Enabling Nuclear Innovation

IN SEARCH OF A SPACEX FOR NUCLEAR ENERGY

A REPORT BY THE
NUCLEAR INNOVATION ALLIANCE

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AUTHOR
Matt Bowen, Ph.D.

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In Search of a SpaceX for Nuclear Energy

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DISCLAIMER

Reviewers and discussants were not asked to concur with the judgments or opinions in this report. All remaining errors are the author's responsibility alone.

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EXECUTIVE SUMMARY

Through innovative and successful approaches to public-private partnerships, the United States has recovered from a trailing role in global launch services. NASA has helped to nurture a U.S. industry that now provides services both in the United States and globally. As Figure 1 (p. 2) shows, as recently as 2012, U.S. companies had no market share in commercial launch services, and the Russian Federation was the dominant supplier. Today, SpaceX, a U.S. company, is a leading global commercial launch provider.[1]

The federal government played an important role in the rise of SpaceX, providing cost sharing for research, development, and demonstration, and acting as a first customer for launch services. Innovative contracting mechanisms, commercially sensitive treatment of proprietary information, the replacement of requirements with goals, and the hiring of a venture capitalist advisor all helped to make NASA's new approach to public-private partnerships a success.

Today, the U.S. nuclear industry is struggling to compete internationally against state-backed entities like Rosatom, analogous to the circumstances in space flight in 2012. However, U.S. nuclear energy companies could change that, if they are able to develop and demonstrate their advanced technologies. Many companies are taking a fresh look at how nuclear power plants are deployed, aiming to deliver competitive costs.

The federal government played an important role in the rise of SpaceX, providing cost sharing for research, development, and demonstration, and acting as a first customer for launch services.

Dozens of countries around the world are interested in purchasing nuclear power plants or developing domestic capabilities to address climate change, air pollution, and energy security and diversity needs. The countries that supply those power plants will benefit from the economic aspects of exports and will foster multi-decade relationships with the customer countries that have important geopolitical impacts. In particular, they will have increased influence over global nuclear safety, security and nonproliferation norms. For over half a century, U.S. influence on global nuclear supplier norms and the setting of nonproliferation conditions in U.S. nuclear cooperation agreements have been in part predicated on marketable U.S. reactor designs to supply under those agreements. For this reason and others, there is a national security case for U.S. investment in advanced reactors.[2]

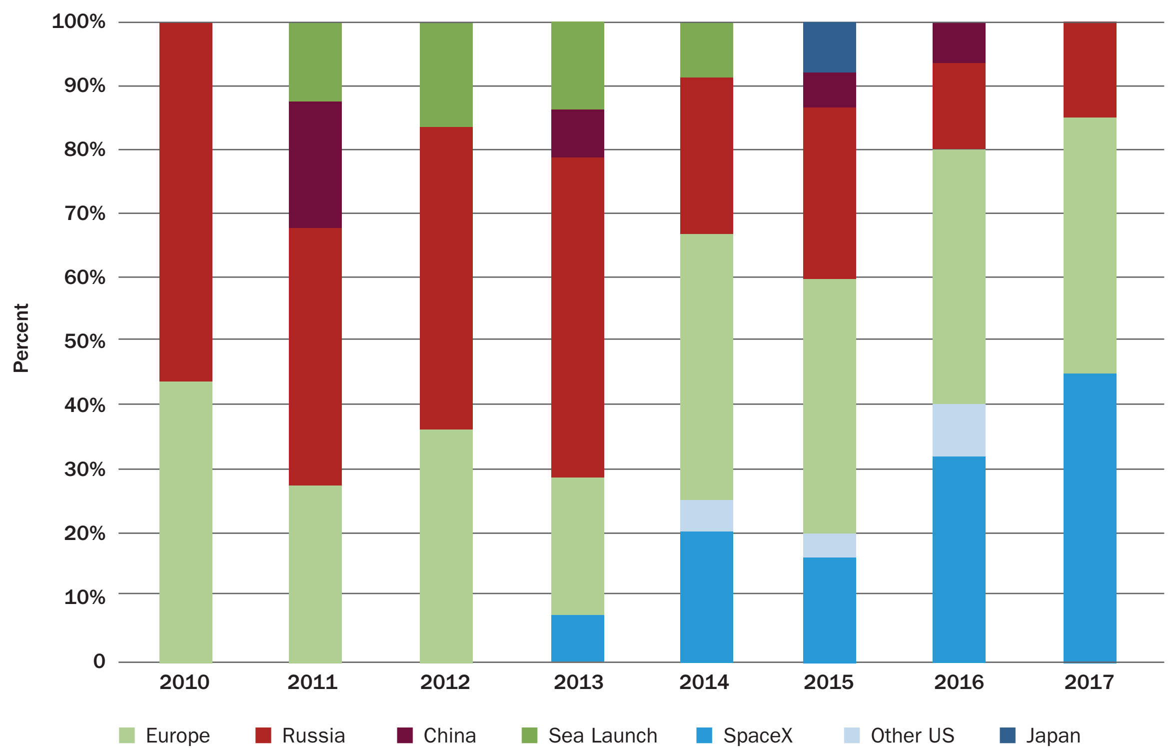
Russia currently dominates the export market for new reactor builds (see Figure 2, p. 3). To return the United States to a leadership role, the U.S. Department of Energy (DOE) can look to the

1 See Figure 1 and the Ars Technica article, "Russia appears to have surrendered to SpaceX in the global launch market," available at: *https://arstechnica.com/science/2018/04/russia-appears-to-have-surrendered-to-spacex-in-the-global-launch-market*; Elon Musk tweeted in February 2019 that SpaceX captured a 65% market share in 2018: *https://twitter.com/elonmusk/status/1098619793844797441?lang=en*

2 See Chapter V of the 2017 Nuclear Innovation Alliance report, "Leading on SMRs," for a more in-depth discussion.

FIGURE 1

Market Share for Commercial Global Launch Services



This chart was created by SpaceX in 2017; a portion of the 2017 figures are projections. The original SpaceX chart projected a 65% market share for SpaceX in 2018.

Source: Written testimony of Tim Hughes, senior vice president for global business and government affairs, SpaceX, before the U.S. Senate Committee on Commerce, Science & Technology, July 13, 2017.

The NASA COTS program used authorities from the 1958 Space Act, as well as an approach grounded in an awareness of commercial business, to fashion an innovative public-private partnership approach.

legacy of the NASA Commercial Orbital Transportation Services (COTS) program. This report reviews key features of that program, presents results of a survey of advanced nuclear energy companies, and recommends policy priorities that can support the demonstration of transformative nuclear energy technologies.

NASA's COTS Program

The NASA COTS program used authorities from the 1958 Space Act, as well as an approach grounded in an awareness of commercial business, to fashion an innovative public-private partnership approach.[3] Detailed in Chapter II, the program used a milestone-based payment system that increased transparency of objectives, reduced resources needed for compliance, and provided a clear path to discontinuing funding in the case of underperformance. NASA used four phases of development to assist companies like SpaceX in developing not just launch vehicles but also the capability to transport astronauts to the International Space Station (ISS). Some of the key characteristics that made the program successful include:

3 Even before COTS, NASA used other innovative approaches. For example, in 1979 NASA signed a Joint Endeavor Agreement with a private company to allow cost-free use of the space shuttle to conduct micro-gravity experiments. Similar cost-free use of nuclear experimental facilities could be of great assistance to nuclear energy companies. *https://www.nasa.gov/sites/default/files/files/SP-2014-617.pdf*

- Milestone-based, fixed-price payments that limit government responsibility for cost overruns compared with traditional "cost-plus" contracts
- Cost sharing with private investors
- Use of "other transactions" authority from the 1958 Space Act that enabled agreements that were neither procurements nor grants, and were not subject to the complete Federal Acquisition Regulations (FAR)
- Conservative treatment of proprietary information, leaving full rights with the private companies
- Consultation with a venture capitalist, who had prior government experience and who assisted in the design and implementation of the program

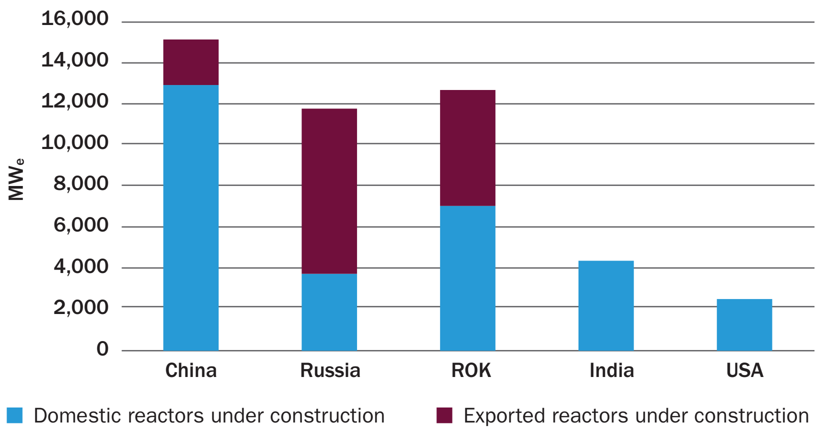
NASA and the federal government also served as early customers for SpaceX, guaranteeing an early revenue stream that quickly expanded to include private-sector customers from around the world.

Advanced Nuclear Energy Demonstration

S.1457, HR.5260, and S.3422, all introduced in the 115th Congress (2017-2018), would have required the Secretary of Energy to enter into agreements by the end of 2028 to demonstrate at least four advanced reactor concepts (to the maximum extent practicable). In 2019, S.903, the Nuclear Energy Leadership Act, was introduced, which would also require the Secretary of Energy to demonstrate at least four advanced reactor concepts. The bills do not specify how the four reactor technologies are to be demonstrated, which leaves some room for interpretation. For example, the construction of a nuclear reactor for disposition of surplus plutonium from the nuclear weapons program could serve to demonstrate a reactor concept. As part of this report, an industry survey was conducted to obtain an estimate of the types of federal support that could be used to accomplish these legislative goals.

Chapter IV describes the results of the survey. The results suggest that the federal resources required to demonstrate four advanced reactor concepts will depend on the specific technologies and the types of assistance offered. DOE Office of Nuclear Energy cost sharing, tax incentives, loan guarantees, and federal power purchase agreements might all play roles in the demonstration of four technologies.

FIGURE 2
Domestic and Exported Reactors Under Construction for Key Countries



Source: World Nuclear Association

Expenditures of this level would allow the Office of Nuclear Energy to continue pursuing a robust research portfolio and simultaneously a NASA-style demonstration program.

The following are rough estimates of what Office of Nuclear Energy resources for such a program might look like, using averages from the industry survey:

- cost-sharing technology development of three to four designs at $36M/year each over the next 10 years
- cost-sharing assistance for construction of two demonstration reactors at DOE sites at $150M/year each following 2028 for a period of four years[4]
- Two 100 MW_e power purchase agreements costing 2 cents/kWh (to cover a potential gap in cost with natural gas combined cycle plants) or $35M/year starting in 2033

These expenditures would represent a minority of the Office of Nuclear Energy's budget and the yearly profile for technology cost sharing is comparable to past DOE reactor cost-share programs. Expenditures of this level would allow the Office

4 The 2019 Nuclear Energy Leadership Act, S.903, has different timelines for the demonstration goals than previous legislation, which would shift some of these dates.

of Nuclear Energy to continue pursuing a robust research portfolio and simultaneously a NASA-style demonstration program. These figures represent a hypothetical program based on survey averages and a variety of support mechanisms; they are not a recommended funding profile, which would require a more detailed study.

Expenditures of this level would allow the Office of Nuclear Energy to continue pursuing a robust research portfolio and simultaneously a NASA-style demonstration program.

Recommendations

DOE should institute a multi-phase approach to achieve advanced reactor demonstration over the next 15 years, similar to the NASA COTS program.[5] DOE could set a range of capabilities it is seeking to develop, as NASA did, which could include electricity production, process heat supply, and remote power. To offer the contracting mechanisms analogous to those used by NASA, DOE may need to be granted similar authorities by Congress.

DOE and the rest of the federal government should likewise step forward as an early customer for power and heat from advanced reactors. The federal government is the largest energy consumer in the United States. Over the past decade, legislative targets and executive orders have driven the federal government's consumption of renewable energy to greater than 8% of total federal electricity procurements. Requiring federal consumption of clean energy (including nuclear energy and other zero-carbon energy sources) at higher levels than existing renewable targets would simultaneously lower greenhouse gas emissions and assist federal government efforts to support all zero-carbon energy development, including advanced reactors. Federal procurements of power from advanced reactor projects could be an important lever to accelerate commercial availability, and the Executive Branch and Congress should work together in this regard.

NASA's use of Space Act Agreement (SAA) awards to support the development of launch and crew transportation capabilities, in combination with its contracts based on the FAR to serve as a first customer for these new capabilities, helped to jumpstart a new, more competitive American industry of strategic importance. The payment-for-milestones cost sharing let industry lead in its business and development approach, and helped to minimize oversight resources needed by both the government and industry; the goal-setting approach enabled industry to innovate relatively unencumbered by extensive "requirements;" and the willingness to protect company proprietary information allowed companies to work with NASA without fear of losing their intellectual property. In total, NASA allocated $2.2 billion to cost share technology development with private companies and is expected to procure over $10 billion in services from private companies for transportation of supplies and crew to the ISS. Following a similar construct, this report recommends the following actions to develop U.S. advanced reactor technologies:

Recommendation 1: *DOE should seek one or more consultants with venture capital and/or start-up experience to advise it on the design and implementation of an advanced reactor demonstration program. DOE should also consult with NASA COTS program leadership and experts to gain further understanding of the success drivers in the program, as well as any potential improvements that NASA identified. DOE should identify any statutory restrictions that would prevent it from implementing an innovation-oriented, public-private partnership modeled after the NASA COTS experience.*

Recommendation 2: *Congress should address any statutory restrictions that would prevent DOE from carrying out an innovation-oriented, public-private partnership similar to the NASA COTS program.*

NASA's statutory authority came from the "other transactions" authority in the 1958 Space Act. DOE's authorities are derived from the Atomic Energy Act of 1954, the Energy Policy Act of 2005 (EPACT05), and other legislation. Congress should work with DOE to determine whether there are any statutory restrictions under existing law that would prevent it from implementing a program

5 The idea that DOE could look to NASA's COTS program for inspiration has been proposed previously. See Breakthrough Institute, "How to Make Nuclear Innovative," 2017; Episode 2 of the Titans of Nuclear podcast with Per Peterson on January 17, 2018; MIT discussed using payment-for-milestones for reactor development on pages 103-106 of its 2018 "The Future of Nuclear Energy in a Carbon-Constrained World" report.

that is comparable to the NASA COTS program in structure. If DOE identifies any potential problems, Congress should make the needed technical fixes to provide the authority to carry out a milestone-driven advanced reactor program. DOE should be permitted to institute reasonable intellectual property assurances and ease contracting and permitting for demonstrations on DOE sites.

Recommendation 3: *Once any statutory restrictions are addressed, DOE should establish a phased advanced reactor development and demonstration program modelled on the NASA payment-for-milestones approach of partnering with private companies.*

This approach, discussed in greater detail in Chapter II, could provide a management approach that is more similar to the way venture capital firms manage their investments, and one that is more transparent, structured, and enduring for longer-term advanced reactor demonstration. DOE should consult with NASA regarding lessons learned from its partnership with SpaceX and other companies in the COTS program, including the partnerships that ultimately did not lead to successes. For example, it would be useful for DOE to better understand how NASA structured its initial funding opportunity announcement, how it went about selecting partners, how it confirmed that partners had met milestones (or not), and in the case where partners did not meet their milestones, how NASA went about ending partnerships with the private companies and re-competing the remaining amounts of money in their agreements.

