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Energy Systems, Strategies, Assessments, and Integration

Economic and Market Challenges Facing the U.S. Nuclear Commercial Fleet - Cost and Revenue Study

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Economic and Market Challenges Facing the U.S. Nuclear Commercial Fleet – Cost and Revenue Study

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EXECUTIVE SUMMARY

The Kewaunee, Vermont Yankee and Fort Calhoun nuclear power plants were retired early for economic and financial reasons. Early retirement was proposed for Clinton and Quad Cities in Illinois and for Nine Mile Point, Fitzpatrick, and Ginna in New York. The owner of other units, including Pilgrim in Massachusetts and Palisades in Michigan has announced near term shutdown dates. Other nuclear power plants, including Davis-Besse, Prairie Island, and Three Mile Island Unit 1, have been identified as facing financial stress that may lead to early retirement. In addition, other units, including Indian Point in New York and Diablo Canyon in California, are facing political pressures to terminate operations prematurely.

These early retirements of operating nuclear power plants will mean the loss of a large amount of zero-emission electricity, inconsistent with the goal of reducing carbon emissions and other air pollutants in the electricity sector. In addition, significant negative effects of these closures are being, and will be experienced, on local economies, electricity grid resilience, fuel diversity and United States world leadership on nuclear issues, including nonproliferation and safety standards.

Since 2016, several studies have been published exploring the causes and effects of current electricity market structures on the economics of the operating nuclear power plant fleet. These studies generally concluded that deregulated electricity markets were reacting to the unexpectedly low costs of natural gas, and various incentives being provided to variable renewable sources, in ways that were causing currently operating nuclear plants to become uneconomic.

This report builds upon an earlier Energy Systems, Strategies, Assessments, and Integration (ESSAI) report titled "The Economic and Market Challenges Facing the U.S. Nuclear Commercial Fleet", issued September 2016, Energy Systems Strategic Assessment Institute, Idaho National Laboratory (INL) (**https://gain.inl.gov/Shared%20Documents/Economics-Nuclear-Fleet.pdf**).

The earlier study identified the underlying economic and market factors that have led to early retirements, assessed the gap between operating revenues and operating costs for a select number of nuclear power plants and discussed a range of actions that might be taken to stop and prevent early retirement of operating nuclear plants. From the evaluation of operating revenue and operating costs for the sample of selected plants, the report confirmed that there is an ongoing industry wide, systemic economic and financial challenge to operating nuclear plants particularly in the deregulated markets.

In this report, the authors expand upon the previous study by assessing the differences between operating revenues and operating costs for all currently operating nuclear power plants in the United States, to understand more fully the magnitude of this gap and types of economic factors that could be applied to correct the market defects causing the shortfalls.

This report also expands the analyses in the previous study by adding three additional economic measures. The analyses in this study consider four different "Gap[1]" measures of economic viability for operating nuclear power units:

- Revenue Gap – revenue from electricity markets compared to nuclear generating cost;
- Purchased Power Gap – cost of purchasing power compared to nuclear generating cost;
- Total Generation Gap – cost of all power generated from sources other than nuclear compared to nuclear generating cost; and
- LCOE Gap – LCOE of a new power plant compared to nuclear generating cost.

The results of these four analyses lead to three conclusions:

1. Market Failure[2] Is the Problem, Not Nuclear Power Plants.

Revenue Gap analyses were done for 79 of the 99 operating reactors in the U.S. that are in a region where public wholesale electricity market prices are available. The Revenue Gap analyses estimate that most (i.e., 63 of 79 units) of these U.S. nuclear power units for which electricity market prices are available) would have lost money in 2016, as shown in Figure 4 and Figure 5.

It would take a relatively small amount of additional revenue to return most of the nuclear power units that would have lost money in 2016 to profitable operation. Additional revenue of about $15/MWh would reduce the number of units with a Revenue Gap of less than zero to 10. This $15/MWh additional revenue amount is less than the ZEC payments approved in New York and Illinois.

Of the 63 units with a Revenue Gap less than zero, 36 are merchant generators, 19 are regulated generators, and 8 are public power generators. The merchant nuclear units face potential early retirement, and the regulated and public power nuclear units would be losing money if they depended on electricity market revenue.[3]

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1 In this study, we refer to Gaps (i.e., Revenue Gap, Purchased Power Gap, Total Generation Gap, and LCOE Gap) as the difference between a relevant measure (e.g., Revenue) and nuclear power unit generating costs. A Gap that is less than zero means that generating costs are higher than the relevant measure, while a Gap that is greater than zero means that generating costs are lower than the relevant measure.

2 Market failure is an economic term that refers to a situation in which the allocation of goods and services is not efficient. For example, market failure for nuclear power is when the private market approach to merchant nuclear power results in early retirement due to financial losses, even though early retirement would result in a loss of public benefits (e.g., zero emissions electricity, grid and system benefits, and economic impacts) that have a value higher than the financial losses experienced by the private owner of the merchant nuclear power plant.

3 Regulated and public power nuclear units have profitability that is determined by the regulatory process in place for each unit. For the purposes of the Revenue Gap analyses in this study, we made a simple assumption that each regulated or public power nuclear unit for which electricity market prices are available would have the same link between profits and electricity market prices as a merchant nuclear unit.

This recent decline in nuclear power plant profitability is not caused by poor nuclear power plant operation. Nuclear power generating costs have been declining since about 2012, as shown in Table 2, and nuclear power plant capacity factors have been high, as shown in Figure 3.

Declining profitability of U.S. nuclear power plants is a result of operation in electricity markets. The electricity markets focus on short-run marginal costs, with no reflection of fixed generating costs or returns on investment for generators.

The U.S. approach to nuclear power requires merchant nuclear power plant owners to rely on revenue in the electricity markets; this approach will likely result in more nuclear power units retiring early to stop additional financial losses to merchant nuclear power plant owners.

The early and permanent retirement of operating nuclear power units will mean that the significant public benefits provided by those nuclear units (e.g., emission-free electricity, reliable baseload capacity, jobs, fuel diversity, etc.) will be lost.

The early retirement of operating nuclear power units is a clear example of market failure. Market failure is an economic concept where the market fails to support operating nuclear power plants and the early retirement of these operating nuclear power plants would significantly decrease the public good.

2. Regulated/Public Power Nuclear Units Provide Value to Owners.

The situation for regulated and public power nuclear plants is different and better than the situation for merchant nuclear power plants.

Purchased Power Gap and Total Generation Gap analyses cover all regulated and public power nuclear units for which relevant information was available. These analyses show that utility owners of most regulated or public power nuclear power units would be worse off if the nuclear power unit was retired early and the owner was required to buy additional purchased power or to generate additional power with existing generation resource, as shown in Figure 6 and Figure 7.

The Purchased Power and Total Generation Gap analyses are not relevant for merchant nuclear units operating in regions with wholesale electricity markets, because the owners of merchant nuclear power units are not required to buy power to replace the power output lost when a nuclear power plant retires early.

The Purchased Power Gap and Total Generation Gap analysis results show that most regulated and public power nuclear units have generating costs that are lower than the cost of purchased power and that are lower than the cost of total generation for the utilities that own them. Early retirement of these regulated and public power nuclear units would result in higher costs for the owner. The cost to replace the output of a retired nuclear power unit may be much higher than the cost estimated in this study, because actual costs of purchasing or generating significant additional power to replace a retired nuclear power unit is likely to be much higher than 2016 purchased power and total generation costs when the nuclear power unit in operation.

The results of the Purchased Power Gap and Total Generation Gap analyses are different from the results of the Revenue Gap analysis because utility purchased power and total generation costs reflect total costs (i.e., marginal costs, fixed costs, ongoing capital expenditures, and initial capital investment), while electricity market prices only reflect short-run marginal costs.

3. Existing Nuclear Units Are Cheaper than Building New Baseload Capacity.

Operating existing nuclear power plants results in lower total costs compared to the cost of replacing the nuclear power plant with a new Combined Cycle Gas Turbine (CCGT) power plant, the least expensive baseload replacement option to build and operate today.

At some point, the capacity and energy lost when a nuclear power unit retires early must be replaced. Figure 8 shows that continuing to operate existing nuclear units has lower costs than building a new advanced gas-fired CCGT.

The Levelized Cost of Electricity (LCOE) for the new CCGT power plant includes the total cost of the unit, costs that would be recovered by any new owner, whether merchant or regulated/public power, while the generating costs of the existing nuclear power plants only include cash generating costs.

CONTENTS

FIGURES

TABLES

ACRONYMS

AEO	Annual Energy Outlook
ANS	American Nuclear Society
ATSI	One of the PJM LMP Zones
BWR	Boiling Water Reactor
CAISO	California Independent System Operator
CCGT	Combined Cycle Gas Turbine
CEO	Chief Executive Officer
CES	Clean Energy Standard
COMED	One of the PJM LMP Zones
CPP	Clean Power Plan
D	Dominion
DNP	Delivering the Nuclear Promise
DOE	U.S. Department of Energy
DOM	One of the PJM LMP Zones
EIA	U.S. Energy Information Administration
EIM	Energy Imbalance Market
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESSAI	Energy Systems, Strategies, Assessments, and Integration
ETR	Entergy
EXC	Exelon Corporation
FCA	Forward Capacity Auction
FCM	Forward Capacity Market
FE	FirstEnergy
FERC	Federal Energy Regulatory Commission
GDP	Gross Domestic Product
GW	Gigawatt
ICAP	Installed Capacity
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
ISO	Independent System Operator
ISO-NE	ISO New England
LCOE	Levelized Cost of Electricity

LCPS	Low Carbon Portfolio Standard
LMP	Locational Marginal Pricing
LSE	Load-Serving Entity
LWRS	Light Water Reactor Sustainability
METED	One of the PJM LMP Zones
MISO	Midcontinent Independent System Operator
MMBtu	Million British Thermal Units
MW	Megawatt
MWe	Megawatt electrical
MWh	Megawatt-hour
NECG	Nuclear Economics Consulting Group
NEI	Nuclear Energy Institute
NRC	U.S. Nuclear Regulatory Commission
NSP	Northern States Power Company
NYISO	New York Independent System Operator
NYPSC	New York Public Service Commission
OPPD	Omaha Public Power District
OVEC	Ohio Valley Electric Corporation
PG&E	Pacific Gas & Electric Company
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PPA	Power Purchase Agreement
PTC	Production Tax Credit
PUC	Public Utilities Commission
PUCO	Public Utilities Commission of Ohio
PWR	Pressurized Water Reactor
RSSA	Reliability Support Service Agreement
RTO	Regional Transmission Organization
SMP	System Marginal Price
SONGS	San Onofre Nuclear Generating Station
SRMC	Short-Run Marginal Cost
TMI	Three Mile Island
TVA	Tennessee Valley Authority
XEL	Xcel Energy
ZEC	Zero Emissions Credit

ECONOMIC AND MARKET CHALLENGES FACING THE U.S. NUCLEAR COMMERCIAL FLEET – COST AND REVENUE STUDY

I. INTRODUCTION

A. Previous Studies

The Kewaunee, Vermont Yankee and Fort Calhoun nuclear power plants were retired early for economic and financial reasons. Early retirement was proposed for Clinton and Quad Cities in Illinois and for Nine Mile Point, Fitzpatrick, and Ginna in New York. The owner of other units, including Pilgrim in Massachusetts and Palisades in Michigan has announced near term shutdown dates. Other nuclear power plants, including Davis-Besse, Prairie Island, and Three Mile Island Unit 1, have been identified as facing financial stress that may lead to early retirement. In addition, other units, including Indian Point in New York and Diablo Canyon in California, are facing political pressures to terminate operations prematurely.

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Since 2016, several studies have been published exploring the causes and effects of current electricity market structures on the economics of the operating nuclear power plant fleet. Some of these include two American Nuclear Society publications, the ANS Toolkit[4] and a second report on the implications of premature plant closures.[5] The National Council of State Legislatures issued a report in early 2017 that further described market structure effects on operating nuclear plants and proposed a number of approaches that could be undertaken by states seeking to preserve their nuclear plants.[6] More recently, the Hoover Institution[7] published a book also concluding that changes were required to current markets to permit operating nuclear power plants to be economically competitive.

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4 American Nuclear Society, "Nuclear in the States Toolkit V2.0," June 2016, http://nuclearconnect.org/wp-content/uploads/2016/02/ANS-NIS-Toolkit-V2.pdf

5 American Nuclear Society, "The U.S. Without Nuclear Energy: A Report on the Impact of Plant Closures," April 2016, http://cdn.ans.org/pi/publicpolicy/docs/the-us-without-nuclear-energy-report.pdf

6 Shea, Daniel and Kristy Hartman, "State Options to Keep Nuclear in the Energy Mix," National Council of State Legislatures, January 2017, http://www.ncsl.org/Portals/1/Documents/energy/StateOptions_NuclearPower_f05_WEB.pdf

7 Carl, Jeremy and David Fedor, Keeping the Lights on at America's Nuclear Power Plants, Hoover Institution Press, 2017.

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The September 2016 ESSAI report identified the underlying economic and market factors that have led to early retirements, assessed the gap between operating revenues and generating costs for a select number of nuclear power plants and discussed a range of actions that might be taken to stop and prevent early retirement of operating nuclear plants. From the evaluation of operating revenue and generating costs for the sample of selected plants, the report confirmed that there is an ongoing industrywide, systemic economic and financial challenge to operating nuclear plants particularly in the deregulated markets.

B. Focus of this Study

In this report, the authors expand upon the previous study by assessing the differences between operating revenues and operating costs for all currently operating nuclear power plants in the United States, to understand more fully the magnitude of this gap and types of economic factors that could be applied to correct the market defects causing the shortfalls.

While this report was being developed, the Secretary of Energy requested that DOE Staff prepare a study of electricity markets and reliability, with emphasis on the evolution of wholesale electricity markets, whether those markets are adequately compensating attributes that strengthen grid resilience, and the extent to which government policies and regulatory requirements are contributing to the premature retirement of baseload power plants. That study, released in August 2017, contains several recommendations intended to address current issues with market structure, valuation of attributes, and impacts on resilience. We hope that the analyses developed for this report will assist in the development of specific policy to help address those recommendations.

This report expands upon the previous report by examining the economics of all 99 currently operating nuclear power plants in the United States, while the previous study only considered selected nuclear units.

