SMR START

To a Clean Energy Future

The Economics of Small Modular Reactors

September 14, 2017

Executive Summary

This report evaluates the market opportunities, commercialization timeframe, and cost competitiveness of light water small modular reactors (SMRs) in the U.S. The analysis concludes that SMRs are commercially viable and needed in the marketplace by the mid-2020s.

The market needs SMRs: SMRs will be needed as large retirements of baseload generation and an increase in intermittent renewables have negative impacts on the grid. SMRs can better match demand growth at lower up front capital costs, provide flexibility to integrate with renewables and repower retired fossil plant sites, and can generate highly resilient baseload power. SMRs will be even more important if the demand for carbon-free generation continues to grow.

SMR capacity additions in the U.S. are conservatively expected to exceed 6 gigawatts-electric (GWe), while more aggressive targets could see more than 15 GWe, by 2035.

Progress continues to commercialize SMRs: Private companies continue to invest in SMRs – more than $1 billion so far – with the pace of development accelerated by support from the Department of Energy. The first SMR licensing applications – by NuScale Power and the Tennessee Valley Authority – have been accepted for review by the U.S. NRC, with the first approval expected in the early-2020s.

Designs are mature enough today for potential owners to evaluate the benefits and risks to move forward with projects. Utah Associated Municipal Power System is planning to locate its first SMR plant at the Idaho National Laboratory as part of the Carbon Free Power Project. TVA is investigating the deployment of an SMR at their Clinch River site to provide highly resilient power to national security facilities. Several companies are interested in following the first movers and deploying SMRs by around 2030.

SMRs are cost-competitive: The analysis of various policy and market uncertainties shows that there are many conditions and scenarios that could occur that would result in SMRs being comparable with the costs of a natural gas combined cycle plant.

The first SMRs are expected to be within the range of natural gas plants costs assuming appropriate private-public partnerships to help reduce technology risks and keep first-of-a-kind costs low. The partnerships incentivize the initial SMR customers by addressing typical first-of-a-kind challenges that create unique regulatory, technology and financial risks that translate into higher costs that most companies are unable or unwilling to accept. The partnerships reduce the barriers to technology adoption and allow the learning curve to bring down the cost of future SMRs.

By 2030, after the first few plants begin operation, SMRs would be cost-competitive without further private-public partnerships. For most scenarios, the costs of SMRs are within the range of natural gas plants, such that a utility could choose an SMR based on factors such as long-term price stability and fuel diversity.

The tremendous potential for SMRs justifies further investment in SMRs and private-public partnerships to support first movers. Successful commercialization of SMRs – a critical addition to the nation's future infrastructure – is essential to a resilient low-carbon energy system, growing jobs and the economy, and to strengthening national security.

Light-water small modular reactors (SMRs) are one of the most promising new nuclear technologies to emerge in decades. There is growing customer interest in SMRs to meet market needs for reliable, clean and flexible baseload electricity. To be sure, there are challenges facing SMR commercialization, namely an environment where electricity demand growth is slow or in some cases negative, where markets do not value all of the generation attributes of nuclear energy, and where new generation capacity is dominated by subsidized renewables and low natural gas prices. However, a few pioneering companies see specific market opportunities and recognize the tremendous potential for SMRs inside and outside of the United States.

For decades, the U.S. has operated a fleet of nuclear reactors, which today generates approximately 20 percent of the nation's electricity – approximately two-thirds of the nation's carbon-free electricity – and provides a uniquely valuable set of attributes. Nuclear power plants produce large quantities of electricity around the clock. They operate whether or not the wind is blowing and the sun is shining and they do not rely on a continuous supply of fuel arriving by truck, barge, rail or pipeline. Nuclear plants provide price stability and without nuclear generation, retail rates would be about 6 percent higher on average.[1] They provide "reactive power" – essential to controlling voltage and frequency and operating the grid. Nuclear power plants have portfolio value, contributing to the fuel and technology diversity that is one of the bedrock characteristics of a reliable, resilient electric sector. Finally, nuclear power plants provide clean air compliance value. In any system that limits emissions of the so-called "criteria" pollutants or carbon dioxide, the emissions avoided by nuclear energy reduce the compliance burden that would otherwise fall on emitting generating capacity. Other sources of electricity have some of these attributes. None of the other sources has them all.

SMRs, together with large light-water and non-light-water reactors, are part of the all-of-the-above nuclear energy portfolio needed to meet national goals on energy independence, economic growth, national security and environmental protection. Of these nuclear technologies, SMRs are uniquely positioned to provide a large share of new nuclear generation capacity added over the next several decades. SMRs are the most mature advanced reactor technology with relatively low technology and licensing risk, and are deployable in the near-term. Although large LWRs are available today, the trend in the market is toward a preference for small capacity additions at lower up front capital costs. With reasonable government policies, SMRs are competitive with other low cost electricity generation sources and could begin operation in the U.S. in the mid-2020s.

This study looks at the economics of SMR deployment in the U.S. Global demand for SMRs is expected to far exceed the demand in the U.S. Although this report may serve to inform the prospects for cost competitiveness in other countries, it is not intended for this purpose as many country specific factors, such as financing, cost of natural gas and policies on carbon, would need to be considered.

[1] Source: Nuclear Energy Institutes *Nuclear by the Numbers*, February 2017

According to the Energy Information Administration's (EIA's) 2017 Annual Energy Outlook (AEO) reference case, U.S. new electricity generating capacity additions are expected to be approximately 119 GWe between 2025 and 2035 (roughly the first 10 years during which new SMRs would begin operations). Using a conservative assumption of SMRs capturing just 5 percent of new capacity additions, the demand for SMR plants in the U.S. would exceed 6 gigawatts by 2035. And the market potential for SMRs with an aggressive target and more favorable market conditions could be 15 GWe or more by 2035. Various factors, including the policies toward new nuclear plants, market compensation for attributes that are not appropriately accounted for today, and the ability to achieve lower costs for SMRs, will influence the rate of SMR deployment.

Slightly more than half of this new capacity is needed to meet growth in electricity demand, with the remainder needed to replace retiring generation capacity. EIA expects that more than half of the capacity additions will come from renewables and most of the rest will come from combined cycle natural gas. At the same time, most of the retirements will come from coal and nuclear plants. This trend would result in a dramatic change to the generation mix – decreasing baseload generation to 31% (down from 40% today) and increasing non-dispatchable intermittent source to 23% (up from 15% today). These changes will have negative impacts on the reliability and resiliency of the electricity supply.