Recommendation 4: *Congress should amend either 40 U.S.C. Section 501 or 10 U.S.C. Section 2922A to allow federal facilities to enter into longer-term (e.g., 30 years or more) power purchase agreements for clean energy technologies.*

Amending 40 U.S.C. Section 501 would change the authorities for all federal entities, though the General Services Administration (GSA) would still have to delegate longer-term authority to individual agencies. Congress could amend Section 501 to allow longer term purchases in general, as S.903 from the 116th Congress would, and then GSA and the White House could work together to determine a policy on longer-term power purchase agreements for clean energy technologies. Amending 10 U.S.C. Section 2922A could provide to other agencies, in particular DOE, an authority that is currently only available to DOD. Either approach would allow at least some federal facilities to take power from clean energy technologies over a time period that better matches loan repayment schedules for new power plants.

Recommendation 5: *Congress should amend Section 203 of the Energy Policy Act of 2005 to require the federal government to purchase higher percentages of clean energy.*

Specifically, Congress should set higher goals for federal facilities to procure all forms of low-emission power. For example, Congress could require federal facilities to procure at least 30% of their power from zero-carbon sources by 2030 or half of their power from such sources by 2035. Alternately or in addition, Congress could consider amending 10 U.S.C. 2911 to establish similarly higher clean energy goals for DOD than currently exist for renewable energy technologies.

Over the past decade, legislative targets and executive orders have driven the federal government's consumption of renewable energy to greater than 8% of total federal electricity procurements.

Recommendation 6: *The White House should issue an executive order directing federal agencies to procure energy from low-emission technologies, including nuclear energy.*

The executive order would contain low-emission energy targets (or emission intensity reduction targets). For example, the President could direct that federal building electric energy and thermal energy consumption from zero-carbon energy sources be greater than 25% in 2025 and greater than 30% in 2030.

Recommendation 7: *DOE and DOD should look for opportunities to purchase power and heat from new advanced reactor demonstrations.*

This could include dedicated units that would supply secure power to DOE and DOD facilities. The federal government is the largest consumer of energy in the United States and DOD and DOE consume the most electricity of all federal agencies.

CHAPTER I

OF ROCKETS AND REACTORS

In the past decade, the emergence of SpaceX has reversed the position of the United States in international aerospace markets from one of near absence to one of leadership. SpaceX's innovative design measures and cost-cutting approaches have been crucial to that outcome, though support from the federal government (primarily NASA) was instrumental in supporting the company's technology development and demonstration. The goal of federal nuclear reactor development efforts should be to accomplish the same: to invert the position of the United States in international nuclear energy markets through design innovation and cost reductions, paired with successful demonstration.

The goal of federal nuclear reactor development efforts should be to invert the position of the United States in international nuclear energy markets through design innovation and cost reductions, paired with successful demonstration.

A decade ago, the United States had effectively ceded the global commercial space launch market to international competitors. To compound this situation, when the space shuttle was retired in 2011, the United States was in the unenviable position of being entirely dependent on the Russian Federation to ferry U.S. astronauts to the ISS. U.S. weakness in this strategically important industry had national security implications, but it also meant that the United States was missing out on an economic opportunity. The market for satellites, related services, and the rocket launches needed to carry them to space has grown tremendously in recent years, to more than $200 billion annually.[6]

A. The SpaceX Cost Revolution

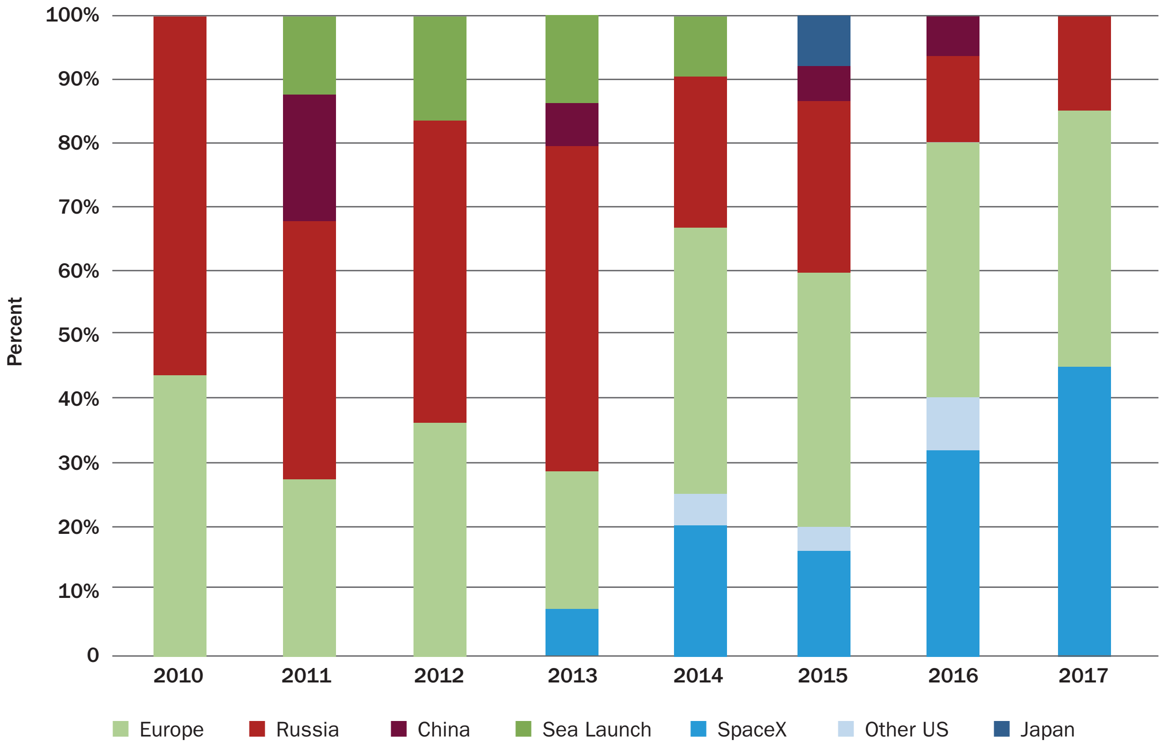
The emergence of SpaceX as an innovative, low-cost provider of reliable launch services to both the U.S. federal government and private customers has vastly improved the United States' position in international markets. SpaceX's Falcon 9 rocket first transported supplies to the ISS for NASA in 2012 and its first commercial customer was Canada's MDA Corporation in 2013. The cost reductions implemented in the Falcon 9 rocket were such that it was immediately cost competitive internationally. As a further demonstration of American ingenuity and technological boldness, SpaceX later began attempting post-launch landing of the first stage of the Falcon 9 rocket to enable its reuse. From 2016 to 2018, SpaceX successfully landed its first stage 26 times in a row.[7] No other company or country is currently landing its rockets for comparable launches, and this innovation is expected to further add to SpaceX's international dominance (see Figure 3). SpaceX has accomplished all of this despite having to compete with state-backed entities from other countries that benefit from cheap labor and government subsidies.[8]

6 See slide 5 of *https://www.sia.org/wp-content/uploads/2015/06/Mktg15-SSIR-2015-FINAL-Compressed.pdf*

7 *https://arstechnica.com/science/2018/12/after-26-straight-successes-spacex-fails-to-land-a-rocket-it-wanted-back*

8 Ashlee Vance, "Elon Musk: Tesla, SpaceX, and the Quest for a Fantastic Future," 2015. Page 215: "Its $60M per launch cost is much less than what Europe and Japan charge and trumps even the relative bargains offered by the Russians and Chinese, who have the added benefit of decades of sunk government investment into their space programs as well as cheap labor."

FIGURE 3
Market Share for Commercial Global Launch Services



This chart was created by SpaceX in 2017; a portion of the 2017 figures are projections. The original SpaceX chart projected a 65% market share for SpaceX in 2018.

Source: Written testimony of Tim Hughes, senior vice president for global business and government affairs, SpaceX, before the U.S. Senate Committee on Commerce, Science & Technology, July 13, 2017.

The 2018 Falcon Heavy launch.

© SpaceX

Starman in space.

© SpaceX

The successful landing of the two side boosters in the 2018 Falcon Heavy launch.

On February 8, 2018, in an additional and unprecedented act of private risk-taking in rocket science, SpaceX successfully launched its Falcon Heavy rocket using 27 Merlin engines. In doing so, SpaceX established its Falcon Heavy as the "most powerful operational rocket in the world by a factor of two."[9] SpaceX estimates that it can lift more than twice the payload of its next closest operational vehicle, and at one-third the cost.

The payload for the Falcon Heavy was not a commercial satellite; instead a cherry-red Tesla was put into orbit around the Sun with "Starman" in the driver seat. Apart from demonstrating the Falcon Heavy, the launch sent another message that the United States is the top innovator in the world when it comes to rockets.

In an additional display of technological superiority, SpaceX successfully landed both side boosters from the Falcon Heavy back at the launch site.

9 From SpaceX website: *https://www.spacex.com/falcon-heavy*; accessed March 25, 2018.

B. Advanced Reactors

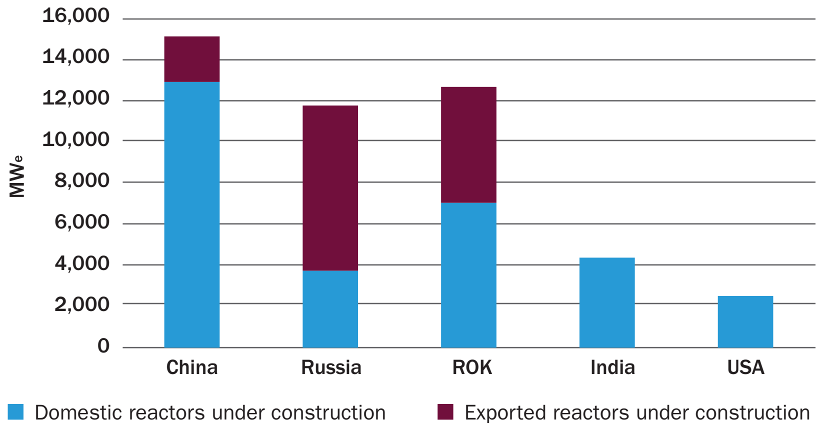
According to SpaceX's website, "Founded in 2002, SpaceX's mission is to enable humans to become a spacefaring civilization and a multi-planet species by building a self-sustaining city on Mars." If the goal of SpaceX is to colonize Mars as a place for humans to live, the goal of advanced reactor companies is to keep Earth a habitable planet. Rising sea levels, ocean acidification, changing food and fresh water availability, and other impacts of climate change pose vast risks for the world's population. Advanced nuclear energy could prove an important tool in lowering greenhouse gas emissions and minimizing climate change.[10]

Similar to the U.S. position in commercial global launch services a decade ago, the U.S. nuclear industry is struggling to compete internationally in a strategically important arena that its technology previously dominated. As shown in Figure 4, Russia has been winning most of the reactor bids around the world in recent years, and China is currently pursuing the largest build-out of nuclear reactors in the world. This construction effort positions China to play a large role, if not a dominant one, in the future global nuclear energy regime.

In addition to concerns about air pollution and climate change, there are also reasons of national security for the United States to remain engaged in the international nuclear energy market. For over half a century, U.S. influence on global nuclear supplier norms and the setting of nonproliferation conditions in U.S. nuclear cooperation agreements have been in part predicated on U.S. reactor designs to supply under those agreements.[11]

FIGURE 4

Domestic and Exported Reactors Under Construction for Key Countries



Source: World Nuclear Association

Reduced Scale

As SpaceX did, U.S. reactor companies will need to uncover innovative ways to bring down costs in their competition with these state-backed entities. For example, SpaceX found it advantageous to build its Falcon 9 rocket composed of nine smaller engines.[12] (By contrast, United Launch, a joint venture between Lockheed Martin Space Systems and Boeing Defense, Space & Security, uses one large engine as part of its Atlas V rocket.) The cost savings derived from this approach include easier transportation, supply chain opportunities, and a greater chance of launch success in the event that one engine fails, among other advantages.[13]

© SpaceX

The Falcon 9 octaweb of Merlin engines.

10 Also, NASA is investigating nuclear fission technology for powering bases on the moon and Mars: *https://www.nasa.gov/press-release/demonstration-proves-nuclear-fission-system-can-provide-space-exploration-power*

11 See Chapter V of the Nuclear Innovation Alliance report "Leading on SMRs" for a review of the national security reasons for the United States to remain engaged in the evolution and growth of the global nuclear energy and nonproliferation regime, as well as Russia and China's displacement of U.S. leadership in this area.

12 "Falcon" is taken from the Millennium Falcon ship in Star Wars; "9" is from the number of Merlin engines used.

13 For a discussion of the advantages of building rockets from multiple smaller engines, see: *https://arstechnica.com/science/2018/02/musks-inspiration-for-27-engines-modern-computer-clusters* and also *https://www.spacex.com/news/2013/03/26/merlin-engines*

FIGURE 5
NuScale Power Plant Layout

The center building houses 12 reactor modules.

Likewise, some advanced reactor companies see a potential advantage to building larger power plants composed of smaller reactors, rather than the conventional paradigm of one large reactor. The NuScale Power plant layout (shown in Figure 5) includes twelve 60 MW_e reactors. The smaller reactor pressure vessels can be transported by truck, and enable the use of U.S. manufacturing capabilities that are not currently capable of manufacturing reactor pressure vessels for larger reactors. Another advantage to using 12 reactors is that under normal operation, the plant can continuously provide at least 92% of full power output as individual modules are taken off-line for refueling. Many other advanced reactor companies are designing small modular reactors or microreactors with similar plans for fabrication efficiencies and transportation.[14]

Efficiency

The Merlin engines in the Falcon 9 are extremely efficient in their thrust-to-weight ratio: SpaceX has in the past asserted that the Merlin engine is the "most efficient booster engine ever built."[15]

Likewise, several reactors under design (e.g., the TerraPower TWR or the General Atomics EM^2) are pursuing nuclear reactor designs that operate at higher temperatures than conventional light water reactors, which would enable greater efficiencies in the conversion of heat to electricity and/or more attractive high temperature process heat for industrial use. Where a conventional light water reactor may be 33% efficient at converting thermal energy to electricity, a high-temperature gas reactor (HTGR) such as X-energy's Xe-100 (shown in Figure 6) could operate at 42% thermal efficiency or greater.

14 Companies include: Advanced Reactor Concepts, General Electric, General Atomics, Holtec, Kairos Power, Oklo, Terrestrial Energy, Thorcon, Urenco, Westinghouse, and X-energy.