In addition, this new ESSAI report builds on the previous report by examining multiple economic measures, while the previous report only considered how nuclear power plant generating cost compared with electricity market revenue. The economic measures considered in this report include:

- How nuclear power plant generating cost compares with electricity market revenue (for nuclear power plants for which wholesale electricity market prices are available);
- How nuclear power plant generating cost compares with the cost of utility purchased power (for nuclear power plants owned by regulated or public power utilities);

- How nuclear power plant generating cost compares with the cost of power generated by utility non-nuclear power plants (for nuclear power plants owned by regulated or public power utilities); and

- How nuclear power plant generating cost compares with the cost of building new generating capacity (for all nuclear units).

This study also provides a discussion of ways to group sites by common characteristics, assess and cluster electricity revenue types and nuclear generating costs and ways to identify and prioritize risks and factors leading to early nuclear power plant retirement.

This report is also intended to provide input to and support for future work that may include developing attribute-based revenue models, assessing ways to monetize attributes of nuclear (and other) energy systems, evaluating current and future energy markets, and other related activities.

C. Current U.S. nuclear industry issues

This report was done to explain the economic issues related to early retirement of operating nuclear power plants in the U.S. This report provides a high-level view of the major factors driving early retirement:

- The U.S. market and private ownership approach to the electricity sector;

- Low electricity market prices resulting from low natural gas prices, low demand growth, increased penetration of renewable generation, and negative electricity market prices; and

- No compensation to nuclear power plants for public benefits including zero-emission electricity, fuel diversity, and grid reliability.

The primary impact of these three major factors is on merchant nuclear power units (i.e., those nuclear power units that depend on wholesale electricity market revenue for profits). These merchant nuclear units do not have the same level of financial certainty as regulated and public power nuclear units, for which profitability is determined by the regulatory arrangements in a state or in a public power entity.

The combination of these three major factors has led to market failure for nuclear power, given the market approach to electricity in some regions combined with sustained low electricity market prices. Continuing financial losses for operating nuclear power plants may increasingly be resolved by early retirement, with this early retirement resulting in the loss of net public benefits.

The additional revenue that will be provided by Zero Emissions Credit (ZEC) payments in NY and IL appears to have stopped the early retirement plans for multiple nuclear units in these states.

More recently, Exelon, on May 30, 2017, announced plans to retire its 852 MW Three Mile Island Generating Station (TMI) Unit 1 in Pennsylvania in September 2019 unless the state government implements new policies that provide additional financial support for the plant.

The Exelon announcement came after TMI and Exelon's Quad Cities nuclear plants failed to clear the latest PJM base residual capacity auction. Low electricity demand, sustained low gas prices and rising renewable energy capacity have driven down wholesale electricity prices throughout the U.S. Deregulated electricity markets in 13 states and the District of Columbia have lower electricity prices by an average of 15 percent across all customer types between 2008 and 2016. The same factors have lowered costs for regulated and public power utilities.

For 2016, the Edison Electric Institute (EEI) reported that U.S. electricity output remained nearly flat nationally, increasing by a mere 0.2 percent, although regions fared differently, with output in New England falling by 2.3 percent, while the Southeast and South-Central regions saw growth of 1.1 percent and 1 percent respectively.

In early 2017, Morgan Stanley[8] projected that natural gas prices would be below $3.00/MMBTU by spring 2018, with a long-term price forecast around $2.75/MMBTU. EIA's 2017 Annual Energy Outlook[9] reference case has the projected price of U.S. natural gas for electricity generation to remain below $6/MMBTU (in 2016$) until about 2048.

With electricity demand growth projected to remain flat to one percent per year, coupled with relatively low natural gas prices, the projected average wholesale price for electricity is expected to remain steady at an average of about $30/MWh, varying by location. For nuclear plants operating in the deregulated markets, this forecasted wholesale power price tends to set a de facto ceiling on revenue generation which is supplemented by capacity payments and other supplemental revenues sources such as those that have been authorized in Illinois and New York, and that are being presently being considered in Ohio, Pennsylvania, and elsewhere.

D. Other Public Studies

There have been several studies and reports from industry, academic and government organizations that have examined and analyzed the underlying economics of operating nuclear plants. These studies and reports are focused on a similar important issue – the economics and competitiveness of U.S. operating nuclear plants.

8 http://www.marketwatch.com/story/morgan-stanley-cuts-price-targets-on-natural-gas-related-firms-2017-03-28

9 https://www.eia.gov/outlooks/aeo/ Table 3, Energy Prices by Sector and Source, Reference case.

These reports and studies have consistent conclusions:

- Many U.S. nuclear power plants have generating costs that are lower than electricity market prices; and
- Many U.S. nuclear power plants face the threat of early retirement due to economic/financial losses.

Minor differences in the results of these studies and reports of operating plant profit margins or losses can be explained by the complex information and analysis needed to support seemingly simple outcomes and conclusions.

Estimating the profitability of a merchant nuclear power plant involves detailed (i.e., hourly) analyses of nuclear plant output and electricity market prices at the generator node and assumptions about nuclear plant generating costs.

II. COST AND REVENUE STUDY

This study, like the 2016 ESSAI study, focuses on the gap between nuclear plant cash generating costs and the revenues earned by nuclear power plants. The gap analysis in this study expands the work in the previous study to all nuclear power plants in operation and expands the gap analyses to include the economics of nuclear power plants that are not merchant plants.

The study starts with a set of assumptions about nuclear power plant generating costs, then compares those generating costs to either market revenue (i.e., for merchant nuclear power plants) or to the cost of alternative sources of electricity (i.e., for regulated and public power nuclear generators).

A. Nuclear Power Plants

This study looks at all 99 U.S. nuclear reactors that were operational in 2016, as shown in Figure 1.

U.S. nuclear power plants have either one, two, or three reactors/units on the same nuclear plant site. A complete list of the U.S. operational nuclear power units is at https://www.nrc.gov/reactors/operating/list-power-reactor-units.html. Figure 1 also indicates U.S. nuclear sites by electricity market types: regulated, public power, or merchant units.

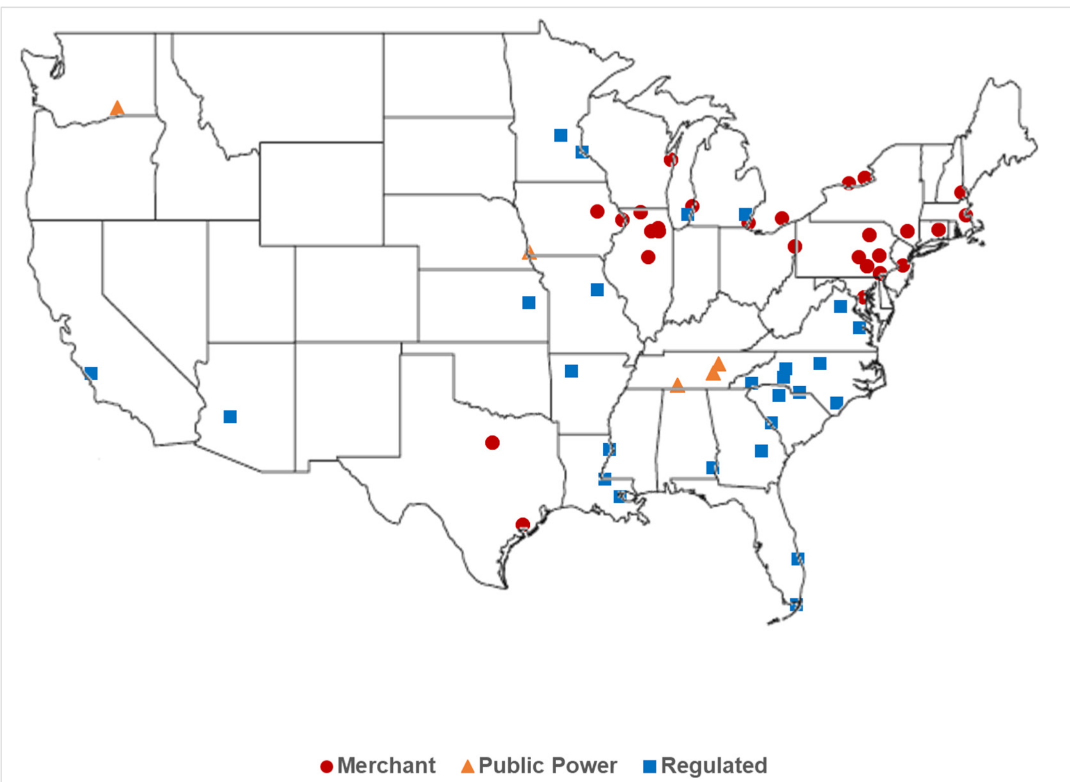

Figure 1. Operating U.S. Nuclear Power Plant Units, Sites, and Types.

This study considers each nuclear unit (i.e., reactor and turbine generator) separately for several reasons. Most nuclear power units on the same site are very similar, if not identical. However, some multiple-unit nuclear power plants sites have nuclear units with different sizes and vintages. The operating performance of different units on a single site may not be the same, even if the units on this site have the same design and vintage. The NRC operating licenses are unit-specific and the license dates for the units in a multi-unit site are rarely the same.

It is simple to combine nuclear unit information to get nuclear plant/site average information, but may not be simple (or even feasible) to unwind nuclear plant/site level combined information into nuclear unit information.

B. Nuclear Power Cash Generating Cost Assumptions

There is industry-wide average information available on nuclear power plant generating costs, but there is little public information on the generating costs of specific U.S. nuclear power plants and no public information on the operating costs of merchant nuclear plants.

We refer to these as "cash generating costs" to reflect that the costs for such things as fuel and on-going capital expenditures are included in annual generating costs, even though these costs involve complex multi-year transactions, accounting conventions, and other factors.

The analyses in this report are based on assumptions about cash generating costs (i.e., the total of annual fuel costs, O&M costs, and ongoing capital expenditures) that are consistent with public information.

In this report, we refer to nuclear generating units (i.e., a single reactor and associated steam plant equipment) and to nuclear power plants (i.e., one or more nuclear generating units on the same physical site). While the primary nuclear power organization is usually the plant or site, there may be differences (e.g., different size or vintage, different operational performance) between the units in a plant. Accordingly, we do these analyses on a nuclear unit basis.

All nuclear power plants do not have the same cash generating cost. To reflect these differences in cost, we developed a range of generating costs for each nuclear unit in categories based on unit size and the number of units located on a single site

A smaller unit will have higher generating costs than a larger unit on a per MW basis, because some nuclear power generating costs (e.g., site security, reactor operators, NRC monitoring) have a level that is similar for every nuclear generating unit, but a smaller nuclear generating unit must spread those costs over fewer MW (and fewer MWh) than a larger nuclear generating unit.

Dual-unit sites have lower costs than single unit sites, when the units are nearly identical. Security is required for one site with multiple units; operators can be licensed to operate both (or all) units on site; and site management and overhead costs can be shared.

It is common nuclear industry practice to discuss nuclear power plant generating costs in units of $/MWh. This may be appropriate if the generating cost is developed for each nuclear generating unit (i.e., by taking annual total costs and dividing by output in MWh). However, presenting nuclear generating unit generating costs in units of $/MWh may lead to some issues, including:

- A mistaken view that nuclear generating unit generating costs are variable or marginal. Plant generating costs in units of $/MWh might suggest that generating costs would be lower if unit output is lower. However, the opposite is true. Nuclear plant generating costs are mostly fixed costs that do not go down as output goes down (i.e., like fuel costs in most fossil-fueled power plants). Instead, lower output for a nuclear generating unit will result in higher costs in units of $/MWh, as annual fixed generating costs are spread over fewer MWh.

- A mistaken view that smaller nuclear generating stations will have lower annual generating costs than larger nuclear generating units (i.e., generating cost in units of $/MWh multiplied by lower output due to smaller generating unit size).

Accordingly, this study has developed generating cost ranges that are targeted at each unit in the study, with four sets, small single unit site, large single unit site, small multiple unit site, and large multiple unit site. The size measures are based on the summer generating capacity of each unit as reported to the EIA.

Table 1 shows the assumptions for generating costs. The assumptions developed for use in this study are based on and consistent with the nuclear generating cost levels presented by NEI. The primary measure is $/MWe/year, but the equivalent amounts in $/MWh (assuming a 91.9% capacity factor) are shown.

The average of the U.S. nuclear fleet using these assumptions as applied to all nuclear units is $33.89/MWh, an amount that is nearly identical to the NEI 2016 U.S. Nuclear Fleet Average of $33.93/MWh.

Table 1. Generating Cost Assumptions.

Category	$/MW/year	$/MWh[10]
Small Single Unit site - less than 800 MW	375,000	46.45
Large Single Unit site - at or greater than 800 MW	290,000	35.92
Small Multiple Unit site - less than 2,000 MW	272,500	33.76
Large Multiple Unit site - at or greater than 2,000 MW	257,500	31.90

1. NEI Generating Costs

The Nuclear Energy Institute (NEI) has been tracking generating plant costs for several years, with particular focus on identifying the reasons for a general cost trend upwards during the first decade of the 2000’s, which occurred coincident with market factors reducing revenues. As can

[10] Based on an assumed capacity factor of 91.9%, the 2016 EIA U.S. nuclear industry average Capacity Factor.

be seen in Table 2, average total generating costs in $/MWh increased each year from 2002 to 2012.

Table 2. Historical Nuclear Generating Costs (Real 2016$).

Year	Fuel	Capital	Operating	Total
2002	5.80	3.97	18.85	28.62
2003	5.67	5.00	19.10	29.77
2004	5.35	5.73	18.79	29.87
2005	5.09	5.88	19.21	30.18
2006	5.11	5.63	19.48	30.22
2007	5.20	6.20	19.33	30.73
2008	5.42	6.85	19.78	32.06
2009	6.02	9.03	20.78	35.82
2010	6.85	9.28	20.92	37.05
2011	7.19	10.20	22.18	39.58
2012	7.57	10.91	21.77	40.25
2013	7.84	8.32	21.22	37.37
2014	7.31	8.29	21.21	36.81
2015	6.95	8.07	21.11	36.13
2016	6.76	6.74	20.43	33.93
2002-2016 change	*+16%*	*+70%*	*+8%*	*+19%*
2011-2016 change	*-6%*	*-34%*	*-8%*	*-14%*

In response to these trends, the nuclear industry, working through NEI, INPO and EPRI, initiated a comprehensive industry-wide review of nuclear power plant operating practices, titled Delivering the Nuclear Promise. The industry stated that its goal was "not merely to tamp down the increases that occurred over the last decade, but to identify opportunities to rethink operating practices, improve efficiencies and reduce costs to help keep nuclear power competitive in a changing electricity market—all while advancing safety at the facilities."[11] The overall expressed goal was to reduce average industry generating costs by 15% by January 2017 and 30% by 2018.