Under current policies, which is reflected in the EIA reference case, it is unlikely that the U.S. will see additions of new nuclear generating capacity that reach over 35 GWe needed by 2035 in order to maintain today's 20 percent share of nuclear energy in the U.S. electricity mix. In this time period, the tremendous benefits provided by nuclear power plants will be greatly diminished. This does not include replacement of premature nuclear retirements due to market shortcomings. If market dynamics are not changed, such that they value and allow monetization of attributes other than short term prices – reliability, resiliency, carbon avoidance and long-term price stability – even more new nuclear generation capacity will be needed to maintain a healthy mix of nuclear generating capacity. And, if the markets maintain the status quo, it will be even more difficult for industry to build that new nuclear generation.

Deployment of SMRs would help maintain the beneficial supply of nuclear energy and baseload generation. The SMR value proposition is particularly strong for the following applications:

Matching Demand Growth and Affordability – Modular plants allow generating companies to better match construction of new capacity with electricity load growth – particularly important in parts of the country where load growth may have slowed for decades and in areas where the electricity grid is not developed enough to support larger nuclear power plants. Capital investments also can be staged as modules are constructed. This could be particularly important for smaller companies – rural electric cooperatives or municipal agencies, for example – that cannot afford the $6 billion to $7 billion up-front costs associated with a 1,000-megawatt reactor.

Repower Retired Fossil Plant Sites – SMRs can repower retired fossil fuel sites, even those that are close to population centers. Safety advances in SMRs are expected to provide public health and safety assurance without the need for large emergency planning zones. Retirement of coal generation alone represents approximately 27 GWe of the total capacity additions from 2025 to 2035. Replacement of retired coal plants with SMRs is attractive in that this helps to preserve the important baseload and grid stabilizing benefits, and it preserves local jobs potentially allowing former coal plant workers to be retrained for higher wage positions at the SMR facility.

Integration with Renewables – SMRs offer flexible baseload capacity allowing these plants to integrate well with intermittent renewables. SMRs are including the capability to load follow early in the design, and when these reactors combine the production of industrial heat into the hybrid energy system, they are able to alternate between heat and electricity to assure a constant output of energy and stream of revenue. The integration of SMRs with renewables will result in a more reliable and resilient supply of electricity at lower costs to the end user. One of the phenomena of higher penetration of intermittent renewables is the tendency toward very low or negative electricity prices during periods when the sun and wind are available, and higher price spikes when they are not. This situation is especially acute in the state of California where excess solar energy has created the “duck curve” during mid-day periods. This dichotomy of pricing during the day is also attributable to the inability of other generating sources to quickly respond to rapid additions or removal of electricity supply from intermittent renewables. SMRs help solve this problem by establishing capabilities to rapidly change power output, which in turn helps to levelize the price of electricity over the day, and ultimately lower the overall cost to the consumers. The integration of SMRs and intermittent renewables is a zero-carbon solution to U.S. electricity generation and without the need to add expensive battery storage options, which are poor at addressing the limitations of the intermittency of renewables in that they only move electricity over short time periods, they are expensive, and in the end they do not generate their own electricity.

Resilient and Highly-Reliable Micro-Grids – Some SMRs are being designed with an electric power system that is entirely self-sufficient, in that all of the power sources required to perform safety functions, startup, shutdown and operations will be located on-site, which provides black start capability. Self-sufficient designs will have independence from the grid, by not relying on power from any offsite source, and may not even be connected to the electric grid at all. These designs would be ideal to provide secure, resilient and highly reliable power to DOE and DOD facilities performing national security and mission critical activities. These designs would also be ideal for remote locations and other areas with small or no electric power grids.

The path to the first commercial operation of an SMR in the mid-2020s depends upon steady progress in developing the design, supply chain and owners' projects. SMR plants could range from a few dozen to over 1,000 megawatts-electric depending on the actual size and number of modules deployed, with the majority of plants expected to produce between 160 to 600 megawatts-electric.[2] The following table depicts U.S. SMR designs from SMR Start members.

Table 1 –U.S. SMR Designs

Companies	**Design**	**Standard Plant Capacity[3]**
Bechtel and BWXT	Generation mPower	390 MWe (2 modules x 195 MWe)
GE Hitachi Nuclear Energy	Very Simple Boiling Water Reactor	300 MWe (1 module)
Holtec SMR LLC	SMR-160	160 MWe (1 module)
NuScale and Fluor	NuScale Power Module	600 MWe (12 modules x 50 MWe)

NuScale Power has had the first-ever SMR Design Certification Application accepted for review by the U.S. nuclear regulator in March 2017 and expects to have its design ready for deployment by the early 2020s to meet the needs of the U.S. first mover projects.

In addition to a market need and a cost competitive product, successful commercialization depends upon a critical mass of customer commitment and the existence of government policies to support the first movers. As in the development of any new technology, there is reluctance in the market to be the first customer due to the first-of-a-kind risks inherent in these new technology projects. Incentives are needed for early adopters to address the new technology risks and pave the way for broader adoption, and this is also true for SMRs.

The first mover projects in the U.S. are being led by UAMPS (Utah Associated Municipal Power System) and TVA (Tennessee Valley Authority). UAMPS, which is partnered with NuScale Power as the technology provider and Energy Northwest as the operator, plans to locate its first SMR plant at the Idaho National Laboratory as part of their Carbon Free Power Project. TVA's early site permit application for a generic SMR– representative of the available designs – located at their Clinch River Site was accepted for review by the U.S. Nuclear Regulatory Commission in December 2016.

There are many more potential customers that are interested in SMRs once the technology risk has been addressed by the first movers, although most have not revealed their interest publicly. SMRs are attractive to utilities that could previously never consider owning a nuclear power plant, such as municipal utilities, in that they are more affordable – with smaller up front capital costs – and have capacities that

[2] SMRs are defined as nuclear power plants that contain one or more reactor modules that produce less than 300 megawatts-electric per module, and make greater use of factory construction.

[3] SMR plants can scale their capacities by deploying fewer or more than the standard number of modules on a given site.

are more in-line with the market need. It is estimated that current U.S. customer interest in SMRs, including the first movers, represents five SMR plants in operation by 2030. This equals a total of 2 GWe of generating capacity (based on a nominal 400 MWe per SMR facility). It is expected that this critical mass, along with fair markets and competitive prices for follow-on SMR plants, will achieve a breakthrough for the technology leading to broad adoption.