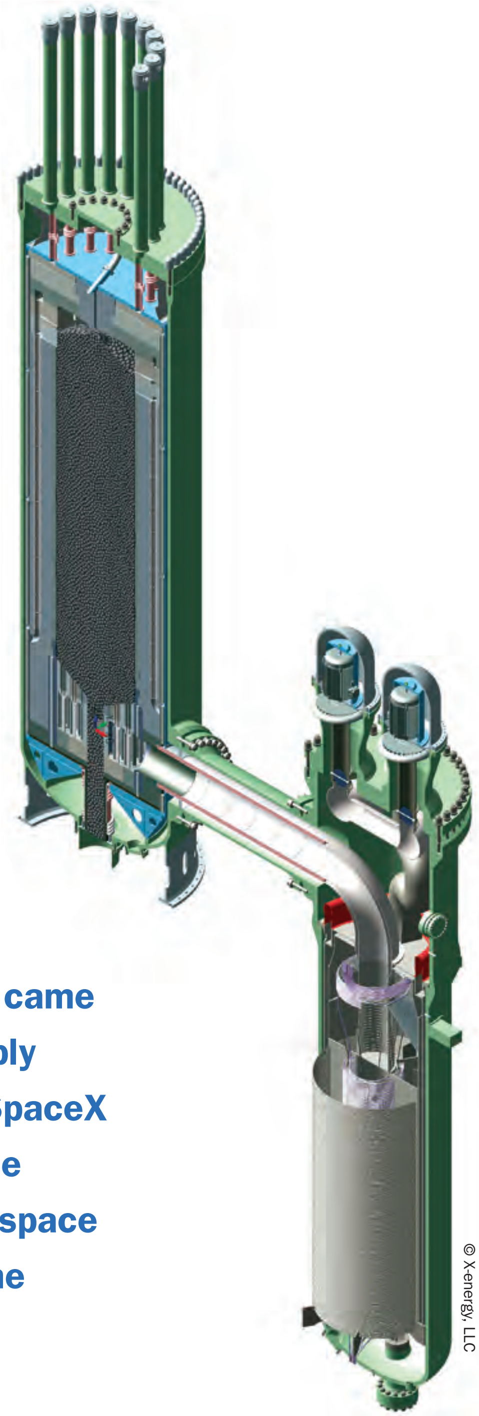
15 *https://www.spacex.com/news/2013/03/26/merlin-engines*

Supply Chain

As part of its design process, SpaceX came up with a variety of ways to bring supply chain costs down. In several places, SpaceX found that it could use readily available consumer electronics as opposed to "space grade" equipment used by others in the industry. For example, a space grade radio may cost $50,000 to $100,000, but a SpaceX radio may cost only $5,000—and weigh less. SpaceX has had to prove to NASA that these standard electronics will work well enough to compete with the more expensive and specialized gear used in the past.[16]

Advanced reactor companies may also have some opportunities to use more off-the-shelf components that are less expensive than the equivalent systems for light water reactors. Oak Ridge National Laboratory has estimated that if a molten salt reactor (MSR) is not dependent on active systems for reactor safety, there could be cost savings from the use of non-class 1E electrical equipment.[17] TerraPower is a company backed by Bill Gates that is developing both a sodium fast reactor, the TWR (shown in Figure 7) and an MSR concept, the Molten Chloride Fast Reactor. In addition to potential cost reductions, TerraPower's Molten Chloride Fast Reactor uses liquid fuel and its fast neutron spectrum would provide greater efficiency in the use of uranium resources and produce fewer actinides in the used fuel.

FIGURE 6
X-energy Xe-100 Power Module



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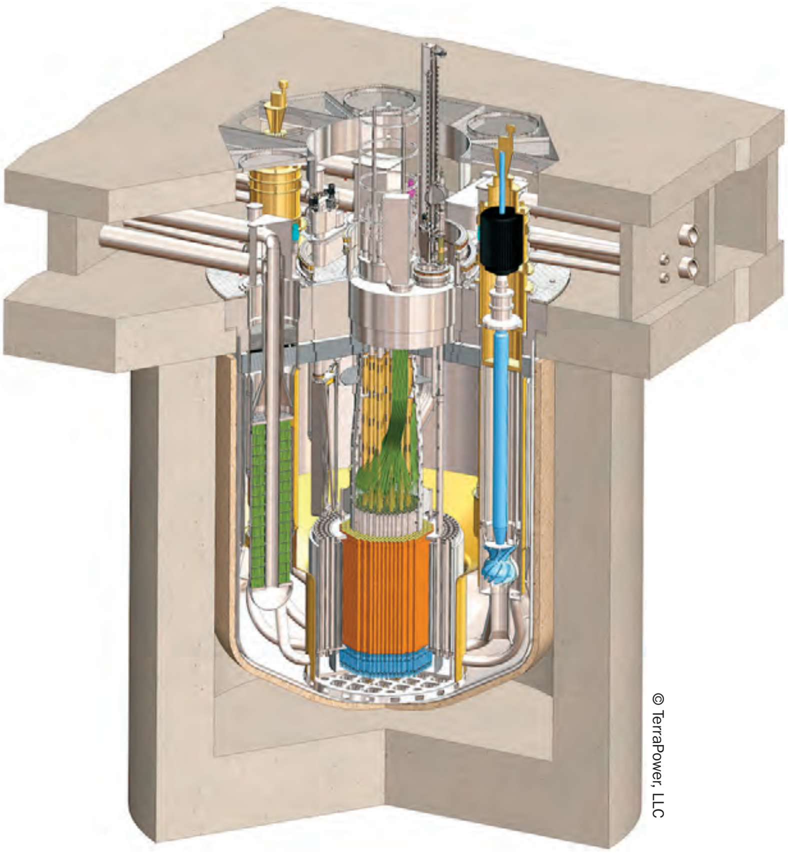
As part of its design process, SpaceX came up with a variety of ways to bring supply chain costs down. In several places, SpaceX found that it could use readily available consumer electronics as opposed to "space grade" equipment used by others in the industry.

16 Page 227 of Vance 2015: "Just by streamlining a radio, for instance, SpaceX's engineers have found that they can reduce the weight of the device by about 20 percent. And the cost savings for a homemade radio are dramatic, dropping from between $50,000 to $100,000 for the industrial grade equipment used by aerospace companies to $5,000 for SpaceX's unit…. The equipment at SpaceX tends to be built out of readily available consumer electronics as opposed to "space grade" equipment used by others in the industry. SpaceX has had to work for years to prove to NASA that standard electronics have gotten good enough to compete with the more expensive specialized gear trusted in years past."

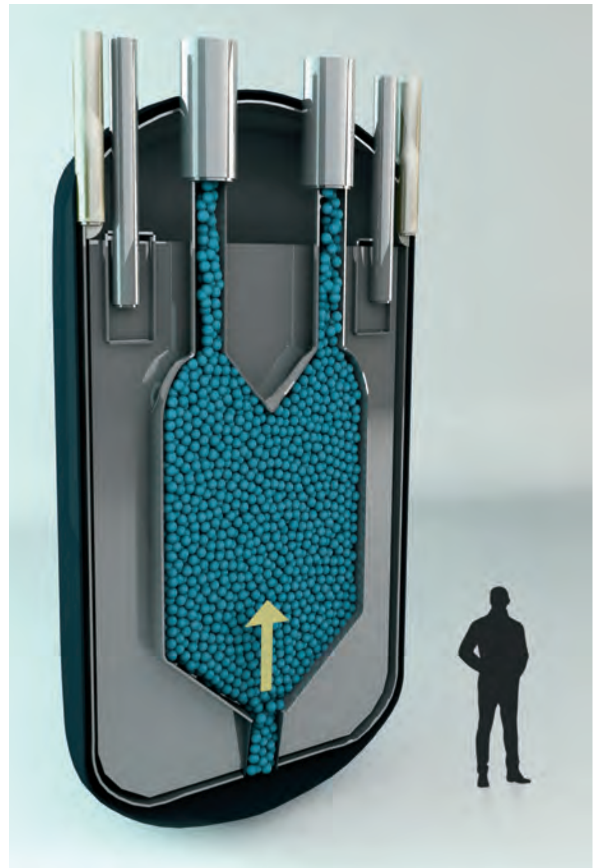
17 See ORNL, "Advanced High Temperature Reactor Systems and Economic Analysis," September 2011. Table 41, for example, estimates a potential cost savings of 28% for power and control wiring compared with a large pressurized water reactor. The NRC concluded that NuScale Power's reactor design could safely operate with the need for class 1E power: *https://newsroom.nuscalepower.com/press-release/company/us-nuclear-regulatory-commission-approves-key-safety-aspect-nuscale-powers-adv*

FIGURE 7
TerraPower TWR



© TerraPower, LLC

FIGURE 8
Kairos Power Reactor Module



© Kairos Power LLC

Kairos Power is a company using fuel similar to that of HTGRs (such as the Xe-100 discussed above), but with a molten salt coolant borrowed from the MSR concept. A very robust fuel form combines with a coolant with significant capacity to retain radioactive fission products to result in a significant reduction in safety-related systems and structures. Kairos Power expects that the economic potential based in the resulting overlap with non-nuclear procurement and construction will significantly enhance opportunities for deployment. An MSR or a reactor using molten salts as a coolant could operate at near-atmospheric pressure (e.g., a few atmospheres), which is much less than a more traditional pressurized water reactor (e.g., around 150 atmospheres), and enable the use of thin-walled piping, vessel, and pump casing components, with potential manufacturing advantages.[18] Kairos Power envisions one to four reactor modules for the typical site, depending on the needs of the customer.[19] An illustration of a Kairos Power reactor module is shown in Figure 8.

Transportability

SpaceX makes the Falcon 9 in Hawthorne, California, but most of its launches are from Cape Canaveral in Florida. The trip is 2,500 miles and the rockets are first transported by truck to the McGregor testing facility in Texas. The diameter of the Falcon 9 is 3.7 meters, which enables it to fit under every bridge on the way. In the past, sea transport had been used to transfer large rockets—for example, when the larger Saturn V rockets were transported to Florida. In that case, the first stage of the Saturn V was made in Huntsville and shipped down the Mississippi River, while the second stage was made

18 Per Peterson and Haihua Zhao, "Preliminary Design Description for a First-Generation Liquid-Salt VHTR with Metallic Vessel Internals," Report UCBTH—05-005, December 29, 2005.

19 Kairos Power website: *https://kairospower.com*

in California and transported by ship through the Panama Canal and back up to Florida.[20] SpaceX's smaller design has enabled transportation cost savings.[21]

Likewise, smaller reactor modules can enable easier transport of major reactor components, such as pressure vessels, which have substantial transportation constraints when made for large light water reactors. As discussed in the Nuclear Innovation Alliance's "Leading on SMRs" report, using trucks or rail to transport entire reactor modules could help to reduce costs.[22]

Manufacturing Approach

Factory fabrication is another key element of SpaceX business approach. The company manufactures a large percentage (between 80% and 90%) of its rockets, engines, electronics, and other parts.[23] The potential to fabricate reactor modules in a factory setting is another way that advanced reactors could reduce costs and construction timelines.[24]

The next chapter will discuss some of the assistance that the federal government provided to SpaceX along the way to its commercial success.

© SpaceX

SpaceX's factory for making the Falcon 9 rocket.

20 See Primal Space video: *https://www.youtube.com/watch?v=oUDes_wpGvg*

21 A picture of the Falcon 9 second stage being transported by truck can be seen at: *https://www.spacex.com/news/2013/02/11/falcon-9-progress-update-1*

22 Nuclear Innovation Alliance, "Leading on SMRs," 2017. See page 11.

23 Page 226 of Vance 2015: "The factory is a temple devoted to what SpaceX sees as its major weapon in the rocket-building game, in-house manufacturing. SpaceX manufactures between 80 percent and 90 percent of its rockets, engines, electronics, and other parts."

24 Ingersoll, Daniel. (2009). Deliberately small reactors and the second nuclear era. Progress in Nuclear Energy. 51. 589-603. DOI: 10.1016/j.pnucene.2009.01.003.

CHAPTER II

PUBLIC-PRIVATE PARTNERSHIPS

The U.S. government has long used public-private partnerships to accomplish important national goals. For example, the completion of the first transcontinental railroads would not have been possible without the support of government bonds and land grants, and the 1925 Contract Air Mail Act incentivized commercial aviation by allowing the U.S. Post Office to contract with private companies for mail delivery.[25] The latter ultimately led to the use of commercial aircraft for affordable passenger travel.

USPS contracting with private companies for air mail delivery ultimately led to affordable passenger air travel.

After President Eisenhower announced his vision for "Atoms for Peace" in 1953, the federal government used a broad spectrum of public-private partnerships to perform R&D on advanced reactor concepts, build test reactors, jointly launch demonstration reactors, and support building the first commercial nuclear reactors. In the process, the United States was firmly established as the global leader in nuclear energy development.[26]

NASA's COTS program led to partnerships with multiple aerospace companies, including SpaceX. This chapter reviews the NASA program, as well as DOE programs from the past decade that have assisted private companies in developing new reactor designs. The chapter concludes with a recommendation that DOE structure its future public-private partnerships to be more like the NASA COTS program and its agreement with SpaceX.

A. The SpaceX and NASA Partnership

As NASA retired the space shuttle, it was of vital importance to the government to establish another means of providing routine access to space to send both supplies and U.S. astronauts to the ISS.[27]

According to NASA, in its earlier relationships with industry, the government was "obligated to pay the additional cost of unforeseen slips in scheduled development" giving contractors "the incentive to do more, less-efficient work, as they [knew they would] not be financially responsible for delays and cost overruns."[28] A 2004 study proposed the idea of offering payments upon reaching milestones, where any additional work required to complete the milestone would be the financial responsibility of the company, not the government.

NASA subsequently committed billions of dollars to help private industry develop capabilities to deliver cargo and crew to the ISS. The way that NASA partnered with private companies was new. The original 1958 NASA Act endowed NASA with "other transactions" authority, which has been used by NASA to enter into SAAs that exist outside of the FAR.

25 See page 2 of NASA's 2014 report, "Commercial Orbital Transportation Services: A New Era in Spaceflight."

26 Steve Krahn and Andrew Sowder, "Historical Assessment of Government-Industry Roles in the Research, Development, Demonstration and Deployment of Nuclear Power," Transactions of the American Nuclear Society, Vol. 117, Washington, D.C., October 29–November 2, 2017.

27 Since the 2011 retirement, the United States has had to rely on Russia to transport U.S. astronauts to the ISS.

28 See page 12 of NASA's 2014 report, "Commercial Orbital Transportation Services: A New Era in Spaceflight."

Several programs that NASA used to jumpstart the private space industry utilized this "other transactions" authority. The approach taken was to encourage private companies to propose milestones and associated payments for them, and then NASA would select companies based on an assessment of best value. As the companies met those milestones, NASA paid them accordingly.

The milestone-based payments in NASA's partnerships provided aerospace companies with greater freedom to structure workable deals.[29] This type of structure arguably also helped to protect the U.S. taxpayer, as when individual companies (such as Rocketplane-Kistler) did not meet their milestones, they were not offered further support and the public-private partnership was ended. As NASA only paid the private companies for delivering on their milestones, this structure protected the taxpayer even though the agreements were not subject to the full FAR requirements; those requirements protect the taxpayer from misuse of funds, but when the payment of funds is contingent on adequate performance, the government knows it has "gotten its money's worth." This reduced oversight costs for both the federal government and the private companies. To verify that companies met their milestones, NASA had a focused, multi-disciplinary team attend flight tests, ground tests, and other milestone-related events.

NASA did not have a specific cost-share percentage targeted for the milestone program, though it emphasized the cost-share element as part of a true partnership. NASA ultimately awarded SpaceX $396M as part of COTS and SpaceX separately put in $454M of its own money, so in the end the private sector share of funding was greater than 50% of the total. Overall, NASA invested $788M in private companies as part of COTS, and those companies invested about $1 billion of their own money.[30] In later cost-share phases (CCDev2 and CCiCap, both discussed in Table 1) NASA would cost share an additional $482M with SpaceX to develop commercial crew transport capabilities.

A milestones approach is one way that the venture capital world manages the companies it invests in, and as part of the COTS program, NASA hired a venture capitalist to advise it. NASA examined each company's business plans and the SAAs incorporated not only technical milestones but also financing milestones for which a company had to demonstrate the continued commitment of private capital.

The milestone-based payments in NASA's partnerships provided aerospace companies with greater freedom to structure workable deals.