[11] See NEI, "Delivering the Nuclear Promise: Advancing Safety, Reliability and Economic Performance", February 2016, https://nei.org/Master-Document-Folder/Backgrounders/White-Papers/Delivering-the-Nuclear-Promise-Strategic-Plan

Nuclear plant cost information for 2016, summarized in Figure 2, appears to indicate that the industry efforts appear to be generally on track.

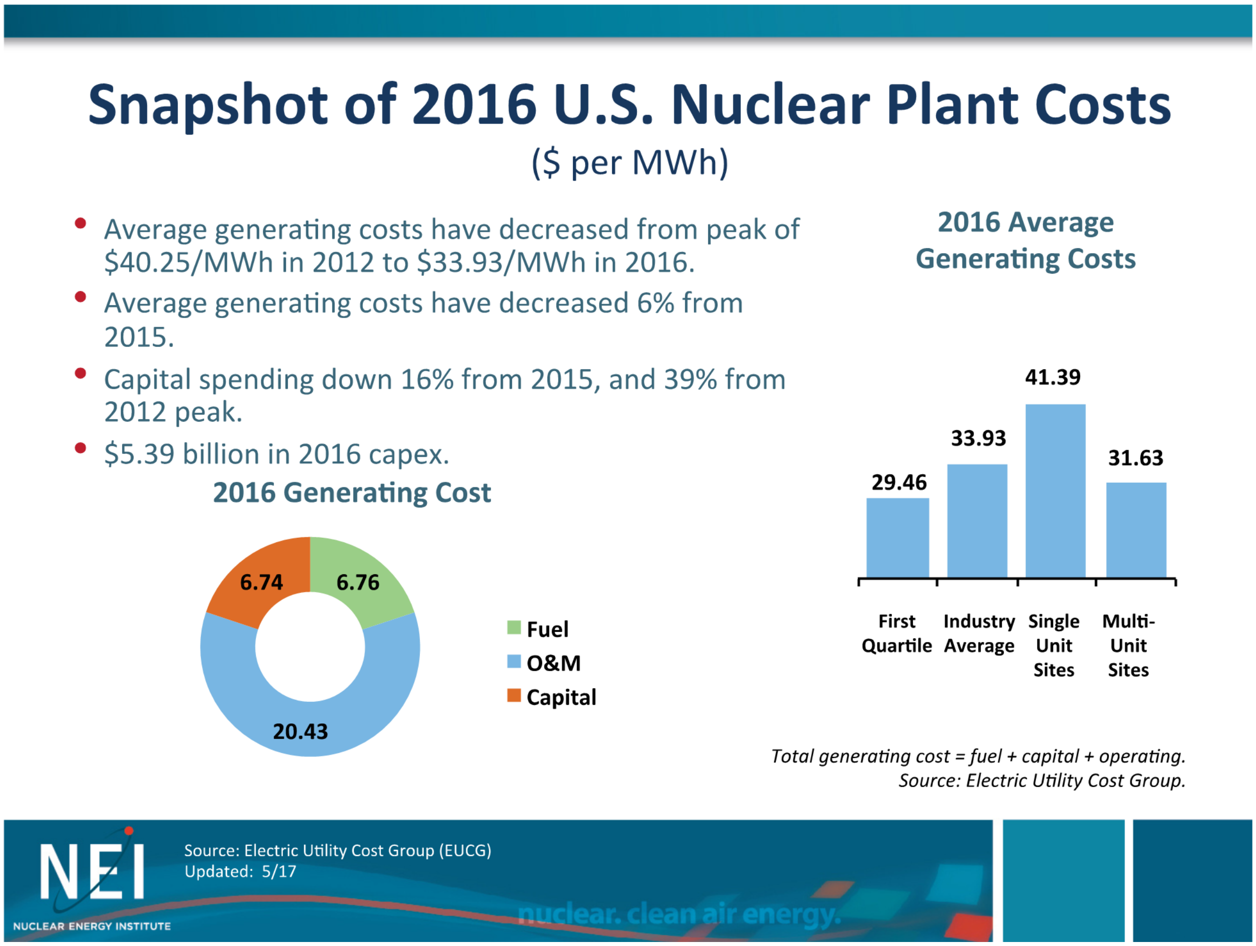

Figure 2. NEI – Snapshot of 2016 Nuclear Plant Costs.

While industry average nuclear power plant generating costs appear to be responding favorably to the operational improvement initiatives underway, this graphic also points out that there is considerable variability in nuclear power plant generating costs over the operating fleet. For example, while the industry average total cost in 2016 was $33.93/MWh, the average for single unit sites was over 20% higher, or $41.39. Similarly, first quartile sites reported costs about 13% below the overall average. The overall average is highly influenced by the higher costs experienced by the single unit sites, which also tend to host smaller and older units.

NEI has analyzed cost information provided by their member companies, and characterized the operating fleet in several ways, including plant size, multiple vs single unit sites, single plant operator vs fleet operator, regulated vs deregulated markets, and BWR vs PWR. In general, results for 2016 reflect what would be expected:

- Single unit sites (25) costs exceeded those of multi-unit sites (35) by over 30%. This was the largest single differentiator.
- On average, units run by a single operator (12) had costs about 10% higher than those run by fleet operators (48).
- Sites in deregulated markets (30) reported costs about 15% less than those (30) in regulated markets.
- While PWR's (37) reported costs in 2016 about 3% lower than BWR's (23), this advantage was not consistently reflected in previous years. It is not evident that the type of reactor is a significant factor in plant costs.

It should be noted that the industry has made significant progress over the past two decades in improving operations of the current fleet. As seen in Figure 3, capacity factors have been over 90% over the past several years, even as cost reduction efforts have taken place. Overall, operating performance has remained at approximately 90% for over a decade. Clearly, the plants are operating well.

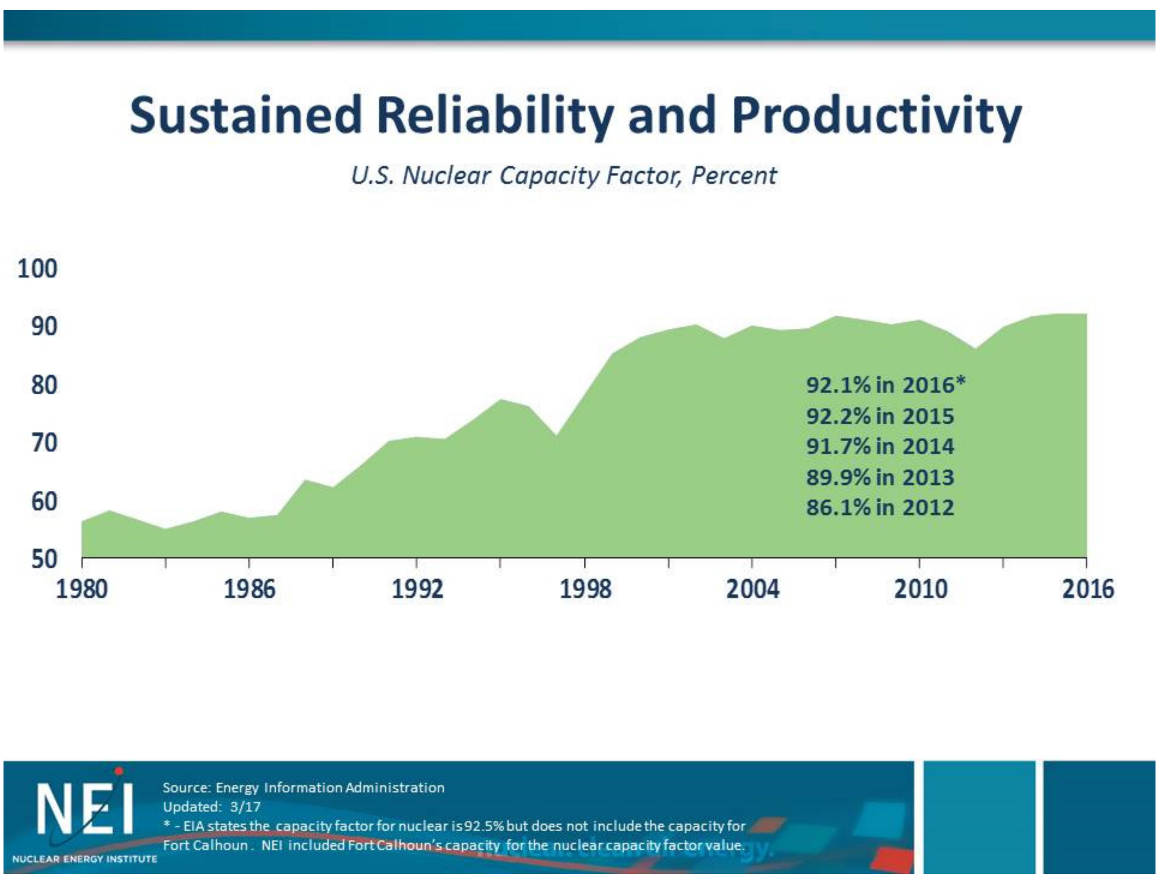

Figure 3. NEI - Capacity Factor Trends.

This report builds on the previous work by examining each of the operating nuclear units in the United States in detail, with the intent of identifying distinguishing cost characteristics and quantifying the revenue/cost gaps presently existing.

2. FERC FORM 1 Information

To obtain information on the costs to purchase power and the cost to generate power from sources other than nuclear power, 2016 FERC FORM 1 information was obtained for regulated utilities that own and operate nuclear power plants.

FORM 1 information also provides a view of the costs of owning and operating a nuclear power plant. However, nuclear generating costs based on FORM 1 information appear to be consistently lower than the estimated cost ranges discussed in Table 1 above. Typically, this lower cost is explained by the type of cost categories reported in the FORM 1. For example, plant level costs reported in the Form 1 may not include costs of ownership including capital expenditures, corporate overhead for regulatory and engineering, and other cost items. NEI indicates that their 2016 information included, on average, a capital expenditure of more than 6.7% of the total reported cost.

Information on public power utilities was found in Annual Reports and similar filings. Like the FORM 1 information for regulated utilities, the public power utility information also contained costs for nuclear generation and these nuclear generating costs may not be the same as the cost ranges in Table 1 above.

C. Gap Analyses

As a general matter, this study has identified four "Gaps" that are defined as the difference between measures of nuclear power plant value and nuclear generating cost. Gaps are estimated based on a comparison of Market Revenue, Purchased Power cost, Total Generation cost, and LCOE of replacement capacity to nuclear power plant generating costs.

For example, the Revenue Gap provides information on the magnitude of measures that might be needed to restore an unprofitable merchant nuclear power plant (i.e., a nuclear plant that depends on market revenue for profits) to profitable operation.

These Gap measures are defined in more detail below.

1. Gap Analyses Approach

The analyses in this study consider four different "Gap[12]" measures of economic viability for operating nuclear power units:

[12] In this study, we refer to Gaps (i.e., Revenue Gap, Purchased Power Gap, Total Generation Gap, and LCOE Gap) as the difference between a relevant measure (e.g., Revenue) and nuclear power unit generating costs. A Gap that is less than zero means that generating costs are higher than the relevant measure, while a Gap that is greater than zero means that generating costs are lower than the relevant measure.

- Revenue Gap – revenue from electricity markets compared to nuclear generating cost;
- Purchased Power Gap – cost of purchasing power compared to nuclear generating cost;
- Total Generation Gap – cost of all generating except for nuclear compared to nuclear generating cost; and
- LCOE Gap – LCOE of a new power plant compared to nuclear generating cost.

Each of these four Gap analyses is discussed in more detail.

a. Market Revenue Gap

The Market Revenue Gap (or "Revenue Gap") is the difference between the costs of operating a nuclear unit located in a market and the electricity market revenue earned by that nuclear unit.

This Gap measure assumes that the nuclear unit must cover costs of operation from revenue in the electricity market (i.e., electricity and capacity sales). No ZEC payments are included in this calendar year 2016 analysis. When ZEC payments commence in 2017 in New York and Illinois, these payments would be included as a part of Market Revenue in future gap assessments.

For merchant nuclear units, this is the primary Gap measure, as it is an estimate of the profits (or losses) of the merchant nuclear unit.

For regulated or public power utilities, this Gap is presented only if wholesale electricity market prices are available for a resulted or public power nuclear unit. When presented for a regulated or public power nuclear unit, the Revenue Gap is an indication of the regulated or public power nuclear unit profits that would be present ***IF*** the nuclear unit was a merchant nuclear unit that depended on revenue from selling power into electricity markets for profit.

b. Purchased Power Gap

The Purchased Power Gap is the difference between the costs of operating a nuclear unit and the cost of purchased power in 2016 for the utilities that own the nuclear unit.

This Gap assumes that a regulated or public power nuclear power plant/unit owner could purchase additional power at the same price as the actual power purchased in 2016 and that this additional purchased power could replace the output of a nuclear power unit that was retired early.

Most likely, purchasing additional power to replace the output of a retired nuclear power plant would be difficult and these additional purchases would be more expensive than the cost of current purchases (i.e., with the nuclear power plant in operation).

This assumption may not be a valid view of the situation for a specific regulated or public power utility, but provides a measure of the economics of the nuclear power plants. The Purchased Power Gap estimated in this study is likely to be lower than the actual Purchased Power Gap (i.e., the value of nuclear would be greater) due to the increased difficulty and higher cost of purchasing additional power to replace a retired nuclear power plant or plants.

This Gap applies to regulated and public power nuclear units, but does not apply to merchant nuclear units (i.e., because there is no requirement for a merchant nuclear unit owner to obtain power to replace a retired nuclear unit to meet customer demand). Some (i.e., two) regulated and public power utilities that own nuclear power units have no reported purchased power costs for 2016.

c. Total Generation Gap

The Total Generation Gap is the difference between the costs of operating a nuclear unit and the cost of power generated by the nuclear unit owner in 2016 using generation other than the nuclear power unit and purchased power.

This Gap measure assumes that a regulated or public power nuclear power plant owner could generate additional power from existing non-nuclear generators at the same cost as the actual power generated in 2016 and that this additional generation could replace one or more nuclear power plants that were retired early.

Most likely, generating additional power to replace the output of a retired nuclear power plant would be difficult and more expensive than the cost of current generation output with the nuclear power plant in operation.

This assumption again may not be a valid view of the situation for a specific regulated or public power utility, but provides another measure of the economics of the nuclear power plants. The Total Generation Gap estimated in this study is likely to be lower than the actual Total Generation Gap (i.e., the value of nuclear would be greater) due to the increased difficulty and higher cost of generating additional power to replace a retired nuclear power plant or plants.