In order to achieve 6 GWe of new SMR capacity by 2035, an additional 10 SMR plants at 400 MWe each would be needed. This equates to an average of two SMR plants per year beginning commercial operation in the five years between 2031 and 2035. Although these SMR plants could be constructed in as little as three years, it typically takes 10 years from the time a company begins an SMR project until the plant begins commercial operations, including the three to five years it takes to gain regulatory approvals before construction can begin. Therefore, the policies necessary to reduce the risks of SMR deployment must be in place by 2018 in order to address the new technology risks and generate sufficient industry interest in deploying SMRs. Figure 1 depicts the major project, licensing and policy milestones to deployment of the first SMR and establishing the foundation for companies to pursue deployment of additional SMRs. Figure 2 depicts the projection of SMR generation capacity through 2035 for both the reference and aggressive deployment targets, and overlaid with existing nuclear generation capacity and nuclear capacity needed to retain a 20% share of generation.

Figure 1 – SMR First Mover Commercialization Timeline

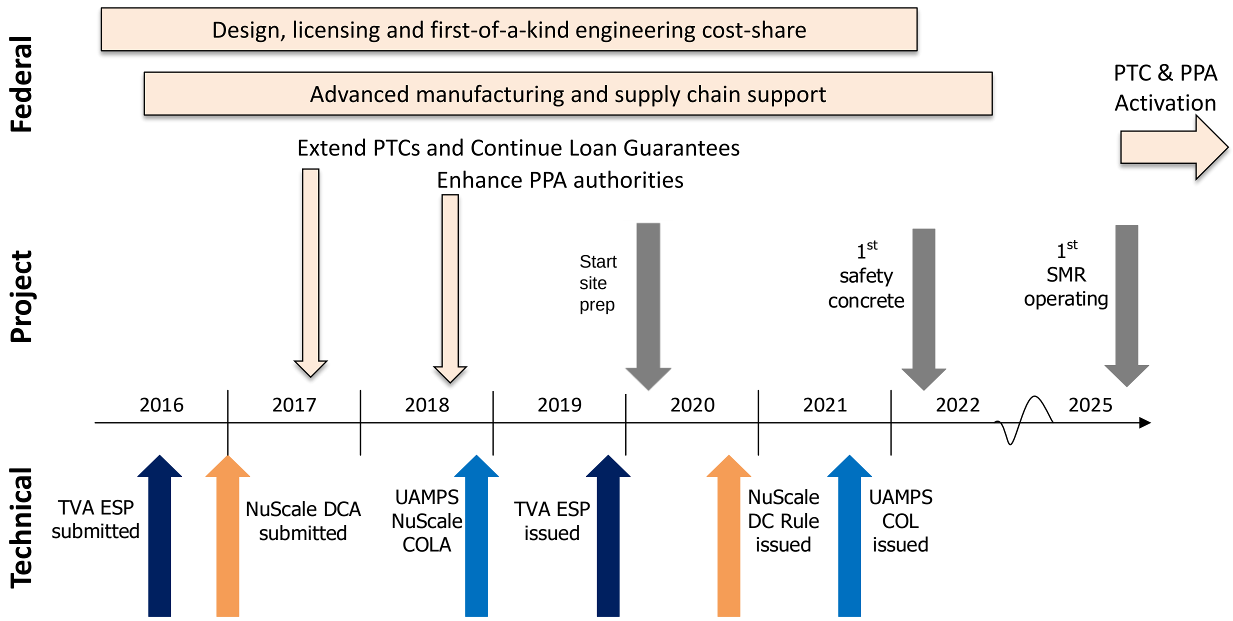
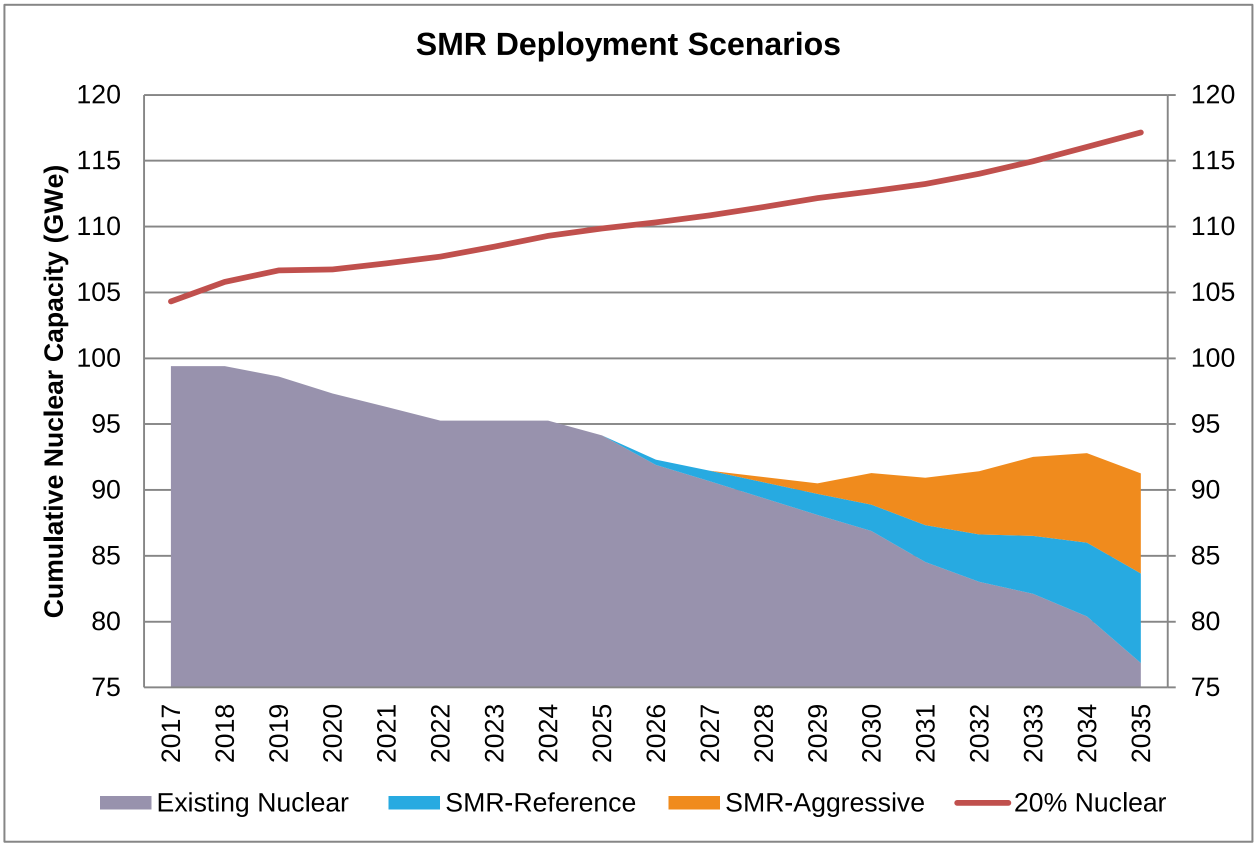


Figure 2 – Projection of SMR Deployments through 2035



Traditionally, nuclear developers have taken to building ever larger designs in an attempt to overcome high up front capital costs through economies of size. SMRs take advantage of the benefits of economies of multiples and simplicity to counterbalance the diseconomies of smaller sizes. Repetition that reduces costs through applying a learning curve is one benefit. SMRs also allow greater factory construction to improve the quality and costs while reducing construction congestion at the site. Simplicity also allows lower costs by requiring fewer components overall.