In terms of implementation, even if a company did not hit a given milestone by the associated date it had listed, NASA took the position that the milestone was the important component of the agreement, not the date. In some ways, NASA was like any other investor in a company or sitting on the board of directors, and it wanted to see the companies succeed. Ultimately, NASA was responsible for determining whether a given company was making an acceptable amount of progress on its milestones.[31]

NASA did not try to set technical parameters for the launch vehicles that the companies were developing. Instead, the companies themselves decided how big the launch vehicles would be, whether they would be pressurized, etc. Each company could bid on any of the four capabilities that NASA put forward: 1) external cargo delivery and disposal, 2) internal cargo delivery and disposal, 3) internal cargo delivery and return, and 4) crew transportation. Some companies bid on one capability, others bid on multiple capabilities. NASA assigned a confidence level to each proposal based on the associated business approach, technical approach, and cost.

NASA received proposals from 20 different companies by March 2006, and did an initial downselection later that year to six finalists.[32]

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29 The discussion in this sub-chapter is informed by the NASA's 2014 report, "Commercial Orbital Transportation Services: A New Era in Spaceflight," and also Bruce Pittman, Dan Rasky, Lynn Harper, "Infrastructure Based Exploration—An Affordable Path to Sustainable Space Development," 2012.

30 *https://www.nasa.gov/feature/celebrating-the-tenth-anniversary-of-the-cots-program*

31 For example, Rocketplane Kistler was not able to raise the financing that it had listed as one of its early milestones. NASA wrote a termination letter and recompeted the $170M that was left on Rocketplane Kistler's agreement. In the end, Rocketplane Kistler met several of its early milestones— enough to earn $32M—but NASA stopped work after that. Pages 62–63 in NASA's "Commercial Orbital Transportation Services," 2014 report describe in greater detail the termination of the agreement with Rocketplane Kistler.

32 *https://www.nasa.gov/feature/celebrating-the-tenth-anniversary-of-the-cots-program*

The finalists were then put through a round of "rigorous interviews and meetings." The two winners—SpaceX and RocketPlane Kistler—were selected in August of 2006.

According to the Office of the Inspector General at NASA,[33] the SAAs used in the COTS program

> … are not typical contracts subject to the Federal Acquisition Regulation (FAR) or other Federal procurement statues and, consequently, NASA and partners have considerable latitude in negotiating their terms. NASA officials believe this enhanced flexibility helps promote creativity and have found SAAs to be more cost-effective than contracts. On the other hand, NASA's use of SAAs has the potential to result in fewer overall protections for the Agency as well as decreased accountability of taxpayer funds.

and

> Funded SAAs are agreements under which NASA transfers appropriated funds to a domestic agreement partner to undertake activities consistent with NASA's missions. Under Agency-developed policy, NASA may only use funded SAAs when it cannot accomplish its objectives using a contract, grant, or cooperative agreement. NASA's use of funded SAAs is a relatively recent occurrence and to date most funded SAAs have related to the Agency's efforts to develop commercial spacecraft capable of transporting cargo and crew to the International Space Station (ISS or Station). Before NASA may enter into a funded SAA, it must develop a cost estimate of the funding anticipated along with the value of any Agency resources it will commit to the project to determine whether the proposed partner's contribution is fair and reasonable.

As Table 1 shows, SpaceX was awarded $396M during the COTS program. SpaceX was awarded $482M combined in two subsequent programs that also utilized SAAs that were focused on development of crew transportation capabilities. Other private companies, including Boeing ($620.9M) and Sierra Nevada ($353.1M), received a total of $1,317.9M, which when added to SpaceX's agreements, came to $2,248.9M in NASA-funded SAAs through 2014.

TABLE 1
NASA Funded Space Act Agreements

Company	Award Date	Total Value ($ in millions)	Purpose
SpaceX	Aug. 2006	396	**Commercial Orbital Transportation Services:** To facilitate U.S. private industry demonstration of cargo and crew space transportation capabilities with the goal of achieving safe, reliable, cost-effective access to low-Earth orbit
Orbital	Feb. 2008	288	
Rocketplane Kistler	Aug. 2006	32	
Sierra Nevada	Feb. 2010	20	**Commercial Crew Development Round 1 (CCDev1):** To provide funding to assist viable commercial entities in the development of system concepts, key technologies, and capabilities that could ultimately be used in commercial crew human space transportation systems
Boeing	Feb. 2010	18	
United Launch Alliance	Feb. 2010	7	
Blue Origin	Feb. 2010	4	
Paragon	Feb. 2010	1	
Boeing	Apr. 2011	113	**Commercial Crew Development Round 2 (CCDev2):** To continue development from CCDev1, ending in Preliminary Design Reviews
Sierra Nevada	Apr. 2011	106	
SpaceX	Apr. 2011	22	
Blue Origin	Apr. 2011	22	
Boeing	Aug. 2012	480	**Commercial Crew Integrated Capability (CCiCap):** To mature the design and development of transportation systems for spacecraft, launch vehicles, and ground and mission systems to achieve a company-defined Critical Design review
SpaceX	Aug. 2012	460	
Sierra Nevada	Aug. 2012	228	
Total: $2,249 million			

Source: NASA Office of Inspector General, "NASA's Use of Space Act Agreements," 2014. Table 1.

33 See pages ii and 2 of the NASA Office of the Inspector General report, "NASA's Use of Space Act Agreements," 2014.

TABLE 2

Initial SpaceX Milestones as Part of COTS and Completion Dates

#	Milestone Description	Award ($M)	Completion Date
1	Project Management Plan	23.1	Sept 15, 2006
2	Demo 1 System Requirements Review	5.0	Nov 29, 2006
3	Demo 1 Preliminary Design Review	18.1	Feb 8, 2007
4	Financing Round 1	10.0	Mar 1, 2007
5	Demo 2 System Requirements Review	31.1	Mar 15, 2007
6	Demo 1 System Critical Design Review	8.1	Aug 22, 2007
7	Demo 3 System Requirements Review	22.3	Oct 29, 2007
8	Demo 2 Preliminary Design Review	21.1	Dec 19, 2007
9	Draco Initial Hot Fire Test	6.0	Mar 21, 2008
10	Financing Round 2	10.0	Mar 21, 2008
11	Demo 3 Preliminary Design Review	22.0	June 27, 2008
12	Multi-Engine Test	22.0	Aug 4, 2008
13	Demo 2/3 System Critical Design Review	25.0	Dec 18, 2008
14	Financing Round 3	10.0	Feb 8, 2009
15	Demo 1 Readiness Review	5.0	Jun 8, 2010
16	CUCU Flight Unit Design, Acceptance, and Delivery	9.0	Jul 23, 2009
17	Demo 1 Mission	5.0	Dec 15, 2010
18	Demo 2 Readiness Review	5.0	Mar 9, 2012
19	Demo 2 Mission	5.0	Jun 7, 2012
20	Cargo Integration Demonstration	5.0	Dec 18, 2009
21	Demo 3 Readiness Review	5.0	Aug 22, 2012
22	Demo 3 Mission	5.0	Jun 7, 2012
	Total	**$278M**	

The completion date is when NASA verified that SpaceX completed the milestone. More milestones (and funds) were added at a later date.

Source: Appendix of NASA's 2014 report, "Commercial Orbital Transportation Services: A New Era in Spaceflight."

To illustrate the payment-for-milestones approach in greater detail, Table 2 shows the initial milestones that SpaceX proposed for the COTS program in 2006 (this initial list was later altered when additional funding became available and additional milestones were added.)

The SAAs used in the programs in Table 1 helped to develop both launch vehicles capable of resupplying the ISS and also crew vehicles to transport U.S. astronauts.

B. Recent DOE Cooperative Agreements for Reactor Development

In the past 20 years, DOE has initiated several programs that partnered with private companies to develop new reactor designs, including Nuclear Power 2010 (NP2010), the Small Modular Reactor Licensing Technical Support (SMR LTS) program, and the Advanced Reactor Concepts 2015 (ARC15) program. These programs awarded cooperative agreements under DOE financial assistance regulations to individual reactor design companies that involved at least 50% cost share coming from the private sector. The amount of money available to private companies in these cooperative agreements was fixed, so the agreements themselves did not provide a reactor vendor recourse to come back and ask for additional cost share. The private entity thus bore any additional cost to develop its reactor design and had a strong incentive to maintain its schedule and keep costs low.

Past DOE programs and the NASA COTS program were in effect both cost-shared efforts, where industry had an incentive to move quickly and keep costs down, but they employed different structures. A phased payment-for-milestones approach for DOE advanced reactor development could help sustain cooperation over longer periods of time, provide greater transparency into what the public is getting for its money, and potentially reduce compliance costs for the government and private industry. A payment-for-milestones approach could help as a management tool for the federal government and keep awardees and the government focused on what is next, while also noting successes along the way.

To provide a starting point for proposing new programs in the future, it is worth reviewing past programs (NP2010, SMR LTS, and ARC15) in greater detail.

A phased payment-for-milestones approach for DOE advanced reactor development could help sustain cooperation over longer periods of time, provide greater transparency, and reduce compliance costs.

Nuclear Power 2010

NP2010 was a joint government-industry effort to identify sites for new nuclear power plants, develop and bring to market advanced nuclear plant technologies, evaluate the business case for building new nuclear power plants, and demonstrate untested regulatory processes.

In total, NP2010 involved $655M of federal government resources for a program that involved two reactor designs: the GE ESBWR and the Westinghouse AP1000. Private entities were required to contribute at least as much as the federal government. Federal government support towards a design certification for the AP1000 and a reference combined construction and operation license application (COLA) totaled $380M. The parallel federal effort towards an ESBWR design certification and reference COLA totaled $216M. (Not shown in Table 3 are appropriations for standby support as they never rose above $400,000 in a single year, though they eventually totaled $0.9M.[34]) While the program lasted from 2001 to 2011, as Table 3 shows, the major cost share with reactor designers and utilities was from 2005 to 2010.

Dominion, System Energy Resources, and Exelon were selected for early site permit (ESP) development and the U.S. Nuclear Regulatory Commission (NRC) issued ESPs for the Clinton, Grand Gulf, and North Anna plants (respectively) in 2007. Westinghouse submitted an amended design certification application to the NRC in 2008, which was approved in 2011.[35] GE submitted a design certification application to the NRC in 2005 and the design was ultimately certified in 2014. Southern Nuclear Operating Company submitted a COLA (utilizing the AP1000 design) to the NRC in 2008, approval for which was issued in 2012. Detroit Edition submitted a COLA in 2008 (utilizing the ESBWR design), which was approved in 2015.

EPACT05 established important financial incentives for first-mover plants, including a production tax credit and a loan guarantee program. In 2010, President Obama announced a conditional loan guarantee commitment for the new AP1000 builds at the Vogtle nuclear power plant in Georgia; DOE issued $6.5B in loan guarantees in 2014 and an additional $1.8B in loan guarantees in 2015 to support the project.[36] Secretary of Energy Rick Perry announced in March 2019 that DOE would provide an additional $3.7B in loan guarantees to the project.[37] As of March 2019, there is $8.8B in remaining loan guarantee authority for other advanced nuclear projects.

TABLE 3
NP2010 Appropriations by Fiscal Year

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Funding (in millions of dollars)	3	5	15	7	66	65	80	134	177	102	1

Source: U.S. Department of Energy.

34 The Energy Policy Act of 2005 contained provisions for "standby support" which were meant to offer protection against the potential impacts of construction and operational delays for new nuclear plants beyond the control of the plants' sponsors.

35 *https://www.nrc.gov/reactors/new-reactors/design-cert/ap1000.html*

36 *https://www.energy.gov/lpo/vogtle*

37 *https://www.energy.gov/articles/secretary-perry-announces-financial-close-additional-loan-guarantees-during-trip-vogtle*

TABLE 4
SMR LTS Appropriations by Fiscal Year

Year	2012	2013	2014	2015	2016	2017
Funding (in millions of dollars)	67	63	48	55	63	95

Source: U.S. Department of Energy.

Small Modular Reactor Licensing Technical Support

More recently, SMR LTS was a DOE program to accelerate the commercial availability of SMRs by providing cost-share assistance in the first-of-a-kind engineering and NRC license application preparation and processing for SMR projects. The funding profile for SMR LTS is shown in Table 4. From FY 2012 to FY 2017, appropriations for SMR LTS totaled $390M.[38] Like NP2010, it involved cooperative agreements with two reactor designers (in this case, B&W and NuScale Power) and two utilities, the Tennessee Valley Authority (TVA) and the Utah Associated Municipal Power Systems (UAMPS). When B&W announced that it was slowing down funding of its mPower development, the DOE cost share ended, and TVA began to work on an ESP application that would accommodate any light water SMR.

NuScale Power submitted a design certification application to the NRC in December 2016 and TVA submitted an ESP application to the NRC in May 2016. (At time of publication, both applications are undergoing review by the NRC.)

Advanced Reactor Concepts 2015

In 2015, DOE issued a funding opportunity announcement through the ARC15 program.[39] Southern Company Services and X-energy each won $40M in DOE funding to develop their advanced nuclear reactor projects.[40] Southern Company Services has formed a partnership with TerraPower, Oak Ridge National Laboratory, the Electric Power Research Institute, and Vanderbilt University to develop a Molten Chloride Fast Reactor Design. X-energy is developing the Xe-100 pebble bed HTGR and is partnered with BWXT, Teledyne Brown Engineering, SGL Group, Oregon State University, Idaho National Laboratory, and Oak Ridge National Laboratory.

The major reactor development cost-sharing element of the NP2010 and SMR LTS programs lasted only six years—just longer than the ARC15 program is expected to continue. However, some advanced reactor concepts that are at an earlier stage of development may take a longer period of time to reach demonstration. The four phases of NASA cost share that have developed launch vehicles and crew transportation vehicles have spanned over a decade and totaled around $2.2B. The federal procurement of the capabilities that were developed in those programs (discussed in Chapter III) is set to total over $10B. As Chapter IV discusses, the scale of the NASA cost-share effort may be around the same order of magnitude of cost-share resources that DOE would need to accomplish the demonstration goals laid out in legislation.

NP2010, SMR LTS, and ARC15 are not the complete set of cost-share programs that DOE has initiated to advance reactor technology. For example, DOE announced a new funding opportunity at the end of 2017, and several awards have been made since then.[41] The programs described above did not cost share the construction of reactor demonstrations. DOE's predecessor, however, the Atomic Energy Commission, did cost share in the design, construction, and operation of a dozen demonstration reactors between 1955 and 1965 under the auspices of the Cooperative Power Reactor Demonstration Program.[42]

38 See Secretary Perry's testimony to the U.S. House Committee on Appropriations, Energy and Water Development Subcommittee on June 20, 2017.

39 *https://www.nrc.gov/docs/ML1615/ML16155A242.pdf*

40 *https://analysis.nuclearenergyinsider.com/us-committee-prioritizes-advanced-reactors-southern-x-energy-win-doe-funds*

41 *https://www.id.energy.gov/NEWS/FOA/FOAOpportunities/FOA.htm; DE-FOA-0001817*

42 Electric Power Research Institute, "Program on Technology Innovation: Government and Industry Roles in the Research, Development, Demonstration, and Deployment of Commercial Nuclear Reactors: Historical Review and Analysis," Technical Report No. 3002010478, December 2017.

