-its-clean-power-plan-targets

[25] http://www.wri.org/publication/how-pennsylvania-can-meet-its-clean-power-plan-targets

[26] http://www.wri.org/publication/how-michigan-can-meet-its-clean-power-plan-targets

[27] http://www.wri.org/publication/how-missouri-can-meet-its-clean-power-plan-targets

[28] http://www.wri.org/publication/how-illinois-can-meet-its-clean-power-plan-targets

[29] "World Resources Institute (WRI) is a global research organization that spans more than 50 countries, with offices in Brazil, China, Europe, India, Indonesia, Mexico, and the United States. Our more than 450 experts and staff work closely with leaders to turn big ideas into action to sustain our natural resources—the foundation of economic opportunity and human well-being." WRI website, About WRI, http://www.wri.org/about

[30] Nicholas Bianco, "New Analysis: Clean Power Plan Compliance Within Reach for Litigating Companies", September 26, 2016, Available at: http://blogs.edf.org/climate411/2016/09/26/new-analysis-clean-power-plan-compliance-within-reach-for-litigating-companies/

[31] https://www.edf.org/sites/default/files/content/state_cpp_momentum_-_20160929.pdf

[32] https://www.edf.org/sites/default/files/content/power_sector_momentum_20161014.pdf

Underlying these Developments is a Surge in Renewable Energy Generation, Which Is Largely Driven by Increasingly Favorable Economics

The last several years has seen a rapid increase in the role of zero-carbon renewable energy generation. From 2013 through 2015, the nation has added roughly 36 GW of new wind and solar capacity, for an average of 12 GW of new renewable generation capacity per year. Recent reports suggest that the renewable industry will set new records in 2016, as they built 21 GW of new wind and solar generation (combined).[33,34] These trends are further evidence that the power sector is already changing in a manner that reduces its carbon pollution.

The vast majority of power sector analysts are predicting that recent increases in renewable development will continue in the years ahead as a result of falling costs and the extension of federal tax credits. For example:

- Bloomberg New Energy Finance estimates that 85 GW of new wind and solar generation capacity will be added to the grid between 2016 and 2021.[35]
- Rhodium Group found that with the tax credit extensions, the renewable industry will add approximately 92 gigawatts of utility-scale wind and solar from 2016 to 2025, even if there was no Clean Power Plan.[36]
- Analysis by GTM Research and SEIA predict that 80 GW of new solar power generation alone could come online from 2017 through 2021.[37]
- NREL analysis found that with the tax credit extensions, the nation could build 105 GW of new wind and solar generation by the end of 2021.[38]
- Estimates of generation from renewable energy resources by M.J. Bradley & Associates for EDF using industry data of annual projections of new builds from the Velocity Suite database suggests that there is sufficient capacity in advanced stages of development today to provide the generation EPA included as part of the best system in 2022, and when capacity in an early stage of development is included, there is almost enough to provide the generation EPA included as part of the best system through 2024.[39] (See MJB&A slide 6 in Appendix 3.)

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[33] http://www.eia.gov/todayinenergy/detail.php?id=29212v

[34] http://www.seia.org/research-resources/solar-market-insight-report-2016-q4

[35] BNEF, Impact of Tax Credit Extensions for Wind and Solar, December 16 2015. Available at https://data.bloomberglp.com/bnef/sites/4/2015/12/2015-12-16-BNEF-US-solar-and-wind-tax-credit-impact-analysis.pdf

[36] http://rhg.com/notes/renewable-tax-extenders-the-bridge-to-the-clean-power-plan

[37] http://www.seia.org/research-resources/solar-market-insight-report-2016-q4

[38] http://www.nrel.gov/docs/fy16osti/65571.pdf

[39] M.J. Bradley & Associates included New Entrants capacity by year in service from the Velocity Suite database, which is maintained by ABB Energy Market Intelligence (as on December 13, 2016). New capacity by type is assumed to operate at the technology-specific capacity factors used by EPA in calculating Building Block 3.

- Analysis by SNL, an industry news and research firm, shows that there were already 56 GW of new wind projects in the planning stages by June of 2016.[40]

These developments are being fueled by declining costs for renewable resources[41] coupled with recent extension of federal tax credits, and sustained technological advances in wind power, which have opened up new wind generation opportunities across the United States.[42]

These trends will only strengthen in the years ahead as sustained deployment at home and abroad[43] can be expected to drive continued technological progress. The recent history of wind power technologies provides a great example of this phenomenon. Wind is already out-competing fossil generation around the country.[44] A September 2016 survey shows that experts expect the cost of new wind generation to decrease an additional 24 to 30 percent by 2030.[45] And, analysis by the U.S. Department of Energy found that the next generation of wind technology could increase the land area suitable for wind by 54 percent nationwide.[46]

Perhaps the most staggering changes are to be found in the solar industry, where prices have been falling for decades as the industry has matured. From 2007 through 2015 alone, the price of solar photovoltaic (PV) modules fell by more than 80 percent.[47, 48] These trends have continued through 2016, with module prices reportedly falling another 40 percent in 2016 alone.[49] And, industry analysts are projecting continued declines in the years ahead.[50]

At today's prices, new wind and solar generation is already cheaper than new coal plants and frequently cheaper than new gas plants in much of the country. As prices continue to fall the economic benefits from these investments will only increase, and investments will grow even further. These robust trends towards expanding zero-carbon generation further demonstrate that the power sector is moving in a manner consistent with the emission reductions estimated under the Clean Power Plan.

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40 https://www.snl.com/web/client?auth=inherit#news/article?id=36759334&KPLT=6&s_data=si%3D1%26kpa%3Dff7015bd-01ec-4685-b9b0-321d4ce2c55c%26sa%3D

41 Bloomberg New Energy Finance and Business Council for Sustainable Energy, "Sustainable Energy in America: 2015 Factbook," February 2015, accessed August 5, 2015, http://www.bcse.org/wp-content/uploads/2015-Sustainable-Energy-in-America-Factbook.pdf

42 U.S. Department of Energy, "Enabling Wind Power Nationwide," May 2015, accessed August 5, 2015, http://energy.gov/sites/prod/files/2015/05/f22/Enabling%20Wind%20Power%20Nationwide_18MAY2015_FINAL.pdf

43 http://www.fool.com/investing/2016/12/17/india-and-china-will-determine-solar-investors-fat.aspx

44 http://www.wri.org/publication/seeing-believing-creating-new-climate-economy-united-states

45 NREL, LBNL, *Eliciting Expert Views on Future Wind Energy Costs*, September 13, 2016, Available at: http://www.nrel.gov/news/press/2016/37738

46 U.S. Department of Energy, "Enabling Wind Power Nationwide," May 2015, accessed August 5, 2015, http://energy.gov/sites/prod/files/2015/05/f22/Enabling%20Wind%20Power%20Nationwide_18MAY2015_FINAL.pdf

47 Bloomberg New Energy Finance and Business Council for Sustainable Energy, "Sustainable Energy in America: 2015 Factbook," February 2015, accessed August 5, 2015, http://www.bcse.org/wp-content/uploads/2015-Sustainable-Energy-in-America-Factbook.pdf

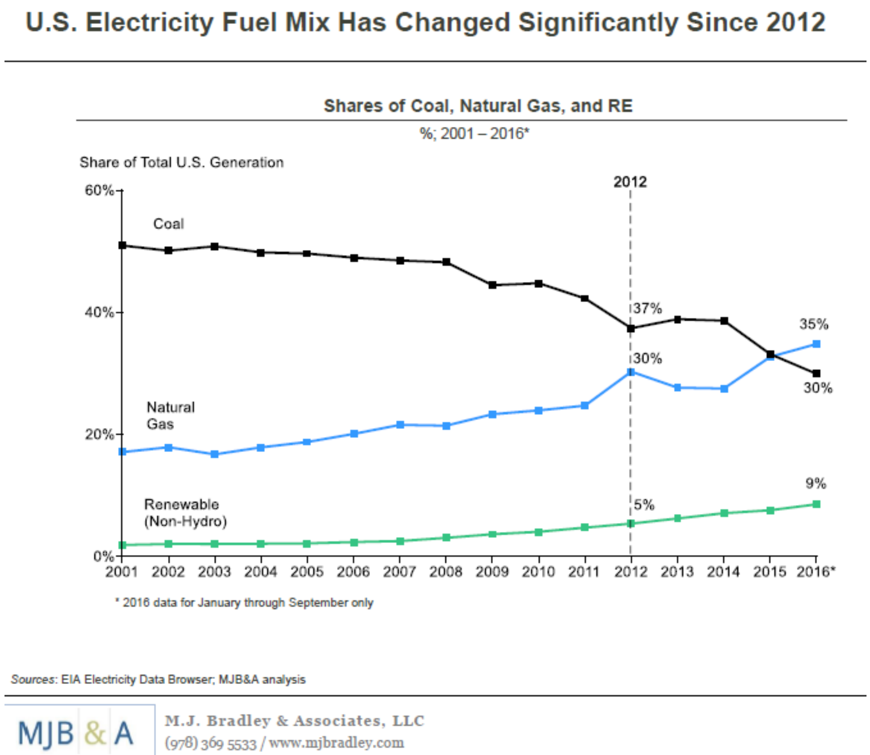
48 David Feldman et al, "Photovoltaic System Pricing Trends," September 22, 2014, accessed August 5, 2015, http://www.nrel.gov/docs/fy14osti/62558.pdf

49 https://cleantechnica.com/2016/10/25/sharp-declines-solar-module-prices-spark-another-gold-rush-us-market/

50 http://www.nrel.gov/analysis/data_tech_baseline.htmlv

Low Natural Gas Prices Continue to Drive Reductions in Climate Pollution As a Result of a Re-dispatch of the Electricity Grid Away from the Highest Emitting Plants

Natural gas represents a growing portion of U.S. electric generation. This shift is the product of significant gas buildouts beginning around the sector's deregulation in the 1990s, coupled with sustained low gas prices driven by new extractive technologies.[51] The growing appetite for low-cost natural gas generation has driven a commensurate reduction in demand for more expensive and higher-emitting coal-fired generation.[52] In 2016, natural-gas-fired generation surpassed coal-fired generation for the first time, reaching 35 percent of total U.S. generation while coal generation fell to 30 percent. M.J. Bradley & Associates Slide 5 in Appendix 3 provides another way of viewing this redispatch, both across the United States and along a selection of states, including Louisiana, New Jersey, North Carolina, Ohio, and Texas.



This re-dispatch accords with EPA's approach to the best system of emissions reductions and to calculating emission reduction potential under the Clean Power Plan. The fact that the sector is already rapidly moving in this direction further demonstrates the reasonableness of EPA's approach. For example, EPA assumed that generation by the existing natural gas fleet would increase by 22 percent above 2012 levels when the targets take effect in 2022. Analysis by M.J. Bradley & Associates shows that through 2015 the natural gas fleet already increased generation 12 percent above 2012 levels. And, EIA data shows that natural gas generation has further increased through 2016. (See MJB&A Slides 4 and 5)

These trends are expected to continue in the years ahead. These low gas prices are largely driven by advances in hydraulic fracturing and horizontal drilling techniques that have opened up new shale gas resources and substantially increased the supply of economically recoverable natural gas. According to the Analysis Group, since 2008 U.S. production of natural gas has grown by

[51] http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/tierney%20-%20coal%20industry%20-%2021st%20century%20challenges%209-26-2016.pdf
[52] http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/tierney%20-%20coal%20industry%20-%2021st%20century%20challenges%209-26-2016.pdf

one-third and average annual natural prices have dropped by 70 percent.[53] In May 2016, the lowest monthly average in 2016, the benchmark market price of natural gas was $2.49 per thousand cubic feet, versus $9.26 per thousand cubic feet in 2008. [54,55] Analysis by the U.S. Energy Information Administration[56] and futures market prices on NYMEX[57] both suggest that these low prices should continue.