The following cost analysis was performed using a proprietary model based upon a nominal 400 MWe SMR plant – consisting of two 200 MWe reactors – and a 550 MWe natural gas combined cycle (NGCC) plant.

Overcoming First-of-a-Kind Challenges

Typical first-of-a-kind challenges create unique regulatory, technology and financial risks that most companies are unable or unwilling to accept. These risks translate into higher costs for the first SMRs that exceed other lower cost generation sources, and create a fundamental barrier to technology adoption. A classic challenge exists in which companies are unwilling to construct SMR plants because the first ones cost too much, and the costs of SMR plants cannot be reduced to the point that meets market demand because companies will not construct the first facilities. It is common for government to help bridge this gap for capital intensive long-timeframe technologies like SMRs.

A comparison of the costs of first mover SMR plants without any private-public partnerships in Table 2 shows that SMRs would not be the lowest levelized cost of electricity (LCOE) for investor owned utilities or for municipal utilities. These first-of-a-kind plants have technology and regulatory risks not associated with more established generation sources like natural gas. These factors make it difficult for owners to choose an SMR, even if it would be the best technological fit.

Table 2: Comparison of Costs for First SMRs without Partnerships and Natural Gas Plants in 2026

	Investor Owned Utility (LCOE)	Municipal Utility (LCOE)
First SMR	$104/MWh	$78/MWh
NGCC	$66/MWh	$57/MWh

Utilities face a financial challenge when considering potential first deployments of SMRs. The SMR Start *Policy Statement on U.S. Public-Private Partnerships for Small Modular Reactors* identifies a combination of private-public partnerships that would encourage customers of the first SMRs. Some of these policy tools are better implemented at the Federal level and others at the State level. Federal policies include Production Tax Credits (PTCs), Loan Guarantees (LG), power purchase agreements for high resiliency for federal facilities (PPAr), and direct investment in facilities. State Incentives include Advanced Cost Recovery (ACR) which is also known as Construction Work in Progress, and tax incentives for facilities and manufacturing, such as sales and use tax exemptions, property tax abatements, and investment tax credits. These policies were evaluated to determine their impact on deployment of the first SMRs.

Attachment B details the values of these private-public partnerships on the LCOE for both investor owned utilities and municipal utilities.

Figures 2 through 4 show examples of how the private-public partnerships may be used by utilities with differing constraints – actual projects will differ based on applicable conditions. The investor owned utility example utilizes PTCs, LGs, ACR and tax incentives. The municipal utility utilizes PTC, LG and tax incentives, but is assumed to not be able to take advantage of ACR and PPAr. The Federal utility utilizes PTC and PPAr, but is assumed to not be able to take advantage of LG and ACR due to their already low cost of borrowing or tax incentives due to their ownership.

Figure 2: Example of Investor Owned Utility Evaluation of SMR with Private-Public Partnerships

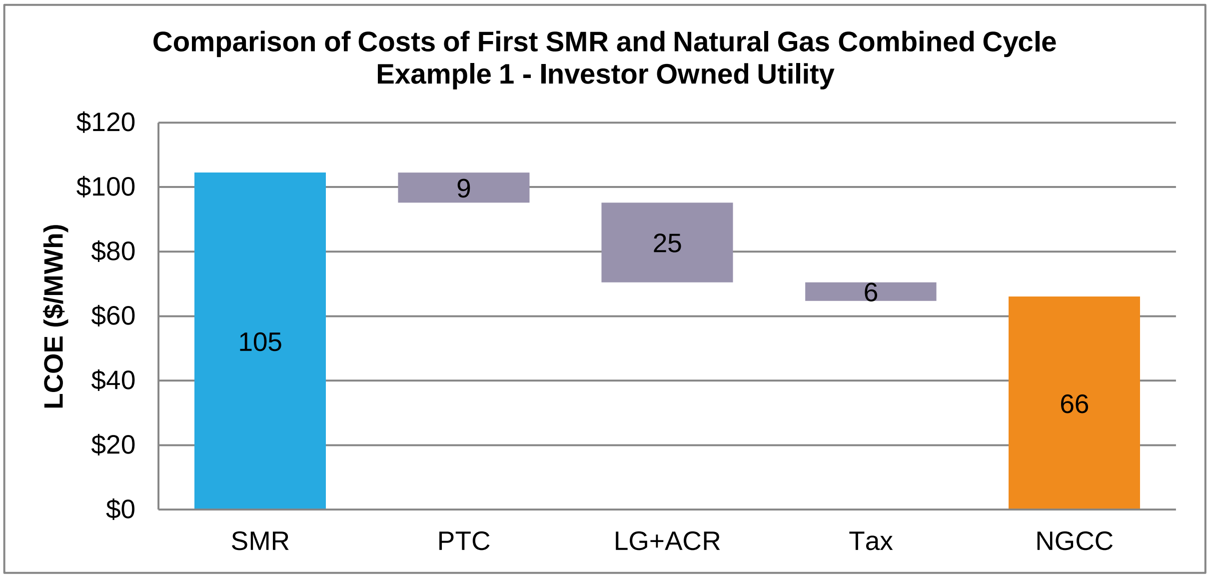


Figure 3: Example of Municipal Utility Evaluation of SMR with Private-Public Partnerships