C. A Payment-for-Milestones Approach in Future DOE Cooperative Agreements

NASA has assessed that partnering with a private company and using "fixed price" contracts, rather than more traditional "cost plus" contracts, to develop the Falcon 9 led to substantial cost savings.[43] Using a similar approach, DOE could accelerate advanced reactor development.[44]

The core concept of payment for milestones in the NASA-SpaceX partnership could be adopted for future DOE cooperative agreements with private reactor developers. Payment for milestones is one manner in which venture capital firms manage their investments that helps to simplify the task of evaluating progress as well as reduce the oversight requirements on the firm.[45]

Just as NASA set goals for supply and crew transportation capabilities to the ISS, DOE could set goals for advanced reactor capabilities for companies to bid on. For example: 1) electricity generation, 2) process heat, and 3) remote or highly secure power. Isotope production or transmutation could be other capabilities for DOE to consider.

The core concept of payment for milestones in the NASA-SpaceX partnership could be adopted for future DOE cooperative agreements with private reactor developers.

In analogy to the NASA COTS, CCDev1, CCDev2, and CCiCap phases, advanced reactor demonstration phases could include:

1. Early reactor design and development
2. NRC licensing application pre-application interactions and application preparation, or preparation of safety cases for DOE or DOD oversight, as applicable
3. Final regulatory approval and design finalization
4. Advanced reactor construction

Purely for illustration purposes, the types of milestones that could be used in different phases could include:

- Securing financing for development or construction
- Project management plan and quality assurance program
- Preliminary safety evaluations performed
- Primary system thermal-hydraulic and code verification testing
- Design completion percentages or milestones (e.g., pre-conceptual, conceptual, preliminary, final)
- Completion of design peer/independent reviews
- Raising the technology readiness level for major subsystems to a target level
- Submission of all necessary and specified safety topical reports
- Submittal of a design certification or construction license to the NRC, or equivalent reports to DOE or DOD
- Progression through construction and safety analysis milestones
- Fuel qualification plan developed
- Completion of fuel testing
- Installation of major reactor components
- Achieving operational readiness
- Loading of fuel
- Low-power reactor operation
- Full-power reactor operation

One of the most important programmatic design details is that companies themselves should propose the milestones that they would meet, so the list above is merely for illustration. Different companies would likely choose different types of milestones. This sort of flexible arrangement would allow DOE to support companies at various stages of development. Meeting all of a given company's milestones in one phase would not guarantee that the same company would be selected in a subsequent phase; this was the case with SpaceX, which was not selected for a CCDev1 award, despite its success in prior and subsequent award rounds.

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43 Bruce Pittman, Dan Rasky, Lynn Harper, "Space-based Infrastructure Exploration – An Affordable Path to Sustainable Space Development," 2012. See also the talk by Dan Rasky "View from the Top," at University of Berkeley: *https://www.youtube.com/watch?v=g3gzwMJWa5w; https://www.nasa.gov/pdf/586023main_8-3-11_NAFCOM.pdf*

44 Breakthrough Institute, "How to Make Nuclear Innovative," 2017. See also, Episode 2 of the Titans of Nuclear podcast with Per Peterson on January 17, 2018. MIT discussed a payment-for-milestones approach on pages 103-106 in its 2018 "The Future of Nuclear Energy in a Carbon-Constrained World" report.

45 "Venture capital funding is commonly provided to start-up firms on a piecemeal basis over several stages. One way in which this can be implemented is through milestone financing, where a venture capitalist commits upfront to providing additional future funding contingent upon the firm meeting certain conditions, or milestones." *http://apps.olin.wustl.edu/faculty/cuny/CJCuny%20Talmor%20VC%20Staging%20Apr2005.pdf*

CHAPTER III

THE FEDERAL GOVERNMENT AS A FIRST CUSTOMER

In the past, the federal government has served as an important early customer for new technologies and those initial procurements helped to pave the way for successful competition in the open market. For example, in the early 1960s, DOD and NASA purchased large numbers of integrated circuits, and those purchases were sufficient to enable firms to achieve economies of scale and reduced per-unit production costs, paving the way for the U.S. integrated circuit industry to become a global competitor.[46] Likewise, the Internet and the Global Positioning System ultimately transitioned from military/government users to primarily serving private demand.

NASA and the U.S. Air Force purchased 10 of the first 20 flights of SpaceX's Falcon 9 (see Table 6, p. 22). In a similar manner, the federal government could purchase services that would provide a customer for advanced reactor demonstrations. For nuclear energy companies, the challenge of raising enough money to support development and design work for their reactor concept is accompanied by the challenge of finding a utility willing to bear the risk of being the initial customer for a first-of-a-kind nuclear reactor technology. The federal government could help to alleviate the second challenge by becoming a first customer for advanced reactor electricity or heat, secure power in a stand-alone unit, plutonium disposition, or other services.

A. First Customers for SpaceX: NASA and the U.S. Air Force

The SAAs discussed in Chapter II, which were employed by NASA to develop cargo and crew transportation capabilities, exist outside of the FAR. However, NASA and other federal government agencies also served as first-customers for these same private companies and procured services under several FAR-based programs.

For nuclear energy companies, the challenge of raising enough money to support development and design work for their reactor concept is accompanied by the challenge of finding a utility willing to bear the risk of being the initial customer for a first-of-a-kind nuclear reactor technology.

As Table 5 shows, NASA first procured transportation of supplies to the ISS from several private companies under the Commercial Resupply Services (CRS) contracts in 2008. NASA did a second round of contracts (CRS-2) in 2016, which are intended to resupply cargo to the ISS through 2024. The first awards went to SpaceX and the company that is now Orbital ATK. Any company could bid on CRS, including entities that were not selected in the COTS program.

After COTS helped to develop launch vehicles, the subsequent cost-sharing capability development rounds – CCDev and CCiCap – helped to develop crew transportation capabilities and NASA has since awarded two FAR-based contracts to Boeing ($4.2B) and SpaceX ($2.6B) to support commercially

46 Congressional Budget Office, "Federal Policies and Innovation," November 2014. *https://www.cbo.gov/sites/default/files/113th-congress-2013-2014/reports/49487-Innovation.pdf*

The NuScale Integral System Test facility located in Corvallis, Oregon.

TABLE 5

NASA FAR-based Contracts for Transporting Supplies and Crew to the ISS

Company	Initial Award Date	Total Value ($ in millions)	Purpose
Orbital ATK	Dec. 2008	$2,889	**CRS-1:** Transportation of supplies to the International Space Station
SpaceX	Dec. 2008	$3,042	
Orbital ATK	Jan. 2016	$639	**CRS-2:** (ongoing) Continuation of CRS-1
Sierra Nevada	Jan. 2016	$893	
SpaceX	Jan. 2016	$1,074	
Boeing	Dec. 2012	$9.9	**Certification Products Contracts:** First phase to discuss and develop data products to implement agency's flight safety and performance requirements
Sierra Nevada	Dec. 2012	$10	
SpaceX	Dec. 2012	$9.6	
Boeing	Sept. 2014	$4,200	**Commercial Crew Transportation Capability:** Second phase of certification for commercially built and operated integrated crew transportation systems
SpaceX	Sept. 2014	$2,600	

Values for CRS-2 are through calendar year 2017.

Source: NASA website and Table 7 of the 2018 NASA Office of the Inspector General report, "Audit of Commercial Resupply Services to the International Space Station."

built and operated integrated crew transportation systems.[47] As of March 2019, NASA expected that SpaceX would transport U.S. astronauts to the ISS by the end of 2019.[48]

As Table 6 shows, NASA and the U.S. Air Force were major early federal customers for SpaceX launch services. While the inaugural Falcon 9 test flight in 2010 was not an explicit milestone in SpaceX's agreement with NASA, the development of the Falcon 9 had been cost shared with NASA in previous years. Not shown are five Falcon 1 flights previous to the Falcon 9 that demonstrated the Merlin engine. The first three Falcon 1 flights were not successful, followed by two consecutive successful launches. DARPA, the U.S. Air Force, and NASA provided support for the first three Falcon 1 attempts.[49]

47 Many—although not all—acquisitions of goods and services by the federal government are subject to the FAR. The FAR is regulation codified in Parts 1 through 53 of Title 48 of the Code of Federal Regulations.

48 *https://www.cnbc.com/2019/03/08/spacex-crew-dragon-splashdown-in-the-atlantic-ocean-for-nasa.html*

49 *https://www.space.com/2196-spacex-inaugural-falcon-1-rocket-lost-launch.html; https://spacexnow.com/past.php*

TABLE 6
SpaceX Launch Manifest for Falcon 9

Date	Customer	Launch Site	Vehicle
6/4/10	FALCON 9 INAUGURAL TEST FLIGHT	CAPE CANAVERAL	FALCON 9
12/8/10	NASA COTS (DEMO 1)	CAPE CANAVERAL	DRAGON/FALCON 9
5/22/12	NASA COTS (DEMO 2/3)	CAPE CANAVERAL	DRAGON/FALCON 9
10/8/12	NASA RESUPPLY TO ISS (FLIGHT 1)	CAPE CANAVERAL	DRAGON/FALCON 9
3/1/13	NASA RESUPPLY TO ISS (FLIGHT 2)	CAPE CANAVERAL	DRAGON/FALCON 9
9/29/13	MDA CORP. (CANADA)	VANDENBERG	FALCON 9
12/3/13	SES (SES-8)	CAPE CANAVERAL	FALCON 9
1/6/14	THAICOM (THAILAND)	CAPE CANAVERAL	FALCON 9
4/18/14	NASA RESUPPLY TO ISS (FLIGHT 3)	CAPE CANAVERAL	DRAGON/FALCON 9
7/14/14	ORBCOMM	CAPE CANAVERAL	FALCON 9
8/5/14	ASIASAT-8	CAPE CANAVERAL	FALCON 9
9/7/14	ASIASAT-6	CAPE CANAVERAL	FALCON 9
9/21/14	NASA RESUPPLY TO ISS (FLIGHT 4)	CAPE CANAVERAL	DRAGON/FALCON 9
1/10/15	NASA RESUPPLY TO ISS (FLIGHT 5)	CAPE CANAVERAL	DRAGON/FALCON 9
2/11/15	U.S. AIR FORCE (DSCOVR)	CAPE CANAVERAL	FALCON 9
3/2/15	ASIA BROADCAST SATELLITE/EUTELSAT	CAPE CANAVERAL	FALCON 9
4/14/15	NASA RESUPPLY TO ISS (FLIGHT 6)	CAPE CANAVERAL	DRAGON/FALCON 9
4/27/15	THALES ALENIA SPACE	CAPE CANAVERAL	FALCON 9
12/22/15	ORBCOMM	CAPE CANAVERAL	FALCON 9
1/17/16	NASA (JASON-3)	VANDENBERG	FALCON 9
3/4/16	SES (SES-9)	CAPE CANAVERAL	FALCON 9
4/8/16	NASA RESUPPLY TO ISS (FLIGHT 8)	CAPE CANAVERAL	DRAGON/FALCON 9
5/6/16	SKY PERFECT JSAT CORPORATION (JAPAN)	CAPE CANAVERAL	FALCON 9
5/27/16	THAICOM 8	CAPE CANAVERAL	FALCON 9
6/15/16	EUTELSAT AND ABS	CAPE CANAVERAL	FALCON 9
7/18/16	NASA RESUPPLY TO ISS (FLIGHT 9)	CAPE CANAVERAL	DRAGON/FALCON 9
8/14/16	SKY PERFECT JSAT CORPORATION (JAPAN)	CAPE CANAVERAL	FALCON 9
1/14/17	IRIDIUM (FLIGHT 1)	VANDENBERG	FALCON 9
2/19/17	NASA RESUPPLY TO ISS (FLIGHT 10)	CAPE CANAVERAL	DRAGON/FALCON 9
3/16/17	ECHOSTAR CORPORATION	CAPE CANAVERAL	FALCON 9
3/30/17	SES (SES-10)	CAPE CANAVERAL	FALCON 9
5/1/17	NATIONAL RECONNAISSANCE OFFICE (NROL-76)	CAPE CANAVERAL	FALCON 9
5/15/17	INMARSAT	CAPE CANAVERAL	FALCON 9
6/3/17	NASA RESUPPLY TO ISS (FLIGHT 11)	CAPE CANAVERAL	DRAGON/FALCON 9
6/23/17	BULGARIASAT-1	CAPE CANAVERAL	FALCON 9
6/25/17	IRIDIUM (FLIGHT 2)	VANDENBERG	FALCON 9
7/5/17	INTELSAT	CAPE CANAVERAL	FALCON 9
8/14/17	NASA RESUPPLY TO ISS (FLIGHT 12)	CAPE CANAVERAL	DRAGON/FALCON 9
8/24/17	NATIONAL SPACE ORGANIZATION (TAIWAN)	VANDENBERG	FALCON 9
9/7/17	U.S. AIR FORCE (OTV-5)	CAPE CANAVERAL	FALCON 9
10/9/17	IRIDIUM (FLIGHT 3)	VANDENBERG	FALCON 9
10/11/17	ECHOSTAR 105/SES-11	FLORIDA LAUNCH SITE	FALCON 9
10/30/17	KOREASAT	CAPE CANAVERAL	FALCON 9

(CONTINUED)

TABLE 6

SpaceX Launch Manifest for Falcon 9 (CONTINUED)

Date	Customer	Launch Site	Vehicle
12/15/17	NASA RESUPPLY TO ISS (FLIGHT 13)	FLORIDA LAUNCH SITE	DRAGON/FALCON 9
12/22/17	IRIDIUM (FLIGHT 4)	VANDENBERG	FALCON 9
1/7/18	ZUMA	CAPE CANAVERAL	FALCON 9
1/31/18	GOVSAT-1	CAPE CANAVERAL	FALCON 9
2/22/18	HISDESAT	VANDENBERG	FALCON 9
3/6/18	HISPASAT	CAPE CANAVERAL	FALCON 9
3/30/18	IRIDIUM (FLIGHT 5)	VANDENBERG	FALCON 9
4/2/18	NASA RESUPPLY TO ISS (FLIGHT 14)	FLORIDA LAUNCH SITE	DRAGON/FALCON 9
4/18/18	NASA (TESS)	CAPE CANAVERAL	FALCON 9
5/11/18	BANGABANDHU SATELLITE-1	FLORIDA LAUNCH SITE	FALCON 9
5/22/18	IRIDIUM-6/GRACE-FO	VANDENBERG	FALCON 9
6/4/18	SES (SES-12)	CAPE CANAVERAL	FALCON 9

U.S. government procurements are highlighted in blue. Explicit COTS milestones that were cost shared are highlighted in green.

Source: SpaceX website: *https://www.spacex.com/missions*

B. Federal Power Purchase Agreements for Advanced Reactors

The federal government is the largest consumer of energy in the United States.[50] In FY 2015, the federal government spent $21.3 billion on energy and consumed 947 billion BTUs.[51] Nearly 62% of energy use went to vehicles and equipment, with the rest consumed by buildings and other facilities. As Figure 9 shows, electricity constituted nearly 75% ($4.5 billion) of energy spending by federal buildings and facilities in FY 2017, though fossil fuels were also used for heating purposes. U.S. government consumption of electricity at federal facilities in FY 2017 was 53 TWh.

As Figure 10 shows, the largest consumer of electricity for buildings and facilities is DOD, comprising 56% of electricity use. DOE was the second-largest consumer of electricity, followed by the U.S. Postal Service and the U.S. Department of Veterans Affairs. (NASA was seventh.)

Typically, federal installations in the United State buy electricity from their local utilities without preference to the type of energy source. The federal installation is then powered by whatever mix of fossil, nuclear, hydro-electricity, and renewable energy is present in the region.