These enduring trends further demonstrate that the power sector is moving in a manner consistent with the best system of emissions reductions as determined by EPA under the Clean Power Plan.

Investment in energy efficiency continue to expand, lowering electric bills while reducing climate pollution

The final Clean Power Plan allows for use of energy efficiency to be used to achieve its pollution reduction targets. Energy efficiency is far and away the most cost-effective compliance option: Analysis by the World Resources Institute finds that state efficiency programs regularly save $2 for every $1 invested, and in some cases up to $5 for every $1 invested.[58] As a result, modeling analyses by M.J. Bradley & Associates, the Bipartisan Policy Center, and others all show that these investments can further reduce the already modest compliance costs under the Clean Power Plan.[59,60]

Thus, it is little surprise that 26 states currently fund and administer utility-sector energy efficiency savings programs. Combined, in 2015, these programs saved approximately 26.5 million MWh. The top ranking states, Rhode Island, Massachusetts, Vermont, and California have all achieved *annual* electricity savings of 2 to 3 percent of total state-wide retail electricity sales.[61]

States continue to explore options for realizing even greater benefits to consumers by expanding on energy efficiency programs. For example, in December 2016, Michigan sets a goal of meeting 35 percent of the state's energy needs through renewables and energy efficiency by 2025,[62] and Illinois expanded energy efficiency targets through its passage of the Future Energy Jobs Bill.[63]

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[53] http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/tierney%20-%20coal%20industry%20-%2021st%20century%20challenges%209-26-2016.pdf
[54] EIA, Natural Gas Prices, https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm
[55] EIA, U.S. Natural Gas Electric Power Price, https://www.eia.gov/dnav/ng/hist/n3045us3a.htm
[56] http://www.eia.gov/outlooks/aeo/
[57] http://futures.tradingcharts.com/marketquotes/NG.html
[58] http://www.wri.org/publication/seeing-believing-creating-new-climate-economy-united-states
[59] http://www.mjbradley.com/sites/default/files/MJBA_CPP_IPM_Report_III_2016-06-01_final_0.pdf
[60] Bipartisan Policy Center, Modeling the Evolving Power Sector and Impacts of the Final Clean Power Plan, June 2016, Available at: http://cdn.bipartisanpolicy.org/wp-content/uploads/2016/06/BPC-Energy-Clean-Power-Plan-Modeling.pdf
[61] ACEEE, State Energy Efficiency Scorecard, 2016, Available at: http://aceee.org/sites/default/files/pdf/state-sheet/2016/usa.pdf
[62] https://www.rtoinsider.com/michigan-energy-bill-35641/
[63] http://blogs.edf.org/energyexchange/2016/12/07/illinois-future-energy-jobs-bill-shows-states-are-taking-the-lead-to-build-the-clean-energy-economy/

A Bloomberg New Energy Finance (BNEF) analysis of total U.S. energy efficiency investments found that incremental energy savings by electric utilities had an average of 17 percent year-on-year growth rate between 2006 and 2014.[64]

Moreover, a number of studies show that there is ample room for energy efficiency programs to continue expanding. For example:

- A February 2014 study by Lawrence Berkley National Laboratory (LBNL) estimated energy efficiency potential in the Western Interconnection in both 2021 and 2032. For 2021, LBNL estimated that aggressive deployment of economically cost-effective energy efficiency measures could reduce annual energy demand in the Western Interconnection by 18 percent relative to a business as usual scenario. For 2032, LBNL found technical potential for a 22 percent decrease in electricity demand *above and beyond* savings that would already occur as a result of energy efficiency programs that are already in place.[65]
- A 2012 report by the Southwest Energy Efficiency Project (SWEEP) reviewed the historical performance of "best practice" energy efficiency programs for both residential and commercial buildings, and estimated the energy savings that could be achieved in six Southwestern states (Arizona, Colorado, Nevada, New Mexica, Utah, and Wyoming) if similar best practice programs were adopted in the region. SWEEP projected that these best practice energy efficiency programs could achieve savings equivalent to over 20 percent of retail sales by 2020.[66]
- A 2010 report by the National Academy of Sciences reviewed a number of studies of energy efficiency in residential and commercial buildings, and found that a 25-30 percent energy savings for the building sector as a whole could be achieved between 2030 and 2035, at a cost of just 2.7 cents per kWh saved. The report also reviewed studies finding that approximately 14 to 22 percent of industrial electricity demand could be cost-effectively reduced by 2020.[67]
- A 2009 analysis by McKinsey & Company analyzed the economic potential to deploy hundreds of already-available technologies in buildings and industrial processes. This study found that America's total end-use energy consumption could be reduced by 23 percent by 2020 relative to a business-as-usual scenario, relying only on measures that pay for themselves over time.[68]

These trends underscore that energy efficiency investments will continue to play a major role in decarbonizing the power sector, and that tremendous potential exists to tap these cost-effective opportunities further.

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[64] BNEF and Business Council for Sustainable Energy Sustainable Energy in America Factbook 2016

[65] *See* Galen Barbose et al., *Incorporating Energy Efficiency into Western Interconnection Transmission Planning,* 19, 36 (LBNL Feb. 2014).

[66] Howard Geller, *The $20 Billion Bonanza: Best Practice Utility Energy Efficiency Programs and Their Benefits for the Southwest* xi (2012).

[67] America's Energy Future Panel on Energy Efficiency Technologies, *Real Prospects for Energy Efficiency in the United States* 7-8, 15-16 (2010).

[68] Hannah Choi Granade et al., *Unlocking Energy Efficiency in the U.S. Economy* v (2009).

Power generators also have important opportunities to reduce emissions through heat rate improvements and other improvements

In setting the Clean Power Plan targets, EPA took into account opportunities to decrease coal-plant emissions through heat rate improvements. Heat rate improvement is a well-recognized opportunity to reduce power plant emissions. A power plant's heat rate is the amount of energy used to generate one kilowatt hour of electricity. When power plants improve their heat rate, they are using less energy to produce the same unit of electricity, therefore, increasing the efficiency of the plant. A more efficient power plant also decreases the level of CO_2 emissions emitted (and other air emissions).

In the final rule, after taking into consideration public comment, EPA established conservative estimates for heat rate improvements at coal-fired units equal to 2.1 percent, based on historical and regional performance.[69]Compared to other studies conducted by the National Energy Technology Laboratory (NETL) [70] and Lehigh University, [71] among others, EPA's final HRI averages appear to be conservative. In addition, there are a number of other measures that can reduce emissions at coal plants, including: co-firing of natural gas at coal-fired power plants, carbon capture and storage at fossil units, or integration of renewable energy for steam preheating or other functions at fossil units. Furthermore, recent analysis by Andover Technology Partners demonstrates that there are opportunities to improve heat rates at existing natural gas combined cycle (NGCC) power plants, which EPA did not consider in setting its emission reduction targets (see Appendix 4).

Conclusion

The Clean Power Plan's targets are achievable, consistent with existing power sector trends and opportunities, and grounded in a robust record of power sector analysis and information. Looking back on 2016, this past year has provided a host of updated information on power sector trends and opportunities as well as new technical analysis that has been conducted since the Clean Power Plan was issued. The expansion of low and zero-carbon generation resources is continuing apace, driven by powerful market trends that are independent of the Clean Power Plan. Multiple opportunities for emission reductions are affordable and at hand. New analyses and developments further build on the trove of information demonstrating that the Clean Power Plan is achievable and affordable. They also demonstrate the vital role it has in ensuring that the power sector achieves the climate pollution targets it set.

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[69] The three regions are defined as: the Eastern Interconnection, the Western Interconnection, and Texas Interconnection (ERCOT)

[70] Phil DiPietro & Katrina Krulla, *Improving the Efficiency of Coal-Fired Power Plants for Near Term Greenhouse Gas Emissions Reductions* 5 (DOE/NETL-2010/1411, 2010).

[71] Lehigh Energy Update, Reducing Heat Rates of Coal-Fired Power Plants, January 2009. Available at: http://www.lehigh.edu/~inenr/leu/leu_61.pdf

APPENDIX 1: DETAILED SUMMARY OF CLEAN POWER PLAN STUDIES – National-scale assessments

Bipartisan Policy Center (BPC)[72]

BPC published an analysis of the feasibility and cost impacts of the Clean Power Plan using the commercial version of the model EPA employed to evaluate the Rule and other air regulations for the power sector: ICF's Integrated Planning Model (IPM). BPC's modeling reflected updated natural gas price assumptions as well as the latest extension of the federal tax incentives for renewable energy sources.

BPC's analysis found that the targets set by the Clean Power Plan are achievable through 2030. BPC also found that the combination of state energy policies, falling natural gas prices, falling renewable prices, and the extension of federal tax incentives for renewables will lead to lower greenhouse gas emissions from the power sector, even in the absence of the Clean Power Plan. As a result, many states are expected to be on track to comply with the Clean Power Plan in the early years.[73] However, they also found that the Clean Power Plan had an important role to play in driving the entire scope of required emissions reductions, concluding that the Clean Power Plan will accelerate and drive additional CO_2 reductions and clean energy investments. As a result of the strong investments in lower-carbon and zero-carbon resources already occurring in the power sector, they found that compliance costs should be minimal, with allowance prices remaining lower than $11 per ton, and possibly much lower under certain circumstances, such as if sources leverage the cost-effective reductions available through investments in energy efficiency.

Center for Climate and Energy Solutions (C2ES)[74]

C2ES completed a review and comparison of five studies[75] that analyzed the anticipated effects of the Clean Power Plan on electricity prices, generation mix, and carbon dioxide emissions, as well as the implications of different state implementation choices.[76] C2ES's report identified results that are common across the suite of multiple studies reviewed.

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[72] "The Bipartisan Policy Center is a non-profit organization that combines the best ideas from both parties to promote health, security, and opportunity for all Americans. BPC drives principled and politically viable policy solutions through the power of rigorous analysis, painstaking negotiation, and aggressive advocacy. As the only Washington, DC-based think tank that actively promotes bipartisanship, BPC works to address the key challenges facing the nation. Our policy solutions are the product of informed deliberations by former elected and appointed officials, business and labor leaders, and academics and advocates who represent both ends of the political spectrum. We are currently focused on health, energy, national and homeland security, the economy, housing, immigration, infrastructure, and governance." BPC website, http://bipartisanpolicy.org/about/who-we-are/

[73] Jennifer Macedonia, Blair Beasley, and Erin Smith (Bipartisan Policy Center), "Modeling the Evolving Power Sector and Impacts of the Final Clean Power Plan", June 2016. Available at: http://bipartisanpolicy.org/library/clean-power-plan-analysis/.

[74] The Center for Climate and Energy Solutions is "an independent, nonpartisan, nonprofit organization working to forge practical solutions to climate change." C2ES website, About Us, http://www.c2es.org/about

[75] This included an examination of a joint study by the Center for Strategic and International Studies and the Rhodium Group, as well as studies by the Nicholas Institute, the Bipartisan Policy Center, M.J. Bradley & Associates, and U.S. Energy Information Agency.

[76] Center for Climate and Energy Solutions, Insights from a Comparative Analysis of Clean Power Plan Modeling, September 2016, available at http://www.c2es.org/docUploads/insights-comparative-analysis-clean-power-plan-

Looking at business as usual scenarios that did not reflect the Clean Power Plan, C2ES's review found that the studies it reviewed consistently predicted continued growth in generation from low and zero carbon resources. Specifically, each of the studies reviewed concluded that natural gas and renewable energy generation would continue to expand substantially in future years, even without application of the Clean Power Plan. The Clean Power Plan, however, was found to play an important role in "accelerating" these trends, as the power sector was not expected to achieve the full scope of emissions reductions contemplated under the Clean Power Plan without it. As a result of these powerful market trends, they found that all the studies were in agreement that implementation of the Clean Power Plan would likely have a very small impact on national average retail electricity rates, and may result in lower electricity rates.