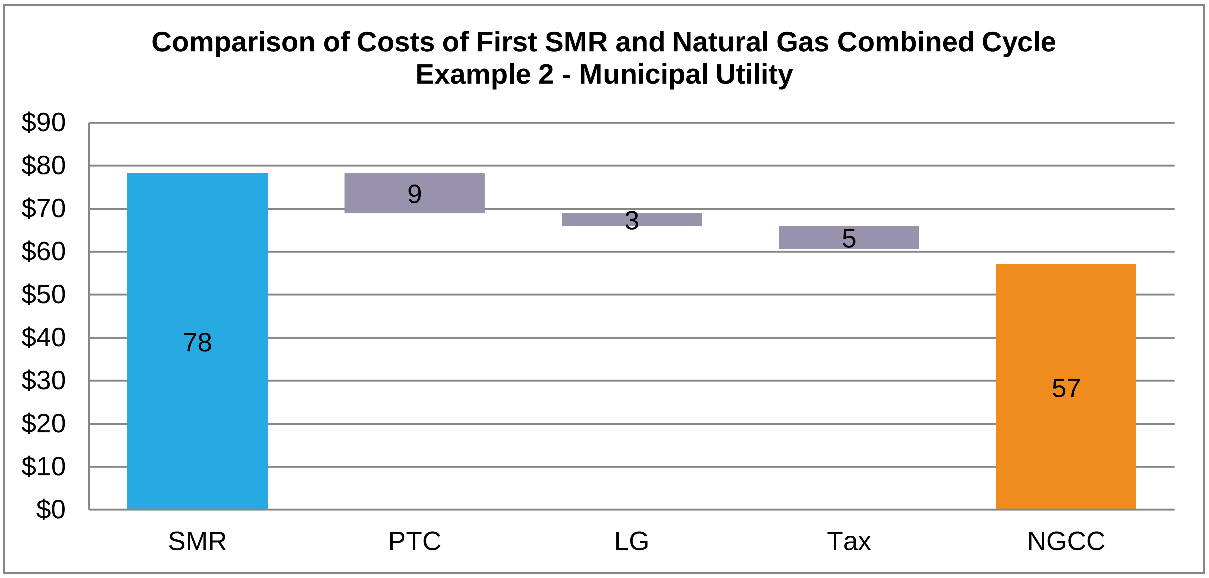
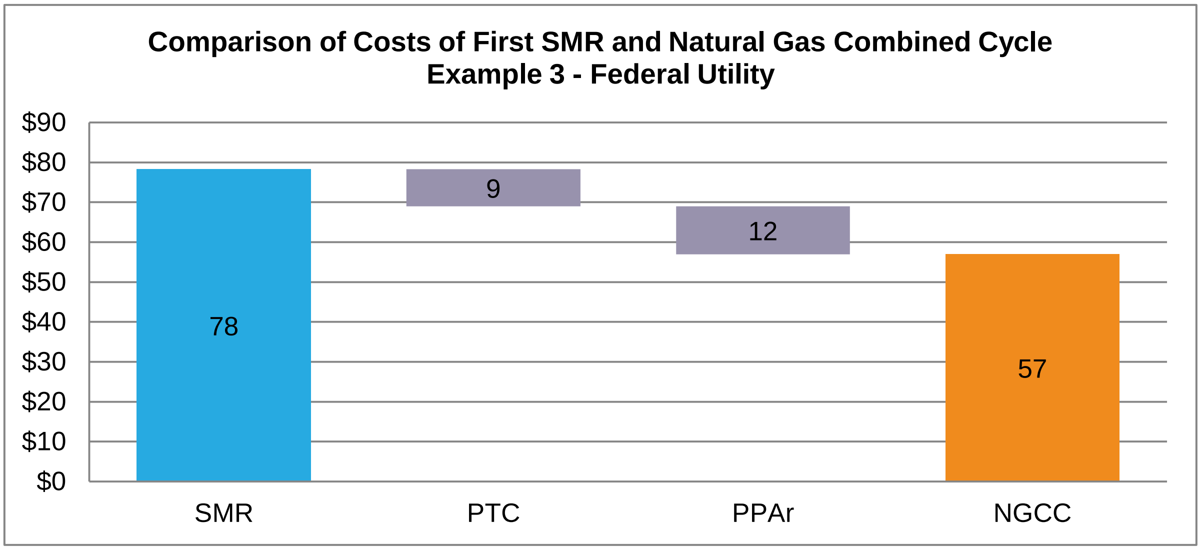


Figure 4: Example of Federal Utility Evaluation of SMR with Private-Public Partnerships



The results show that, with a combination of policy tools available, the costs for the first SMR plants will be comparable to the costs for the current lowest cost option of NGCC. Specifically, Federal production tax credits, loan guarantees and power purchase agreements for resiliency, and State advanced cost recovery and tax incentives are all needed to accomplish the goals of deploying the first SMRs. Additionally, Federal support for finalizing the first-of-a-kind engineering and manufacturing is needed to keep costs low and reduce technology risk.

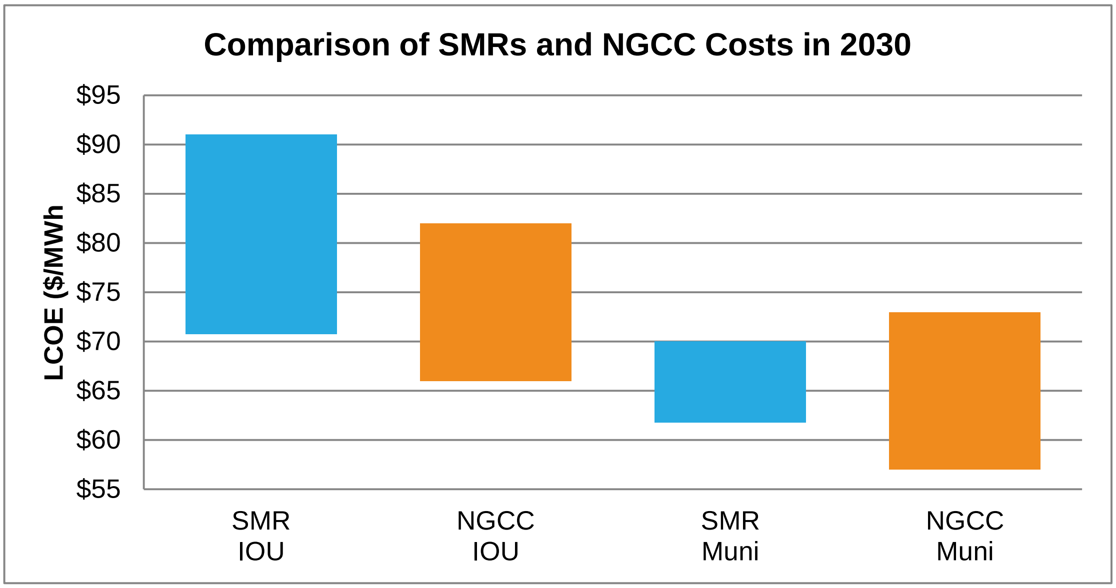
Long Term Cost Competitiveness

Starting around 2030, after lessons learned through deploying the first few facilities are incorporated, SMRs can be cost competitive without private-public partnerships. This occurs due to applying a learning curve that achieves cost reductions – a well-established phenomenon where repetition leads to improvements in productivity as a result of the experience gained.