However, the federal government has at times procured energy specifically from renewable energy projects in response to legislative targets, executive orders, and policy direction. For example, the U.S. Navy procured 150 MW_e of solar power for 25 years from a developer in Arizona for 12 naval installations in California.[52]

Section 203 of EPACT05 set renewable energy targets for the federal government to meet by certain dates:

> SEC. 203. FEDERAL PURCHASE REQUIREMENT.
> (a) REQUIREMENT.—The President, acting through the Secretary, shall seek to ensure that, to the extent economically feasible and technically practicable, of the total amount of electric energy the Federal Government consumes during any fiscal year, the following amounts shall be renewable energy:
> (1) Not less than 3 percent in fiscal years 2007 through 2009.
> (2) Not less than 5 percent in fiscal years 2010 through 2012.
> (3) Not less than 7.5 percent in fiscal year 2013 and each fiscal year thereafter.

50 Kutak Rock and Scully Capital, "Purchasing Power Produced by Small Modular Reactors: Federal Agency Options," 2017.

51 *https://www.energy.gov/sites/prod/files/2018/01/f46/fy15_annual_report.pdf*

52 *https://www.pv-magazine.com/2015/08/19/us-navy-to-sign-its-largest-solar-ppa-at-150-mw-ac_100020672*

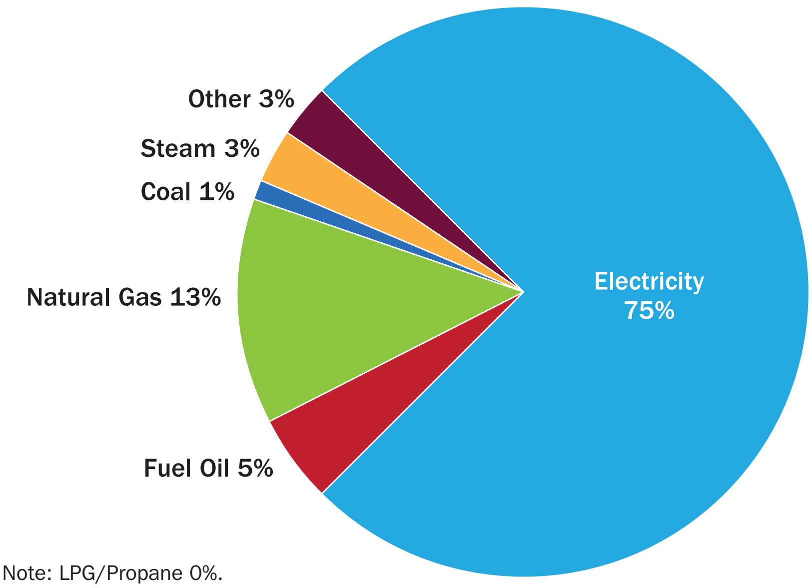
The National Defense Authorization Act for Fiscal Year 2007 also amended Section 2911 of Title 10 of the United States Code to establish a goal for DOD to produce or procure not less than 25 percent of the total energy it consumes within its facilities from renewable energy sources in fiscal year 2025 and thereafter.

In 2015, President Obama issued Executive Order 13693 (since revoked), and Section 3 of that order directed the head of each federal agency "where life-cycle cost-effective, beginning in fiscal year 2016" to

> (b) ensure that at a minimum, the following percentage of the total amount of building electric energy and thermal energy shall be clean energy, accounted for by renewable electric energy and alternative energy:
> (i) not less than 10 percent in fiscal years 2016 and 2017;
> (ii) not less than 13 percent in fiscal years 2018 and 2019;
> (iii) not less than 16 percent in fiscal years 2020 and 2021;
> (iv) not less than 20 percent in fiscal years 2022 and 2023; and
> (v) not less than 25 percent by fiscal year 2025 and each year thereafter;
>
> (c) ensure that the percentage of the total amount of building electric energy consumed by the agency that is renewable electric energy is:
> (i) not less than 10 percent in fiscal years 2016 and 2017;
> (ii) not less than 15 percent in fiscal years 2018 and 2019;
> (iii) not less than 20 percent in fiscal years 2020 and 2021;
> (iv) not less than 25 percent in fiscal years 2022 and 2023; and
> (v) not less than 30 percent by fiscal year 2025 and each year thereafter;

The combination of legislative requirements and executive order targets led to an increase in federal agencies purchasing power from renewable energy projects. In FY 2015, the federal government's renewable energy procurements were 8.3% of its electricity consumption, thus meeting the legislative target in EPACT05.[53]

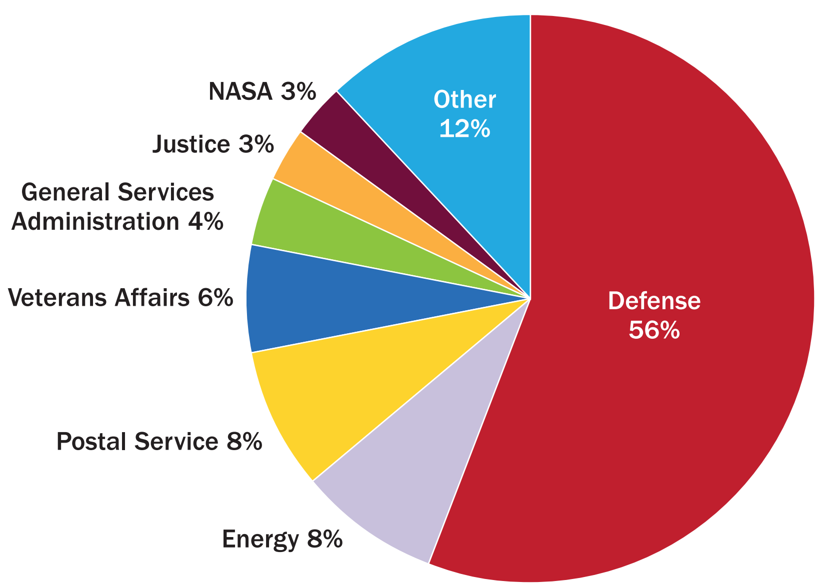
FIGURE 9
Government-Wide Energy Costs for Federal Buildings and Facilities in FY 2017



Note: LPG/Propane 0%.

Source: U.S. Department of Energy

FIGURE 10
Largest Electricity Consumers Among Federal Agencies in FY 2017



Percentage of government-wide facility electricity use by agency.

Source: U.S. Department of Energy

53 *https://www.energy.gov/sites/prod/files/2018/01/f46/fy15_annual_report.pdf*

While energy from new small modular reactors qualified as alternative energy in Section 3(b) of Executive Order 13693, the high levels of renewable energy specified in Section 3(c) meant that a far smaller amount of energy was demanded from alternative energy sources such as SMRs and power plants utilizing carbon capture and sequestration.

The combination of legislative requirements and executive order targets led to an increase in federal agencies purchasing power from renewable energy projects.

In 2017, Kutak Rock and Scully Capital produced reports for DOE that broadly evaluated authorities for federal installations to purchase power from new SMR projects.[54] In particular, the two reports provided case studies of the specific mechanisms available to federal facilities to purchase power from the SMR projects that the two utility cost-share partners (UAMPS and TVA) in DOE's SMR LTS program are pursuing.

As Kutak Rock and Scully Capital discussed, 10 U.S.C. Section 501 of U.S. law limits federal facilities to purchasing power for periods of time no greater than 10 years. In general, the GSA allows federal installations to purchase energy up to five years in advance, though it has delegated 10-year authority to DOE. DOD has 30-year authority to purchase power under specific conditions from 10 U.S.C. Section 2922a. The length of time for a power purchase agreement is important to power plant developers in that the amortization of the loan repayment periods for most new base-load power facilities, including nuclear plants, are typically much longer than 10 years.

The DOE Quadrennial Energy Review from 2017 recommended that Congress authorize all federal agencies to negotiate 20-year power purchasing authorities for clean energy:

> **Increase power purchasing authorities for the Federal Government from 10 to 20 years.** The Federal Government is currently subject to goals and mandates for the purchase of clean energy which, if achieved, can help to catalyze action in the private, state, and local sectors. However, widespread Federal Government clean energy purchases are constrained by generally applicable procurement rules that prohibit entering long-term contracts. Congress should authorize all Federal agencies to negotiate 20-year power purchasing authorities for clean energy.

The Nuclear Innovation Alliance recommended in late 2017 that Congress enable federal facilities to enter into power purchase agreements for low-emission technologies for periods of 20 years or greater.[55] In 2019, S.903 was introduced in the U.S. Senate, and Section 2 of S.903 would authorize the federal government to purchase energy for up to 40 years (regardless of the type of energy).[56] S.1274 from the 114th Congress and HR.6538 from the 115th Congress would have authorized federal facilities to enter into power purchase agreements for renewable energy for up to 30 years by amending the National Energy Conservation Policy Act.

As an example of how the federal purchase of power from an advanced reactor demonstration project could work, the utility group UAMPS has targeted $65/MWh as the rate it would pay for power from the SMR project that it is developing at the Idaho National Laboratory (INL).[57] DOE's Office of Nuclear Energy recently announced a Memorandum of Understanding between DOE, UAMPS, and Battelle Energy Alliance (the operator of INL) which highlights the Department's intent to use two modules from the NuScale Power plant for research and providing power to INL.[58] Power from that project could also be purchased by other DOE or DOD facilities in the western United States. The Western Area Power Administration services DOE and DOD facilities in the west

54 Kutak Rock and Scully Capital, "Purchasing Power Produced by Small Modular Reactors: Federal Agency Options," 2017. Kutak Rock and Scully Capital, "Small Modular Reactors: Adding to Resilience at Federal Facilities," 2017.

55 Nuclear Innovation Alliance, "Leading on SMRs," 2017.

56 *https://www.congress.gov/bill/116th-congress/senate-bill/903*

57 *https://www.publicpower.org/periodical/article/uamps-sees-cost-and-safety-benefits-with-nuscale-smr-technology*

58 *https://www.energy.gov/ne/articles/doe-office-nuclear-energy-announces-agreement-supporting-power-generated-small-modular*

and is capable of delivering power from an advanced reactor to federal facilities in the region, including facilities in New Mexico and California. For example, the Los Alamos County Utility Department in New Mexico, which serves Los Alamos National Laboratory, is a member of UAMPS and could potentially take power from the SMR project in Idaho.[59]

Future advanced reactor projects could also benefit from federal power purchase agreements. Table 7 shows the largest electricity consumers in the DOE complex. Another type of procurement could involve process heat. As Figure 9 showed, the federal government uses a substantial amount of fossil energy for heating purposes at its facilities and some of that energy could be replaced by zero-carbon heat from an advanced reactor.

TABLE 7
DOE Facilities that Consumed the Most Electricity in FY 2015

Facility	GWh
Oak Ridge National Laboratory	453
Fermi National Accelerator Laboratory	430
Los Alamos National Laboratory	425
Lawrence Livermore National Laboratory	400
Savannah River Site	319
Sandia National Laboratory – New Mexico	272
Y-12	270
Argonne National Laboratory	262
Brookhaven National Laboratory	258
Portsmouth Gaseous Site	244
Idaho National Laboratory – Scoville	220
Stanford Linear Accelerator Center	155
Richland Operations Office	145
Thomas Jefferson National Accelerator Facility	141
Lawrence Berkeley National Laboratory	108
Bonneville Power Administration	90
Kansas City Plant	89
Pantex Plant	72
Bettis Atomic Power Laboratory	70
Pacific Northwest National Laboratory	68

Note: For reference, a single 60 MW_e NuScale Power Module would be expected to produce just under 500 GWh of electricity each year, assuming a capacity factor of 92%.

Source: Kutak Rock and Scully Capital, "Purchasing Power Produced by Small Modular Reactors: Federal Agency Options," 2017.

C. Other Federal Government Missions

A completely separate instance where the government could be the first customer for a new reactor design is the plutonium disposition program at DOE. The United States government has assessed that it has over 60 metric tons of surplus plutonium from its nuclear weapons program.[60] As part of a nonproliferation initiative, the United States and the Russian Federation signed the Plutonium Management and Disposition Agreement (PMDA) in 2000, which was later amended in 2010. As part of the PMDA, the United States plans to dispose of 34 metric tons of surplus weapons-grade plutonium by converting it to a form that would prevent it from being used in nuclear weapons in the future.[61]

The National Academy of Sciences published a study in 1994 on plutonium disposition strategies.[62] The study recommended that options for the long-term disposition of weapons plutonium should seek to meet a "spent fuel standard" where the goal is "to make the plutonium roughly as inaccessible for weapons use as the much larger and growing quantity of plutonium that exists in spent fuel from commercial reactors." In 2002, DOE announced that it was conducting reviews of a mixed-oxide (MOX) only approach. This pathway would involve the production of MOX fuel from the surplus plutonium with subsequent irradiation in existing light water reactors.

As part of that approach, the United States was planning to construct a MOX Fuel Fabrication Facility in South Carolina to produce fuel suitable for use in a commercial light water reactor. However, due to rising costs associated with the MOX program, the Obama Administration cancelled the program and proposed an approach that involved diluting the plutonium and disposing of it at the Waste Isolation Pilot Program site ("dilute and dispose"). The Trump Administration signaled in its FY 2018 budget request that it would also pursue

59 *https://www.losalamosnm.us/government/departments/utilities/top_features/carbon_free_power_project___small_modular_nuclear*

60 DOE, Final Surplus Plutonium Disposition Supplemental Environmental Impact Statement. EIS-0283-S2. Washington, DC.

61 Congressional Research Service, "Mixed-Oxide Fuel Fabrication Plant and Plutonium Disposition: Management and Policy Issues," December 14, 2017.

62 *https://www.nap.edu/catalog/2345/management-and-disposition-of-excess-weapons-plutonium*

a dilute and dispose option. The National Academy of Sciences recently published an interim report on this approach which identified several barriers to implementation of DOE's current conceptual plans:[63]

- Insufficient current statutory and current physical capacity within WIPP for disposal of 34 MT of diluted plutonium throughout the lifetime of the dilute and dispose project.
- Unclear strategy for development of the National Environmental Policy Act (NEPA) environmental impact statement for disposing of 34 MT of surplus plutonium in WIPP using the dilute and dispose process.
- Lack of Russian Federation approval for dispositioning 34 MT of surplus plutonium using the dilute and dispose process to meet the requirements of the PMDA.

Russia plans to dispose of plutonium by consuming it in sodium fast reactors.

By contrast, Russia plans to dispose of plutonium by consuming it in sodium fast reactors. Among others, Dr. Peter Lyons, a former Assistant Secretary for Nuclear Energy and NRC Commissioner, has suggested that the United States and DOE do the same and build an advanced reactor to destroy the plutonium.[64] This could accomplish two U.S. goals at the same time: fulfilling a nonproliferation commitment to destroy weapons-grade plutonium and advancing nuclear power technology as a resource capable of meeting the nation's energy and environmental goals. An advanced reactor could also serve other missions, such as target irradiation for isotope production, including plutonium-238 for NASA missions.[65]

A technician places a full-size test fuel pin bundle in TerraPower's pin duct interaction test apparatus.

63 National Academies of Sciences, Engineering, and Medicine, "Disposal of Surplus Plutonium at the Waste Isolation Pilot Plant: Interim Report," 2018.

64 *https://www.politico.com/agenda/story/2018/02/07/russia-not-disposed-plutonium-000641*

65 *https://rps.nasa.gov/about-rps/about-plutonium-238/*

CHAPTER IV

INDUSTRY SURVEY ON ADVANCED REACTOR DEMONSTRATION

The previous two chapters have described past federal government programs to accelerate complex technologies, and how the federal government could accelerate reactor development and first-of-a-kind demonstration. This chapter presents the results of an industry survey to provide additional detail on what types of assistance might be necessary for the federal government to accomplish the goals laid out in the three pieces of legislation from the 115th Congress and the 2019 Nuclear Energy Leadership Act (S.903). These bills set a goal for the U.S. Department of Energy to demonstrate at least four advanced reactor concepts. What the Secretary of Energy considers to be an advanced reactor demonstration and also which advanced reactor concepts are the ones to be demonstrated will affect the total amount of federal resources needed to accomplish these goals.