Energy Information Administration (EIA) Annual Energy Outlook 2016

EIA's 2016 Annual Energy Outlook (AEO)[77] reviewed current and historic U.S. power sector emission trends and found that 2015 emissions are already nearly 22 percent below 2005 levels.[78]

In the AEO, EIA separately evaluated *future* power sector trends—and their findings here also underscored the feasibility of the Clean Power Plan targets. EIA modeled future electricity sector emissions, including an analysis of the Clean Power Plan that examined a number of possible implementation scenarios, including: mass and rate-based programs; scenarios where allowances are allocated to load serving entities or covered entities; patchwork implementation scenarios; and even a scenario where the Clean Power Plan's targets were modestly extended through 2040. The analysis found that the nation will continue building significant amounts of zero-carbon and lower-carbon emitting generation in the years ahead. This is the case even if the Clean Power Plan was not in place, though these trends were found to be strengthened under the Clean Power Plan. Like the other studies examined, they also found that the Clean Power Plan was essential for driving sustained emissions reductions consistent with those it requires. Finally, they concluded that price impacts from any Clean Power Plan-related shift in generation will be minimal.[79]

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modeling.pdf. The studies reviewed by the C2ES analysis included analyses by MJ Bradley & Associates; the Energy Information Administration; the Bipartisan Policy Center; a joint study by the Center for Strategic and International Studies and the Rhodium Group; and the Nicholas Institute for Environmental Policy Solutions at Duke University.

[77] U.S. Energy Information Institute, "Annual Energy Outlook 2016" http://www.eia.gov/outlooks/aeo/. See also Early Release: Annotated Summary of Two Cases (May 17, 2016) (available https://www.eia.gov/forecasts/aeo/er/pdf/0383er(2016).pdf); Issues in Focus: Effects of the Clean Power Plan (June 20, 2016) (available http://www.eia.gov/forecasts/aeo/section_issues.cfm#cpp); Projections Tables by Case (available http://www.eia.gov/forecasts/aeo/tables_ref.cfm).

[78] 2005 CO_2 emissions from the electric power sector were 2,416 MMT and 2015 emissions were 1,891 MMT (see Early Release: Annotated Summary of Two Cases, slide 6).

[79] Issues in Focus: Effects of the Clean Power Plan, "Electricity Prices" section.

M.J. Bradley & Associates [80]

M.J. Bradley & Associates (MJB&A) performed two rounds of comprehensive modeling analysis of the Clean Power Plan—one in January 2016 and another in June 2016—employing the Integrated Planning Model (IPM) used by EPA for electric power system modeling.[81] In both instances, MJB&A examined a range of scenarios for implementing the Clean Power Plan under varying amounts of energy efficiency, different degrees of compliance flexibility to trade climate pollution allowances and credits, and the policy options of mass-based or rate-based state plan approaches.

The June 2016 analysis concluded that under a variety of compliance scenarios and assumptions about future conditions, the Clean Power Plan's targets are achievable and eminently affordable. This more recent analysis included important updates to reflect the latest market conditions, including updated natural gas prices (based on EIA AEO 2015) and the extensions of the renewable energy tax credits for wind and solar. MJB&A noted that recent extension of the renewable energy tax credits will incentivize greater investments in wind and solar energy before the Clean Power Plan compliance period, which will make compliance with the targets even easier to achieve. As a result, the industry is projected to be closer to the Clean Power Plan's targets under reference case assumptions, resulting in very low estimated costs for compliance instruments.

The results of the June 2016 analysis further underscored the conclusions of the earlier January 2016 modeling, which similarly found that the electricity sector can achieve the Clean Power Plan's goals using a diverse mix of resources, including energy efficiency, renewable power, nuclear, natural gas and coal. Notably, this earlier analysis concluded that across a range of scenarios, customers could see savings on their electricity bills from 5 percent to 20 percent, on average.

[80] "M.J. Bradley & Associates LLC (MJB&A) provides strategic and technical advisory services to address critical energy and environmental matters including: energy policy, regulatory compliance, emission markets, energy efficiency, renewable energy, and advanced technologies. Our multi-national client base includes electric and natural gas utilities, major transportation fleet operators, clean technology firms, environmental groups and government agencies." M.J. Bradley and Associations, About Us, http://www.mjbradley.com/about-us.

[81] MJB&A IPM Modeling January 2016, *Available at* http://mjbradley.com/sites/default/files/MJBA_CPP_IPM_Summary.pdf; MJB&A IPM Modeling June 2016, *available at* http://www.mjbradley.com/sites/default/files/MJBA_CPP_IPM_Report_III_2016-06-01_final_0.pdf.

Nicholas Institute for Environmental Policy Solutions at Duke University (Nicholas Institute)[82]

The Nicholas Institute modeled the impact of market conditions and different Clean Power Plan compliance options on greenhouse gas emissions from the power sector and presented these results in a July 2016 report.[83] The analysis used the Dynamic Integrated Economy/Energy/Emissions Model (DIEM), which includes a detailed electricity dispatch model of domestic wholesale electricity markets. The model represents intermediate- to long-run decisions of the industry regarding generation, transmission, capacity planning, and dispatch of units.

The report concludes that compliance with Clean Power Plan (CPP) targets is highly achievable and affordable. Their analysis also shows that without the Clean Power Plan, emissions from the power sector will be influenced by shifting market forces. If gas prices remain low, then they found that power sector emissions would continue to fall. But, they found that those trends could slow or reverse if gas prices rise. Regardless, they also found that "costs are quite low…across most assumptions about future trends in the industry," falling in the 0.1%–1.0% range. They further found that these modest costs could decline further still if states and power companies leverage opportunities to invest in energy efficiency.

[82] "The Nicholas Institute for Environmental Policy Solutions at Duke University improves environmental policymaking worldwide through objective, fact-based research to confront the climate crisis, clarify the economics of limiting carbon pollution, harness emerging environmental markets, put the value of nature's benefits on the balance sheet, develop adaptive water management approaches, and identify other strategies to attain community resilience. The Nicholas Institute is part of Duke University and its wider community of world-class scholars. This unique resource allows the Nicholas Institute's team of economists, scientists, lawyers and policy experts to not only deliver timely, credible analyses to a wide variety of decision makers, but also to convene these decision makers to reach a shared understanding regarding this century's most pressing environmental problems." The Nicholas Institute, About Us, https://nicholasinstitute.duke.edu/about.

[83] Martin T. Ross, David Hoppock, and Brian C. Murray (Nicholas Institute for Environmental Policy Solutions, Duke University), "Ongoing Evolution of the Electricity Industry: Effects of Market Conditions and the Clean Power Plan on States", July 2016, Available at: https://nicholasinstitute.duke.edu/sites/default/files/publications/ni_wp_16-07_final.pdf.

APPENDIX 2: DETAILED SUMMARY OF CLEAN POWER PLAN STUDIES – State and individual power company assessments

M.J. Bradley & Associates

Analysis conducted for EDF by M.J. Bradley & Associates found that all 27 states opposing the Clean Power Plan are in a position to achieve compliance with their emission reduction targets through 2030 by fully harnessing the power of planned investments, making investments consistent with existing state law, and capturing the market certainties from the Clean Power Plan.[84]

The analysis also considered conservative scenarios in which states do not take advantage of program flexibilities that allow them to capture cross-state abatement opportunities even if so doing would result in cost savings. Such constraints seem unlikely, given that most of the litigating states are already taking advantage of interstate trading in other Clean Air Act programs and requested that interstate trading be an option under the Clean Power Plan.

Even in these conservative scenarios, as many as 21 of the 27 states challenging the Clean Power Plan could fully achieve their emission targets through the first three-year period of the Clean Power Plan (from 2022-2024) by relying exclusively on existing generation, investments already planned within each state, and implementation of respective existing state policies. The study also found that as many as 18 of these states could achieve their targets all the way through 2030 as a result of these measures. Also, since this analysis was completed, Arkansas announced that it was already achieving its 2030 emissions targets. This suggests that at least 22 of the states could comply through 2024 as a result of planned investments, and that 19 states could comply through 2030.

For the minority of states that were not found to meet their Clean Power Plan emission reduction targets through planned investments alone, this analysis indicates that very modest additional measures would be sufficient to close the gap. For example, it finds that all of the states could achieve their targets in the first three-year period merely by deploying cost-effective energy efficiency measures and developing new clean resources at a rate comparable to the average of their neighboring states.

While the analysis shows that states are well positioned for compliance, it also reaffirms the importance of the Clean Power Plan in delivering needed reductions in climate pollution over the long term. This is because building new clean generation alone is not enough–it is also vital to ensure that the benefits of investments are fully realized. The Clean Power Plan ensures that cost-effective measures will be implemented in all states and drives the deployment of these measures throughout the nation—while providing certainty to guide optimal investment decisions.

[84] http://blogs.edf.org/climate411/files/2016/09/MJB-study-on-CPP-compliance.pdf

World Resources Institute (WRI)[85]

WRI examined state compliance options for the Clean Power Plan, including for the states of Virginia, Pennsylvania, Michigan, Missouri, and Illinois. This analysis was conducted using an in-house emissions modeling platform. The results are briefly summarized below.

- **Illinois –** WRI found that Illinois could achieve 78 percent of the reductions in climate pollution required through 2030 by implementing policies in place coupled with better leveraging existing natural gas infrastructure and adopting low-cost operational improvements and best practices at coal plants.[86] The more efficient use of existing infrastructure includes better leveraging existing natural gas infrastructure and adopting low-cost operational improvements and best practices at coal plants, both of which are incentivized under the Clean Power Plan. Since WRI's analysis was published, Illinois passed The Future Energy Jobs Bill, which significantly expands their renewable and energy efficiency programs, driving increased investment in the state and reductions in electric bills. As a result, the state is even better positioned for meeting its targets under the Clean Power Plan.
- **Michigan –** WRI found that Michigan is well-positioned to meet its Clean Power Plan targets—it can get 98 percent of the reductions required under its mass-based emission target with its existing clean energy policies. Michigan can make up the small remaining gap, and even exceed its targets, by better leveraging existing natural gas infrastructure and adopting low-cost operational improvements and best practices at coal plants, which would be incentivized under the Clean Power Plan.[87]
- **Missouri –** WRI found that Missouri can get almost all of the required reductions by: 1) meeting voluntary energy efficiency goals; 2) meeting the existing renewable energy standard; and 3) better leveraging existing natural gas infrastructure and adopting low-cost operational improvements and best practices at coal plants (which would be incentivized under the Clean Power Plan). This suite of measures would allow the state to get 90 percent of the reductions required.[88]
- **Pennsylvania** – WRI found that Pennsylvania can meet its targets under the Clean Power Plan for the first several years of the program through existing clean energy policies coupled with better leveraging existing natural gas infrastructure and adopting low-cost operational improvements and best practices at coal plants (which would be incentivized under the Clean Power Plan).[89]

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[85] "World Resources Institute (WRI) is a global research organization that spans more than 50 countries, with offices in Brazil, China, Europe, India, Indonesia, Mexico, and the United States. Our more than 450 experts and staff work closely with leaders to turn big ideas into action to sustain our natural resources—the foundation of economic opportunity and human well-being." WRI website, About WRI, http://www.wri.org/about

[86] http://www.wri.org/publication/how-illinois-can-meet-its-clean-power-plan-targets

[87] http://www.wri.org/publication/how-michigan-can-meet-its-clean-power-plan-targets

[88] http://www.wri.org/publication/how-missouri-can-meet-its-clean-power-plan-targets

[89] http://www.wri.org/publication/how-pennsylvania-can-meet-its-clean-power-plan-targets; see Figure 1