The costs of an SMR and an NGCC that would begin operation in 2030 are reflected as ranges of LCOE due to the uncertainty of future conditions. Uncertainties that affect the future costs of SMRs include a longer operating lifetime (60 years instead of 40 year), material escalation, and opportunities to further reduce the up-front capital costs by achieving higher rates of learning and incorporating advanced manufacturing and construction technologies. Uncertainties that affect the future costs of NGCC include future natural gas prices and policies or market dynamics that value nuclear energy's attributes such as resiliency, reliability and zero carbon emissions.

Figure 5 presents the range of costs expected in 2030 for an SMR and a natural gas plant. For most scenarios, the costs of SMRs are within the range of natural gas plants, such that a utility could choose an SMR based on qualitative factors such as long-term price stability and fuel diversity. Although there are some scenarios that place SMRs at costs higher that NGCC, there are also many scenarios where SMRs would cost significantly less. Therefore, SMRs are a valuable option for utilities in the future.

Figure 5: Range of Costs for SMR and Natural Gas Plant in 2030s



Production tax credits, power purchase agreements for reliability and tax credits evaluated for the first-of-a-kind SMRs are not included in these Figure 5 estimates, as SMRs should be competitive without further government support. A nominal carbon cost of $9/MWh was included in the NGCC LCOE uncertainty.

When deciding on a generation technology, utilities consider a variety of other factors not considered in this analysis. Table 3 provides a comparison of some of these other factors based on 1,000 MW of capacity. Note that these are based on capacity and not amount of electricity generated. The comparative benefits of nuclear are even more evident when adjusted for capacity factors. Also note that values for nuclear are based on data from operating nuclear plants, and SMRs are expected to have higher capacity factors with lower usage of land and water. Local community opinions are also a factor, and, according to a 2015 survey by the Nuclear Energy Institute, current operating nuclear plants enjoy an 83% local community favorability rating in the U.S.

Table 3: Additional Factors Considered in Selecting Generation Technology (per 1,000 MWe)

	Nuclear SMR	**NGCC**	**Wind**	**Solar**
Capacity factor (%)	> 92.1	56	41.2	26.7
Land requirements (sq. mile)	< 0.5	-	260 - 360	45 - 75
Jobs during operation	500	50	50	-
Plant life (years)	60 to 80	40 to 50	20 to 25	20 to 30

Successful commercialization of U.S. SMR technology is important to the nation and depends upon private-public partnerships. The benefits are the creation of a critical piece of the nation's future infrastructure that strengthens national security, and fuels jobs and economic growth, in addition to previously described benefits of a resilient affordable low-carbon energy system.

National security

The U.S. has historically been a leader in nuclear technology driving exports of reactors around the world, leading to strong domestic job creation and close relationships with host countries. Sadly, U.S. policies regarding nuclear energy over the past few decades have led to an erosion of U.S. nuclear leadership and commercial competitiveness. Today China and Russia are supplying 65% of the reactors planned or under construction around the world, compared to 7% by the U.S.

Commercializing SMRs would provide the U.S. with the technology and credibility to begin increasing the supply of new plants around the world. Other countries are already seeking out U.S. SMR technology, which represents a golden opportunity to improve U.S. leadership in nuclear energy and geopolitical influence.

Economic growth

Construction and operation of a 400 megawatt SMR plant with multiple reactors is estimated to employ about 600 manufacturing and construction workers for about 4 years and about 200 permanent positions for the 60+ years the SMR operates. The data shows that each permanent position creates a multiplier effect resulting in 1.66 additional jobs in the local community and 2.36 additional jobs in the rest of the state. Nuclear jobs pay 36 percent more than average salaries in the local area.

Based upon experience with a 1,000 MWe nuclear facility, a 400 MWe SMR plant is expected to generate over $377M in direct and indirect economic output annually. This includes over $181M in the plant's electricity sales and induced spending at the local, state and national levels of $7M, $32M, and $157M, respectively. The SMR plant is expected to pay about $6M in state and local taxes and $27M in federal taxes annually.

Deployment of the first five SMRs could create up to 1,000 permanent jobs and $280M in local, state and federal taxes per year by 2030. By 2035, 6 GWe of SMRs in operation could support 3,000 permanent jobs and $840M in local, state and federal taxes per year. At a more aggressive target of 15 GWe from SMRs, this increases to 7,500 permanent jobs and $2.1B in local, state and federal taxes per year. This does not include manufacturing and construction jobs which could reach 4,800 workers in the mid-2030s, assuming eight SMRs are under construction simultaneously.

The UK National Nuclear Laboratory estimates there is a global market potential for SMRs of about 65 GWe to 85 GWe by 2035. Assuming the U.S. captures just one-third of the global market – more than 28 GWe – SMRs would create (or sustain) tens of thousands of high-paying American jobs in addition to generating billions of dollars in domestic economic activity and tax revenues.

	First of a Kind SMR	NOAK SMR	NGCC
Facility Size	400 MWe (200MWe x 2 units)		550 MWe
Construction Time	42 months (including 6 months for start-up)		33 months
Deployment Year	2026	2030	2026
Overnight Capital Cost	\$5,150/kWe	\$4,600/kWe	\$1,210/kWe
O&M Costs (2017\$)	Fixed O&M: \$135/kW-yr Variable O&M: \$3/MWh Fuel: \$8.5/MWh (includes costs of used fuel disposal at \$1/MWh)		Fixed O&M: \$27/kW-yr Variable O&M: \$4/MWh Fuel: \$3.75/Mbtu (equals \$24.7/MWh)

	IOU	Muni
Equity Share	45%	N/A
Equity Return	10.5%	N/A
Debt Rate	5.5%	4.5%
Discount Rate	8%	

Private-Public Partnerships for First of a Kind Deployment

This analysis evaluates the value of the following private-public partnerships to address first-of-a-kind costs to incentive utilities to deploy the first SMRs.