A. Related Congressional Legislation

In the 115th Congress (2017-2018), several bills were introduced that set goals for advanced reactor demonstration. S.1457, S.3422, and HR.5260 all would have required the Secretary of Energy to enter into one or more agreements to carry out at least four advanced nuclear reactor demonstration projects. S.3422 also contained this language, as well as provisions to extend the federal government's authority to make long-term power purchase agreements from terms of 10 years to 40 years, and other provisions. In addition, S.3422 would have required the Secretary of Energy to enter into a power purchase agreement with a nuclear power plant by 2023. The report language accompanying the Senate Energy and Water Appropriations bill for 2018, S.1609, contained the following direction to DOE:

> Advanced nuclear technologies hold great promise for reliable, safe, emission-free energy and should be a priority for the Department. Absent a clear set of goals for completing a program that demonstrates new technology can be deployed, the Department will continue to research concepts that never make it to the marketplace. The Committee directs the Department to provide a report to Committees on Appropriations of both Houses of Congress within 180 days of the date of enactment of this act that sets aggressive, but achievable goals to demonstrate a variety of private-sector advanced reactor designs and fuel types by the late 2020s. The report shall include anticipated costs, both Federal and private, needed to achieve the goals. The Department shall collaborate with national laboratories, nuclear vendors, utilities, potential end users (such as petrochemical companies), and other stakeholders to identify subprogram priorities necessary to meet the identified goals.

In 2019, S.903 was introduced, which would also require the Secretary of Energy to demonstrate four advanced reactor concepts. The aims of the survey discussed below are to provide information on the costs of advanced reactor development and demonstration as well as the federal support mechanisms that might be most useful.

B. Industry Survey Results

The Nuclear Innovation Alliance performed an industry survey that was used to gather information on estimated resource requirements needed to demonstrate various advanced reactor concepts. Survey questions (shown in Appendix A) were sent to advanced reactor companies, which provided responses to the survey (under the condition of anonymity) regarding 13 reactor designs. The results of the survey are described below.

The first question in the survey asked what the companies would consider to be their "demonstration reactor." Half of the companies surveyed stated that their "demonstration reactor" would be the first commercial-scale reactor. The other half intend to first build a smaller-scale reactor in order to test expected science and engineering behaviors for later commercial-scale deployment. In some cases, this smaller-scale reactor would still be used for electricity, heat, or medical isotope production, or another function.

As Figure 11 shows, the reactor companies surveyed are pursuing a wide range of thermal outputs for their commercial-scale reactors. (For reactor plants composed of a variable number of reactor "modules," the power output of a single reactor module is shown.)

For the companies planning to first build a smaller-scale reactor as their "demonstration reactor," the range of thermal outputs for the demonstration was correspondingly smaller: 4 MW_{th} to 750 MW_{th}, with an average of 161 MW_{th}.[66]

Companies also indicated that they were considering several different licensing pathways, including 10 CFR Part 50 and 10 CFR Part 52 commercial power licenses with or without the use of NRC prototype provisions, and also non-power/medical isotope licenses. Some companies indicated that they had not yet decided which licensing pathway was optimal for them. Most companies that had not already entered NRC license review were willing to consider DOE (10 CFR Part 830) oversight in lieu of NRC licensing where that was possible, and pointed out various advantages and disadvantages of each option. For example, stated advantages of DOE oversight included:

- Well-suited to accommodating advanced reactors and more flexible
- Well-suited to a demonstration at a national lab
- Appropriate for simpler design and/or non-nuclear prototype as part of safety case

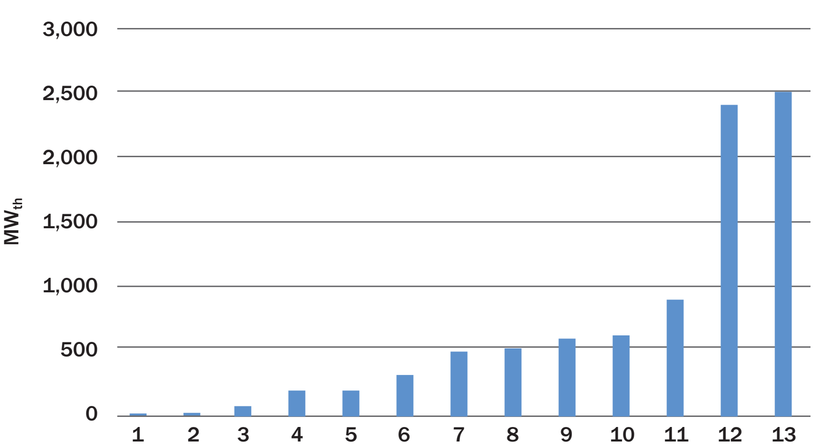
Stated disadvantages included:

- May not provide a revenue option demonstration plant
- Less useful than an NRC license in an export market
- Requires two licensing pathways for domestic deployment, with additional costs and delays
- DOE regulations have not been exercised under this type of approach before, introducing risk

One respondent suggested that the development of a defined path forward for transition from DOE oversight into NRC license would make this more feasible.

The survey asked companies to estimate what the cost was for design, licensing and first-of-a-kind engineering for their demonstration reactor. (Many companies had already spent some of this money.) Given the different stages of each concept's development, as well as the size of the intended demonstration project, the costs of development varied considerably: a range of roughly $50M to $1600M with an average of $720M. The estimated cost to construct each company's demonstration reactor ranged from roughly $100M to $3B, with an average of $1.2B. The smaller reactors fell on the less costly side to both develop and demonstrate. Estimated construction timelines to build the demonstration reactor mostly fell between 2.5 and 5.5 years, with an average of about four years. Some

FIGURE 11
Survey Results: Commercial Reactor Module Power Outputs



Source: Nuclear Innovation Alliance 2018 industry survey

66 For light water reactors, the conversion efficiency of thermal heat to electricity production is around 33%; for higher temperature designs, that efficiency may be closer to 50%.

companies estimated that in a factory setting, a module could be built in six months.

Companies were asked what type of federal support they judged was needed to attain the development timelines similar to what is stated in congressional legislation. For development, licensing and first-of-a-kind engineering activities, companies generally estimated that between a 50% and 80% federal cost share—depending on the stage of development—would be sufficient to attract the necessary private sector share. For the construction of advanced reactor demonstration projects, companies had a range of estimated federal support mechanisms they thought would be needed to meet the congressional timelines, including cost sharing, loan guarantees, tax incentives, or power purchase agreements. One suggestion was that the federal government provide assistance needed to close the economic gap with natural gas combined cycle generation. For companies that listed cost-shared assistance as a possible mechanism to support the actual construction of a demonstration reactor, most thought that a 50% federal share was the appropriate level. One company thought that DOE should focus instead on cross-cutting infrastructure, including access to siting, fuel fabrication, high-assay, low-enriched uranium fuel availability, and legacy data support.

All of the companies surveyed expressed an openness to building their demonstration reactor at a DOE site, and some indicated reasons why they thought there would be advantages to doing so, including co-location of relevant experts and facilities, greater site characterization (i.e., potentially easier siting), greater local public support, potentially reduced security and access costs, and the federal facility potentially taking power or heat from the demonstration.

The results of the survey provide at least an order of magnitude estimate for what a federal program is likely to need in order to be successful at demonstrating advanced reactor concepts similar to target dates in congressional legislation. The results do pose a challenge to decision making in the federal government, as the smaller reactor options may cost substantially less to support their initial development and construction, making them an attractive option for reasons of federal cost share. However, the economics of both small and large reactors are uncertain and either could end up more economical in the long run. This report does not attempt to weigh in on which option is likely to be more economical.

The results provide an estimate for what a federal program is likely to need in order to demonstrate advanced reactor concepts as called for in congressional legislation.

Companies were also asked what type of criteria they thought the Secretary of Energy should use in deciding what technologies to demonstrate. The list of criteria mentioned by participating companies varied widely, but included (in no particular order):

- Completion of third-party design reviews that evaluate the design maturity, design completeness, and risks to licensing and construction
- Long-term viability and cost competitiveness
- Nonproliferation considerations
- Waste stream characteristics
- Advanced safety features
- Technology readiness levels
- Thermal efficiency
- Designs that do not require large supplies of cooling water
- Screening reviews for licensability in given demonstration locations
- Availability of a first customer (government or private)
- Transformational nature (impact on how nuclear power is deployed and how widely)
- Potential for exports
- Existence of an NRC regulatory engagement plan
- R&D complexity
- Viability and availability of a U.S.-based supply chain
- Level of private investment

Participating companies were also asked about other types of support that the federal government could provide in order to support advanced reactor demonstration. The answers included:

- Loan guarantees
- Long-term power purchase agreements (20–40 years)
- Leveling the playing field on the electrical grid (e.g., priority dispatch)
- Provision of high-assay, low-enriched uranium
- Provision of irradiation and post-irradiation examination facilities
- Fast neutron source/facility

- Tax credits (production and research investment; some analogous to oil and gas industry incentives, including an untaxed portion of nuclear plant generation output)
- Fuel and materials qualification
- Development of computer codes for modeling
- Government flexibility on intellectual property/ proprietary rights
- More efficient NRC licensing process
- Private limited partnership (e.g., allow accelerated deduction on large portions of investment; treat nuclear plant operational profits as long-term capital gains)

The federal resources needed to demonstrate four advanced reactor technologies in the future will necessarily depend greatly on which reactor concepts are demonstrated.

One company thought that DOE should not enter into cost-share agreements for development and licensing, and should instead focus on cross-cutting infrastructure development, such as high-assay, low-enriched uranium infrastructure.

Finally, some companies had participated in previous DOE cooperative agreement programs and were asked what had worked well, not worked well, and what could be improved in the future.

When asked how valuable previous DOE programs were, responses included that they were "critical" and "extremely valuable," and helped to accelerate technology and licensing development by multiple years. When asked what worked well as part of the agreements, responses included:

- DOE Office of Nuclear Energy was flexible in tailoring the agreement to maintain or accelerate the work scope
- The DOE national laboratories provided valuable expertise and assistance

When asked what did not work well, responses included:

- Substantial effort expended to comply with administrative and financial requirements
- Bureaucratic challenges in working with DOE and the national laboratories

Finally, companies were asked what could make future programs better and suggestions included:

- Milestone-based set of payments that do not rely upon submission and audit of paid invoices and payroll accounting systems
- Greater flexibility for use of foreign services, facilities or products

C. Implied Resource Requirements and Associated Uncertainties

Given the range of responses in the previous sub-chapter, the federal resources needed to demonstrate four advanced reactor technologies in the future will necessarily depend greatly on which reactor concepts are demonstrated. The uncertainties in the cost estimates of individual first-of-a-kind demonstration reactors are not possible to quantify here and this report does not attempt to do so.[67] The reactor designs themselves are at varying stages of completion and some may change, which could have cost implications.

Those caveats aside, the rest of this chapter provides a rough estimate of the magnitude of federal resources that may be needed to accomplish the goals set out in congressional legislation.

Proposed legislation would direct the Secretary of Energy "to the maximum extent practicable" to enter into agreements to demonstrate at least four advanced reactor technologies.

DOE has in recent years been reconsidering its approach to the disposition of surplus weapons-grade plutonium from its nuclear weapons program. As discussed in Chapter III, the U.S. government had reached agreement with the Russian Federation to each "destroy" plutonium from their respective nuclear weapons programs. The United States specifically committed to destroying 34 metric tons of weapons grade plutonium, and the initial method of choice was converting it into MOX fuel to be burned in light water reactors. However, after schedule delays and cost overruns, the Department proposed in 2014 to instead "dilute and dispose" of the plutonium. As part of the deliberations, the Department did consider the construction of an

67 See pages 70-75 of MIT's 2018 report, "The Future of Nuclear Energy in a Carbon Constrained World," for a discussion of uncertainties in advanced reactor cost estimates.

68 "Report of the Plutonium Disposition Working Group: Analysis of Surplus Weapon-Grade Plutonium Disposition Options," Department of Energy, April 2014.

advanced reactor as an alternative,[68] and more recently this approach has been advocated by Dr. Pete Lyons, former NRC Commissioner and DOE Assistant Secretary for Nuclear Energy.[69]

If the plutonium disposition campaign were re-oriented to a reactor disposal option, the federal support mechanisms might be in a government procurement model, albeit with majority financial support presumably coming from the National Nuclear Security Administration, rather than the Office of Nuclear Energy. Some of the advanced reactors described in Chapter I could consume plutonium, and the additional costs for commercial development would center around fuel fabrication and other technical differences between using commercial uranium fuels versus plutonium-based fuels for a disposition campaign.

Proposed legislative language requiring the Secretary of Energy to demonstrate advanced reactor technologies could be interpreted to mean loan guarantees and power purchase agreements, so long as those were supportive enough to result in construction of a demonstration plant. The Department's Office of Loan Guarantee Programs has $8.8 billion remaining in loan guarantee authority for advanced nuclear.[70] Kutak Rock and Scully Capital have studied how the federal government could take power from advanced reactor projects through the use of power purchase agreements.[71] The Nuclear Innovation Alliance has suggested that the federal government could request proposals from advanced reactor companies to supply some amount of power to federal facilities.[72] For utilities considering a nuclear power plant versus a natural gas combined cycle plant, the difference in levelized cost of electricity for public power entities may be on the order of 1.5-2 cents/kWh and federal power purchase agreements that compensated for carbon-free or secure power could help a utility to instead choose the more secure, zero-carbon option.[73] The Breakthrough Institute, ClearPath, and the R Street Institute recommended in 2018 that Congress establish a pilot program for utilizing power purchase agreements to procure power from advanced reactors, and estimated that above-market rate agreements for the first microreactors could cost $2 billion over 10 years for four reactor vendors to build their first three units.[74]

Some companies indicated that they were not looking for cost sharing of the construction of their demonstration reactor, but were instead looking to use the DOE loan guarantee program, tax credits, or power purchase agreements to assemble the financing needed to demonstrate their concept.

As a rough estimate, a 50% cost share on the average estimate of $720M in development costs for an advanced reactor concept over 10 years would imply a $36M/year commitment. For three to four concepts, this would imply a range of $108M/year to $144M/year cost-share effort within the DOE Office of Nuclear Energy. There is substantial uncertainty associated with this range for a variety of reasons. Apart from uncertainties associated with the estimates themselves, the wide range of development costs cited above would push these numbers up or down depending on the specific reactor concepts chosen to develop.

Some companies indicated that they were not looking for cost-sharing of the construction of their demonstration reactor, but were instead looking to use the DOE loan guarantee program, tax credits, or power purchase agreements to assemble the financing needed to demonstrate their concept. Other companies indicated an interest in cost sharing the construction of a demonstration unit. The average construction cost of $1.2B cited above for demonstration reactors, if averaged over a

69 *https://www.politico.com/agenda/story/2018/02/07/russia-not-disposed-plutonium-000641*

70 *https://www.energy.gov/lpo/advanced-nuclear-energy-projects-solicitation;* Secretary Perry has announced that DOE would provide an additional $3.7 billion to the Vogtle project, leaving $8.8 billion for other advanced nuclear projects: *https://www.energy.gov/articles/secretary-perry-announces-financial-close-additional-loan-guarantees-during-trip-vogtle*

71 Kutak Rock and Scully Capital, "Purchasing Power Produced by Small Modular Reactors: Federal Agency Options," 2017.

72 Nuclear Innovation Alliance, "Leading on SMRs," 2017. Page 39.

73 Table 1 on page 21 of the "Leading on SMRs" estimates a 1.5 cents per kWh difference between SMRs and NGCC plants based on public power financing. Page 52 of the 2017 report by Kutak Rock and Scully Capital, "Small Modular Reactors: Adding to Resilience at Federal Facilities," estimates a 2.4 cents/kWh difference or, accounting for resiliency benefits, a 1.8 cents/kWh gap between SMRs and NGCC plants as a notional customer cost analysis for Oak Ridge National Laboratory.