- **Virginia –** WRI found that Virginia's planned coal retirements and planned investment in clean energy will achieve almost one-third of the required reductions in climate pollution. They further found that the state can close the gap that remains, and even surpass its targets, if it achieves existing clean energy goals and increases utilization of its existing natural gas fleet.[90]

Pace Global[91]

Pace Global modeled Clean Power Plan compliance paths to help the Arizona Utilities Group "simulate the economic dispatch of power plants within a competitive framework across the western interconnect for the base case outlook" using Aurora, an hourly chronological dispatch model, and based on generation supply and load outlook provided by participating utilities. Pace Global found that Arizona can comply with the Clean Power Plan based on investments already planned under business-as-usual. The Arizona Utilities Group consists of Arizona Electric Power Cooperative, Inc., Arizona Public Service Company, Salt River Project Agricultural Improvement and Power District, Tucson Electric Power Company, and UniSource Energy Services. [92]

[90] http://www.wri.org/publication/how-virginia-can-meet-its-clean-power-plan-targets
[91] "Pace Global, A Siemens Business, is a leading provider of strategic energy consulting services. For nearly 40 years, Pace Global has provided innovative services to support the execution of business strategies, complex energy transactions, asset development, and operations focusing on select markets in the Americas." Pace Global, About, http://www.paceglobal.com/about/
[92] Pace Global, CPP Rate-Mass Assessment, February 2016, Available at: http://legacy.azdeq.gov/environ/air/download/pace_cpp_rate.pdf

Recent Trends in the Electric Power Sector

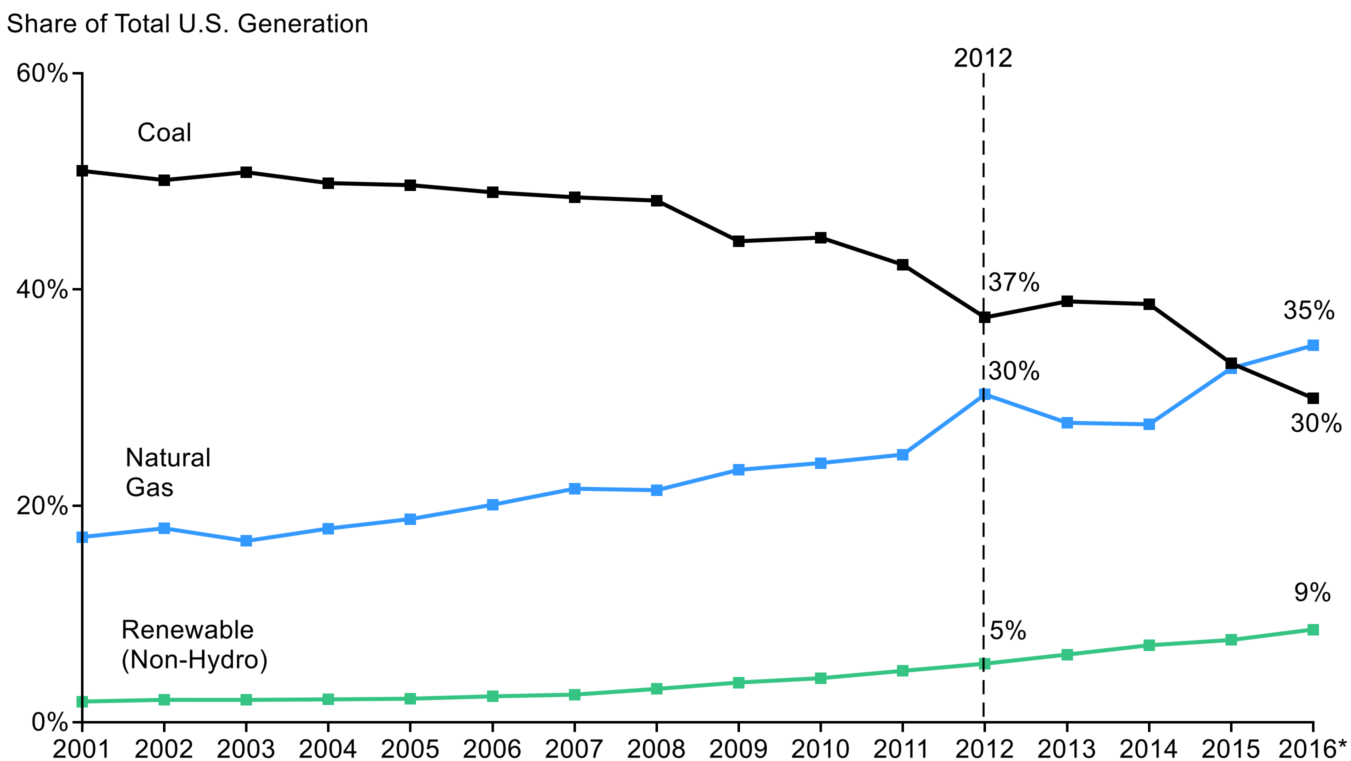
DECEMBER 2016

MJB & A

U.S. Electricity Fuel Mix Has Changed Significantly Since 2012

Shares of Coal, Natural Gas, and RE

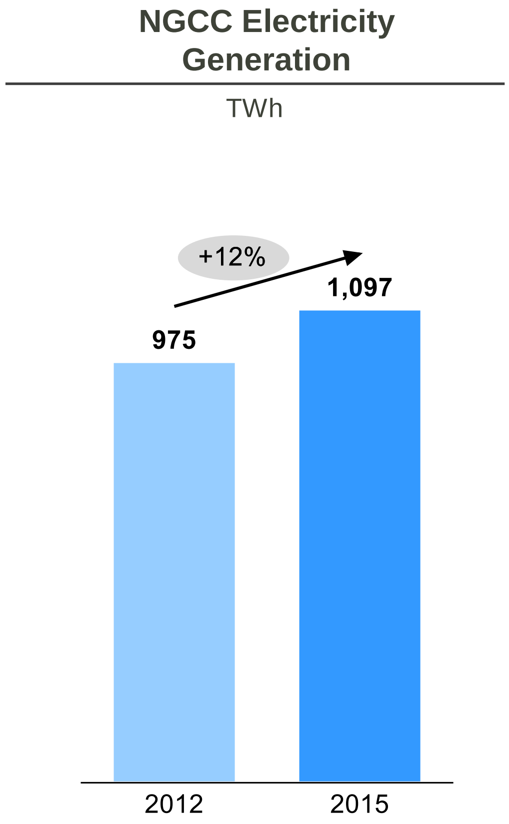
%; 2001 – 2016*



* 2016 data for January through September only

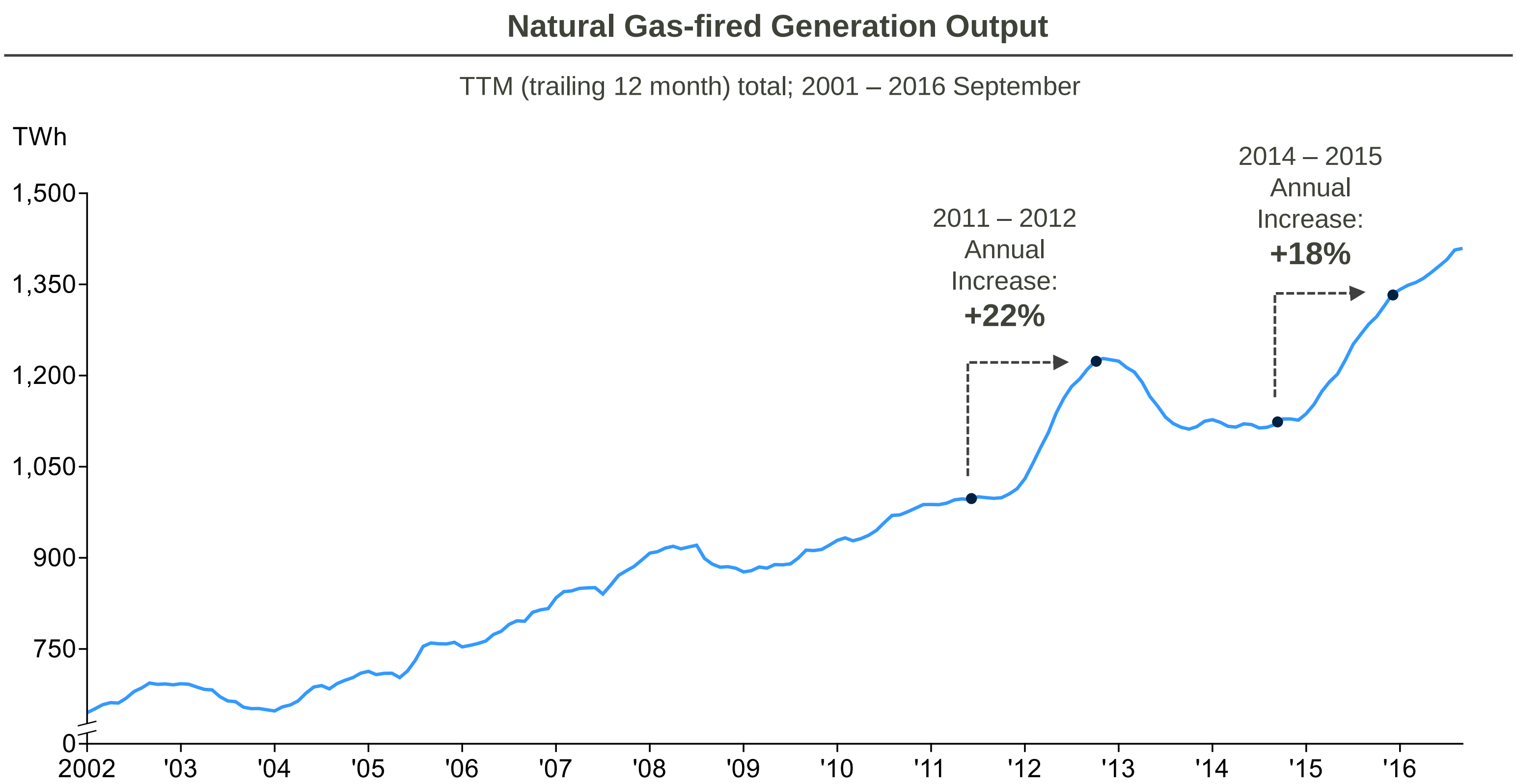
Sources: EIA; MJB&A analysis

Overall, NGCC Generation Increased by 12% from 2012 to 2015



Analysis Notes:
1. Data from EIA Form 923; EPA U.S. GHG Inventory; EPA Air Markets Program Data; MJB&A analysis
2. This analysis excludes simple cycle units, natural gas steam units, and industrial NGCC units in TX and LA to arrive at an estimate of U.S. electric power sector NGCC generation. Due to its efficiency, NGCC is responsible for most natural gas-fired generation in the electric power sector. Between 2012 and 2015, NGCC plants, on average, accounted for 84% of all natural gas-fired generation in the U.S.

