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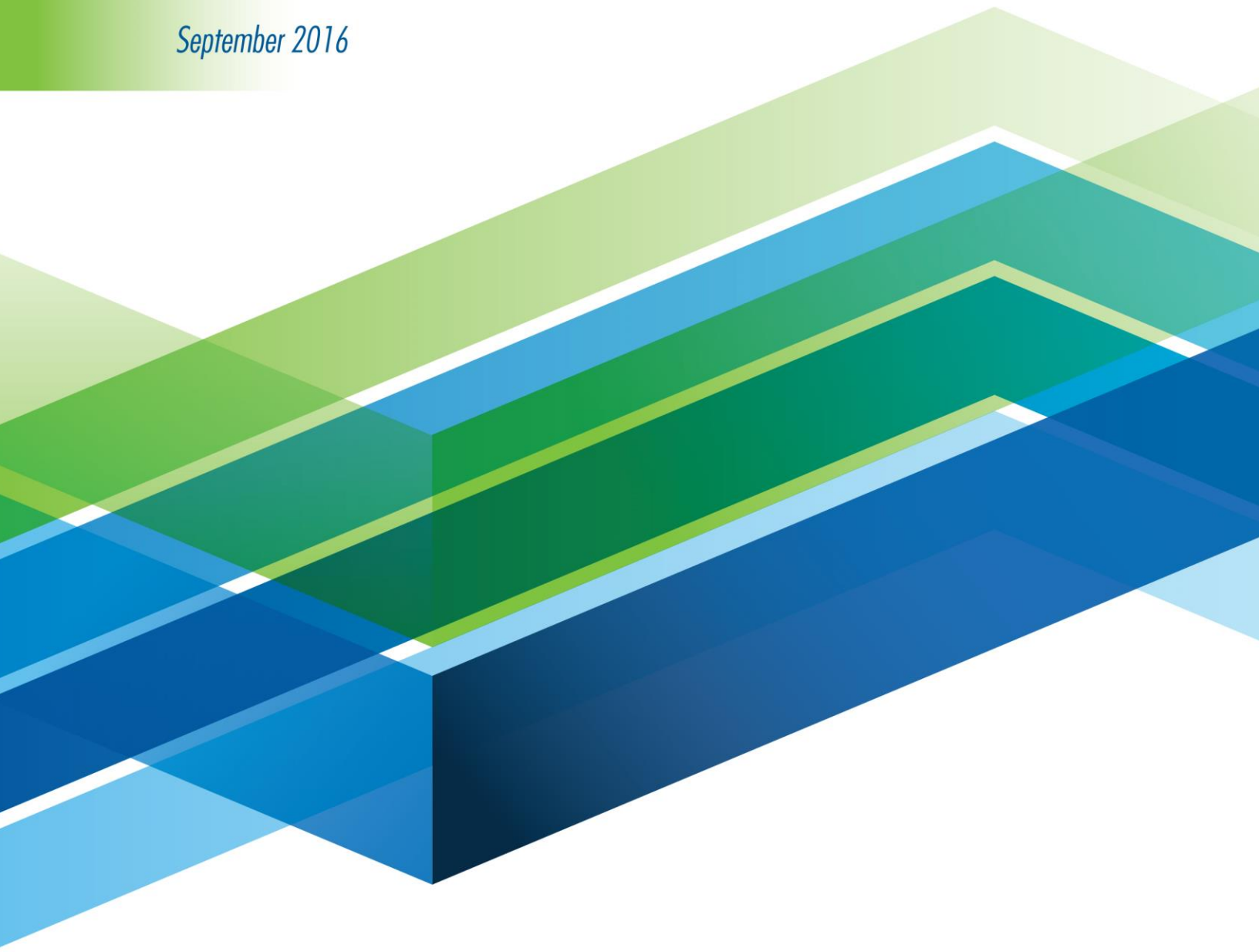
Energy Systems Strategic Assessment Institute

Summit on Improving the Economics of America's Nuclear Power Plants

September 2016



Idaho National Laboratory INL | CAES Center for Advanced Energy Studies

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Summit on Improving the Economics of America's Nuclear Power Plants

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EXECUTIVE SUMMARY

On May 19, 2016, Secretary of Energy Ernest Moniz convened a meeting of experts and stakeholders to discuss the economic challenges facing a number of nuclear power plants (NPPs) and the unintended consequences that could arise from early NPP closures. The objective was to identify policy options that can be pursued at federal and state levels to address these concerns, as well as technical options that utilities can use to improve the economic competitiveness of operating NPPs. The event was recorded and archived at the Gateway for Accelerated Innovation in Nuclear (GAIN) website.[a]

Nuclear energy, which generates approximately 60% of the carbon-free electricity in the United States, provides significant baseload electrical capacity and plays a major role in efforts to reduce carbon emissions. Continued U.S leadership in nuclear power is critical to meeting the nation's objectives in the areas of clean energy, electricity reliability, economic competitiveness, national security, and nuclear-weapons nonproliferation.[b]

The current NPP operating fleet (99 reactors) represents approximately 54 GWe of generating capacity in regulated markets and 45 GWe in restructured electricity markets. In states with restructured electricity markets, nuclear operators have found increasing difficulty competing in a low-energy price environment arising from flat or declining energy demand, low natural gas prices, increased operating costs, and other factors. Since a peak of 104 operating reactors in 2013, five of them have shut down earlier than their licensed lifetime (note that three of these also faced costly repairs). As of July 1, 2016, another seven units had filed with the Nuclear Regulatory Commission to close prior to the end of their current operating licenses (5.5 GW total). However, as a result of New York's recently approved Clean Energy Standard (CES) and the subsequent sale of the James A. FitzPatrick NPP, one of these reactors is now expected to remain online, as are two other reactors in New York (Ginna and Nine Mile Point-1) that would have been added to the list of early retirements if the New York CES had not been approved. As in New York, the decision to close could be reversed for three reactors in Illinois pending passage of proposed legislation targeting a similar CES. Additionally, as a result of California's evolving energy policy, Pacific Gas and Electric Company announced that it would not pursue a license extension of its two-reactor Diablo Canyon Power Plant. While a few retirements have been driven by mechanical failures that were deemed too costly to repair in a less than favorable energy market, the majority are due to NPPs in wholesale markets facing a poor economic outlook. If current market conditions persist, it is plausible that 50% or more of the current nuclear fleet could be at risk of retirement before 2030, making it much more difficult for the United States to meet its clean-energy, national-security, and economic objectives.

Recent Actions

Actions taken that may help to address the situation include:

- Industry, through the Nuclear Energy Institute, has launched an initiative called "Delivering the Nuclear Promise" to enable a significant reduction in costs (30%) by 2018,[c] because the generating costs of NPPs have increased during the previous decade. Estimates are that costs have increased approximately 28% over 12 years.
- The U.S. Department of Energy (DOE) organized a working group to identify technology development options that, when deployed, could reduce operating costs.

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[a] https://gain.inl.gov/SitePages/Workshops.aspx

[b] https://www.whitehouse.gov/the-press-office/2015/11/06/fact-sheet-obama-administration-announces-actions-ensure-nuclear-energy

[c] Nuclear Energy Institute, *Delivering the Nuclear Promise: Advancing Safety, Reliability and Economic Performance*, February 2016.