Production Tax Credit (PTC): The PTC in this analysis is modeled based upon the PTC for renewables that has been effective in promoting those new technologies for the past couple of decades. This methodology was used instead of the existing nuclear PTC from the Energy Policy Act of 2005 so that the value would reflect escalation that has occurred since the original Act was passed. The PTC is assumed to be available to stimulate SMR deployment beyond 2020, the current expiration date of the existing program. The PTC is also assumed to be transferable from public entities to non-public project participants. The PTC is modeled as an energy credit of \$24/MWh for 10 years escalated for inflation, which equals \$9/MWh in the LCOE reduction. It is noted that the current nuclear production credit of \$18/MWh for 8 years would be worth \$6/MWh in LCOE reduction.

Loan Guarantee (LG): The LG modeled in this analysis is based upon the current DOE Loan Guarantee program. It is assumed that the utility with a loan guarantee finances the project with 80% debt and that the LG reduces the interest on the loans to 4.3% for an IOU and 3.9% of a Muni. It is also assumed that the utility pays a 0.5% fee on the LG.

Advanced Cost Recovery (ACR): The ACR (also known as Construction Work in Progress – CWIP) modeled in this analysis is based upon the authorities granted in Florida, Georgia and South Carolina. The ACR is modeled as recovery of 100% of the financing charges as they are incurred.

Power Purchase Agreements for Resiliency (PPAr): The PPAr modeled in this analysis is a broad contractual vehicle between the SMR owner and a Federal entity (e.g., DOE) being served products and services. Under this PPA, the Federal entity provides compensation to the SMR project annually, an amount sufficient to compensate for the value of those products and services (e.g., very high reliability of 99.9999%). SMRs can efficiently provide these benefits, in comparison to resiliency in the form of diesel generators, fuel oil and maintenance for dozens of MWe of backup power would be expensive and not carbon-free. The PPAr is modeled as a capacity credit of $60M per year for 40 years.

Direct Investment: It is conceivable that the Federal government may wish to directly support the engineering, procurement and construction of one or more of the first SMRs. This program would directly address the near-term aspects of technology uncertainty in deploying the SMR, and could be an attractive value proposition for the government and first mover customer. This analysis models a direct investment at $350M in the SMR plant as a 'buy down' of the overnight capital cost to $4,275/kWe.

While the values of other private-public partnerships are not calculated in this report, they are included in the assumptions for SMR costs, and deployment rates. These include:

Design and Licensing Cost-Share – A DOE program that builds upon the success of the SMR Licensing Technical Support program and provides a cost share to support technical, first-of-its-kind engineering and design and regulatory development for SMRs. A funding level and duration is assumed that results in an SMR design and several initial facilities that are ready to manufacture and construct prior to the start of construction. Further DOE cost-share is important to accelerate commercialization of SMRs in order to meet the goal of first deployment in the mid-2020s. It is also important to reduce uncertainty in the cost and schedule of SMR construction by assuring that the design and engineering is completed prior to beginning construction.

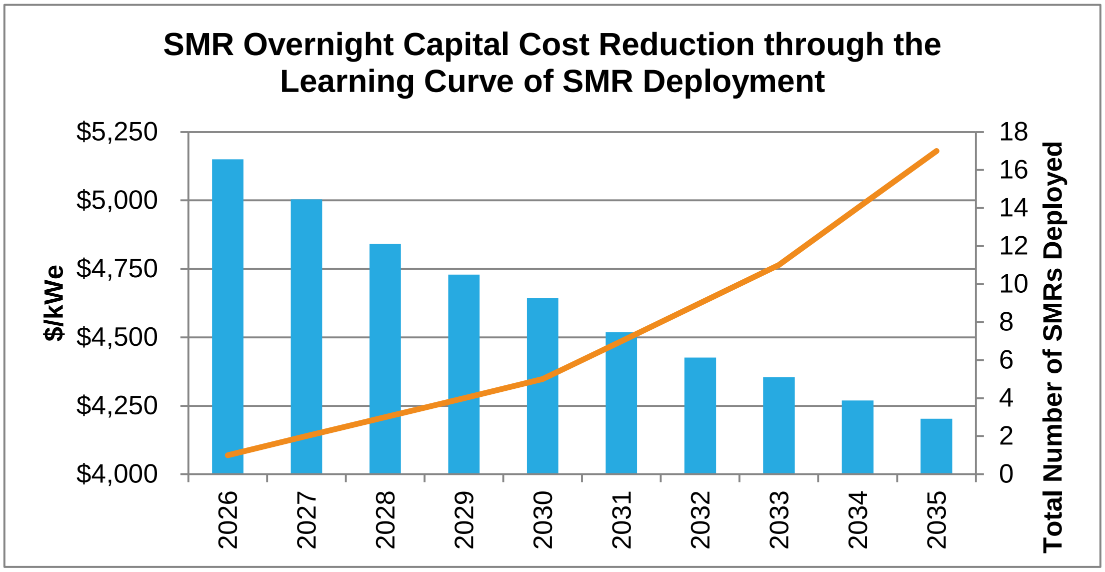
Manufacturing and Supply Chain Support – A DOE program to support SMR manufacturing of innovative first-of-a-kind components (e.g., the integral reactor pressure vessel and containment module) during the licensing phase to demonstrate advanced manufacturing techniques and allow fabrication of commercial units to occur at lower costs and in a compressed delivery schedule by incorporating lessons learned. Support also includes investment tax credits to incentivize a domestic supply chain for SMR deployment in the U.S. and for export. Manufacturing and supply chain support is important to achieve the expected cost and schedule of SMR construction, as well as reduce the uncertainty of these cost and schedule.

Uncertainties around Deployments in 2030 and Beyond

This analysis evaluates the following uncertainties around the cost of SMRs once lessons learned through deploying the first few facilities are incorporated.

Operating Lifetime: The analysis assumes that the operating lifetime of an SMR is 40 years to make a conservative comparison with an NGCC. However, it is expected that many of the current fleet nuclear plants will operate for 60 years and some will operate for 80 years. The uncertainty analysis models the operating lifetime as an increase of an SMR life to 60 years, consistent with the design life, which equals -$4/MWh for IOU and -$2/MWh for Muni $. Further, the analysis did not include potential component replacement costs to extend the life of the SMR beyond 40 years, but also did not include the need to replace the NGCC at the end of its lifetime, which would be expected to occur well short of the 60 year life of the SMR.