This Gap applies to regulated and public power nuclear units, but does not apply to merchant nuclear units (i.e., because there is no requirement for a merchant nuclear unit owner to obtain power to replace a retired nuclear unit to meet customer demand). One regulated or public power utility that owns a nuclear power unit has no other generation.

d. LCOE Gap

The LCOE Gap is the difference between the cost of operating an existing nuclear power plant and the LCOE of a new advanced gas-fired CCGT power plant.

This Gap is based on the EIA LCOE estimate for a new Advanced CCGT. This LCOE estimate includes a range of assumptions about capital cost, operating costs, and fuel costs. The EIA estimate includes a forecast of natural gas costs.

Comparing a life-cycle LCOE for a new CCGT power plant to the annual generating costs of an existing nuclear power plant may not be a valid comparison. However, it is an indication of the relative cost of replacing a retired nuclear unit with the most likely replacement capacity, a gas-fired CCGT power plant.

This Gap analysis is applied to all three types of nuclear power units, even though it may be less relevant for merchant nuclear units (i.e., because there is no requirement for a merchant nuclear unit owner to obtain power to replace a retired nuclear unit to meet customer demand).

2. Application of Gap Analyses

The Gap analyses were applied to three types of nuclear power plants, merchant, regulated, and public power.

a. Merchant Nuclear Units

Two of the four Gap measures, the Revenue Gap and the LCOE Gap, were estimated for merchant nuclear units.

The Market Revenue Gap provides an estimate of the profits (or losses) of a merchant nuclear unit.

Estimates of 2016 full-year revenue for merchant nuclear units are based on electricity market information from 2016[13] to estimate electricity and capacity market revenue.

A merchant nuclear power plant depends on revenue from the electricity market to cover generating costs and provide profits. Lower wholesale electricity market prices and/or lower capacity market prices results in lower merchant nuclear plant profits or even losses.

The Purchased Power Gap and Total Generation Gap are not relevant for merchant nuclear units.

The LCOE Gap was also estimated for merchant nuclear units. This LCOE Gap is relevant to the market in which the merchant nuclear unit operates, not to the merchant nuclear unit owner. In other words, the retirement of a nuclear power unit may mean that a region or electricity market area will need additional baseload capacity, but there is no requirement that the owner of a retired merchant nuclear power unit invest in that replacement capacity.

b. Regulated and Public Power Nuclear Units

All four Gap measures were estimated for regulated and public power nuclear units, if relevant information was available.

The Market Revenue Gap measure is estimated for those regulated or public power nuclear units that have market prices available (i.e., some regulated nuclear units operate in electricity markets). The regulated or public power status of these units does not mean that they are facing the same financial losses that a merchant nuclear unit might face.

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[13] This report obtained information from Bloomberg New Energy Finance (BNEF) and used some of this information. It is unclear whether the information provided by BNEF is the same as the information that was used in the BNEF analysis of nuclear plants in 2016 (i.e., “Reactors in the Red) or 2017.

Regulated and public power nuclear units are subject to regulation that allows the owners to recover costs of operating the nuclear units in customer rates as part of earning an authorized rate of return on assets. A regulated or public power nuclear power unit may have costs that are higher than the cost of other generating options for the regulated or public power utility. If this is the case, the utility regulator or public power utility may, subject to the constraints of the regulatory process and laws, consider if the higher costs of nuclear electricity are justified by other attributes of nuclear power (e.g., clean power, fuel diversity, system reliability, economic impact).

The Purchased Power and Total Generation Gap were estimated for regulated and public power nuclear units. These Gaps rely on utility costs[14] that may

- Cover multiple nuclear units (i.e., if a utility owns more than one nuclear unit or nuclear plant);
- Cover only a part of a nuclear unit (i.e., if a utility is a co-owner of a nuclear unit); or
- Be composed of the costs of multiple regulated utilities that are co-owners of a nuclear unit.

The Purchased Power and Total Generation Gap estimates provide a view of how the costs of nuclear electricity compare to options available to the regulated or public power owner to use existing source of electricity to replace the energy and capacity lost if a nuclear unit is retired early.

The LCOE Gap was estimated for regulated and public power nuclear units. This is a simplistic approach to estimating the relative cost of replacing a retired nuclear power unit with a new gas-fired CCGT power plant.

A more robust analysis of the economics of existing regulated or public power nuclear power plants would look at the lifecycle impact on rates of retiring a nuclear power plant and replacing it as needed to meet current and forecast customer demand. This would require, at a minimum, a detailed production cost and planning model and a complex set of assumptions and inputs for these models for each utility. This study is not a replacement for these more detailed analyses, but this study provides information on the relative economics inn 2016 of existing nuclear power plants/units owned by regulated and public power utilities

If a regulated or public power utility was presented with a convincing case that retiring a nuclear power plant would lower rates, this might lead the regulated utility, state regulators, or public power utility members to consider whether the value of nuclear power attributes (e.g., clean air, reliable generation, fuel diversity, long-term operation, etc.) outweighed any projected lower rates.

[14] FERC FORM 1 information is the primary source for regulated utilities, financial reports are the primary information source for public power utilities

The early retirement of the Fort Calhoun generating station in 2016 provides some insight into the process that might be followed in a public power utility that is considering the potential early retirement of an existing nuclear power plant.

Fort Calhoun was owned and operated[15] by Omaha Public Power District. The early retirement of Fort Calhoun involved a nuclear generating unit with relatively high generating costs (i.e., a small, single site unit) and the availability of low-cost energy and capacity to replace the unit.

According to OPPD public statements, power to replace the output of the retired nuclear unit was available at prices below $20/MWh and OPPD had more capacity than it needed. Also, generating costs at Fort Calhoun were reported to be very high (i.e., $71/MWh).[16] The unique situation at Fort Calhoun may not apply to other regulated or public power nuclear units.

3. Gap Analyses Results - Charts

The results for each of the four Gap measures are provided here.

Gap analysis are presented in four charts, with each chart containing units of all three types:

- Figure 4 – Revenue Gap,
- Figure 6 – Purchased Power Gap,
- Figure 7 – Total Generation Gap, and
- Figure 8 – LCOE Gap

Each of these four Gap results charts has the same format and a similar approach:

- Each Gap chart has a plot of Gap level (in units of $/MWh) for each unit for which relevant information is available.
- The nuclear units included in the chart have one of three symbols (i.e., a blue diamond for regulated units, a yellow triangle for public power units, and a red circle for merchant units).
- To provide a clear indication of how the units stack up, each chart has the units sorted from smallest Gap to largest Gap and the zero line is shown in bold.

A summary of the results and conclusions for each Gap analysis are provided just prior to each of these charts. Later sections provide a more complete discussion of the logic and approach for the four Gap analyses and the way that the Gap analyses were applied in this study.

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15 Exelon Nuclear Partners was providing services related to operation to OPPD when a decision was reached to retire Fort Calhoun early, with the Exelon contract terminated (see http://www.omaha.com/money/oppd-will-pay-million-early-exit-fee-to-fort-calhoun/article_a00ac19f-a1bd-50d3-9998-7a34fa6d4e5f.html)

16 https://www.worldnuclearreport.org/Nebraska-Reactor-Fort-Calhoun-Closes-Permanently.html and http://www.omaha.com/money/oppd-announces-official-closing-date-for-fort-calhoun-nuclear-plant/article_b8cf2e6f-ce65-56fb-9a0b-cb7ad80f8ce4.html

a. Market Revenue Gap

The Revenue Gap is the difference between the electricity market revenue (i.e., this includes electricity spot market revenue, capacity market revenue, if any) earned by a nuclear unit located in a wholesale electricity market and the generating costs of that nuclear unit.

ZEC payments[17] were approved in New York[18] and Illinois[19], but ZEC payments in both states will start in 2017. No ZEC payments are included in this 2016 calendar year Gap analysis.

The results of the Revenue Gap analyses are presented in Figure 4.

Revenue Gap analyses were done for 79 of the 99 operating reactors in the U.S. that are in a region where public wholesale electricity market prices are available. Of the 79 nuclear power units shown in Figure 4, 63 have a Revenue Gap that is less than zero (i.e., would be losing money if the unit depended on market revenue for profits). If all U.S. nuclear power plants/units were valued only on profits in electricity markets (i.e., as merchant nuclear units) and no additional revenue (e.g., ZEC payments) were available, these 63 units would likely retire early to stop losses.

Figure 5 shows the amount of additional revenue needed to return each unit with a negative Revenue Gap to breakeven. An additional revenue source of about $15/MWh for the units that have a Revenue Gap of less than zero would reduce the number of units with a Revenue Gap of less than zero from 63 units to only 10 units. This $15/MWh additional revenue amount is slightly less than the ZEC payments approved in New York and Illinois.

Figure 4 and Figure 5 show the results for a total of 79 nuclear power units for which electricity market prices are available. Of these units, 46 are merchant generators, 25 are regulated generators, and 8 are public power generators. Of the 63 units with a Revenue Gap that is less than zero, 36 are merchant generators, 19 are regulated generators, and 8 are public power generators.

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[17] ZEC payments have been established by New York and Illinois and represent a state approach to stopping early nuclear retirements. ZEC payments are similar to the out-of-market payments to renewables in many states. See page 15 in the ESSAI report "Economic and Market Challenges Facing the U.S. Nuclear Commercial Fleet" issued in September 2016, for a discussion of the New York ZEC program.

[18] The first ZEC compliance year in New York is from 1 April 2017 to 31 March 2018. This means that ZEC payments will start too late for inclusion in this 2016 calendar year analysis. ZEC prices are expected to be $17.48/MWh when payments commence in 2017. See https://www.nyserda.ny.gov/All-Programs/Programs/Clean-Energy-Standard/REC-and-ZEC-Purchasers

[19] Illinois has approved ZEC payments for Quad Cities and Clinton (i.e., with a price of $16.50/MWh), with the effective date of the Act at 1 Jun 2017 and a process started in July 2017 to implement the ZEC procurement Plan (see https://www.illinois.gov/sites/ipa/Documents/2018ProcurementPlan/Draft-Zero-Emission-Standard-Procurement-Plan.pdf). There are no Illinois ZEC payments included in this 2016 calendar year analysis.

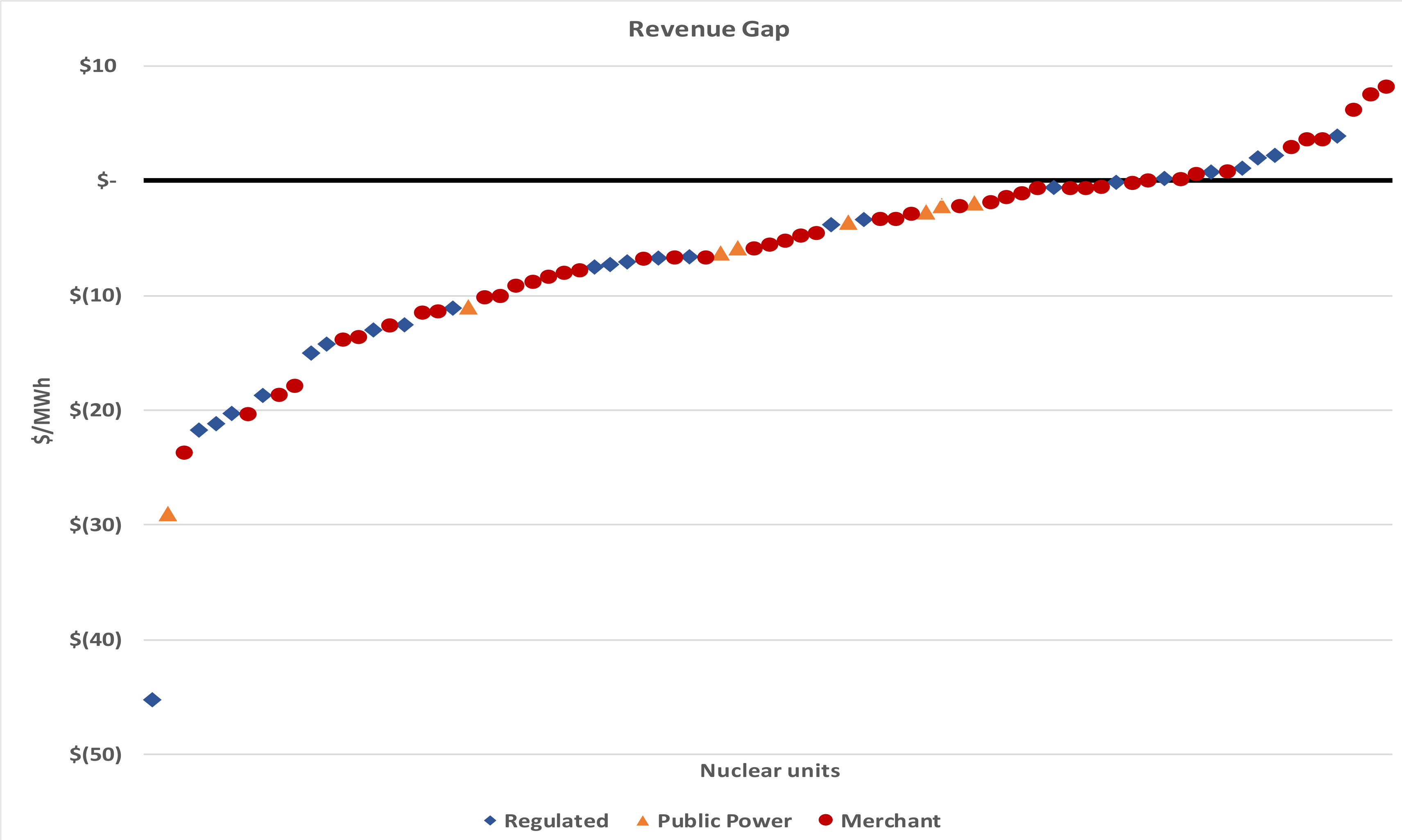

Figure 4. Revenue Gap.[20]

[20] Each symbol in this chart represents a single nuclear unit, with the symbols sorted from smallest Gap to largest Gap.