- Modifications were made to capacity markets to better account for capacity performance,[d] although the modifications proved insufficient in the most recent PJM Interconnection LLC (a Mid-Atlantic region power pool) capacity auction due to even lower natural gas prices.
- The New York Public Service Commission issued an Order Adopting a CES and determined "that a series of deliberate and mandatory actions to build upon and enhance opportunities for consumer choice are necessary to achieve State environmental, public health, climate policy and economic goals; to enhance and animate voluntary retail markets for energy efficiency, clean energy and renewable resources; to preserve existing zero-emissions nuclear generation resources as a bridge to the clean energy future; to ensure a modern and resilient energy system; and to accomplish its objectives in a fair and cost-effective manner" (Cases 15-E-0302 and 16-E-0270 -2, Filing No. 352).[e]
- Pending legislation in Illinois could provide a CES similar to New York's, among other things.[f]
- The Federal Energy Regulatory Commission's (FERC's) price formation proceeding was initiated in June 2014, and, in June 2016, FERC issued a new ruling[g] requiring pricing in real time rather than based on an hourly integrated price; this distorted price signals and, in some cases, created a disincentive for baseload resources such as nuclear power.
- The Public Utility Commission of Ohio approved an arrangement that would allow for the continued operation of a nuclear facility, though this agreement was challenged by FERC.
- The American Nuclear Society issued its Nuclear in the States Toolkit,[h] which provides a fairly comprehensive list of possible actions.

Potential Solutions

Nuclear power is an important source of baseload, zero-carbon electricity in the United States. The Clean Power Plan[i] recognizes this, and states have opportunities to incorporate new and existing nuclear energy into their implementation plans. Yet NPPs are closing, and more closures are expected by the end of the decade. Therefore, near-term solutions are needed to serve as a bridge to the Clean Power Plan.

The following were identified during the summit as actionable steps that could be taken; note that this is not necessarily a complete list of all options:

- Level the playing field, i.e., treat all clean energy technologies equally
- Consider price formation by FERC
- Consider valuing important energy attributes (i.e., zero carbon, baseload, reliability, resiliency, affordability, fuel diversity, sustainability, security, flexibility, etc.)
- Develop CESs
- Negotiate power purchase agreements
- Consider carbon price, production tax credit, or a cap on Nuclear Regulatory Commission fees.

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[d] http://www.pjm.com/~/media/about-pjm/newsroom/2015-releases/20150610-ferc-approves-capacity-performance.ashx

[e] http://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterCaseNo=15-e-0302

[f] http://www.nextgenerationenergyplan.com/

[g] FERC Order 825, "Settlement Intervals and Shortage Pricing in Markets Operated by Regional Transmission Organizations and Independent System Operators," Federal Energy Regulatory Commission, June 16, 2016.

[h] http://nuclearconnect.org/issues-policy/nuclear-policy-in-the-states

[i] https://www.epa.gov/cleanpowerplan/clean-power-plan-proposed-rule-technical-documents#

CONTENTS

FIGURES

ACRONYMS

CASL	Consortium for Advanced Simulation of Light Water Reactors
CES	Clean Energy Standard
CPP	Clean Power Plan
DOE	U.S. Department of Energy
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
GAIN	Gateway for Accelerated Innovation in Nuclear
GHG	Greenhouse Gas
INPO	Institute of Nuclear Power Operations
ISO	independent system operator
LWRS	Light Water Reactor Sustainability
NEI	Nuclear Energy Institute
NGO	non-governmental organization
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
PCI	pellet clad interaction
PSEG	Public Service Electric and Gas
RGGI	Regional Greenhouse Gas Initiative
RISMC	Risk-Informed Safety Margins Characterization
RPS	renewable portfolio standard
RTO	regional transmission organization

Energy Systems Strategic Assessment Institute

Summit on Improving the Economics of America's Nuclear Power Plants

1. INTRODUCTION

On May 19, 2016, the Summit on Improving the Economics of America's Nuclear Power Plants was convened by Secretary of Energy Ernest Moniz and sponsored by Idaho Senator Mike Crapo (R-ID). The summit was held to stress the importance of existing nuclear power plants (NPPs) in meeting our nation's clean-energy and national-security goals and to identify potential actions to address the early closures of some NPPs. The summit, held in the Hart Senate Office Building in Washington, D.C., was attended by more than 175 leaders from industry, state and federal governments, labor organizations, non-governmental organizations (NGOs), universities, and national laboratories. The summit focused on a near-term actionable path forward to address the challenges facing a number of existing NPPs and the unintended consequences that could arise from early plant retirements (see Appendix A for the summit agenda). Held as a Gateway for Accelerated Innovation in Nuclear (GAIN) event, the summit was broadcast via live webcast to nearly 1,000 additional participants, and the discussions reached more than 24 million Twitter accounts, with nearly 3,000 tweets (#actfornuclear). It is now archived at the GAIN website [1].

The summit was designed to identify and discuss policy options that can be pursued at federal and state levels to address economic challenges facing NPPs, as well as technical options that utilities can use to improve the economic competitiveness of operating NPPs and avoid early NPP retirements that are driven by temporary market conditions. This report summarizes key policy and/or technical options that may be considered for action by federal, state, and industry leaders.

2. BACKGROUND

Nuclear power, which generates about 20% of the total electricity and approximately 60% of the carbon-free electricity in the United States [2], provides baseload capacity with limited variability and plays a major role in efforts to reduce carbon emissions (Figure 1). As the world transitions to a low-carbon economy, U.S. leadership in nuclear power is critical in meeting the nation's objectives in the areas of clean energy, electricity reliability, economic competitiveness, national security, and nuclear-weapons nonproliferation. As part of the 2015 United Nations Climate Change Conference, COP21, "The United States has committed to reduce its greenhouse gas (GHG) emissions by 26–28 percent below the 2005 level by 2025 and to make 'best efforts' to reduce emissions by 28 percent. That would include curbs on carbon dioxide, methane, nitrous oxide, perfluorocarbons, sulfur hexafluoride and nitrogen trifluoride, all of which contribute to global warming" [3]. The early retirement of NPPs not only makes carbon-reduction targets more difficult to achieve, it also impacts energy security and national security. Nuclear power is expanding worldwide. In order to have a major role in setting international standards of safeguards, physical security, and safety, the United States must set the example.

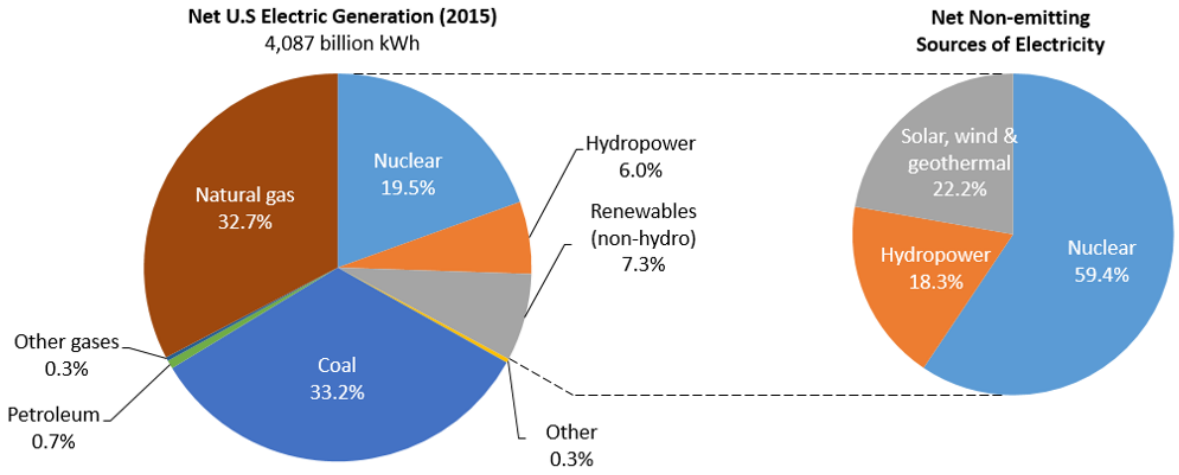

Figure 1. Breakdown of net U.S. electricity sources and net carbon-free (i.e., non-emitting) sources [2].