Output from Natural Gas-fired Units Has Continued to Rise



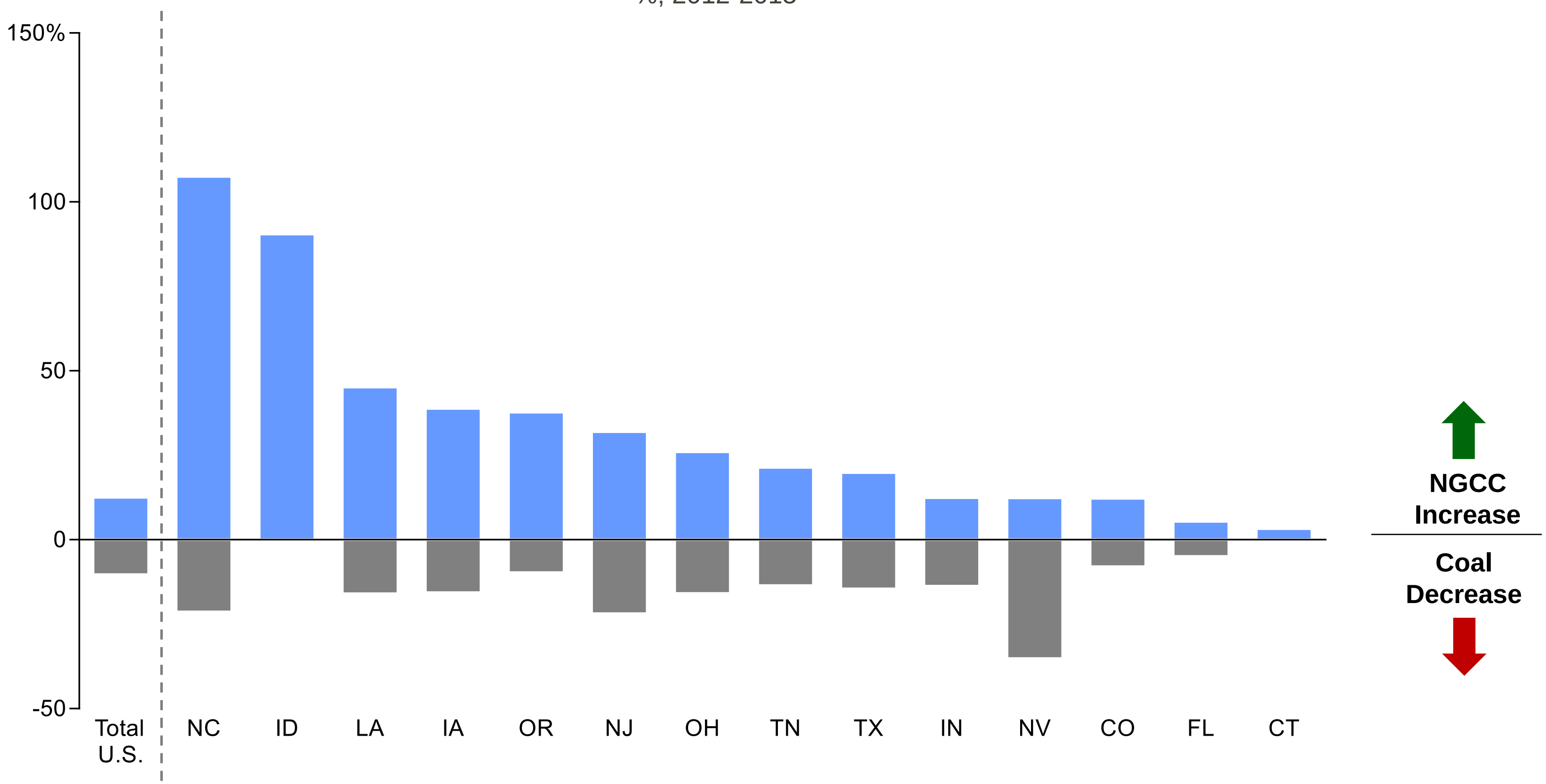
Annual Average Growth Rate: **5.8%**

Sources: EIA; MJB&A analysis

Across the U.S., Output from NGCC Plants* Has Increased, While Output from Coal-fired Plants Has Declined

Change in Output by Fuel Type Across U.S. & Selected States

%; 2012-2015

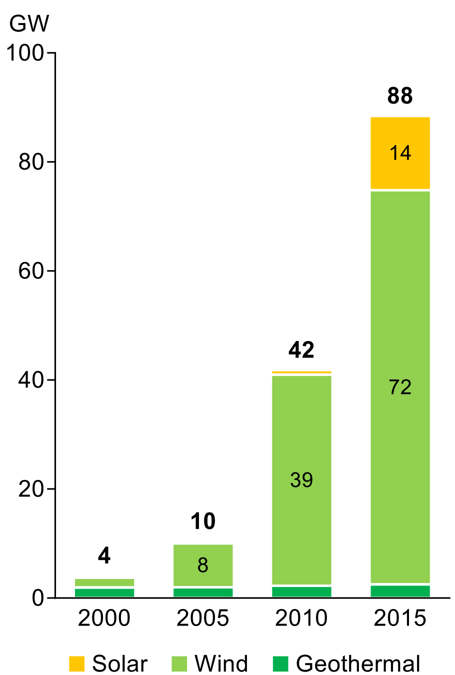


Sources: EIA Form 923; MJB&A analysis
*Most natural gas-fired generation happens at NGCC units, the most efficient sort of natural gas-burning generating resource. Between 2012 and 2015, for example, NGCC plants accounted for, on average, 84% of all natural gas-fired generation in the U.S.

Projected Output from Planned Renewable New Build Capacity Is Higher Than EPA Assumptions

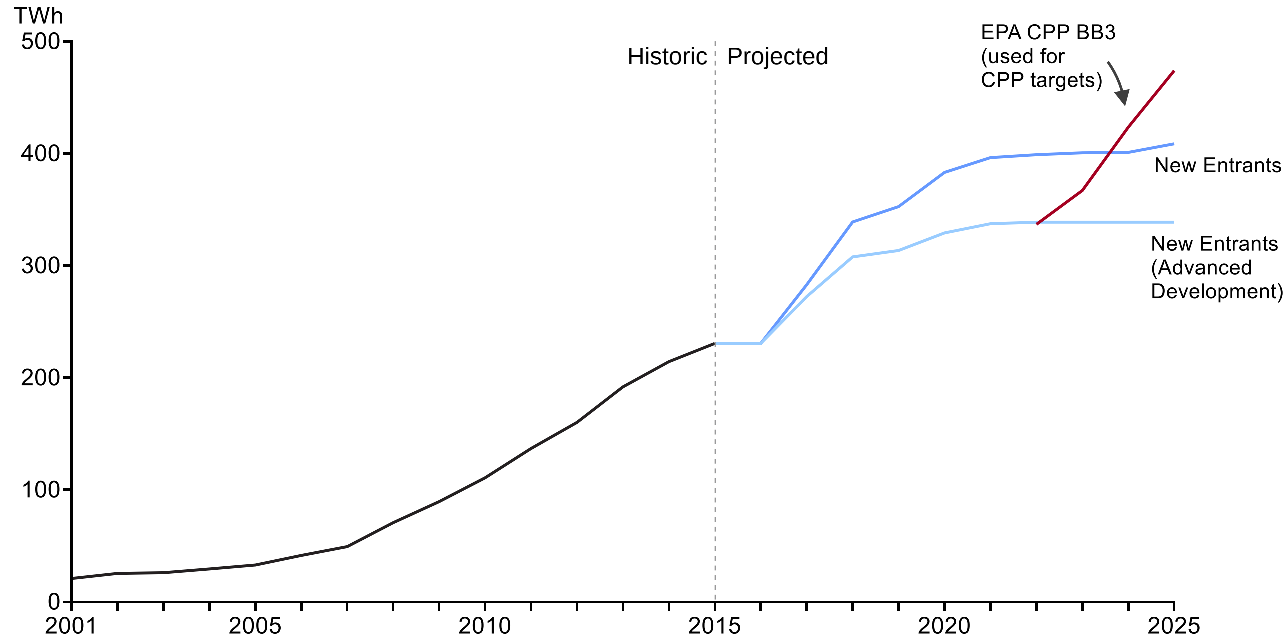
Historic Capacity by Type

GW



Renewable Electricity Generation

TWh; Solar, Wind, and Geothermal



Analysis Notes:

1. Data for continuous U.S. (excludes Alaska and Hawaii).
2. Historic capacity and generation data from EIA.
3. “2013-2015 AAGR Continued” projection based on continuation of 2013 to 2015 average annual growth rate (AAGR).
4. “EPA CPP Building Block 3 (used for CPP targets)” estimated using EPA methodology from CPP Technical Support Documents (TSD) but excludes incremental Hydro, and is added as incremental generation to historic 2012 levels. The adjustment for the amount used for CPP targets is estimated using the rate goal calculation from CPP TSD.
5. “New Entrants” generation projection based on new capacity (as on December 13, 2016) by year in service from ABB Velocity suite. Capacity by type is assumed to operate at capacity factors used by EPA in calculating Building Block 3. “New Entrants (Advanced Development)” includes projects identified as being in advanced stages of development (projects with ABB Velocity status of Permitted, Site Prep, Under Construction, or Testing). “New Entrants” also includes projects in early development (projects with ABB Velocity status of Feasibility or App Pending).

Andover Technology Partners 978-683-9599
Consulting to the Air Pollution Control Industry

Improving Heat Rate on Combined Cycle Power Plants

Working Draft

December 31, 2016

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Contents

Background

Improving the heat rate of fossil fueled power plants is an important step toward reduction of CO_2 emissions from these plants. Natural gas combined cycle (NGCC) plants have been an important part of the electric energy infrastructure and will play an increasingly important role as existing NGCC plants operate more frequently due to the increased availability of natural gas for power generation.

Program Results

Summary of Results

This report reviews several technologies that offer the potential for improving heat rates of combined cycle power plants. There are several technologies that offer substantial promise.

Turbine inlet cooling and related technologies, such as wet compression, offer the potential to improve output of the turbine generator and improve heat rate at elevated ambient temperatures. These technologies have been installed at over 400 facilities, with about half in the United States. While the benefits are greatest in warm climates, and this is where most facilities are located, these have also been installed in more moderate climates, such as Nebraska, New York, Connecticut, Pennsylvania, Massachusetts, New Jersey, Maine and Maryland.

Upgrading of gas turbine components is another promising approach that is offered by the various turbine manufacturers as well as aftermarket suppliers. Older turbines can benefit from replacement of existing components with newer components with improved designs or materials that offer the potential for heat rate improvements over the original equipment.

There are several approaches that can be used to improve the heat rate of the steam system. Steam turbine upgrades or overhauls, condenser cleaning, and rebuilding of feed pumps are among the means that can provide heat rate improvements. Installation of variable speed drives for pumps and fans can improve heat rate by reducing parasitic loads. In addition, there are operating and maintenance practices that will minimize losses in the steam system.

1. Introduction to Natural Gas Combined Cycle (NGCC) Power Plants

A NGCC power plant is distinguished as being comprised of two power cycles: a gas turbine Brayton cycle; and a steam Rankine cycle.

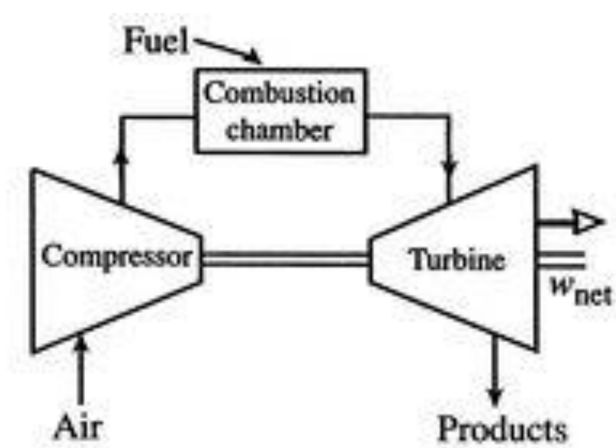
1.1 Gas Turbine Brayton Cycle

Gas turbines are considered Open Brayton Cycles, as depicted in Figure 1, and operate by:

- first compressing air to a high pressure,
- then adding fuel and combusting the high pressure fuel and air mixture in a combustor or combustion chamber, and
- then producing power by expanding the hot, high pressure gases in a turbine that produces power,
- the power from the turbine drives the compressor and the remainder is available to power a generator.

In fact, the power consumed by the compressor is on the order of two thirds of the output of the turbine. Therefore, techniques that reduce the power consumed by the compressor can have a large impact on efficiency.