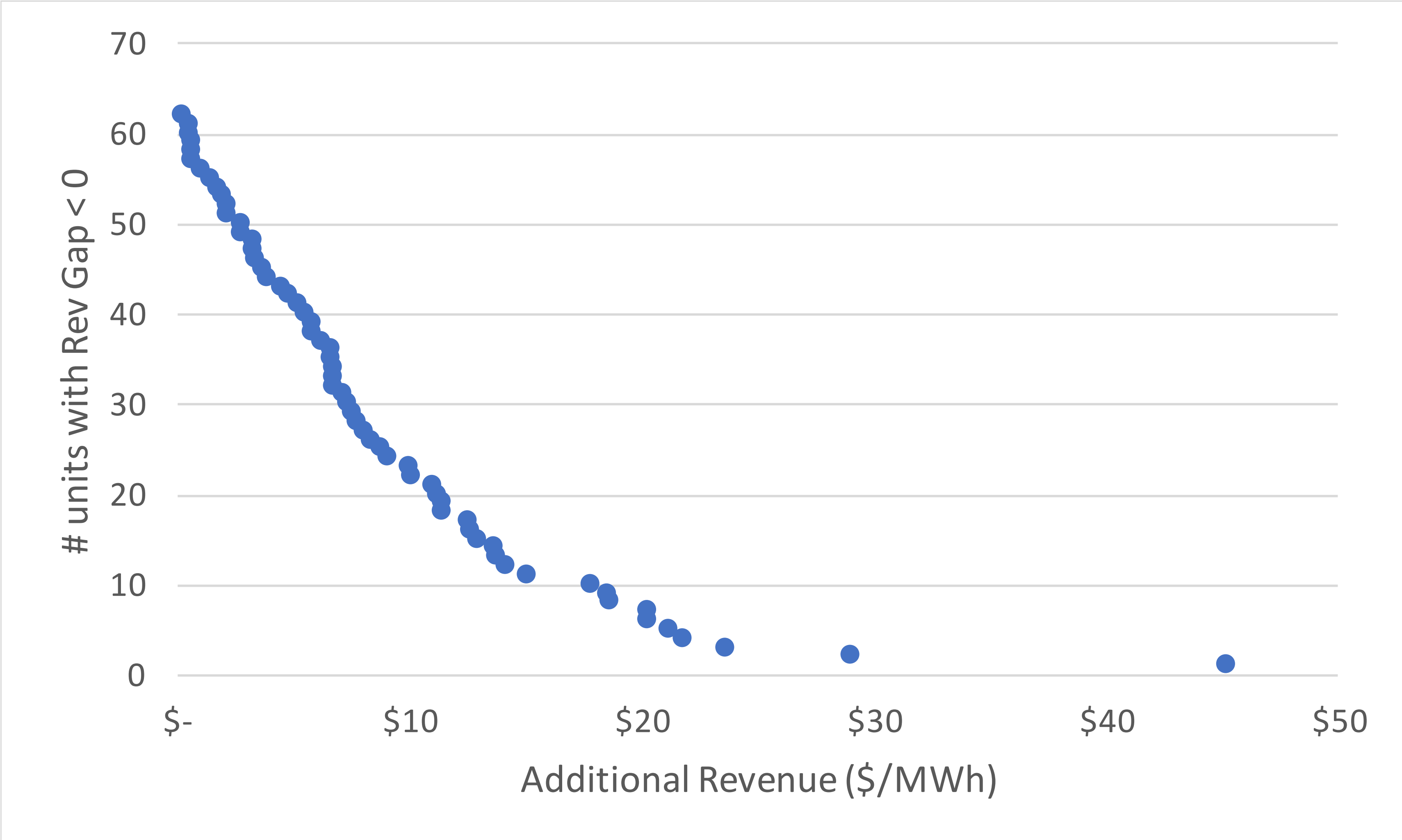

Figure 5. Additional Revenue Needed.

b. Purchased Power Gap

The Purchased Power Gap is the difference between the cost of purchased power in 2016 for a nuclear unit utility owner and the generating costs of the nuclear unit.

The results of the Purchased Power Gap analyses are presented in Figure 6.

Purchased Power Gap analyses cover 51 regulated and public power nuclear units for which relevant information was available. Of the 51 regulated and public power nuclear power units shown in Figure 6, only two have a Purchased Power Gap that is less than zero.

This means that almost all (i.e., 49 of 51) regulated and public power utilities that own nuclear power plants/units are better off keeping their nuclear power plants rather than retiring the nuclear plant/unit and replacing the nuclear power plant/unit output with additional purchased power at the same price as they purchased power in 2016 (assumes that this is feasible).

Figure 6 shows results for a total of 51 nuclear power units for which purchased power cost information is available. Of these units, 43 are regulated generators and eight are public power generators.

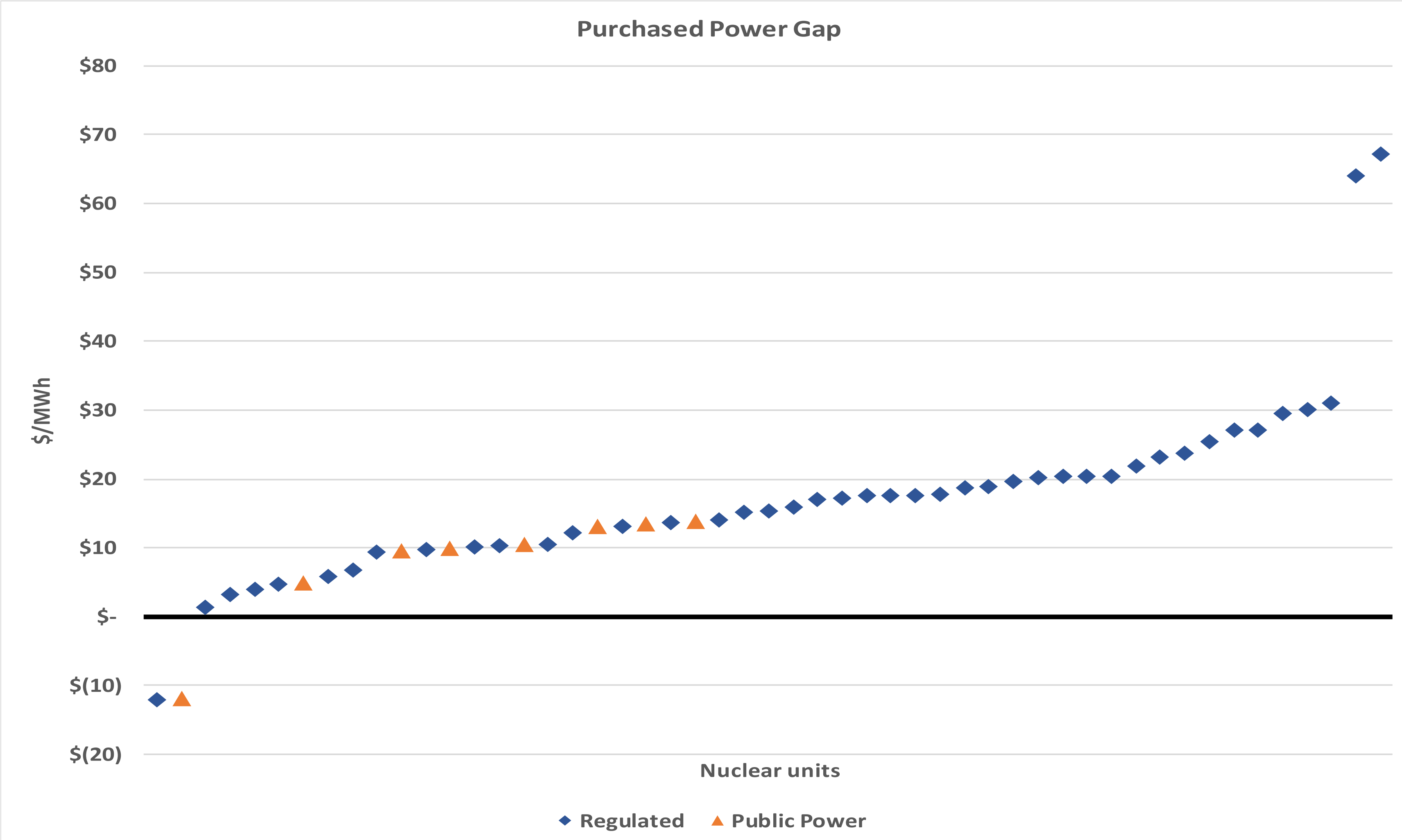

Figure 6. Purchased Power Gap.[21]

[21] Each symbol in this chart represents a single nuclear unit, with the symbols sorted from smallest Gap to largest Gap.

c. Total Generation Gap

The Total Generation Gap is the difference between the cost of power generated by the nuclear unit owner in 2016 using plants other than the nuclear power unit and the generating costs of the nuclear unit.

The results of the Total Generation Gap analyses are presented in Figure 7.

Total Generation Gap analyses cover 52 regulated and public power nuclear units for which relevant information was available. Of the 52 regulated and public power nuclear power units shown in Figure 7, there are 15 units with a Total Generation Gap that is less than zero.

This means that most (i.e., 37 of 52 units) regulated and public power utilities that own nuclear power plants/units are better off keeping their nuclear power plant/unit rather than retiring the plant and replacing the nuclear power plant/unit output with more power generated by existing non-nuclear power plants at the same cost as 2016 power generated from sources other than nuclear and purchased power (assumes that this is feasible).

Figure 7 shows results for a total of 52 nuclear power units for which total generation cost information is available. Of these units, 43 are regulated generators and nine are public power generators.

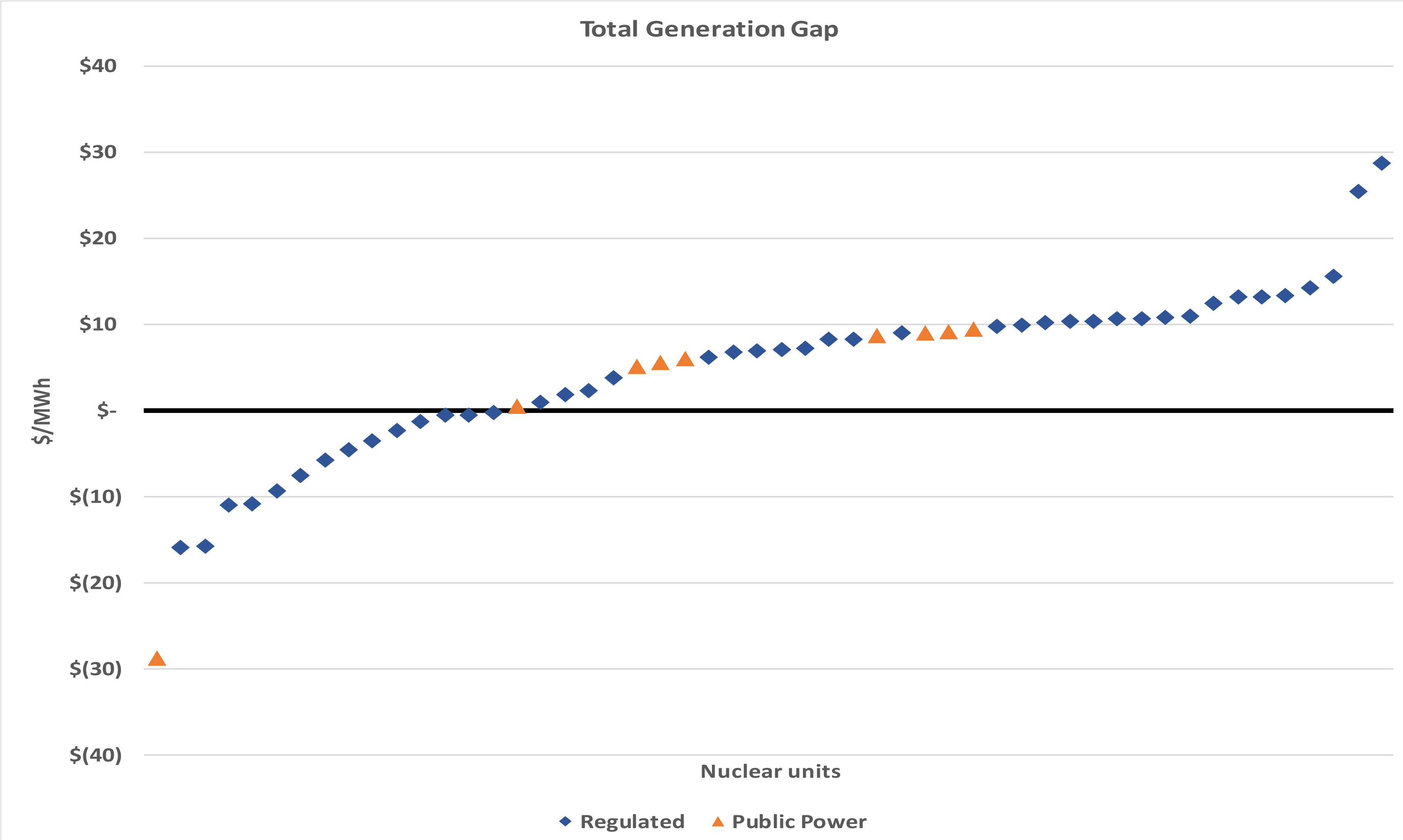

Figure 7. Total Generation Gap.[22]

[22] Each symbol in this chart represents a single nuclear unit, with the symbols sorted from smallest Gap to largest Gap.

d. LCOE Gap

The LCOE Gap is the difference between the LCOE of a new advanced gas-fired CCGT power plant and the generating cost of an existing nuclear power unit.

A positive LCOE Gap means that nuclear unit generating cost is less than the cost of a new advanced gas-fired CCGT power plant, while a negative LCOE Gap means that nuclear unit generating cost is greater than the of a new advanced gas-fired CCGT power plant.

The results of the LCOE Gap analyses are presented in Figure 8.

Of all 99 U.S. nuclear power units shown in Figure 8, only one has an LCOE Gap that is less than zero.

This means that virtually all (i.e., 98 of 99) U.S. nuclear power units have a 2016 generating cost that is less than the total cost of building and operating the least expensive baseload replacement option (i.e., advanced natural gas fueled CCGT).

Figure 8 shows results for all 99 U.S. nuclear power units. Of these units, 46 are merchant generators, 44 are regulated generators, and nine are public power generators.