2.1 Operational Plant Impact

Of the 61 operating NPPs in the United States, 26 have a single reactor, while 35 NPPS have two or more reactors. The 99 total reactors represent a generating capacity of approximately 54 GW (50 reactors) in regulated markets and 45 GW (49 reactors) in restructured electricity markets. Eighty-one of the currently operating reactors have received a 20-year license extension (extending operating life from 40 to 60 years), and another 10 reactors are currently in the application process. Additionally, in the past year, two plants (Surry Power Station and Peach Bottom Nuclear Generating Station) have announced intentions to seek subsequent license renewals to 80 years, and others are expected to do the same. Five nuclear reactors are currently under construction in the Southeast. Tennessee Valley Authority's Watts Bar Unit 2 nuclear generating unit in Spring City, Tennessee, will be the first of these to come online, reaching commercial power operation this fall.

In states with restructured electricity markets, NPP operators have found increasing difficulty competing in an environment of low energy prices brought on by factors such as low-cost natural gas, flat or declining demand for energy, increasing operating costs, and other market conditions. Economic pressure on nuclear plants grew during 2015 as average monthly wholesale electricity prices declined from their 2014 levels by approximately 30% at most major trading hubs, again due largely to lower natural gas prices. Since 2013, when the United States operated 104 nuclear reactors, five of them have been shut down before the end their licensed lifetime:

- Crystal River NPP in Florida (February 2013)[a]
- Kewaunee NPP in Wisconsin (April 2013)[a]
- San Onofre NPPs (two) in California (June 2013)[a]
- Vermont Yankee NPP in Vermont (December 2014).

As of July 1, 2016, another seven units had filed with the Nuclear Regulatory Commission (NRC) to close prior to the end of their current operating licenses (5.5 GW total). However, as a result of New York's recently approved Clean Energy Standard (CES) and the subsequent sale of the James A. FitzPatrick NPP, one of these reactors is now expected to remain online, as are two other reactors in New York that would have been added to the list of early retirements if the New York CES had not been

a. Faced costly repairs.

approved. As in New York, the decision to close could be reversed for three reactors in Illinois pending passage of proposed legislation targeting a similar CES. Additionally, as a result of California's evolving energy policy, Pacific Gas and Electric Company announced that, via a negotiated agreement, it would not pursue a license extension of its two reactors at Diablo Canyon Power Plant, which are now projected to close in 2024 and 2025. While a few retirements have been driven by mechanical failures that were deemed too costly to repair in a less than favorable energy market, the majority are due to plants in wholesale markets facing a poor economic outlook. If current market conditions persist, it is plausible that 50% or more of the current nuclear fleet could be at risk of retirement before 2030, making it much more difficult for the United States to meet its clean-energy, national-security, and economic objectives.

Addressing the issues causing operational plant impact is required before future domestic NPPs will be built.

2.2 Climate Impact

Losing these (and potentially more) plants could make it extremely difficult, if not impossible, for states to meet their Clean Power Plan (CPP) [4] goals and for the United States to meet its international commitments. The closure of Vermont Yankee, for example, has resulted in a 5% increase in emissions in New England [5]. The closure of Illinois' Clinton and Quad Cities plants will result in the loss of 20 million metric tonnes of avoided carbon emissions [6].

The CPP sets state goals leading to a 32% reduction in carbon emissions by 2030. States have the opportunity to develop implementation plans that value existing (and new) nuclear generation as part of a balanced approach to achieving their specific carbon emission goals. However, CPP implementation is not set to begin until 2022, and as such, it is likely that near-term bridging solutions will be required to ensure that economically challenged NPPs continue generating zero-emitting electricity for as long as the NRC deems feasible with current and future operating license extensions. These bridging actions should be developed to address near-term issues and help utilities make decisions consistent with long-term national clean energy goals.

> The Quad Cities NPP in Illinois "produces about as much electricity in a single year as all of the utility-scale solar in America." – Marv Fertel, president and chief executive officer of the NEI

A number environmental organizations are realizing the value associated with nuclear energy and, accordingly, the danger associated with premature closures of NPPs. This shift in attitudes is expanding the dialogue on this critical issue and may result in developing technology-neutral clean-energy standards. For instance, the organization known as Environmental Progress reports, "Illinois generates more zero-emissions electricity than any other state. Most of it comes from the state's six nuclear power plants, which produce about half of Illinois' total generation and 90 percent of its low-carbon generation. If Clinton and Quad Cities nuclear plants were replaced by natural gas, carbon emissions would immediately increase the equivalent of adding two million cars to the road. If they were replaced by coal, the carbon emissions would more than double" (equivalent to adding 4 million cars to the road) [7].

2.3 Economic Impact

NPPs are also important to local economies, and closures impact household income and the standard of living in areas surrounding an NPP. Michael Shellenberger, president of Environmental Progress, said, "If Quad and Clinton are closed, Illinois will lose one-quarter of all its clean energy, over 1,500 jobs, and its standing as a clean-energy leader" [8]. Further, the average NPP generates $470 million in economic value in direct and indirect effects. The Exelon Corporation noted, "The Clinton and Quad Cities plants support approximately 4,200 direct and indirect jobs and produce more than $1.2 billion in economic activity annually. A state report found that closing the plants would increase wholesale energy costs for

the region by $439 million to $645 million annually. The report also found that keeping the plants open would avoid $10 billion in economic damages associated with higher carbon emissions over 10 years" [9]. For rural communities, NPP closures can be stifling, noted Patricia O'Donnell, chair of the selectboard for Vernon, Vermont, home of the now-closed Vermont Yankee NPP.

2.4 Energy and National Security Impact

Nuclear power is expanding worldwide. The United States must be a major player in domestic nuclear energy to be taken seriously on the international stage and to continue its leading role in setting and maintaining international standards for safety and nuclear security. "Nuclear power could make a major contribution to reducing dependence on imported gas and curbing CO_2 emissions in a cost-effective way, since its uranium fuel is abundant," according to the World Nuclear Association. "However governments needed to play a stronger role in facilitating private investment, especially in liberalized electricity markets where the trade-off between security and low price had been a disincentive to investment in new plant and grid infrastructure" [10].

3. SUMMIT OVERVIEW

The owners of NPPs face difficult economic decisions and are working to improve the performance of existing NPPs. However, it became clear through speeches given and panel discussions held during the summit that some of the actions taken by states (i.e., renewable portfolio standards [RPSs]) have had an impact on the economic viability of existing power plants, including carbon-free NPPs. Summit speakers identified concepts and actions that could be taken at state, regional, and federal levels to improve the economics of the existing fleet within these regulated and restructured electricity markets.