Figure 1. Open Brayton Cycle[1]

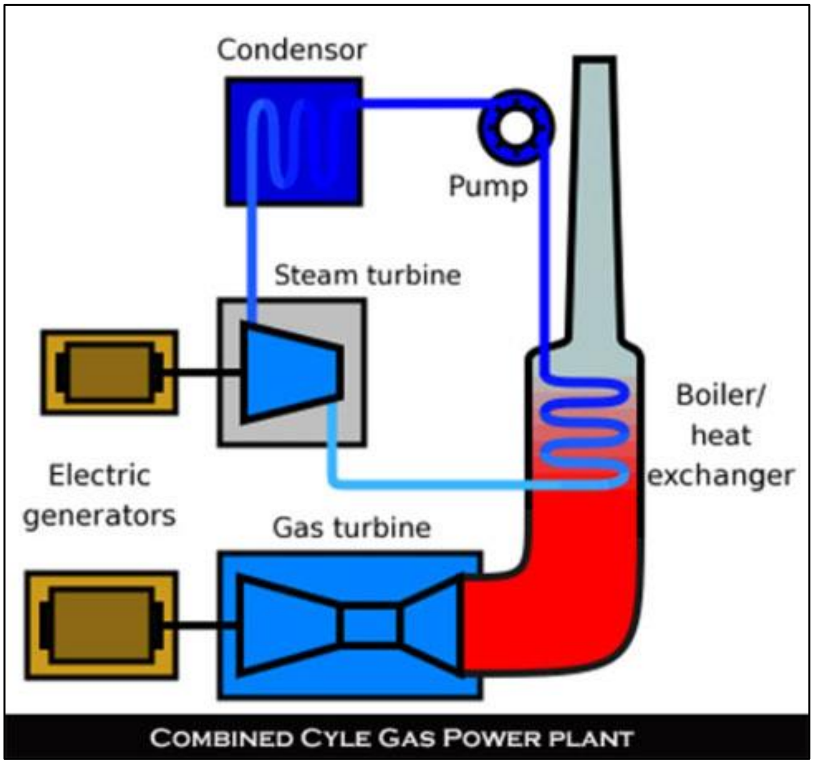


In a Simple Cycle configuration the Open Brayton Cycle would be stand alone and the exhaust gases from the turbine would be released to the atmosphere. However, these gases have substantial energy value since they have temperatures on the order of 900°F. To utilize the energy that is available in the turbine exhaust gas, the hot gases pass through a Heat Recovery Steam Generator (HRSG) and heat water into steam to drive a steam turbine, as shown in Figure 2. In fact, in most cases additional fuel is added to the exhaust gases from the turbine because there is substantial excess oxygen available in the turbine exhaust to react with fuel. The fuel is combusted in order to increase the exhaust gas

[1] Massachusetts Institute of Technology, http://web.mit.edu/16.unified/www/SPRING/propulsion/notes/node27.html

temperature further and permit the steam cycle to operate at a higher temperature to be more efficient.

Figure 2. Simplified diagram of a combined cycle power plant.[2]

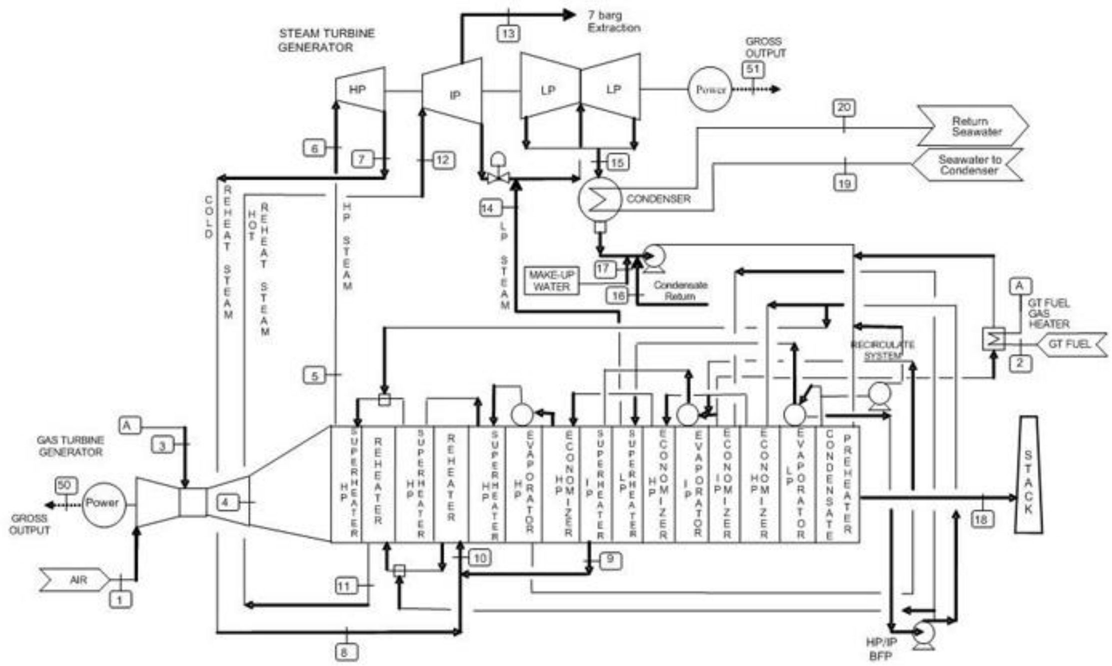


1.2 Steam Plant

The high-pressure, high-temperature steam is used to drive a series of steam turbines, as shown in Figure 3. In order to optimize the turbine design for the steam conditions and also to permit the use of reheat – which is reheating of steam after it has been expanded at least once in a turbine – multiple turbines are used, which improves steam cycle efficiency. Figure 3 shows the exhaust from the low pressure (LP) turbine being cooled in the condenser with seawater. In practice, many NGCC facilities do not have access to seawater, a lake, river, or other body of water for cooling and therefor use either a closed loop cooling system with water circulating between the condenser and an air-cooled heat exchanger (cooling tower) or alternatively an air cooled condenser, where the exhaust steam from the turbine passes through tubes and cooling air is blown past the tubes, cooling and condensing the steam without the water circulation loop.

[2] Union of Concerned Scientists, http://www.ucsusa.org/clean-energy/coal-and-other-fossil-fuels/uses-of-natural-gas#.WFG-6LIrKUk

Figure 3. Simplified diagram of NGCC steam plant.[3]



For NGCC plants, the total MW capacity of the plant is equal to the sum of the output of the steam turbine generator and the output of the gas turbine generator. The output of the gas turbine generator portion of the plant is typically in the range of about 60% to about 67% of the total output of both generators. In some cases there may be more than one gas turbine exhausting into a single HRSG.

1.3 Changes in operation of and advancements in combined cycle gas turbine plants

For many years NGCC power plants were dispatched after coal plants due to the higher cost of natural gas fuel; however, the increased availability and low cost of natural gas in recent years has caused NGCC plants to dispatch ahead of many coal plants. Figure 4 shows the historical price of natural gas supplied to the electric generating industry. As shown, natural gas prices are near historical lows. This has resulted in changes in operations for NGCC plants, resulting in higher capacity factors. In fact, in 2015 the average capacity factor of NGCC power plants in the US exceeded that of coal fired power plants.[4] Due to the higher capacity factors versus historical levels, NGCC plants will experience more frequent maintenance intervals and may find investment in improvements more economically attractive than in the past when capacity factors were lower.

Moreover, technology has improved. As demonstrated in Figure 5, the peak in installation of natural gas power plants occurred in the 2002-2003 time period, more than ten years ago. Newer NGCC plants

[3] Department of Energy, https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/igcc-process

[4] Energy Information Administration, https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_07_a

utilize advanced materials that permit operation at higher temperatures and higher efficiencies. New designs for seals and other components reduce losses. For existing NGCC plants replacement parts of superior design and materials than the original create opportunities for improved performance and reliability. In addition to advanced materials, other methods for improving the performance of NGCC plants have been developed over time that can be deployed. In general, improvements can be broken down into:

- Methods to improve the efficiency of the gas turbine, or
- Methods to improve the efficiency of the Rankine cycle.

Figure 4. Natural Gas Price History to the Electric Power Industry.[5]

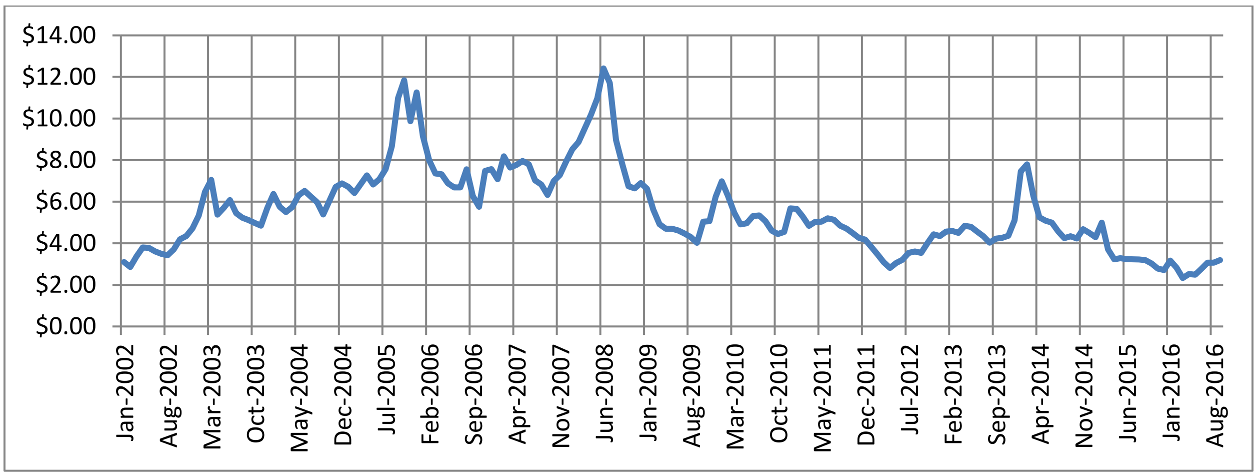
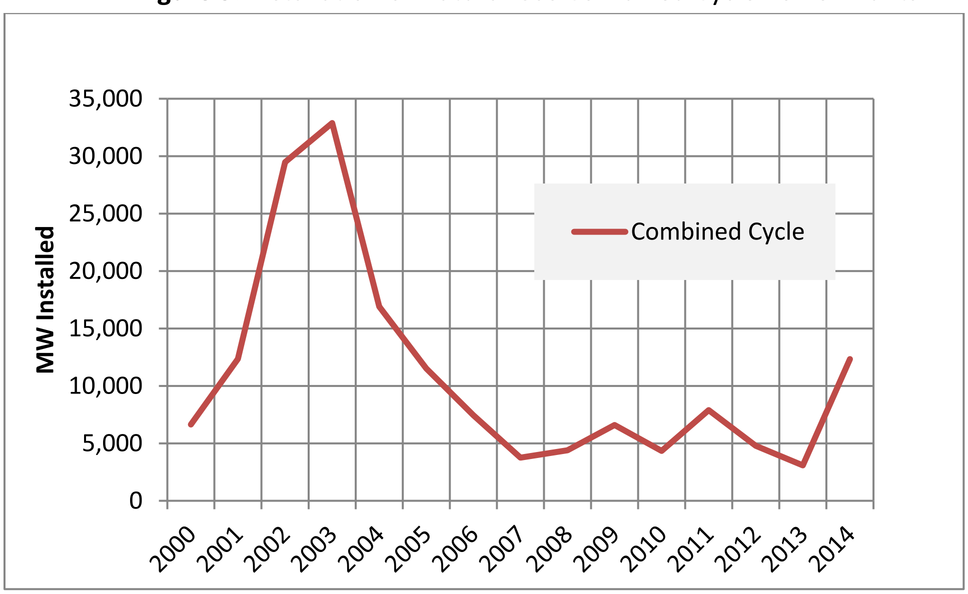