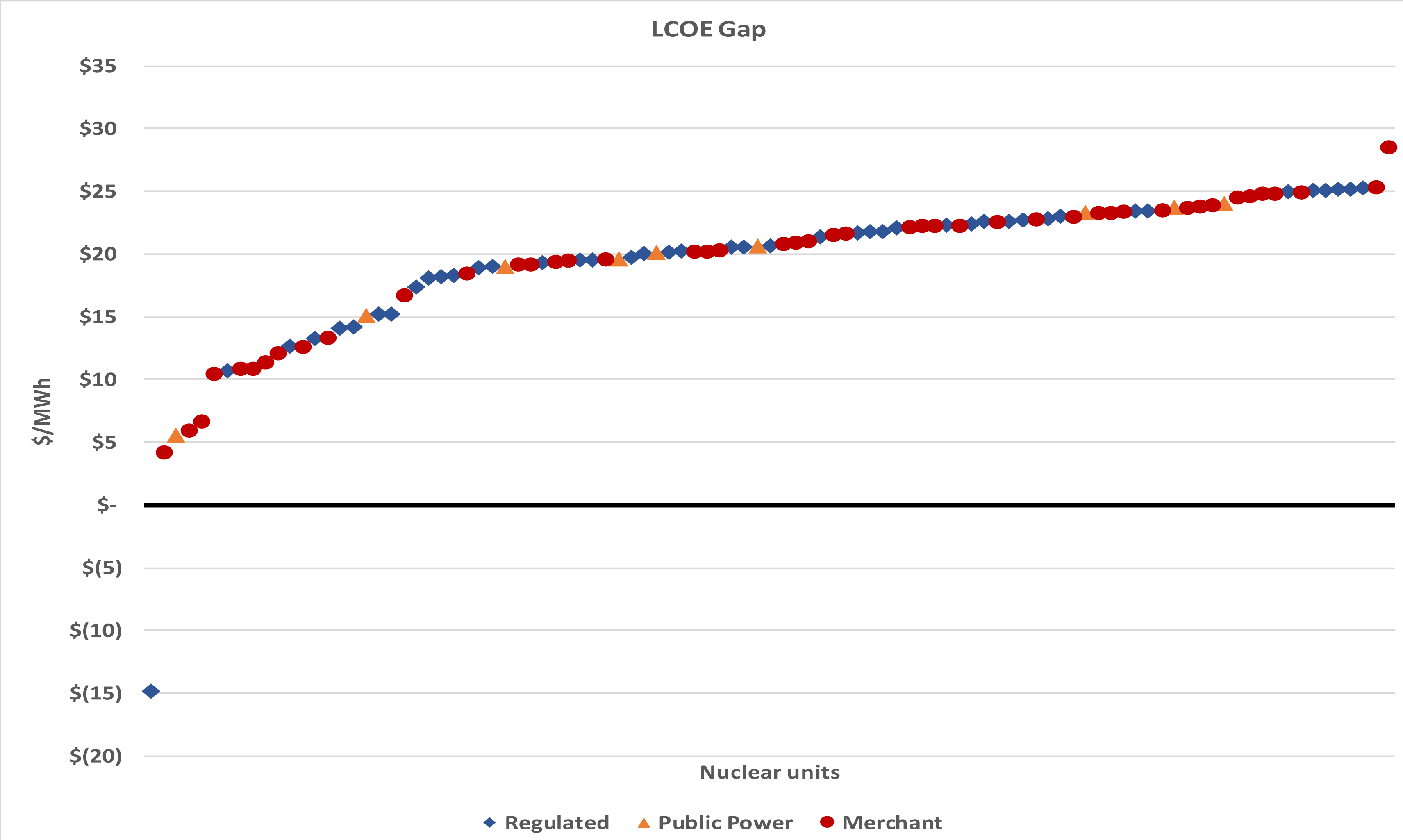

Figure 8. LCOE Gap.[23]

[23] Each symbol in this chart represents a single nuclear unit, with the symbols sorted from smallest Gap to largest Gap.

4. Gap Analyses Results - Tables

This section presents the results of the Gap analyses in a different format to provide more detailed insights. The Charts in the prior section focused on the type of Gap analysis, while the results in this section are presented in table form for each of the three types of nuclear units – Merchant, Regulated, and Public Power.

The Gap analyses cover every operating nuclear plant unit to the extent to which relevant information is available. The results are presented here in an aggregate and summary form.[24]

a. Merchant

The Revenue Gap and the LCOE Gap were assessed for merchant nuclear units.

Table 3 shows the results of the Revenue Gap analysis for merchant nuclear units. The information has been presented for all merchant nuclear units, with those in the PJM and NYISO markets broken out and those in other markets (i.e., ISO-NE, ERCOT, and MISO) lumped together.

36 of the 46 merchant nuclear units have a Revenue Gap below zero (i.e., almost 80% of merchant nuclear power units are estimated to be losing money).

An amount of additional revenue of about $15/MWh would return most units losing money to profitability and many of the units would require a smaller amount.

This situation is similar across all electricity markets.

Table 3. Merchant Nuclear Revenue Gap

Merchant $/MWh Revenue Gap	**All**	**PJM**	**NYISO**	**Others**
Total units	**46**	**27**	**6**	**13**
Units with Gap <0	**36**	**21**	**5**	**10**
Average	**($5.11)**[25]	**($3.27)**	**($8.53)**	**($7.37)**
Max	**$8.24**	**$8.24**	**$7.52**	**$3.66**
Min	**($23.66)**	**($18.57)**	**($20.25)**	**($23.66)**

[24] One of the objectives of this study is to avoid providing unit-specific information that might cause financial or regulatory difficulties for the nuclear unit owners.

[25] This is a negative number. This report uses accounting notation, where negative numbers are presented in parentheses.

Table 4 shows the results of the LCOE Gap analysis for merchant nuclear units. The information has been presented for all merchant nuclear units, with those in the PJM and NYISO markets broken out and those in other markets (i.e., ISO-NE, ERCOT, and MISO) lumped together.

All 46 merchant nuclear units have an LCOE Gap greater than zero (i.e., the generating cost of all these units are lower than the LCOE of a new CCGT power plant).

This situation is similar across all electricity markets.

Table 4. Merchant Nuclear LCOE Gap

Merchant $/MWh LCOE Gap	**All**	**PJM**	**NYISO**	**Others**
Total units	**46**	**27**	**6**	**13**
Units with Gap <0	**0**	**0**	**0**	**0**
Average	**$19.54**	**$20.52**	**$16.57**	**$18.87**
Max	**$28.54**	**$28.54**	**$24.55**	**$24.90**
Min	**$4.21**	**$4.21**	**$10.56**	**$6.00**

b. Regulated

All four Gaps are estimated for regulated nuclear units.

As discussed above, wholesale electricity market prices are available for some regulated nuclear units, allowing an estimate of the market revenue and Revenue Gap for these regulated nuclear units. This is not an indication of the profits or losses of these regulated nuclear units (i.e., the profitability of a regulated nuclear unit is determined by the regulatory process in each state), but an estimated Revenue Gap is an indication of the relative economic status of regulated nuclear units if those units were merchant generators.

Table 5 shows the results of the Revenue Gap analysis for regulated nuclear units for which wholesale electricity market prices are available (i.e., 28 of the 47 regulated nuclear units).

Of the 28 regulated power nuclear units for which wholesale electricity market prices are available, 20 of these have a Revenue Gap that is less than zero (i.e., would be losing money if the units depended on market revenue for profitability).

Table 5. Regulated Nuclear Revenue Gap.

Revenue Gap	**28 units**
Number with Gap <0	**21 units**
$/MWh	
Average	($9.06)
Max	$3.88
Min	($45.19)

Table 6 shows the results of the Purchased Power Gap analysis for regulated nuclear units for which purchased power cost information is available (i.e., 46 of 47 regulated nuclear units).

Only 2 of the 46 regulated units have a Purchased Power Gap of less than zero (i.e., these units have generating costs that are greater than the cost of the utility's 2016 purchased power).

Table 6. Regulated Nuclear Purchased Power Gap.

Purchased Power Gap	**46 units**
Number with Gap <0	**2 units**
$/MWh	
Average	$18.07
Max	$67.14
Min	$12.08

Table **7** shows the results of the Total Generation Gap analysis for regulated nuclear units for which alternative generation cost information are available (i.e., 46 of 47 regulated nuclear units).

15 of the 46 regulated units have a Total Generation Gap of less than zero (i.e., these units have generating costs that are greater than the cost of the utility's 2016 generation from sources other than nuclear and purchased power).

Table 7. Regulated Nuclear Total Generation Gap

Total Generation Gap	**46 units**
Number with Gap <0	**15 units**
$/MWh	
Average	$4.86
Max	$28.63
Min	($15.94)

Table 8 shows the results of the LCOE Gap analysis for all regulated nuclear units.

Only two of the 47 regulated units have an LCOE Gap that is less than zero (i.e., the generating costs of these two units are higher than the LCOE of a new CCGT).

Table 8. Regulated Nuclear LCOE Gap

LCOE Gap	**47 units**
Number with Gap <0	**2 units**
$/MWh	
Average	$19.44
Max	$25.25
Min	($14.86)

c. Public Power

The same four Gaps assessed for regulated nuclear plants are also assessed for public power nuclear plants.

As discussed above, wholesale electricity market prices are available for some public power nuclear units, allowing an estimate of market revenue and Revenue Gap for these public power nuclear units. This is not an indication of the profits or losses of these public power nuclear units (i.e., the profitability of a public power nuclear unit is determined by the implicit regulatory process of these public power utilities), but is an indication of the relative economic status of these public power nuclear units if those units were merchant generators.

Table 9 shows the results of the Revenue Gap analysis for public power nuclear units for which wholesale electricity market prices are available (i.e., eight of nine public power units).

All eight of the public power nuclear units for which wholesale electricity market prices are available have a Revenue Gap of less than zero (i.e., the generating cost of these nuclear units is higher than the market revenue that they might earn in the market, if the units depended on market revenue).

Table 9. Public Power Nuclear Revenue Gap.

Revenue Gap	**8 units**
Number with Gap <0	**8 units**
$/MWh	
Average	($7.83)
Max	($1.96)
Min	($28.98)

Table 10 shows the results of the Purchased Power Gap analysis for public power nuclear units for which purchased power cost information is available (i.e., eight of nine public power units).

Only one of the eight public power nuclear units has a Purchased Power Gap of less than zero (i.e., the generating cost for this unit is higher than the 2016 purchased power cost for the owner).

Table 10. Public Power Nuclear Purchased Power Gap.

Purchased Power Gap	**8 units**
Number with Gap <0	**1 units**
$/MWh	
Average	$7.94
Max	$13.87
Min	($11.81)

Table 11 shows the results of the Alternative Generation Gap analysis for all public power nuclear units for which total generation cost information are available (i.e., nine public power units).

Only one of nine public power units has a Total Generation Gap of less than zero (i.e., the generating cost of this unit is higher than the cost of generating power from sources other than nuclear and purchased power for the owner).

Table 11. Public Power Nuclear Total Generation Gap.

Total Generation Gap	**9 units**
Number with Gap <0	**1 units**
$/MWh	
Average	$2.75
Max	$9.47
Min	($28.77)

Table 12 shows the results of the LCOE Gap analysis for all nine public power nuclear units.

None of the nine public power nuclear units have an LCOE Gap of less than zero.

Table 12. Public Power Nuclear LCOE Gap.

LCOE Gap	**9 units**
Number with Gap <0	**0 units**
$/MWh	
Average	$19.03
Max	$24.06
Min	$5.58

III. GROUPING NUCLEAR POWER UNITS

One of the objectives of this report is to provide information on ways to group nuclear power units into categories that can be used in further analysis and research.

This Section is a more complete discussion of the potential ways to group nuclear power units, building on the discussion earlier in this report.

A. Nuclear Unit Location

The location of nuclear units may be an important factor that can be used to group units. However, the location of a nuclear unit may largely be a proxy for the electricity market structure (i.e., whether and how a state has reformed and restructured its electricity industry), the type of nuclear plant (e.g., some states only have public power nuclear plants), and local electricity market prices that determine revenues.

A more detailed study of nuclear unit generating costs might reveal that there is a difference in these costs that is related to location. This difference might reflect local and regional labor costs, climate differences, local and state tax regimes, and other factors. It is not clear that such differences exist in a significant way and unclear if such differences will be useful for policy considerations.

The limited number of nuclear power plants and the limited detailed information on generating costs for these nuclear power plants may make such locational differences difficult or impossible to develop.

B. Nuclear Unit Ownership

Appendix A provides a detailed discussion of the owners and operators of U.S. nuclear power plants. It may be possible to use this information to group nuclear power plants by ownership attributes. For example, nuclear power units that are 100% owned and operated by a single company may be different from nuclear power units that are co-owned.

C. Nuclear Unit Regulatory Status

An important grouping factor is whether a nuclear unit is a merchant unit, a regulated unit, or a public power unit.

There are important differences in hot these types of nuclear power companies. The economic drivers of early retirement and the economic impact of electricity market factors differ significantly between merchant nuclear units and regulated/public power nuclear units.

These terms are discussed in the earlier sections in this report and defined in Appendix B.

D. Markets and Electricity Industry Structure

In grouping operating nuclear plants in terms of revenues and costs, revenue generation tends to be highly dependent on the region based on the form and nature of the electricity market and the dominant fuel mix in the region. Today, about 45 GWs of nuclear capacity (49 plants) operate in deregulated markets and 54 GWs of nuclear capacity (50 plants) operate under rate-based, state regulation. Electricity industry restructuring in deregulated markets has resulted in nuclear plants becoming merchant generators. Merchant nuclear power plants are particularly vulnerable to fluctuations in the price of the electricity and capacity they sell because lower prices can result in some cases in financial losses.

Figure 9 is a U.S. map with the electricity markets identified in colors. The gray and reddish areas in the west and the brown area in the Southeast are regulated. Public power in the U.S. exists in all regions, even those with electricity markets.