Summit discussions highlighted the following issues:

1. The current fleet of nuclear reactors must continue to operate to ensure the nation meets its climate, energy-security, and national-security objectives.
2. Factors that result in early NPP closures must be addressed with a sense of urgency.
3. Policies should focus on the end goal and be technology neutral (i.e., treat all clean energy technologies equally, thereby leveling the playing field)—for example, by moving from RPSs, which do not include nuclear energy, to CESs, which do include nuclear energy.
4. NPP closures appear not to be isolated events but are at least partially the result of systemic problems resulting from electricity markets, state standards, and federal regulations that were established for specific reasons and are now required to meet a different end goal. For instance, the Federal Energy Regulatory Commission (FERC) and the regional markets have the mandate to ensure reliable electricity at a reasonable cost but are not currently required to ensure climate goals are addressed.
5. Much of the nation's electricity load has moved from traditional wholesale electricity markets with bilateral transactions and power pool agreements to independent system operator (ISOs)/regional transmission organization (RTOs), which operate/manage the transmission system independent of electricity generation to foster competition. This equitable access creates a large, dynamic, and complex system that must be better understood to avoid negative unintended consequences.
6. Policies, regulations, and markets need to identify energy-source attributes that are desired for a robust domestic power system and appropriately value attributes, including:
    a. Reliability/baseload stability
    b. Price stability
    c. Carbon-free
    d. Resilience
    e. Flexibility/availability corresponding with demand

f. Diversity of supply

g. Fuel firmness (onsite fuel availability).

4. OPPORTUNITIES

The summit speakers and panelists focused on challenges facing NPPs, opportunities that utilities can use to improve the economic competitiveness of operating NPPs, and policy opportunities that can be pursued at federal and state levels. The following subsections summarize the opportunities described by speakers and panelists at the summit.

4.1 Industry Opportunities

Total electricity-generating costs at U.S. NPPs have increased 28% to an industry average of 3.6¢/kWh over the past 12 years [11], largely due to expenditures on safety and security upgrades in response to 9/11 and the Fukushima Daiichi accident. The increased operating costs combined with low natural gas prices and policies biased toward other carbon-free power sources have led to the current situation. "Premature shutdown of nuclear plants can cause social, economic and reliability harm to those communities and make it difficult to address climate change," said Ann McCabe, an Illinois Commerce Commission member.

The industry has challenged itself to improve efficiency and increase value while maintaining operational focus [12]. For instance, industry-wide teams have analyzed the cost drivers common to all nuclear plants and will redesign programs and processes to improve their efficiency and effectiveness. The goal of the Delivering the Nuclear Promise initiative is to provide companies that operate nuclear power plants with innovative solutions, enabling a significant reduction in operating expenses across the industry by 2018, while continuing to advance safety and reliability."

The industry looks to "address cost performance and improve productivity… On the cost side, NEI [Nuclear Energy Institute] and the industry have focused on optimizing industry or regulatory requirements that have been layered over decades. Throughout this process, we are maintaining industry standards for excellence in safety, yet developing more efficient approaches to meeting and exceeding those standards. On the revenue side, the industry is taking steps to gain value for the attributes of nuclear energy, many of which are not fully valued or recognized in competitive electricity markets. These attributes must be rewarded through a two-step approach to market reforms: changes to capacity markets and improved energy price formation in energy markets. Unless they are recognized and compensated, additional nuclear plants will be prematurely closed and the reliability of the electric grid threatened in some regions" [12].

> "It is terrifying to think about the loss of our nuclear fleet." – Matt Bennett, Third Way

The industry should focus on achieving the following outcomes:

- Advance the fundamentals of industry operation and training that have resulted in high levels of safety, and sustain this commitment to excellence through safety enhancements that will be derived during this transformation process
- Coupled with lower uranium fuel prices and reduced capital spending, redesign NPP processes to improve efficiency and effectiveness to enable a 30% reduction in electric generating costs, on average industrywide (i.e., a 15% reduction by January 2017 and a 30% reduction by January 2018)
- Drive changes in federal regulation at the NRC and FERC and in the RTOs/ISOs so that industry is able to monetize the value that NPPs provide
- Optimize resourcing throughout the nuclear enterprise to spur greater efficiencies at nuclear energy facilities and among suppliers

- Analyze technological and operational changes that could enhance safety and provide greater efficiency
- Leverage technology to ensure widespread industry adoption of innovative tools and techniques that could reduce costs
- Recognize the cultural shift among the millennial-based workforce that provides incentives for innovation
- Engage the industry workforce in the strategic plan through a broad-based industry-wide communications plan.

The industry opportunity lies in reducing costs, finding efficiencies within its control, and improving reliability while advancing safety in nuclear power plants.

4.2 State Opportunities

Twenty-nine states and the District of Columbia have adopted RPSs that incentivize renewables and, in some cases, impact the economic feasibility of baseload generation, including carbon-free nuclear power. Only two states (Ohio and Indiana) currently include nuclear energy in their RPSs. Figure 2 illustrates the state standards currently in effect. These policies effectively subsidize renewable energy, rendering an uneven playing field. In addition to producing larger overall power production costs, such outcomes raise the specter that these states, and the nation as a whole, will find themselves in a difficult position in the next decade and perhaps be unable to produce sufficient volumes of carbon-free energy to meet national or international goals and commitments. For example, the Quad Cities plant in Illinois has low production costs (2.8¢/kWh) and yet is forced to accept *negative* prices at certain times, because it competes directly with subsidized wind energy. These subsidies allow energy from wind to be profitable even when given away. These market issues are a part of the reason that Exelon announced the week before the summit that it is planning to close both the Quad Cities and Clinton NPPs in Illinois.

To avoid such an undesirable outcome, forward-looking states are identifying policy approaches that focus on reduced carbon, particulate, and noxious-gas emissions and that treat similar energy sources in a similar manner. One opportunity for creating such a competitive environment would be to include all carbon-free sources, including nuclear energy, in CESs; New York recently followed such a course of action [13]. This approach would be consistent with the recent announcement coming out of the North American Leader's Summit, which called for a 50% target for clean-energy generation (including renewable, nuclear, and carbon-capture and storage technologies) by 2025 across North America [14]. For states that adopt clean energy policies, such as a CES, or some variation of carbon pricing, such as emissions-trading methods, it is important to recognize that switching power production from fossil fuels to nuclear energy is a legitimate source of carbon reduction.

NPPs provide one of the only sources of zero-emitting baseload generation to the grid, thus ensuring reliability and resilience. Such benefits are not well-valued in most current and proposed market-based programs. To reduce GHG production in power generation, policies that recognize such benefits could be well-advised.

The clearest and most straightforward state opportunity lies in expanding RPSs toward CESs, which recognize the carbon-free power source represented by nuclear power. These state policies would be technology neutral and promote all carbon-free power sources.

There are also opportunities to selectively promote NPP—for example, by entering into power purchase agreements or by offering production tax credits to firms operating NPPs.