Overnight Capital Cost: Two factors could further reduce the overnight capital cost in 2030 below the assumed $4,600/kWe, advancements in manufacturing and construction technologies and higher learning curve rates. A more focused effort by industry and the Department of Energy to develop advanced manufacturing and construction technologies could significantly reduce the materials, labor and time needed to construct SMRs. The NOAK SMR conservatively assumes a 5% reduction in cost due to learning, which is applied every doubling of the number of SMRs deployed. For comparison, the learning curve reduction seen in the building of large light-water reactors by KHNP is estimated to be 15% every doubling during construction of 16 reactors. The figure below shows the expected reductions to overnight capital costs due to applying the learning curve. This analysis models overnight capital cost uncertainty as a moderately aggressive target of $4,245/kWe, which is -$4/MWh for IOU and -$2/MWh for Muni.



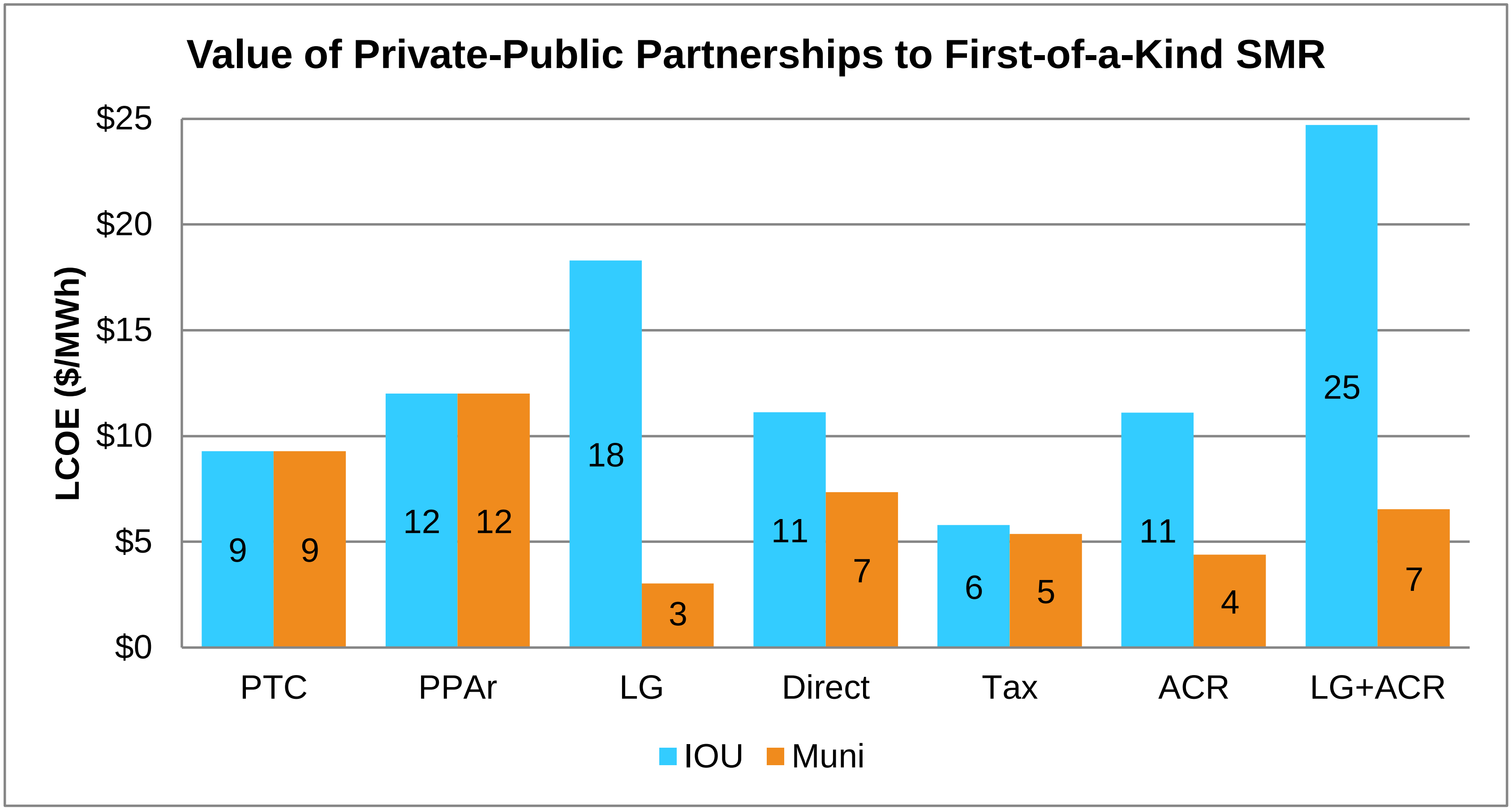
Material Escalation: Part of the reason the overnight capital cost of SMRs are so high compared to NGCC, is that they require a lot of commodity materials, such as concrete and steel. Commodity material prices can be volatile. This analysis models future commodity price uncertainty as an increase in the overnight capital cost of $100/kWe, which is +$3/MWh.

Financing: Loan guarantees and advanced cost recovery are programs that could be used after the first few SMRs as they are designed to not cost the tax payers money, and would significantly reduce the costs to the consumer. Due to the uncertainty in the availability of these programs, only 50% of their impact in reducing costs is included, which is -$12.3/MWh for IOUs and -$3.3/MWh for Muni.

This analysis evaluates the following uncertainties around the cost of NGCC deployed in 2030.

Natural Gas Prices: The consensus view is that natural gas prices will remain historically low for the foreseeable future. The 2017 Energy Information Administration (EIA) Annual Energy Outlook (AEO) reference case projects very little increase in the price of natural gas from 2026 to 2030. However, fossil fuel prices are volatile and large price increases can be unexpected and occur rapidly. This analysis models future gas price uncertainty as an increase in the gas price of $1/MBtu (or MBTU or MMBtu), which equals +$7/MWh.

Market Reform: It is reasonable to expect that market dynamics in 2030 may be different than today through market reforms to appropriately value attributes that are not accounted for today, such as resiliency and carbon-free generation. There is a precedent for valuing the cost of carbon, which has been set around $18/MWh for operating nuclear power plants through the zero carbon emission credits in New York and Illinois. The recent DOE Grid Study also observed that "Society places value on attributes of electricity provision beyond those compensated by the current design of the wholesale market." This analysis models market reforms as half of the value established in New York, equal to +$9/MWh for NGCC generation costs.


Value of Private-Public Partnerships to First-of-a-Kind SMR
LCOE ($/MWh)
$25
$20
$15
$10
$5
$0
9
9
12
12
18
3
11
7
6
5
11
4
25
7
PTC
PPAr
LG
Direct
Tax
ACR
LG+ACR
IOU
Muni