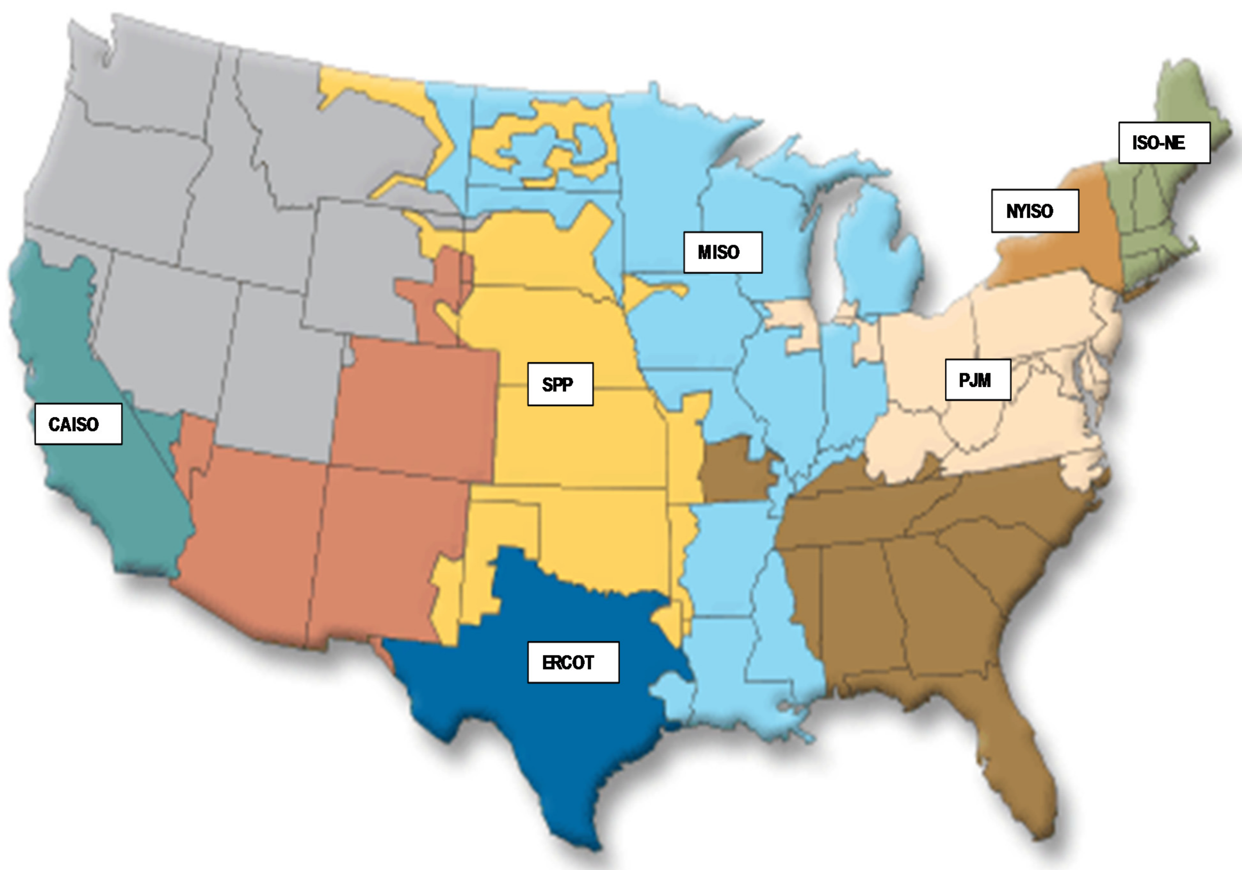

Figure 9. U.S. Electricity Market Regions.

Deregulated regional markets place an implicit emphasis on electricity and capacity as short-term commodities in these markets and make it difficult or impossible for any generator participant to have a long-term view of plant value or to focus on externality benefits, such as zero carbon emissions and/or grid reliability that are not reflected in market prices. The focus on efficient electricity markets results in low electricity market prices. These lower electricity market prices directly impact merchant nuclear power plant operating cash flow.

In regulated markets, such those in the southeast region, nuclear plants operate as part of a fully-regulated, vertically-integrated electrical system in which plants are "rate-based" and therefore are relatively decoupled from short-term fluctuations in the wholesale power markets. Nonetheless, their annual generating costs must remain competitive with alternative fuel sources in the mid to long term.

Appendix B provides a more detailed discussion that may be used to group nuclear power plants on attributes related to electricity industry structure and electricity markets.

E. Nuclear Unit Generating Costs

In terms of nuclear plant generating costs, the nuclear industry has closely examined nuclear power generation costs to determine their correlation with a variety of factors such as size, number of units, type of reactor, etc. Based on industry studies, the significant correlation tends to be based on size and number of reactors per site. Industry studies have shown that small, single unit sites tend to have the highest generating costs as compared to large, single units and especially large, multi-unit sites.

As discussed above in Section II.A, we present an approach to dividing nuclear units into groups based on the level of generating cost based on unit size and whether the unit is in a single-unit or multiple-unit site.

The Gap analyses in this study only reflect generating cost differences related to unit size and number of units on each plant site. However, it may be possible to group nuclear power plants based on differences in generating costs related to other nuclear power unit features. For example, information might be available to differentiate units into categories that include:

- Industry approach (i.e., merchant vs regulated vs public power units);
- Size and sophistication of Operator (i.e., fleet operator vs single plant/unit operator);
- Type of reactor (i.e., BWR vs PWR)

IV. PRIORITIZE RISKS OF AND FACTORS LEADING TO EARLY RETIREMENT

In terms of early retirement, there are several factors that may influence a decision by a utility to opt for early retirement of an operating nuclear plant prior to the expiration of its operating license from the NRC. These factors can be grouped in three main categories: technical and regulatory, economics, and political. Technical and regulatory issues can be major drivers and sometimes occur at site due a unique set of circumstances, such as that which occurred at Crystal River and San Onofre units. Of course, what begins as a technical operating issue can quickly morph into an economic issue when costs of necessary recovery or repairs must be considered. Operating nuclear plants have for the most part have a declining period to recover any capital costs associated with major repairs, such as steam generator or reactor head replacement, and therefore these major plant repair costs must be carefully considered in any decision to invest in large capital repairs. While operating nuclear plants have the potential for extending their operating life beyond 60 years, the first applications for subsequent license renewal have yet to be filed with the NRC[26]. Therefore, capital repair costs must be recovered over shorter and shorter periods of time which in turn becomes a major investment decision consideration.

Even when an operating plant faces no specific technical issue, a nuclear plant may be retired due to strictly economic reasons alone, such was the case at Kewaunee by Dominion and Fort Calhoun by Omaha Public Power. From an economics perspective, operating nuclear plants in deregulated markets face continued economic stress to due low forecasted wholesale power prices in their respective regions.

Finally, an operating nuclear plant can be shut down due to political or other reasons. Examples include

- Indian Point 2 & 3, which are planned for early retirement in 2024/2025 because of a political agreement between the unit owner and the State of New York;
- Diablo Canyon 1 & 2, which are planned for early retirement at the end of their current license periods (i.e., 2024/2025) because of an agreement facilitated by the State of California; and
- Oyster Creek, which is planned to retire early in 2019 because of a negotiated settlement of direct cooling issues with the State of New Jersey.

[26] The NRC has been notified by the licensees of the Peach Bottom and Surry units that they intend to file applications for subsequent license renewals in 2018 and 2019, respectively. In addition, another licensee has provided notification to the NRC that it intends to file an application in 2017. The identity of that licensee is being withheld by the NRC at the request of the licensee.

V. CONCLUSIONS

The analyses in this study consider four different "Gap[27]" measures of economic viability for operating nuclear power units:

- Revenue Gap – revenue from electricity markets compared to nuclear generating cost;
- Purchased Power Gap – cost of purchasing power compared to nuclear generating cost;
- Total Generation Gap – cost of all generating except for nuclear compared to nuclear generating cost; and
- LCOE Gap – LCOE of a new power plant compared to nuclear generating cost.

The results of these four analyses lead to three conclusions:

1. Market Failure[28] Is the Problem, Not Nuclear Power Plants.

Revenue Gap analyses were done for 79 of the 99 operating reactors in the U.S. that are in a region where public wholesale electricity market prices are available. The Revenue Gap analyses show that most (i.e., 63 of 79 units) of these U.S. nuclear power units for which electricity market prices are available) would likely have lost money in 2016, as shown in Figure 4 and Figure 5.

It would take a relatively small amount of additional revenue to return most of the nuclear power units that would have lost money in 2016 to profitable operation. An additional revenue source of about $15/MWh for the units that have a Revenue Gap of less than zero would reduce the number of units with a Revenue Gap of less than zero to 10. This $15/MWh additional revenue amount is less than the ZEC payments approved in New York and Illinois.

Of the 63 units with a Revenue Gap less than zero, 36 are merchant generators, 19 are regulated generators, and 8 are public power generators. The merchant nuclear units face potential early

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[27] In this study, we refer to Gaps (i.e., Revenue Gap, Purchased Power Gap, Total Generation Gap, and LCOE Gap) as the difference between a relevant measure (e.g., Revenue) and nuclear power unit generating costs. A Gap that is less than zero means that generating costs are higher than the relevant measure, while a Gap that is greater than zero means that generating costs are lower than the relevant measure.

[28] Market failure is an economic term that refers to a situation in which the allocation of goods and services is not efficient. For example, market failure for nuclear power is when the private market approach to merchant nuclear power results in early retirement due to financial losses, even though early retirement would result in a loss of public benefits (e.g., zero emissions electricity, grid and system benefits, and economic impacts) that have a value higher than the financial losses experienced by the private owner of the merchant nuclear power plant.

retirement, and the regulated and public power nuclear units would be losing money if they depended on electricity market revenue.[29]

This recent decline in nuclear power plant profitability is not caused by poor nuclear power plant operation. Nuclear power generating costs have been declining since about 2012, as shown in Table 2, and nuclear power plant capacity factors have been high, as shown in Figure 3.

Declining profitability of U.S. nuclear power plants is a result of operation in electricity markets. The electricity markets focus on short-run marginal costs, with no reflection of fixed generating costs or returns on investment for generators.

The U.S. approach to nuclear power requires merchant nuclear power plant owners to rely on revenue in the electricity markets; this approach will likely result in more nuclear power units retiring early to stop additional financial losses to merchant nuclear power plant owners.

The early and permanent retirement of operating nuclear power units will mean that the significant public benefits provided by those nuclear units (e.g., emission-free electricity, reliable baseload capacity, jobs, fuel diversity, etc.) will be lost.

The early retirement of operating nuclear power units is a clear example of market failure. Market failure is an economic concept where the market fails to support operating nuclear power plants and the early retirement of these operating nuclear power plants would significantly decrease the public good.

2. Regulated/Public Power Nuclear Units Provide Value to Owners.

The situation for regulated and public power nuclear plants is different and better than the situation for merchant nuclear power plants.

Purchased Power Gap and Total Generation Gap analyses cover all regulated and public power nuclear units for which relevant information was available. These analyses show that utility owners of most regulated or public power nuclear power units would be worse off if the nuclear power unit was retired early and the owner was required to buy additional purchased power or to generate additional power with existing generation resource, as shown in Figure 6 and Figure 7.

The Purchased Power and Total Generation Gap analyses are not relevant for merchant nuclear units operating in regions with wholesale electricity markets, because the owners of merchant nuclear power units are not required to buy power to replace the power output lost when a nuclear power plant retires early.

The Purchased Power Gap and Total Generation Gap analysis results show that most regulated and public power nuclear units have generating costs that are lower than the cost of purchased

[29] Regulated and public power nuclear units have profitability that is determined by the regulatory process in place for each unit. For the purposes of the Revenue Gap analyses in this study, we made a simple assumption that each regulated or public power nuclear unit for which electricity market prices are available would have the same link between profits and electricity market prices as a merchant nuclear unit.

power and that are lower than the cost of total generation for the utilities that own them. Early retirement of these regulated and public power nuclear units would result in higher costs for the owner. The cost to replace the output of a retired nuclear power unit may be much higher than the cost estimated in this study, because actual costs of purchasing or generating more power to replace a retired nuclear power unit may be much higher than 2016 purchased power and total generation costs with the nuclear power unit in operation.

The results of the Purchased Power Gap and Total Generation Gap analyses are different from the results of the Revenue Gap analysis because utility purchased power and total generation costs reflect total costs (i.e., marginal costs, fixed costs, ongoing capital expenditures, and initial capital investment), while electricity market prices only reflect short-run marginal costs.

3. Existing Nuclear Units Are Cheaper than Building New Baseload Capacity.

Operating existing nuclear power plants results in lower total costs than replacing the nuclear power plant with a new Combined Cycle Gas Turbine (CCGT) power plant, the least expensive baseload replacement option to build and operate today.

At some point, the capacity and energy lost when a nuclear power unit retires early must be replaced. Figure 8 shows that continuing to operate existing nuclear units has lower costs than building a new advanced gas-fired CCGT.

The Levelized Cost of Electricity (LCOE) for the new CCGT power plant includes the total cost of the unit, costs that would be recovered by any new owner, whether merchant or regulated/public power, while the generating costs of the existing nuclear power plants only include cash generating costs.

APPENDIX A – Ownership

The ownership of U.S. nuclear power plants is an issue that may have an impact on the potential for early retirement.

The classification of nuclear power units into merchant or regulated or public power is usually based on how the Owner/Operator participate in the electricity industry.

Nuclear power plants in the U.S. have a mix of units that are 100% owned by a single owner and units that are jointly owned by two or more companies.

When there is a single 100% owner of the nuclear power unit that is also the Operator, classification into merchant, regulated, or public power is relatively clear.

However, several U.S. nuclear power plants have multiple owners and in some cases these owners have a different industry status (e.g., a regulated utility is Operator with minority public power owners).

As discussed below, the decision-making process related to early retirement will likely be made by the Operator and the details of the Participation Agreement in jointly-owned nuclear power plants will define that decision-making process.

For the purposes of this study, we assume that any nuclear generating unit that faces economic issues is at danger of early retirement, regardless of ownership or type (i.e., merchant vs regulated vs public power).

A. Single-Owner Plants

Many U.S. nuclear power plants have a single owner that is also the Operator. For these nuclear power plants, any major economic decision related to the nuclear power plant will be made by the single owner/operator. As discussed later, it is easy to classify these single owner nuclear power plants as merchant, regulated, or public power based on the electricity industry role of the owner.

B. Multiple-Owner Plants

Other nuclear power plants have multiple owners.

Multiple owner nuclear power plants may have a clear government approach that allows (or requires) that co-owner that is designated as the Operator will make economic decisions about the nuclear power plant.

1. Participation Agreements

In each of these plants, there are agreements between the owners (usually called Participation Agreements) that specify how decisions (up to and including early retirement) are made, who makes these decisions, and how the parties split the costs of operation and the power generated. In most instances, the owner with a majority ownership share is the Operator (as defined by the NRC).

2. NRC Antitrust Review

An artifact of the nuclear power industry antitrust issues is that there are many examples where a nuclear generating unit includes smaller public power utilities as co-owners. Until 1997[30], the NRC included an antitrust review in the Part 50 license process. Smaller utilities, including public power utilities, were concerned about getting access to low-cost nuclear electricity, and many intervened in the NRC license process. The typical resolution of these antitrust concerns was a settlement in which the intervenor utilities could take an ownership share of the nuclear generating unit.

The antitrust rules created a situation where the majority owner and operator of a nuclear power plant might be a regulated investor-owned utility, but the smaller co-owners were public power utilities. The overall economic situation of these two types of utilities are similar.

3. Regulated Utility Majority Owner/Operator with Public Power Co-Owners

With a few exceptions, the regulated utility is a majority owner and the Operator of the nuclear units.