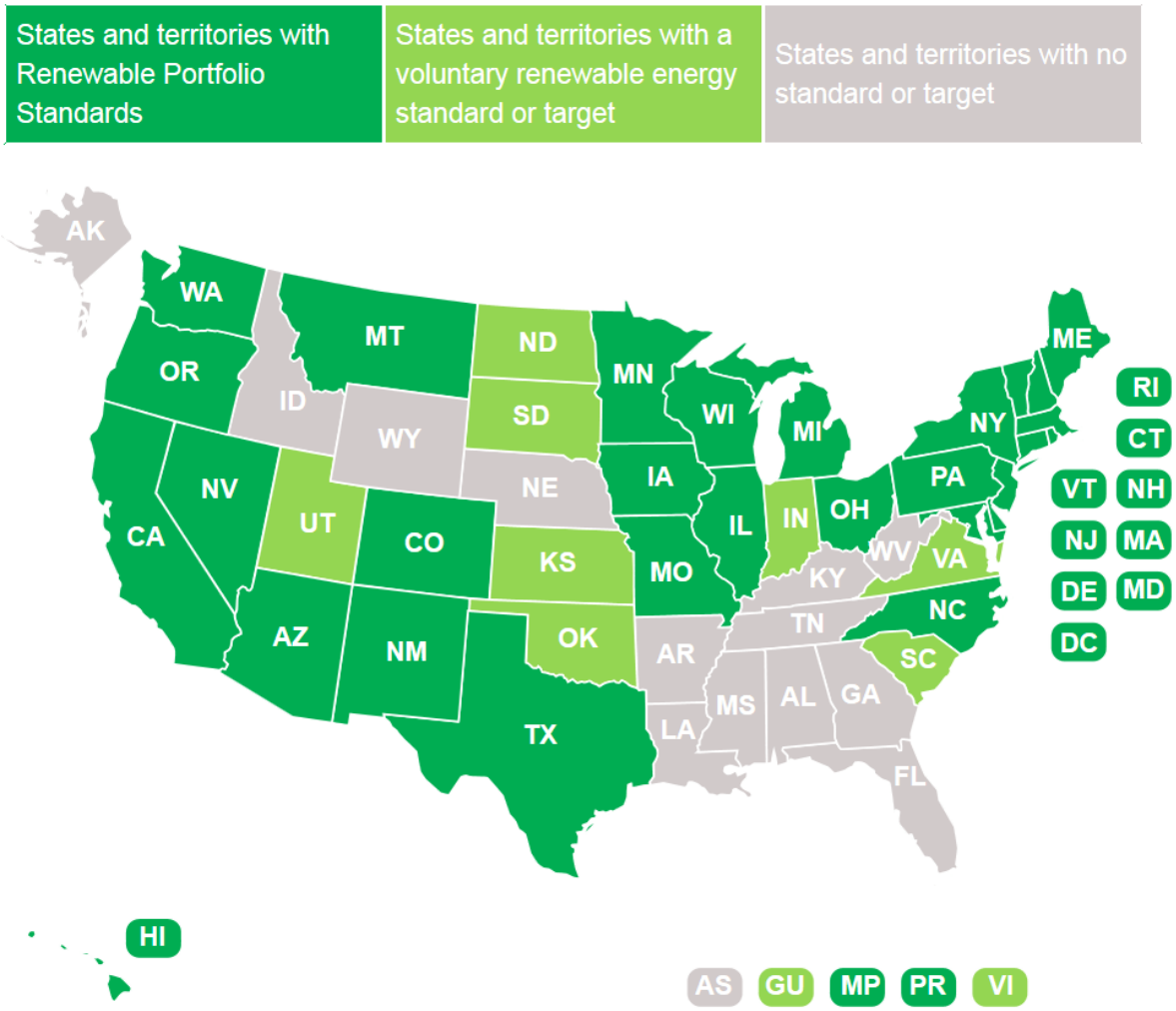

Figure 2. Current state standards.

4.3 Federal Opportunities

Because the benefits that accrue from maintaining NPPs are likely to be most apparent at the national or international level, the federal government plays an important role in the future of NPPs—in particular, developing a national policy that explicitly recognizes that the clean-energy and national-security value associated with current NPPs is critical.

Nuclear power is an important source of zero-carbon electricity in the United States. The CPP recognizes this and sets state goals for a 32% reduction in carbon emissions by 2030. However, CPP implementation is not set to begin until 2022.

One opportunity at the federal level is to institute direct rewards for production of carbon-free electricity. Two policy levers could fulfill this opportunity. First, instituting a production tax credit for the use of NPP would offset some of the costs of operating an NPP, thereby providing extra motivation for keeping plants in operation. Second, instituting a price on carbon, either via a carbon tax or through some variation of a cap-and-trade scheme, would reward carbon-free production sources such as nuclear power; again, this would motivate continued operation of NPPs. A less direct opportunity is to look for ways to

streamline the regulatory process—for example, by revising NRC fee structures that were based on old business models and may not reflect contemporary practices.

During the recent North American Leader's Summit, the United States, Canada, and Mexico issued a statement targeting 50% clean-energy generation (including renewable, nuclear, and carbon-capture and storage technologies) by 2025 across North America [14]. If this were to become U.S. energy policy, it could go a long way toward addressing the economic challenges currently facing U.S. NPPs, thus ensuring the nation is well positioned to meet this target.

There are also opportunities for the federal government to develop technical solutions that, once implemented, could improve economics although some of these opportunities are unlikely to be available for at least a few years. In keeping with the summit's immediate sense of urgency to identify near-term solutions, these longer-term solutions should be monitored and quick wins mined, as needed. The DOE organized working groups and several initiatives, with both near- and longer-term solution potential, to identify technology-development options that, when deployed, could reduce operating costs.

- Prior to this summit, DOE convened a working group made up of experts from industry, national laboratories, academia, and regulators to identify research, development, and demonstration opportunities that could prove economically beneficial. The highest priority activities related to improved materials (reactor pressure vessel internals, coolant systems, concrete, piping, cables, and non-destructive analysis methods for examinations), an area in which the DOE currently does extensive work. Digital technology research and development, including work on updated and improved control room design, was the second highest priority. Expanded use of probabilistic risk assessment and risk-informed and performance-based applications also ranked high, as did work on advanced fuels.

> "I would love to see Congress addressing a production tax credit as an urgent matter and available for existing nuclear generators on a nondiscriminatory basis." – Sue Tierney, Analysis Group

- The Light Water Reactor Sustainability (LWRS) Program conducts research that will collectively enable significant plant performance gains and minimize operating costs [15]. Significant progress has been made in demonstrating near-term beneficial digital applications that improve performance at lower cost [16]. The Risk-Informed Safety Margins Characterization (RISMC) Pathway is currently investigating applications of Risk-Informed Engineering Programs as part of the NEI Nuclear Promise; this research aims to leverage and enhance risk models in order to identify low-risk, safety-significant components under 10 CFR 50.69 [17], which allows for a reduced regulatory burden and the potential for significant cost savings. The material degradation research within LWRS is examining the long-term behavior of steel, concrete, and cable order to better understand and manage the key systems and structures found within the existing fleet of NPPs. In addition, the researchers are investigating cost-effective mitigation strategies for these systems and structures.
- Accident-tolerant fuels offer a number of benefits including higher performance and improved safety. DOE is currently working with industry partners to quantify the potential economic benefits resulting from these performance improvements. The enhanced safety offered by these fuels may enable less stringent safety margins which would also prove economically beneficial.
- DOE's work on modeling and simulation through activities like the Consortium for Advanced Simulation of Light Water Reactors (CASL) can also further improve operational performance of the existing fleet. CASL, which was the first Energy Innovation Hub, was established to provide leading-edge modeling and simulation capability to improve the performance of currently operating NPPs. CASL's challenge problems are in areas that currently lead to addition costs or less efficient operation. The Chalk River Unidentified Deposits (CRUD)-induced power shift challenge problem,

for example, is estimated by the Electric Power Research Institute (EPRI) to add $80M per year in terms of additional fuel and operation costs. Similarly, the pellet clad interactions (PCIs) challenge problem has the potential to allow more rapid power ascension that can result in increased generation.

- DOE's combined Offices of Nuclear Energy and Energy Efficiency and Renewable Energy work in nuclear-renewable hybrid energy systems [18] has the potential to tightly integrate each of the major energy sectors: electric grid, industrial manufacturing, transportation, and residential/commercial consumers. This integration at a system level could optimize financial efficiency, maximize thermodynamic efficiency, reduce environmental impacts, and provide resources for grid management.