74 Breakthrough Institute, ClearPath, R Street Institute, "Planting the Seeds of a Distributed Nuclear Revolution," 2018.

construction period of four years, would imply a commitment of $150M/year in federal resources to demonstrate a given advanced reactor concept. For similar reasons to the uncertainty involved in the development cost estimates discussed above, there is also substantial uncertainty to this estimate.

It should be clear from the arguments and estimates above that cost sharing the development and demonstration of a micro-reactor at a federal facility and using that demonstration to ultimately provide electricity and/or heat to the given federal facility would likely be a less expensive pathway than supporting a demonstration of a gigawatt-scale technology. However, the economics and markets are different for both classes of reactors and at this point there is not a clear indication which investment would provide the highest chance of commercial success or which investment would provide the greatest potential for worldwide supply of zero-carbon energy. It should be possible to demonstrate both in a DOE program.

Taken together, these rough estimates of federal resource requirements are consistent with historical Office of Nuclear Energy budgets.

Without picking small versus large, and instead using averages, a rough estimate of DOE Office of Nuclear Energy resources could look like:

- cost-sharing technology development of three to four designs at $36M/year each over the next 10 years (the first case assumes a reactor for plutonium disposition is counted as the fourth demonstration)
- cost-sharing assistance for construction of two demonstration reactors at DOE sites at $150M/year each following 2028 for a period of four years[75]
- Two 100 MW_e power purchase agreements costing 2 cents/kWh (to cover a potential gap in cost with natural gas combined cycle plants) or $35M/year starting in 2033

The resources described above are meant as one illustration of the type of resources that could be used to demonstrate four advanced reactor concepts —they are not budget recommendations. Within the Office of Nuclear Energy's roughly $1B/year budget, however, the technology development cost estimates above are in the same realm as previous DOE program (e.g., NP2010 and SMR LTS) budgets. DOE has not in recent decades cost shared the construction of demonstration reactors at its sites, and this would be a new undertaking. If more than two advanced reactor concepts are looking to utilize the DOE Loan Guarantee Program, the estimated remaining $8.8B in authority may not be sufficient. Assuming that the AP1000 projects in Georgia take up 2200 MW of the available 6000 MW in production tax credits, the remaining 3800 MW may be sufficient to provide some support to potentially up to four advanced reactor demonstrations if each demonstration is producing electricity. Alternately, the construction of a micro-reactor could be a cost-shared project at relatively low additional cost. Taken together, these rough estimates of federal resource requirements are consistent with historical Office of Nuclear Energy budgets.

A recent report estimated that the federal government has provided more than $51B in incentives over the last decade to help deploy renewable technologies.[76] Those subsidies have helped renewable energy technologies reach manufacturing scale and bring down costs. No advanced reactor technologies have reached manufacturing scale in the United States, but a program such as the one roughly described above could help demonstrate new dispatchable and affordable zero-carbon energy technologies to help supply energy to the world's economies and mitigate the risk posed by climate change.

75 The 2019 Nuclear Energy Leadership Act, S.903, has different timelines for the demonstration goals than previous legislation, which would shift some of these dates.

76 Kutak Rock and Scully Capital, "Examination of Federal Financial Assistance in the Renewable Energy Market," October 2018.

CHAPTER V

OBSERVATIONS AND RECOMMENDATIONS

Two of the biggest challenges in demonstrating new advanced nuclear energy technologies are: 1) assembling the investment needed to complete the design, licensing, and first-of-a-kind engineering work, and 2) financing the construction of the demonstration reactor. In general, investors are looking for a shorter period of time for a return on their investment and U.S. utilities would prefer to be the second or Nth customer for a new advanced reactor design, rather than the first customer for a first-of-a-kind concept.

The approach that NASA took to partnering with private companies could apply to DOE advanced reactor development in helping to overcome these challenges: flexible agreements to cost share industry-proposed milestones in parallel with the federal procurement program serving as at least a partial first customer. To accomplish this, the federal government could set forth policies that orient federal facilities towards taking power or heat from advanced reactor projects, just as NASA procured services from SpaceX in the CRS program. These procurements could be an important lever to accelerate commercial availability of advanced reactor designs, and the Executive Branch and Congress should work together in this regard. This chapter recommends actions for the federal government to take in order to help accomplish these goals.

NASA's programs to assist private companies like SpaceX produced a result that is exactly analogous to what DOE's advanced reactor programs should be aiming for: to invert the position of the United States in a geostrategically important industry through innovation and cost reduction. As this report has argued, an examination of how NASA partnered with and procured services from SpaceX is useful for considering what DOE could do differently to assist advanced reactor demonstration. However, this chapter also discusses the differences between the global and domestic launch service market for rockets and the electricity market for advanced reactors.

NASA's programs produced a result that is exactly what DOE's advanced reactor programs should be aiming for: to invert the position of the United States in a geostrategically important industry through innovation and cost reduction.

A. Limits to the Analogy

To begin with, the federal government makes up a larger percentage of the launch services market in the United States than it does for the U.S. electricity market. While a federal facility (e.g., a DOE national laboratory) could easily take all of the power from a micro-reactor on the order of several megawatts, as the size of the advanced reactor demonstration project grows, any nearby federal installations would likely be taking a smaller and smaller percentage of the total power output. That would still likely be helpful to the success of the demonstration project, but it is different than the federal government procuring an entire rocket launch (or a dozen launches).

Another difference is that without the development of advanced reactors, federal installations will still have multiple options for obtaining electricity. It is also a mission need of NASA and the federal government to launch satellites and transport supplies and astronauts to the ISS, while it is not currently a mission of the federal government to procure nuclear energy or zero-carbon energy. (The legislation and executive orders proposed in this report, however, would alter federal agencies' requirements.)

Even after a successful demonstration, advanced reactor companies will have to find additional customers to achieve broader success, and those subsequent customers will have a variety of non-nuclear options for electricity generation, in addition to any other nuclear options. In other words, electricity is a commodity and there are many ways to produce it: currently, only rockets will get you to space.

There are other limits to the analogy, including regulatory regimes, but this report judges that the differences do not ultimately argue against the federal government using similar programmatic elements for advanced reactor development. On the contrary this report argues that borrowing elements from NASA's initiatives, such as COTS, to assist DOE in its efforts to develop advanced nuclear reactors would be valuable and should be pursued. To that end, the remainder of this report recommends actions for Congress and the Executive Branch. Some of the recommendations below are not specific to nuclear energy and instead apply to all zero-carbon energy sources.

Borrowing elements from NASA's initiatives, such as COTS, to assist DOE in its efforts to develop advanced nuclear reactors would be valuable and should be pursued.

B. Recommendations to Congress and the Executive Branch

Recommendation 1: *DOE should seek one or more consultants with venture capital and/or start-up experience to advise it on the design and implementation of the advanced reactor demonstration program. DOE should also consult with NASA COTS program leadership and experts to gain further understanding of the success drivers in the program, as well as any potential improvements that NASA identified. DOE should identify any statutory restrictions that would prevent it from implementing an innovation-oriented, public-private partnership modeled after the NASA COTS experience.*

Recommendation 2: *Congress should address any statutory restrictions that would prevent DOE from carrying out an innovation-oriented, public-private partnership similar to the NASA COTS program.*

NASA's statutory authority came from the "other transactions" authority in the 1958 Space Act. DOE's authorities are derived from the Atomic Energy Act of 1954, EPACT05, and other legislation. Congress should work with DOE to determine whether there are any statutory restrictions under existing law that would prevent it from implementing a program that is comparable to the NASA COTS program in structure. If DOE identifies any potential problems, Congress should make the needed technical fixes to provide the authority to carry out a milestone-driven advanced reactor program. DOE should be permitted to institute reasonable intellectual property assurances and ease contracting and permitting for demonstrations on DOE sites.

Recommendation 3: *Once any statutory restrictions are addressed, DOE should establish a phased advanced reactor development and demonstration program modelled on the NASA payment-for-milestones approach of partnering with private companies.*

This approach, discussed in greater detail in Chapter II, could provide a management approach that is more similar to the way venture capital firms manage their investments, and one that is more transparent, structured, and enduring for longer-term advanced reactor demonstration. DOE should consult with NASA regarding lessons learned from its partnership with SpaceX and other companies in the COTS program, including the partnerships that ultimately did not lead to successes. For example, it would be useful for DOE to better understand how NASA structured its initial funding opportunity announcement, how it went about selecting partners, how it confirmed that partners had met milestones (or not), and in the case where partners did not meet their milestones, how NASA went about ending partnerships with the private companies and re-competing the remaining amounts of money in their agreements.

Recommendation 4: *Congress should amend either 40 U.S.C. Section 501 or 10 U.S.C Section 2922A to allow all federal facilities to enter into longer-term (e.g., 30 years or more) power purchase agreements for clean energy technologies.*

Amending 40 U.S.C. Section 501 would change the authorities for all federal entities, though the GSA would still have to delegate longer-term authority to individual agencies. Congress could amend Section 501 to allow longer term purchases in general, as S.903 from the 116th Congress would, and then GSA and the White House could work together to determine a policy on longer-term power purchase agreements for clean energy technologies. Amending 10 U.S.C. Section 2922A could provide to other agencies, in particular DOE, an authority that is currently only available to DOD. Either approach would allow at least some federal facilities to take power from clean energy technologies over a time period that better matches loan repayment schedules for new power plants.

Recommendation 5. *Congress should amend Section 203 of the Energy Policy Act of 2005 to require the federal government to purchase higher percentages of clean energy.*

Specifically, Congress should set higher goals for federal facilities to procure all forms of low-emission power. For example, Congress could require federal facilities to procure at least 30% of their power from zero-carbon sources by 2030 or half of their power from the same sources by 2035. Alternately or in addition, Congress could consider amending 10 U.S.C. 2911 to establish similarly higher clean energy goals for DOD than currently exist for renewable energy technologies.

Recommendation 6: *The White House should issue an executive order directing federal agencies to procure energy from low-emission technologies, including nuclear energy.*

The executive order would contain low-emission energy targets (or emission intensity reduction targets). For example, the President could direct that federal building electric energy and thermal energy consumption from zero-carbon energy sources be greater than 25% in 2025 and greater than 30% in 2030.

Recommendation 7: *DOE and DOD should look for opportunities to purchase power and heat from new advanced reactor demonstrations.*

This could include dedicated units that would supply secure power to DOE and DOD facilities. The federal government is the largest consumer of energy in the United States and DOD and DOE consume the most electricity of all federal agencies.

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The NuScale control room simulator.

ABBREVIATIONS

ARC15	Advanced Reactor Concepts 2015
CCiCap	Commercial Crew Integrated Capability
CCDev	Commercial Crew Development
COLA	Combined Construction and Operation License Application
COTS	Commercial Orbital Transportation Services
CRS	Commercial Resupply Services
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EPACT05	Energy Policy Act of 2005
ESP	Early Site Permit
FAR	Federal Acquisition Regulations
GSA	General Services Administration
HTGR	High Temperature Gas Reactor
INL	Idaho National Laboratory
ISS	International Space Station
MOX	Mixed Oxide
MSR	Molten Salt Reactor
NASA	National Aeronautics and Space Administration
NP2010	Nuclear Power 2010
NRC	U.S. Nuclear Regulatory Commission
PMDA	Plutonium Management and Disposition Agreement
SAA	Space Act Agreement
SMR LTS	Small Modular Reactor Licensing Technical Support
TVA	Tennessee Valley Authority

APPENDIX

2018 Industry Survey Questions

Background

Legislation has been introduced (e.g., S.1457/HR.5260) that directs the Secretary of Energy "to the maximum extent practicable" to "enter into one or more agreements" by the end of fiscal year 2028 to "carry out not fewer than 4 advanced nuclear reactor demonstration projects." While the exact year may not match all companies' plans, this survey is intended to gather information about the scale of the resources that would be needed to meet a similar goal, even if, for example, the ultimate date was changed in a future version of the legislation.

Assume that whatever reactor your company is intending to build first is your "demonstration reactor," regardless of size or intent to sell commercial electricity/products. The "demonstration reactor," however, must enable subsequent commercial-scale deployment and attendant NRC licensing as the next step if the demonstration reactor was not licensed by the NRC.

Questions

1. Given the definition above, what would you consider to be your demonstration reactor?
   a. A commercial reactor at your intended ultimate thermal output for either electricity or heat production
   b. A smaller-scale commercial reactor that is still licensed for electricity or heat production
   c. A smaller-scale reactor that is not built to produce commercial electricity or heat
   d. Other—please explain.
2. What is your intended ultimate power output (thermal) for your commercial reactor?
3. If you intend to build a smaller scale reactor first, what do you expect the smaller-scale reactor's power output (thermal) to be?
4. What is your estimated cost for design, licensing and first-of-a-kind engineering work for your demonstration reactor?
5. What is the federal support, and in what form (e.g. cost-share percentage), that you estimate would be needed to sustain the private investment required to complete design, licensing, and first-of-a-kind engineering?
6. What type of criteria/milestones do you think the Secretary needs to specify to enable him or her, should he or she choose to do so, to make a "go/no-go" decision as to whether to enter into an agreement to help build your demonstration reactor?
7. What would you estimate is the construction cost of your demonstration reactor?
8. How long do you expect it will take to construct your demonstration reactor?
9. What do you estimate is the needed federal support, and in what form (e.g., cost-share percentage), to bring sufficient private investment along to successfully construct the demonstration project?

10. What licensing path do you intend to take with your demonstration reactor?
    a. Part 50 – 103
    b. Part 52 – 103
    c. The NRC prototype provision
    d. Other. Please explain

11. Would you be open to building your demonstration reactor at a DOE site? Why or why not?

12. Would you be open to licensing your demonstration reactor under DOE regulations (10 CFR Part 830) rather than NRC licensing? Why or why not?

13. Is there other support, aside from funding, that the federal government either could provide or would need to provide in order to enable your demonstration reactor (e.g. loan guarantees, HA-LEU supply, PPAs)? Please provide details if possible.

Enabling Nuclear Innovation

IN SEARCH OF A SPACEX FOR NUCLEAR ENERGY

NUCLEAR INNOVATION ALLIANCE

A REPORT BY THE NUCLEAR INNOVATION ALLIANCE

The purpose of this report is to propose actions for the U.S. Congress and the Executive Branch that will accelerate the availability of advanced nuclear reactors to meet energy, environmental, and national security goals. The report reviews NASA's successful partnership with the private company SpaceX, whose innovations and cost reductions have led to renewed American leadership in the global launch services market. The report analyzes NASA programs that partnered with private entities such as SpaceX and assesses where the U.S. Department of Energy may be able to benefit from similar strategies in its future advanced reactor programs. NASA and other federal agencies procured services from SpaceX, and the report explores analogous federal procurements for power from advanced reactor projects. Finally, the report presents the results of a survey of advanced reactor companies on the costs associated with advanced reactor demonstration.

Recommendations include an executive order directing federal agencies to procure power from low-emission energy sources, congressional legislation to alter the federal government's authority and mission to procure low-emission power, and public-private partnership structures for the U.S. Department of Energy to pursue with private advanced reactor companies.

info@nuclearinnovationalliance.org • www.nuclearinnovationalliance.org