Figure 5. Installation of Natural Gas Combined Cycle Power Plants[6]



[5] US Energy Information Administration, https://www.eia.gov/dnav/ng/hist/n3045us3m.htm
[6] Developed from US EPA data

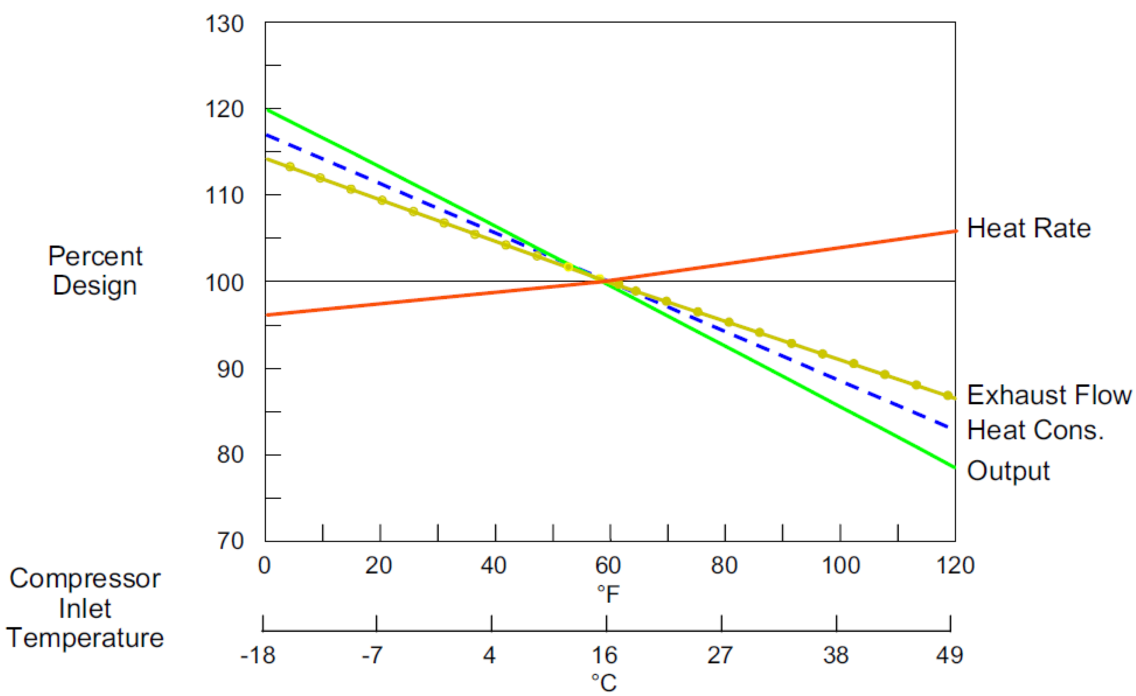
2. Methods to improve the heat rate of the gas turbine

Gas turbine and gas flow improvements include methods to improve efficiency from reducing compressor load and improved parts from advanced materials that provide superior performance or methods for enhancing the output and efficiency of the gas turbine.

2.1 Compressor Inlet Cooling (Turbine Inlet Cooling) and Intercooling Methods

The output and heat rate of a gas turbine is very sensitive to the ambient temperature. This is because the compressor operates more efficiently when gases are at lower temperature. Therefore, as inlet temperature to the compressor is increased, output of the gas turbine will drop off and heat rate will increase. For this reason all gas turbine system power plants have a rated load at standard conditions, typically 60°F. These trends are shown in Figure 6.

Figure 6. Effect of compressor inlet temperature on Heat Rate, Output, Exhaust Flow, and Heat Consumption (fuel input) on a simple cycle gas turbine power plant.[7]



Lower compressor inlet temperature can be achieved in a number of ways:

- Inlet cooling – This is cooling the inlet air prior to admission to the compressor
- Intercooling – This is cooling that occurs between compressor stages.

The Turbine Inlet Cooling Association's database[8] shows over 400 installations of different forms of inlet cooling or intercooling with about half in the United States. These are mostly installed in warm climates, but also in very moderate climates. While the benefits are greatest in warm climates, and this is where

[7] Brooks, F., "GE Gas Turbine Performance Characteristics", GE Power Systems, GER-3567H, http://www.up.farsscript.ir/uploads/13316846411.pdf
[8] http://www.turbineinletcooling.org/data/ticadatap.pdf

most facilities are located, TIC has also been installed in more moderate climates, such as Nebraska, New York, Connecticut, Pennsylvania, Massachusetts, New Jersey, Maine and Maryland.

Inlet cooling can be performed in a number of ways. One method may be use of refrigeration chillers powered by electricity. A second way is pulling the inlet gas through a wetted media where moisture is evaporated. This is called evaporative cooling. A third is inlet fogging, where moisture is sprayed into the inlet gases as a fine mist. The amount of temperature reduction by evaporative cooling or fogging is limited by the increased moisture level in the gas that raises the dew point temperature, however evaporative cooling and fogging have two advantages: 1) they are very simple to deploy, involving simple equipment, and; 2) the increased mass flow from the moisture will increase turbine output somewhat. Inlet cooling by any of the methods increases gas turbine output by reducing the compressor load. It also increases efficiency, reducing heat rate.

The additional capacity available from any of the inlet cooling methods is at a capital cost that is well below the cost of a new combustion turbine. [9] This additional capacity is also available when it is most needed – on hot days when power demand is greatest.

Intercooling can be performed with heat exchangers installed between compressor stages; however, this is normally impractical for an existing turbine. There are other wet approaches available for intercooling. General Electric offers Spray Intercooling (SPRINT) on its aeroderivative gas turbines, which are most often used in simple cycle applications but may be used in NGCC applications. SPRINT injects water into the compressed gas after the low pressure portion of the compressor and before the high pressure portion of the compressor.

Another approach is called Wet Compression. Wet Compression is depicted in Figure 7. Moisture is injected in an amount in excess of that needed to reach the dew point through spray nozzles that generate a fog. This moisture carried in the gas into the compressor cools the gas as the gas is compressed, reducing the power needed to compress the gas while also increasing the mass flow through the machine.[10] Both SPRINT and Wet Compression have the effect of improving both power output and cycle efficiency (heat rate).

GE's SPRINT technology can increase output by as much as 17% on hot days, but more typical conditions showed 9% increase in output. [11] Fuel demand will also increase, but the increase in power output will more than compensate for the increased fuel – improving heat rate.

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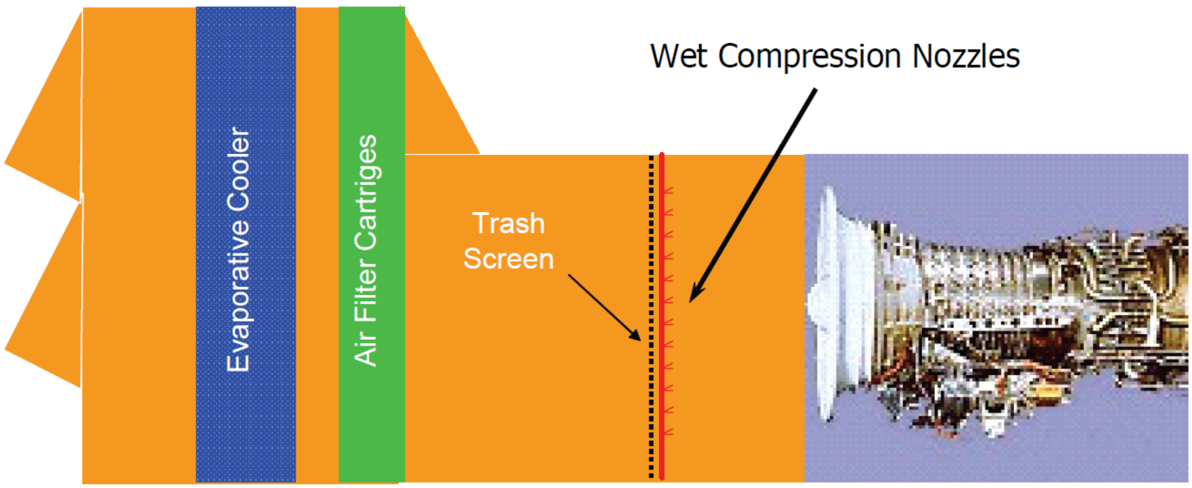
[10] Shepherd, D., Fraser, D., "IMPACT OF HEAT RATE, EMISSIONS AND RELIABILITY FROM THE APPLICATION OF WET COMPRESSION ON COMBUSTION TURBINES", http://www.energy.siemens.com/US/pool/hq/energy-topics/pdfs/en/gas-turbines-power-plants/5_Impact_of_Heat_Rate.pdf.

[11] http://www.modernpowersystems.com/features/featuresprintsprayintercoolingaugmentslm6000output/

Figure 7. Wet Compression Technology[12]



2.1 Improvements to Turbine, Compressor and Combustor parts.

Existing gas turbines can be upgraded, resulting in improved performance and reliability. This is not only due to degradation of components from wear and tear. It is also due to improved materials, designs and methods for manufacture.

All of the major manufacturers and some aftermarket companies offer uprate packages that improve performance and/or reliability. For example, GE offers at least 400 firing temperature uprates for their heavy duty gas turbine field units.[13] These improvements include new seal designs that reduce leakage, improved inlet guide vanes to the compressor, advanced technology updates that include parts made of new materials or new designs. One example of this is that GE has developed improved wire brush seals for the compressor shaft that work better than labyrinth seals originally supplied on some existing units. The wire brush seals will provide tighter clearances and less leakage; this individual improvement can increase output by about 1% and heat rate by about 0.5%. High pressure packing seals on the turbine can also be replaced with brush seals, particularly on GE's frame 5, 7 and 9 units. Performance improvement is typically 0.3% in output and 0.2% heat rate.

With an uprate package of the numerous improvements available, significant increases in output and heat rate are possible. [14]

An example of how new technology will improve output and heat rate is new turbine blade materials and designs that reduce the need for bleed air to cool the turbine blades. Figure 8 shows the impact of bleed air (air that is taken from the compressor discharge to cool turbine blades) on output and heat rate. As shown, at an ambient temperature of 60F, a 10% bleed rate will increase heat rate by about 20% and decrease power output by over 20%.

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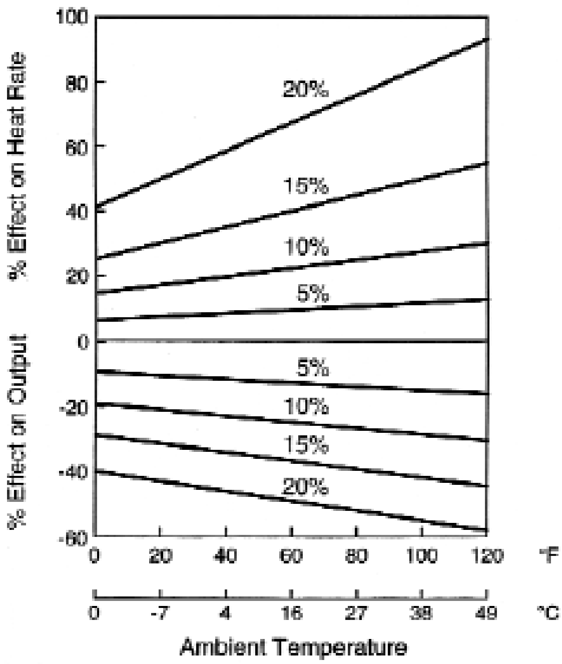
[12] Ibid.
[13] Johnston, J., "Performance and Reliability Improvements for Heavy-Duty Gas Turbines", GER-3571H (summarizing uprate options for the GE MS6001B).
[14] Ibid

Figure 8. Effect of air bleed on output and heat rate as a function of ambient temperature[15]



Use of advanced materials will reduce the need for bleed air. An alternative for NGCC plants is steam cooling for the turbine blades, which offers the advantage of recovering the steam in a closed loop. This is available on GE's H class turbines and it allows for significantly higher turbine inlet temperature.[16]

Coatings –

Coatings can provide advantages in terms of heat resistance (for turbine blades and combustor components), resistance to fouling (especially compressor blades), reduced surface friction, and resistance to corrosion (especially if the turbine is located near saltwater).