> We should "not make short-term decisions that have long-term impact on people, energy and our future."
> – William Levis, president and chief operating officer of PSEG Power

- In the longer term, more far reaching work could be performed in support of regulation and licensing to reduce the burden. There are two ways that this could be happen. One is by having NRC adopt improved simulation capabilities that can reduce the licensing time and the burden that NRC places on industry through requests for additional information. The other approach is by having industry adopt the tools to support licensing activities that can result in a better basis for licensing approaches that might improve performance.

The primary federal opportunity lies in finding ways to encourage the development and adoption of carbon-free mechanisms—for example, by offering production tax credits or putting a federal price on carbon either directly (via a carbon tax) or indirectly (via a cap-and-trade scheme).

4.4 Market Opportunities

The energy market structure has changed significantly since the design and construction of many of the existing nuclear reactors. Electricity and natural gas markets were heavily regulated into the late 1970s but have become progressively less regulated since then. In particular, the restructuring or deregulation of electricity markets has created a new set of incentives that tend not to provide secure payment streams. This and other changes have complicated the economics for NPPs. The fracking revolution has unleashed vast amounts of natural gas into the market, driving down prices and making this fuel substantially more attractive. While these changes have yielded benefits to electricity consumers, the changes have combined to obscure a number of the benefits associated with nuclear power—most notably risking the ability of the United State to achieve its climate change mitigation goals.

Another market lever may be available via FERC. Starting with an energy and ancillary services price formation proceeding initiated in June 2014, FERC now recognizes the potential value of changing allowable price formation rules. The challenge here is to find mechanisms that recognize the implicit value, what economists and financial analysts refer to as "option value," associated with these important attributes without creating a cumbersome regulatory regime that is costly and difficult to negotiate for nuclear power and other sources (Appendix B provides examples of the option values). A new June 2016 FERC ruling [19] requires that pricing occur in real time and not be based on an hourly integrated price. The hourly integrated price leads to distorted price signals and, in some cases, creates a disincentive for baseload resources, such as nuclear power; it is also consistent with modern financial market analyses that promote pricing of option values. Going forward, FERC and the regional markets should place a value on specific attributes, such as zero-emitting generation, similar to what is currently considered for reliability.

Additionally, it will be important to recognize jurisdictional boundaries and not intrude into areas where state authorities have primacy. Moving forward in this complex regulatory environment may require greater communication and transparency among regulatory agencies in these different jurisdictions, as well as a greater willingness to negotiate.

One arena where such transparency and negotiations are likely to be of particular importance is in multi-state trading organizations (such as Regional Greenhouse Gas Initiative [RGGI] Inc.) or ISOs and RTOs. These ISOs and RTOs do not necessarily fit neatly within the political boundaries of states, yet they have the task of operating a system that must reflect the policies of the states in which they operate. In this context, there is a concern that the multi-state entities will want to adopt different policy approaches from some of their constituent states, underscoring the importance of greater transparency, as well as an increased need to negotiate arrangements in good faith.

The market opportunity lies in adopting mechanisms that properly price the benefits associated with nuclear power, in particular its ability to produce a consistent stream of carbon-free electricity. Examples include some variant of a carbon price, as well as adjusting regulatory structures to properly recognize the potential future value of carbon-free electricity, via option values.

5. POTENTIAL SOLUTION CONCEPTS AND ACTIONS

This section describes potential solutions discussed during the summit and noted in the previous section. This section details the benefits of each solution and the actions needed to enact them. This is not intended to be an exhaustive list but instead a focused description of some of the most promising options.

5.1 Industrial Efficiencies

Concept: NPP operators should do everything they can to reduce costs by improving efficiencies and enhancing performance.

Benefit: Reducing operating and maintenance costs will improve economic competitiveness.

Ongoing Activities:

1. Industry, through NEI, has launched an initiative, "Delivering the Nuclear Promise," to enable a significant reduction in costs (30%) by 2018 [12], down to 2002 levels.
2. The DOE has sponsored the Light Water Reactor Working Group to identify technical solutions, although these are longer-term options that may not be ready until the 2020 timeframe.

Actions:

1. Nuclear utilities could create and encourage synergy among **cross-company industry teams** to examine work practices and identify efficiency improvements.
2. **DOE in combination with the private sector (industry, NGOs) could evaluate and understand the economics** required to maintain or achieve economic feasibility for existing NPPs. Analyze the economics at an appropriate time constant to track price (¢/kWh) at a given time. This allows for efficient control and transparency of power generation and use to promote hybrid energy solutions.
3. **DOE could expand the nuclear energy voucher program** (GAIN) [20] to include industrial plant assistance and analysis. This would likely require opening the voucher program beyond small businesses. Additionally, DOE could consider increasing the frequency of award cycles, and if possible establish a continuously open solicitation.
4. **The nuclear community must communicate**, via public relations efforts, the carbon-free benefits of nuclear power.

5. **Industry could reevaluate and propose changes to the Institute of Nuclear Power Operations (INPO), EPRI, and NRC fee structures**, which may be based on old business models and may not reflect contemporary practices.
6. Industry should work with DOE to **develop and implement new technologies** aimed at improving efficiencies and performance.

5.2 Clean Energy Standards in Anticipation of CPP

Concept: States should set CESs that include all clean energy technologies. This could be an expansion of existing RPSs or creation of new CESs.

Benefit: CESs would treat all clean-energy technologies equally and would result in further reduction of carbon emissions, avoid eroding the diversity of the nation's energy sources, and stimulate efficiencies and innovation while placing the nation on an appropriate trajectory toward decarbonization over the next decades.

Recent Relevant Precedent: New York regulators considered the inclusion of nuclear power in the state's CESs [21, 22]. And, on Augusts 1, 2016, Governor Andrew Cuomo, announced the New York State Public Service Commission's approval of New York's Clean Energy Standard, a first-ever state mandate to require 50% of New York's electricity to come from carbon-free sources, including nuclear power [23]. Pending legislation in Illinois would provide a similar CES, among other things.

Actions:

1. **States could develop CESs** that represent durable, market-based, technology-neutral, and fuel-neutral policy applied to *all* carbon-free power sources, on an equal footing, while making RPS tiers obsolete.
2. **DOE could create CES templates** for quick consideration by affected states.
3. **Markets could recognize carbon-related costs** as an externality of electricity markets and internalize these costs.

5.3 Proper Valuation

Concept: Nuclear energy provides several attributes important to U.S. economic sustainability, including carbon-free electricity, baseload capacity, price stability, fuel firmness, reliability, and availability. These attributes should be properly valued.

The presence of option value would naturally be built into the current price of a commodity trading in an unfettered market. But because electricity markets are not unfettered and because of a variety of interventions supporting competing fuels (e.g., renewable energy standards), the price paid for nuclear power generally does not embody any option value; this implies the market does not allocate resources to the socially optimal distribution and the positive externalities are undervalued.

Benefit: Proper valuation realizes the future value in today's pricing and thereby creates a U.S. energy supply system built with resiliency for the future. It is important that the value of these attributes be monetized; currently, they are not. In addition, the value of maintaining the existing nuclear fleet will likely increase in the future as a result of increased U.S. commitments to GHG reductions; increased pressure to restrict fracking, which would inevitably lead to reduced natural gas supplies and increased prices; or the imposition of a significant carbon price. Such potential increases in value create an extra implicit value today, or an option value (see Appendix B).