Where the regulated utility does not own more than 50% of the nuclear unit, we assume that the Participation Agreement that is in place for the nuclear power plant designates the Operator and defines the decision-making power of the Operator. A major decision like early retirement may require input and agreement from co-owners.

4. Merchant Nuclear Plant Operator with Public Power Co-Owners

When nuclear power plants were divested by the original regulated utility owners, the smaller public power utility co-owners retained ownership in what was a merchant nuclear plant.

The merchant nuclear units with public power co-owners all have the merchant power generator as the majority owner and Operator. The Participation Agreement that is in place for the nuclear power plant defines the decision-making power of the Operator. A major decision like early retirement may require input and agreement from co-owners.

5. Multiple Merchant Generating Company Owners

There are also some merchant nuclear units with ownership by more than one merchant generating company. The Participation Agreement that is in place for the nuclear power plant

[30] The NRC issued a Final Policy Statement on Restructuring and Economic Deregulation of the Electric Utility Industry in 1997 that discussed the end of NRC antitrust review as a part of nuclear power plant licensing.

defines the decision-making power of the Operator. A major decision like early retirement may require input and agreement from co-owners.

6. Co-Owned Nuclear Units with Operator Not Majority Owner

Some nuclear units have an Operator that is not the majority owners. A jointly-owned nuclear power plant where the Operator is not a majority owner may make decisions about major issues such as early retirement in a different manner than single-owner plants or jointly-owned nuclear power plants with a majority owner as Operator.

The Participation Agreement that is in place for the nuclear power plant defines the decision-making power of the Operator. A major decision like early retirement may require input and agreement from co-owners.

7. Special Nuclear Operating Companies

The final category of nuclear units is those with a nuclear operating company that is different from any of the owners. Typically, this involves a Participation Agreement that specifies the governance and cost recovery for the Nuclear Operating Company.

In at least one of these nuclear units, the owners are comprised of a merchant generating company and multiple public power utilities, none of which have a controlling or majority interest.

The Participation Agreement that is in place for the nuclear power plant defines the decision-making power of the Operator. A major decision like early retirement may require input and agreement from co-owners.

APPENDIX B – Merchant, Regulated & Public Power

In discussions of the issues facing nuclear power plants and early retirement, we refer to merchant units, regulated units, and public power units. It is important to understand what these terms mean and how these different types of nuclear power plant ownership models influence the potential for early retirement.

First, we classify a nuclear unit as regulated, public power or merchant based on the electricity industry status of the Operator, even if the ownership is mixed (i.e., as discussed in Appendix A).

This Appendix further defines what these terms mean.

A. Merchant

A merchant power plant depends on revenue from electricity markets and does not have the same revenue support as a regulated or public power plant.

No nuclear power plant has been developed and built as a merchant nuclear plant. However, the electricity reform process in the United States started in about 2000, when almost all nuclear power units in operation today were already completed and in operation.

Some vertically-integrated regulated electricity companies had nuclear power plants as a part of their generation portfolio prior to U.S. electricity industry restructuring and reforms.

The electricity industry reform/restructuring process was implemented in states. Some states required that generation assets (including nuclear power plants) be divested. In other states (e.g., Ohio), the regulated utility was required to create a new unregulated subsidiary that owned the formerly regulated power plants, including nuclear power plants.

Some states (e.g., California and Virginia[31]) allowed regulated utilities to maintain nuclear power plants as regulated assets even while the utilities joined a formal electricity market.

1. Capacity Markets

Some merchant nuclear plants operate in electricity markets that run capacity market auctions, with the capacity markets providing another source of revenue separate from the electricity spot market.

The basic requirement for capacity is driven by NERC capacity requirements. Each retail utility, also referred to as a Load-Serving Entity (LSE), is required to own or control capacity that is equal to the projected peak demand plus a reserve market (e.g., 15%).

31 Original Virginia deregulation legislation intended for generation to be deregulated and for generation to be spun off into a separate corporate entity. However, the Virginia legislature re-regulated generation in 2007, while maintaining membership in PJM, largely because of very large power imports into the state.

LSEs in electricity markets are expected to enter into bilateral arrangements for capacity to meet NERC requirements. The ISO capacity markets also undertake a process to examine the un-met need for capacity by LSEs (e.g., one or more LSEs may not have procured capacity in amounts needed to meet NERC requirements) and to examine the need for locational capacity needed to operate the ISO as a nodal spot market.

LSEs that have not met their NERC capacity requirements will be assigned a cost by the ISO as determined by the ISO capacity auction. The cost of capacity procured to facilitate the operation of the nodal spot market is recovered from all market participants.

If the nuclear power plant clears the capacity auction, it enters into an agreement with the market operator to operate during the period covered by the capacity auction. The revenue from capacity sales is much less than the revenue from sales of electricity into the electricity spot market.

These capacity agreements are like PPAs and may restrict the ability of a nuclear power plant to retire early until after the end of the period covered by the capacity auction. Retiring early would trigger, depending on the details of the capacity contract, penalties.

2. PPAs

U.S. nuclear power plants were all built by a regulated or public power utility. When electricity reform was being implemented, some of these nuclear power plants were sold to new merchant owners. The nuclear plants were typically sold along with a bundled power purchase agreement (PPA). These PPAs had terms that were about 10 years, or to the end of the original 40-year NRC operating license.

These PPAs insulated the merchant nuclear power plant from market prices. In the current low market price outcomes, this situation seems like a better alternative to earning revenue from market sales of electricity and capacity. However, when market prices were higher, some of these PPAs limited the upside for the merchant generation owners.

The PPA might also limit the ability of a nuclear power plant to retire early, as the PPA might require the nuclear power plant to pay damages to the counterparty if it were to cease operation prior to the end of the PPA.

A discussion of several relevant PPAs.

a. Point Beach

The Point Beach facility in Wisconsin, owned and operated by NextEra, signed a PPA[32] in 2006 with Wisconsin Electric Power Co. The contract for Unit 1 runs through 2030, and the contract for Unit 2 runs through 2033. These PPAs have guaranteed the Point Beach facility revenue—

[32] See SEC filing at https://www.sec.gov/Archives/edgar/data/783325/000119312507041253/dex1046b.htm

even as nuclear plants elsewhere are struggling to compete in the current market—and offer the plant some much-needed stability.

b. Kewaunee and Vermont Yankee

As discussed above, like other regulated nuclear power plants that were divested by the original owners, the Kewaunee and Vermont Yankee nuclear power plants were sold with a bundled PPA. These PPAs were scheduled to expire when the nuclear power plant original operating license expired. When the PPAs expired, the merchant nuclear plants were solely dependent on revenue in the electricity market. The financial issues that resulted in the early retirement of Vermont Yankee arose when the original PPA expired or was approaching expiration and the owner of the plant was unable to get a replacement PPA with prices high enough to cover generating costs.

The situation with Kewaunee was a bit more complex. The plant was shut down some 6 months before the PPA expiration, with Dominion purchasing power in the market to meet PPA obligations in the period between plant shutdown and the expiration of the PPA. The PPA prices were structured in a way to reflect the utility's planned costs for each of the agreement years, and the years toward the end of the PPA term reflected the utility's expectation that the plant would shut down in 2013, with correspondingly lower capital costs. Therefore, PPA payments were decreasing each year as the end of PPA approached, and finally reached a point where Dominion decided it was more economic to shut down and buy the power on the open market to complete its commitment to the utility.

c. Duane Arnold

Duane Arnold had a PPA that was to expire in February 2014. NextEra negotiated a PPA extension to 2025 that was approved by the Iowa PUC. According to industry sources, the Duane Arnold plant also reached agreements with suppliers of good and services to reduce generating costs to allow lower PPA prices.

d. Palisades

Palisades nuclear power plant, owned and operated by Entergy, has a PPA with the original owner, Consumers Power, that expires in April 2022. Palisades is a profitable operation for Entergy under the PPA, but Consumers Power has access to power that is much cheaper than the prices in the PPA. It had been expected that Palisades would retire early when the PPA expired.

However, Entergy, consistent with its overall corporate goal of exiting the merchant nuclear power business, negotiated a deal with Consumers Power to terminate the PPA early and to retire the Palisades generating unit early (i.e., in 2018).

A key part of this arrangement is that the savings from early termination of the PPA (i.e., Consumers Power will replace power under the PPA with low-cost power from the regional power markets) will be shared between Entergy and Consumers Power.

B. Regulated

In this context, the regulation refers to the economic regulation done by a state utility regulator. A regulated nuclear power plant is one that is owned or operated by a regulated electric utility company. The key economic issue is that a regulated electricity company that has a nuclear power plant in its portfolio of power plants will recover the costs of operating that nuclear power plant in customer rates. Also, approved/prudent capital expenditures for that regulated nuclear power plant will be placed into rate base and earn a return on and of the investment (again, recovered in customer rates).

So long as the state utility regulator allows the costs and returns for a regulated nuclear power plant to be recovered in customer rates, the utility company owning the regulated nuclear power plant has sufficient and certain revenue.

Most regulated nuclear power plants are in states that did not implement electricity reform and did not implement wholesale electricity markets.

Because the approach to electricity industry reform was done on a state-by-state basis, some states entered an electricity market but allowed generation assets (including nuclear power plants) to remain regulated assets of the vertically-integrated regulated utility.

These regulated power plants typically sell all output to the market operator, with the owning utility buying all power needed from the market operator. Aside from locational and timing differences, the owner may be making or losing money through this arrangement and the gains or losses are part of the total costs recovered in electricity rates.

The level of market prices at the generator node for these nuclear power plants can be compared to estimated cash generating costs, in a manner like a merchant nuclear plant. However, the regulated status of these nuclear power plants may mean that the financial pressure to retire early is quite different from the financial pressure faced by a merchant nuclear plant.

C. Public Power

The U.S. has a diverse group of public power and government utilities. These include municipal utilities (i.e., owned by a city or county), electric cooperatives, G&T cooperatives, Federal Power Agencies, and Public Power Districts.

These utilities have some common features. They are typically non-profit, non-taxed entities that recover costs from customers or members.

Like a regulated nuclear power plant, a public power nuclear power plant has the capability to recover generating costs and capital investments from customers.

APPENDIX C – Information Sources

This Appendix provides a summary-level discussion of the information used in this Gap Analysis. The Gap Analysis model[33] has the actual information used and detailed information on the sources of that information.

The information used to develop Gap analyses in this study is from multiple sources.

The primary source is public information that was collected and processed by NECG.

DOE provided NECG with nuclear power plant cost, revenue, and other information from Bloomberg New Energy Finance (BNEF), that may have been used by BNEF in the 2016 "Reactors in the Red" study and in the 2017 BNEF report on nuclear power plant profitability. Where feasible, NECG obtained information for this study from independent sources, but some BNEF information was used.

A. Generating Costs

The generating cost assumptions are discussed above. In addition to the NEI reports discussed in Section II.B, NECG undertook analyses to develop the assumptions and to verify that the U.S. operating fleet average in the NECG Gap analysis model for 2016 was consistent with the NEI information.

The entire study team reviewed the resulting generating cost assumptions presented in Table 1.

B. Market Revenue Gap

The information used to estimate a Market Revenue Gap includes electricity market prices, unit electricity production level/output, and capacity revenue.

1. Electricity Market Prices

Daily average electricity day-ahead market prices were used for units for which such price information is available.

Most of these electricity market prices were obtained from RTO/ISO sources by NECG.

For some units and some markets, daily electricity market prices from BNEF were used.

2. Unit Electricity Production

The daily operating output (in MWh) for each unit was estimated.

[33] Certain details of this model have been omitted to avoid providing unit-specific information.

The 2016 daily electricity output profile from BNEF was used, with minor adjustments to the BNEF daily amounts made to ensure that the annual total output matched the amounts reported by EIA.

3. Capacity Revenue

Capacity market revenue is used for all units that participate in capacity markets.

Most capacity prices were obtained from RTO/ISO sources, where this information was available to the public.

Unless the RTO/ISO indicated a different amount of capacity, the EIA Summer Capacity amount for each unit was used to estimate capacity market revenue.

The BNEF information included information on capacity market prices and an assessment as to which nuclear units had cleared the capacity auctions.

In some electricity markets, there is little public information about which units clear the capacity auctions, how much capacity from the units cleared, and other information. We assumed that the units cleared the auction unless there was public information that they did not.

4. ZEC Revenue

ZEC Revenue was approved for selected nuclear units in New York and Illinois.

NECG reviewed multiple state documents and regulatory filings. As discussed elsewhere in this report, no ZEC revenue is reflected in these Gap analyses because ZEC payments in both states do not begin until after the end of 2016.

C. Purchased Power and Total Generation Gap

The information for Purchased Power and Total Generation was obtained for regulated utility owners and public power utility owners.

1. Regulated Utilities

The primary source for purchased power quantity and cost was the FERC Form 1 filings of the utility owner/Operator of each nuclear unit.

To obtain information on the costs to purchase power and the cost to generate power from sources other than nuclear power, 2016 FERC FORM 1 information was obtained for regulated utilities that own and operate nuclear power plants. We note that merchant nuclear plant owners are not required to file FORM 1 information, so that similar information is not available for these nuclear power plants.

FORM 1 information was used to develop the cost of purchased power and the cost of generation from other sources than nuclear and purchased power.

As discussed in APPENDIX A – Ownership, there is a wide range of ownership approaches in the U.S.

FORM 1 information for utilities that were 100% owners of a nuclear power plant should provide the best information about the Purchased Power and Total Generation costs for that utility.

FORM 1 information for utilities that are a co-owner and Operator of a nuclear power plant will only provide information relevant to the share of the nuclear power plant owned by the utility. This study used the information for the utility that was the Operator for most co-owned units. A more detailed analysis might consider information for the other co-owners.

For a few nuclear units, the Purchased Power and Total Generation cost for multiple co-owners was averaged (e.g. Palo Verde, with multiple regulated utility co-owners with relatively small ownership shares).

2. Public Power Utilities

The information on Purchased Power and Total Generation cost for public power utilities was taken from financial and other public reports. Some of the public power utilities have a fiscal year that covers a period different from the calendar year covered in report. For this study, FY 2016 information was used without adjustment.

3. LCOE Gap

To estimate the LCOE Gap, the 2016 generating cost of each unit in $/MWh was compared to the LCOE of the lowest-cost new baseload generation.

The LCOE benchmark amount was the EIA LCOE estimate for a new Advanced CCGT. This LCOE estimate includes a range of assumptions about capital cost, operating costs, and fuel costs. The EIA estimate includes a forecast of natural gas costs.

Idaho National Laboratory