The Combustion Turbine Combine Cycle Users Organization performed an analysis that showed that adding a 10 mil coating to the 1st stage blades and vanes of a GE Frame 7EA would allow an increase in firing temperature from 2020 °F to 2035 °F. The report calculated that this small increase could provide $4 million of net revenue over the life of the coating. [17]

Another study by Fern Engineering, Inc. for the Electric Power Research Institute, Palo Alto, Calif., concluded that the addition of thermal barrier coatings to a GE Frame 7B would provide an increase of 5.5 MW in power (from 91 MW base power), at an incremental cost that would be a small fraction of the cost of new combustion turbine capacity. [18, 19]

Other options to increase the mass flow through the compressor and often reduce losses include installing higher flowrate inlet guide vanes that are aerodynamically thinner and allow greater flow into the compressor. [20]

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[15] Brooks, F., "GE Gas Turbine Performance Characteristics", GER-3567H
[16] Ibid
[17] Phillips, J., Levine, P., "GAS TURBINE PERFORMANCE UPGRADE OPTIONS", http://www.fernengineering.com/pdf/gt_upgrade_options.pdf
[18] Ibid
[19] EIA's 2017 Annual Energy Outlook Table 8.2 indicates new combustion turbine capacity at $632/kW to $1026/kW and combined cycle at $911/kW to $1000/kW. http://www.eia.gov/outlooks/aeo/assumptions/pdf/electricity.pdf
[20] Phillips, J., Levine, P., "GAS TURBINE PERFORMANCE UPGRADE OPTIONS", http://www.fernengineering.com/pdf/gt_upgrade_options.pdf.

Another approach to increase mass flowrate, output and improve heat rate is supercharging, which amounts to adding a blower to the inlet of the compressor. This approach when used in combination with inlet fogging increases power much more than the amount consumed by the blower. [21]

Comprehensive upgrades might include replacement of combustion liners, transition pieces, 1st stage turbine vanes, and 2nd stage vanes and blades with Frame 7EA parts. This allowed operators to increase the firing temperature of the machines by 170 deg F. After the upgrades, the eight machines yielded power increases of 16 to 26%, while the heat rate decreased by 4.5 to 11% − improvements that are approximately three times greater than what could have been expected from a normal overhaul using new Frame 7B parts.[22]

2.2 Pressure Drop Reduction

A reduction in pressure drop in the HRSG gas pathway will improve turbine output and heat rate. This can be achieved with newly available SCR and CO catalysts that have lower volumes and therefore lower pressure losses than before. In this case at least 20% reduction in total catalyst pressure drop can be achieved with newer combination catalysts.[23] This will result in a heat rate improvement, the magnitude of which will depend upon the pressure ratio of the turbine.

2.3 Maintenance efforts

Regular HRSG cleaning is beneficial to maintaining low pressure drop across the HRSG. Although natural gas has very low sulfur levels, some ammonium bisulfate can accumulate in the HRSG, leading to pressure losses. Other contaminants can build up on the HRSG over time. With increased operation of combined cycle plants regular HRSG cleaning will become more important. The extent of the improvement in output will depend upon the degree of the deposit and the turbine pressure ratio. One example is described in a Case Study on GE's Pressurewave HRSG cleaning technology. After one cleaning effort removed three tons of debris from the HRSG of a NGCC facility, GE removed an additional 14 tons of debris, and reduced turbine back pressure by 8 inches water column, with net annual fuel savings or increased power output estimated at $500,000/year.[24]

Gas turbine flow path components also suffer degradation and build up. Regular cleaning of or replacement of components is therefore an important part of maintenance. With increased operation, increased maintenance will be necessary.

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[21] Ibid

[22] Ibid

[23] Niklas Jakobsson & Hans Jensen-Holm, "Catalytic multi-pollutant abatement of gas turbine exhaust", Haldor Topsoe, http://www.topsoe.com/sites/default/files/catalytic_multi_pollutant_abatement_of_gas_turbine_exhaust.ashx__2.pdf

[24] GE Power, "When is a 28,000 lb rust pile a good thing?", GEA32737 (08/2016), https://powergen.gepower.com/content/dam/gepower-pgdp/global/en_US/documents/service/hrsg%20services/pressurewave-case-study.pdf

3. Methods to Improve the Heat Rate of the Steam Plant

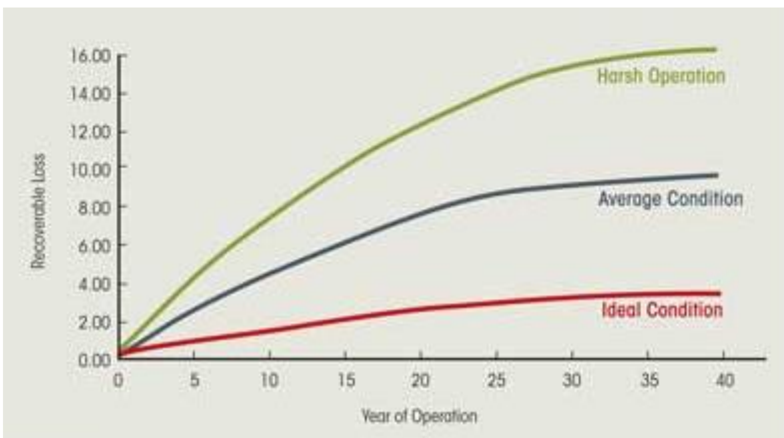
Many of the improvements to the steam plant available to NGCC operators are similar to what is available to operators of steam generating units, such as coal-fired generating units. These include:

3.1 Turbine upgrade

While there are some differences, for the most part steam turbines used in NGCC plants are similar to those of coal or oil fired steam generating units, and therefore many of the same improvements that can be made to those units are possible for the steam turbines of NGCC plants. Upgrades provide opportunities for heat rate and reliability improvements for the following reasons:

- Deterioration – Over time the steam turbine components will deteriorate, making the turbine less efficient. The rate at which the steam turbine deteriorates will depend upon the operation and maintenance of the facility. If the turbine is operated under harsh conditions, such as conditions of poor steam quality, this may cause degradation to be faster. Figure 9 shows an example of upgrade opportunities for steam turbines showing the recoverable loss.

Figure 9. Upgrade opportunities for Steam Turbine [25]



- Technology Improvements – With time newer technology enables turbines to be more efficient. This may include improvements to materials or designs. Increased use of computational methods for designing turbine components has led to much more efficient turbine blade designs than previously available.
- Changes in operation – Turbines are designed to suit the expected operation and if the operation changes the original design may no longer be ideally suited to the application. For example, steam turbines designed for cycling duty may not be optimally designed for base load duty.

[25] Morris, L., "Steam Turbine Upgrades Boost Plant Reliability, Efficiency", *Power Engineering*, 11/1/12, http://www.power-eng.com/articles/print/volume-116/issue-11/features/steam-turbine-upgrades-boost-plant-reliability-efficiency.html

Because many steam turbines at NGCC plants are in excess of ten years old and some approaching 20 or more years of operation, there is the potential for significant improvements in performance.[26]

3.2 Condenser upgrades and cleaning

Because the condenser impacts the exhaust pressure of the turbine, it has a substantial impact on power output and heat rate. The condenser should be regularly cleaned. Air cooled condensers, which are very common on natural gas combined cycle plants, can be fouled by airborne dust and debris and should be regularly cleaned. For air-cooled heat exchangers the cost and benefit would likely be on the same order or less as the cost of cleaning the once-through condensers. Unlike once through condensers, air cooled condensers do not require draining of the cooling (air) side, and are therefore easier to clean. [27]

Other improvements to condenser cooling could be larger or enhanced condensers, use of evaporative cooling if water is available.

3.3 Rebuilding boiler feed pumps

Boiler feed pumps raise the pressure and pump the water through the HRSG. They consume a substantial amount of power. Feed pumps wear over time, reducing their efficiency. Pumps must therefore be periodically rebuilt to maintain efficiency. [28]

3.4 Installation of variable speed drives for pumps and blowers

Older existing plants may have installed single speed pumps and motors that regulate flow by throttling the discharge of the pump. This is wasteful at low loads, but may have been an economical choice depending upon operation. The use of variable speed drives that match the pump motor speed to the desired flowrate is a more efficient approach. Feed and circulating water pumps as well as cooling tower fans are the largest loads. According to NETL's base case for natural gas power plants, boiler feed pumps consume 3550 kWe, circulating water pumps 2570 kWe and cooling tower fans 1330 kWe for a 219,000 kWe steam plant power output and 641 MWe total NGCC power plant output.[29] These total 3.4% of the steam turbine generator output and 1.16% of the total NGCC plant output. The level of savings that may be possible from installation of variable speed drives will depend upon the operating characteristics of the plant.

3.5 Minimizing Steam System Losses

Loss of some heat that could be utilized is inevitable; however, it should be minimized. There are a range of practices that can be adopted to minimize losses. Table 1, shows some of the

[26] Sargent & Lundy, "COAL-FIRED POWER PLANT HEAT RATE REDUCTIONS", SL-009597, FINAL REPORT JANUARY 22, 2009 PROJECT 12301-001

[27] Ibid

[28] Ibid

[29] US Department of Energy, National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity Revision 3", July 6, 2015, DOE/NETL-2015/1723, pg 179

methods available for minimizing losses from the steam systems. This table has been adapted from a table developed by the Department of Energy for industrial steam plants to make it applicable to NGCC plants. The costs of these practices are small – requiring negligible capital and usually modest increases in maintenance activities.[30]

Table 1. Opportunities for minimizing losses in steam systems[31]

Opportunity	Description
Steam Generation	
Minimize HRSG excess air	Reduces the amount of heat lost up the stack, allowing more of the fuel energy to be transferred to the steam
Clean HRSG heat transfer surfaces	Promotes effective heat transfer from the combustion gases to the steam
Improve water treatment to minimize HRSG blowdown	Reduces the amount of total dissolved solids in the HRSG water, which allows less blowdown and therefore less energy loss
Recover energy from HRSG blowdown	Transfers the available energy in a blowdown stream back into the system, thereby reducing energy loss
Add/restore HRSG and steam plant insulation	Reduces heat loss from the HRSG and steam plant and restores HRSG and steam plant efficiency
Optimize deaerator vent rate	Minimizes avoidable loss of steam
Steam Piping	
Repair steam leaks	Minimizes avoidable loss of steam
Minimize vented steam	Minimizes avoidable loss of steam
Ensure that steam system piping, valves, fittings, and vessels are well insulated	Reduces energy loss from piping and equipment surfaces
Implement an effective steam-trap maintenance program	Reduces passage of live steam into condensate system
Isolate steam from unused lines	Minimizes avoidable loss of steam and reduces energy loss from piping and equipment surfaces
Recovery	
Optimize condensate recovery	Recovers the thermal energy in the condensate and reduces the amount of makeup water added to the system, saving energy and chemicals treatment

[30] Department of Energy, "Steam Trap Performance Assessment", pg 12; https://www1.eere.energy.gov/femp/pdfs/FTA_SteamTrap.pdf.

[31] This has been adapted from Table 2: Department of Energy, "Improving Steam System Performance: A Sourcebook for Industry", Second Edition, https://energy.gov/sites/prod/files/2014/05/f15/steamsourcebook.pdf; changes have been made to make it applicable to NGCC plants rather than for industrial steam plants. Therefore, some opportunities that are not applicable to NGCC plants have been removed.