Recent Relevant Precedent: Pipeline regulations, which also fall under FERC's jurisdiction, exist with capacity charges that represent payment for option value. Modifications were made to capacity markets to better account for capacity performance, mentioned Arnie Quinn, FERC's director for Energy Policy and Innovation, although the modifications proved insufficient in the most recent PJM

Interconnection LLC (a Mid-Atlantic region power pool) capacity auction due to even lower natural gas prices. Quadrennial Energy Review 1.2 includes several actions that focus on valuation.

Actions:

1. Because electricity markets do not appear to incorporate option values into prices, the Quadrennial Energy Review should continue evaluating and considering methods to **incorporate option value**. For example, capacity values created by existing nuclear energy should be quantified.
2. **Universities, through the Nuclear Energy University Program or other funding sources, could model option value methods** and their impact on markets.
3. **Congress could pass legislation expanding** FERC's authority to properly value all attributes important to meeting national policy objectives.
4. **ISOs/RTOs could propose valuation** in their rate making. This is an alternate bottoms-up approach that may be an easier path forward than the commonly thought of top-down approach, which would likely require legislation. Some believe that an ISO/RTO could propose valuation under current FERC authority.

5.4 Efficient Price Signals

Concept: A key attribute of markets is their ability to effectively signal to participants which sources of production are best suited to meet demand and where additional production is needed. Price signals can be used to ensure that system reliability is maintained through the provision of adequate capacity to meet unknown contingencies that may occur and the provision of other services necessary to ensure grid reliability. Optimally, such signals reflect both current value (associated with current demand and current operating costs), as well as the value of benefits provided by sources that offer additional capacity and other services. Price formulation works best when the cost of running a system at any moment in time is accurately reflected in price, explained William Levis, president and chief operating officer of Public Service Electric and Gas (PSEG) Power. Efficient price signals analysis should be developed to promote efficient operation and transparency, particularly with respect to market pricing. Price signals to the market how to allocate resources. As long as the implicit values provided by nuclear industry are missing from the prices, then market outcomes will not be in society's best interest.

Benefit: "Accurate price levels incentivize efficient operations and minimize out-of-market solutions," said Levis.

Recent Relevant Precedent: FERC's energy and ancillary services price formation proceeding was initiated in June 2014, said Levis, and proposed initial price formation fixes at the end of last year and early this year. FERC is in the process of considering other price formation issues.

Actions:

1. FERC and ISO/RTOs could **set rates to reflect all costs and values of electricity production,** including capacity charges as well as transmission charges.
2. FERC could **settle energy transactions in real-time** markets at the same time interval for dispatching energy.
3. FERC could **settle operating reserves transactions in real-time** markets at the same time interval for pricing operating reserves.
4. FERC could **settle intertie transactions in the same time interval** for scheduling intertie transactions.

5.5 Power Contracts

Concept: Clean energy power purchase agreements could be established. States mandate the purchase of renewable capacity, yet baseload capacity purchase remains uncertain. Power purchase agreements between the NPPs and the RTO or ISO serve to remove that uncertainty.

Benefit: Power purchase agreements provide revenue streams and revenue certainty, which are attractive to the bondholders and maintain baseload and grid reliability for the future.

Recent Relevant Precedent: Ohio is pursuing a power purchase agreement. Some states require purchase of renewable capacity and/or energy. This may provide a template or precedent for similar requirements for purchase of nuclear capacity/energy [24, 25].

Action:

1. **An RTO/ISO could create power purchase agreement templets** for use between other NPPs and RTOs or ISOs.
2. States could mandate that regulated retail **utilities purchase** nuclear capacity and/or energy [22].

5.6 Incentivize Carbon-Free Electricity

Concept: If carbon reduction is an important goal, then all carbon-free energy sources should be rewarded (incentivized) according to option values accruing to society.

Benefit: Greater generation of carbon-free energy will be realized if all possible sources are incentivized by leveling the playing field to all such generation and avoiding the introduction of unintended market distortions.

Actions:

1. **Congress should promote all carbon-free electrical production,** which could be accomplished via a national energy policy promoting a clean energy target by a given date.
2. **The American Nuclear Society and a number of other organizations could help to enhance understanding of carbon impacts** by comparing and analyzing mass versus rate-based carbon tax models.
3. **Congress could create proper market incentives by putting a price on carbon.**
4. As noted above, states could establish CESs absent a national CES**.**

6. REFERENCES

[1] U.S. Department of Energy, *Workshops*, https://gain.inl.gov/SitePages/Workshops.aspx.

[2] U.S. Energy Information Administration, *EIA Monthly Electricity Reports, 2015*, Table 3.1.A (Net Generation by Energy Source: All Sectors) and Table 3.1.B (Net Generation from Renewable Sources: All Sectors), accessed at http://www.eia.gov/electricity/data.cfm#generation.

[3] Earth Institute, *What is the U.S. Commitment in Paris?*, http://blogs.ei.columbia.edu/2015/12/11/what-is-the-u-s-commitment-in-paris/, published December 11, 2015, Web page visited July 18, 2016.

[4] U.S. Environmental Protection Agency, *Clean Power Plan Proposed Rule Technical Documents*, https://www.epa.gov/cleanpowerplan/clean-power-plan-proposed-rule-technical-documents#.

[5] David Abel, *Carbon emissions rising at New England power plants*, https://www.bostonglobe.com/metro/2016/05/15/carbon-emissions-rising-new-england-power-plants/9WfbtQMJEMBszzxPzf2OLO/story.html, published May 16, 2016.

[6] U.S. Energy Information Administration, *How much carbon dioxide is produced per kilowatt hour when generating electricity with fossil fuels?*, http://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11.

[7] Environmental Progress, *Climate Scientists for Nuclear*, http://www.environmentalprogress.org/climate-scientists-for-nuclear/.

[8] Environmental Progress, *Still Time to Save Nuclear in Illinois & California – But We Must Act Now*, http://www.environmentalprogress.org/big-news/2016/6/2/edf, published June 2, 2016.

[9] Exelon, *Exelon Announces Early Retirement of Clinton and Quad Cities Nuclear Plants*, http://www.exeloncorp.com/newsroom/clinton-and-quad-cities-retirement, June 2, 2016.

[10] World Nuclear Association, *World Energy Needs and Nuclear Power*, http://www.world-nuclear.org/information-library/current-and-future-generation/world-energy-needs-and-nuclear-power.aspx, updated June 2016.

[11] ISO New England, *New England's 2015 Average Wholesale Power Price Fell to Second-lowest Level Since 2003*, http://www.iso-ne.com/static-assets/documents/2016/03/20160329_prelim_2015_prices_release.pdf, published March 29, 2016.

[12] Nuclear Energy Institute, *Delivering the Nuclear Promise: Advancing Safety, Reliability and Economic Performance*, February 2016.

[13] New York State, *Cases 15-E-0302 and 16-E-0270 -2, Filing No. 352*; http://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterCaseNo=15-e-0302, published August 1, 2016.

[14] Jason Furman and Brian Deese, *The Economic Benefits of a 50 Percent Target for Clean Energy Generation by 2025*, https://www.whitehouse.gov/blog/2016/06/29/economic-benefits-50-percent-target-clean-energy-generation-2025, published Jun 29, 2016.

[15] U.S. Department of Energy, *Nuclear Energy Research and Development Roadmap, Report to Congress*, April 2010.

[16] Bruce P. Hallbert, *US Department of Energy Light Water Reactor Sustainability Program – Advanced Instrumentation, Information and Controls R&D Overview*, http://www.energy.gov/sites/prod/files/2015/11/f27/3.%20LWRS%20Advanced%20II%26C%20R%26D%20Overview.pdf, October 28, 2015.

[17] 10 CFR 50.69, "Risk-Informed Categorization and Treatment of Structures, Systems and Components for Nuclear Power Reactors," Code of Federal Regulations.

[18] Shannon M. Bragg-Sitton, et al., *Nuclear-Renewable Hybrid Energy Systems 2016 Technology Development Roadmap (DRAFT)*, INL/EXT-15-37446, Idaho National Laboratory, December 2015.

[19] FERC Order 825, "Settlement Intervals and Shortage Pricing in Markets Operated by Regional Transmission Organizations and Independent System Operators," Federal Energy Regulatory Commission, June 16, 2016.

[20] The White House Office of the Press Secretary, *FACT SHEET: Obama Administration Announces Actions to Ensure that Nuclear Energy Remains a Vibrant Component of the United States' Clean Energy Strategy*, https://www.whitehouse.gov/the-press-office/2015/11/06/fact-sheet-obama-administration-announces-actions-ensure-nuclear-energy, published November 6, 2015.

[21] PJM, *FERC Approves PJM Capacity Performance Proposal*, http://www.pjm.com/~/media/about-pjm/newsroom/2015-releases/20150610-ferc-approves-capacity-performance.ashx, June 10, 2015.

[22] Christian Roselund, *New York throws $5 billion at clean energy, includes nukes in RPS proceeding*, http://www.pv-magazine.com/news/details/beitrag/new-york-throws-5-billion-at-clean-energy--includes-nukes-in-rps-proceeding_100022917/, published January 22, 2016.

[23] New York State, *Governor Cuomo Announces Establishment of Clean Energy Standard that Mandates 50 Percent Renewables by 2030*, https://www.governor.ny.gov/news/governor-cuomo-announces-establishment-clean-energy-standard-mandates-50-percent-renewables, published August 1, 2016.

[24] Next Generation Energy Plan Campaign, *Next Generation Energy Plan*, http://www.nextgenerationenergyplan.com/.

[25] John Funk, *FERC rejects PUCO-approved FirstEnergy, AEP power deals*, http://www.cleveland.com/business/index.ssf/2016/04/ferc_rejects_puco_approval_of.html, updated April 28, 2016.

Appendix A

Agenda

Summit on Improving the Economics of America's Nuclear Power Plants

Agenda:

(12:30 pm – 12:35 pm) Welcome - Master of Ceremonies (MC), John Kotek

(12:35 pm – 12:55 pm) Keynote – Secretary of Energy, Ernest Moniz

(12:55 pm – 1:10 pm) General Industry Perspective - Marv Fertel, NEI

(1:10 pm – 1:15 pm) Congressional Remarks – Representative Kinzinger (R-IL)

(1:15 pm – 1:20 pm) Congressional Remarks – Senator Booker (D-NJ)

(1:20 pm – 2:10 pm) Panel 1 – What Industry Can Do

- Moderator David Owens, EEI
- Utility CEO, Bill Mohl, Entergy
- NEI perspective Maria Korsnick, NEI
- Delivering the Nuclear Promise, William Levis, PSEG
- Representative from LWR Research Development, and Demonstration Working Group, Mark Peters, INL

(2:10 pm – 2:15 pm) – Lightning Talk, Labor/Jobs, Mike Langford, UWUA

(2:15 pm – 2:25 pm) – Break

(2:25 pm – 2:30 pm) – Lightning Talk, Climate (Michael Shellenberger, Environmental Progress)

(2:30 pm – 3:25 pm) Panel 2 – What the States Can Do

- Moderator Gene Grecheck, ANS
- Clean Power Plan Joe Kruger, Resources for the Future
- NARUC, Ann McCabe, Illinois Commerce Commission
- NCSL Nuclear Legislative Workgroup, Sally Jameson, MD
- State Coalitions, Jessica Lovering, Breakthrough Institute
- Utility Perspective, Joe Dominguez, Exelon

(3:25 pm – 3:30 pm) – Lightning Talk, Local Leader, Patricia O'Donnell, Former Select board Chair of Vernon, Vermont

(3:30 pm – 4:20 pm) Panel 3 – What Congress, FERC, and Regional Markets Can Do

- Moderator (Dan Utech, Deputy Assistant to the President for Energy and Environment)

- Opportunities for the Federal Government, Matt Bennett, Third Way
- General Market Perspective, Sue Tierney, Analysis Group
- FERC, Arnie Quinn, Director for Energy Policy and Innovation
- RTO or ISO representative, Craig Glazer, PJM

(4:20 pm – 4:25 pm) Congressional Remarks – Representative McNerney (D-CA)

(4:25 pm – 4:30 pm) Closing Remarks – Senator Crapo (R-ID)

Appendix B
Option Value

A variety of potential benefits associated with maintaining the existing nuclear fleet will arise in the future, depending on a host of potential uncertainties. These uncertainties include significant increased U.S. commitments to greenhouse gas reductions; increased pressure to restrict hydrological fracturing (fracking), which would inevitably lead to reduced natural gas supplies and increased prices; and the imposition of a significant carbon price. Under any of these scenarios, the value associated with nuclear energy would increase substantially. Such potential future increases in value create an extra implicit value today, which economists and financial analysts commonly refer to as "option value."

The presence of option value would naturally be built into the current price of a commodity trading in an unfettered market. But because electricity markets are not unfettered and because of a variety of interventions supporting competing fuels (e.g., renewable energy standards), the price paid for nuclear power generally does not embody any option value.

A related notion to option value is that of a hedge. If a dramatic increase in the price of a competing fuel, say natural gas, were to occur in the next several years, the value of a substitute fuel would be enhanced. Maintaining production capacity of a substitute fuel, such as nuclear energy, offers a form of insurance; i.e., in the event the competing fuel results in a price increase, we could switch some power production to nuclear energy, which would have become comparatively inexpensive after the price increase for natural gas. Thus, maintaining current production capacity induces a value associated with hedging against this future risk. As with option value, we would expect the value of this hedge to be built into the price of a commodity that trades in an unfettered market, but as noted above, electricity markets are generally not unfettered.

Currently, electricity markets do not appear to incorporate option and hedging values into prices. One possible method for incorporating such incentives into electricity markets would be to split payments for electricity into two aspects in a manner analogous to the pricing of pipeline services. As with nuclear energy, pipelines offer variations on hedging benefits: if there is a significant increase in the demand for commodities delivered by pipeline, then having capacity available is worth something to market participants. This value does not apply to materials shipped at any point in time; it is a value associated with potential future needs. Noting this distinction, these markets commonly apply a capacity charge (one pays for the right to use a portion of pipeline capacity at some future time) and a delivery charge (one pays for the amount that is actually transmitted). A similar arrangement in the current context might be to pay nuclear power plants a capacity charge, reflecting their capability to deliver energy at times when other sources are unable to do so (or could only do so at substantially higher costs), as well as a variable price reflecting actual market conditions at a particular point in time.

Under this interpretation the capacity charge would reflect two types of future potential benefits, reflecting two different timeframes. The hedging value might best be viewed as arising for relatively short periods—e.g., in periods of extreme weather when the demand for natural gas outstrips the potential deliveries; such periods would likely pass within a few days, so that the realized hedging value is temporary. Option value, on the other hand, refers to a situation where a significant and somewhat permanent change occurs, such as the imposition of a carbon tax or a change in internationally agreed upon carbon reductions. For this sort of phenomenon, the increased value of nuclear energy would likely persist for a lengthy period of time. Noting this distinction, one might want to explore two variations on capacity charges; alternatively, a second form of ancillary instrument might be brought into electricity markets to reflect the different potential future values.