NASA-COTS, SpaceX, and Advanced Reactor Demonstration

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(All views expressed are those of the author, not CGEP.)

Why Demonstrate Advanced Reactors?

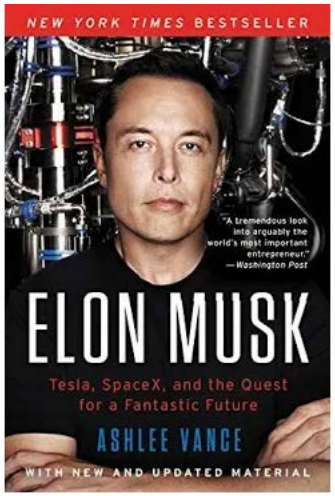
Primary reason: creating dispatchable options for decarbonization

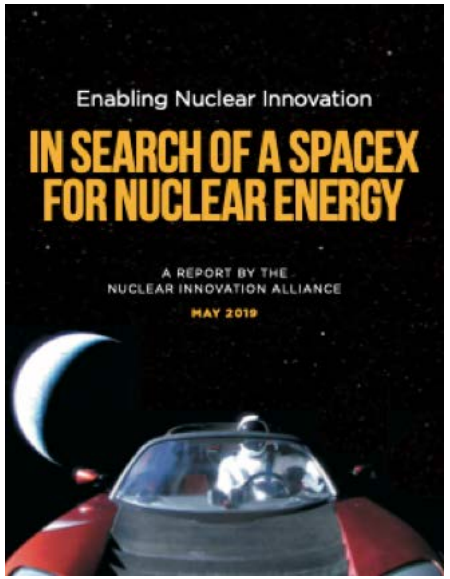
- "A cost-effective, reliable, and decarbonized grid requires firm generating capacity…While today's renewable generation and battery storage technologies will play large roles in the future New England system, relying on these resources alone would require very large quantities of renewables and storage and would be extremely costly… The availability of low-carbon firm generation technologies – such as advanced nuclear or natural gas with CCS – could provide significant cost savings and reduce the pressure of renewable development on New England's lands and coastal waters." – Energy Futures Initiative and E3, "Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future," November 2020. Page 71.
- "At NuScale costs, SMRs reduce the cost of achieving a 100% electric sector GHG reduction by nearly $8 billion per year." – E3, "Pacific Northwest Zero-Emitting Resources Study," Executive Summary, January 29, 2020. Page 8.
- "To achieve net-zero, ZELFR [zero-emitting load following resource] technologies are needed that can respond to dynamic changes in both customer demand and renewable generation. *The next decade is critical because these technologies need to be developed, demonstrated, refined and scaled on a very aggressive timeline to enable timely, cost-effective fossil retirements.* While solar, wind and currently available energy storage have important roles to play now and in the future, as noted above their contribution begins to diminish as higher levels of renewable and storage penetration are reached, and resources capable of following load over long durations become increasingly needed to meet system capacity and energy needs reliably as fossil based resources are retired over time." – Duke Integrated Resource Plan 2020 Biennial Report. Page 140.

See also: Matt Bowen, "Why the United States Should Remain Engaged on Nuclear Power: Climate Change and Air Pollution," Center on Global Energy Policy, June 2020; Matt Bowen, "Why the United States Should Remain Engaged on Nuclear Power: Geopolitical and National Security Considerations," Center on Global Energy Policy, September 2020.

Background to the NIA Report

- In 2018, there were several bills (e.g., S.1457, S.3422, HR. 5260) with advanced reactor demonstration goals
- CBO estimated that implementing S.1457 would cost $12.6 billion over 2019-2028

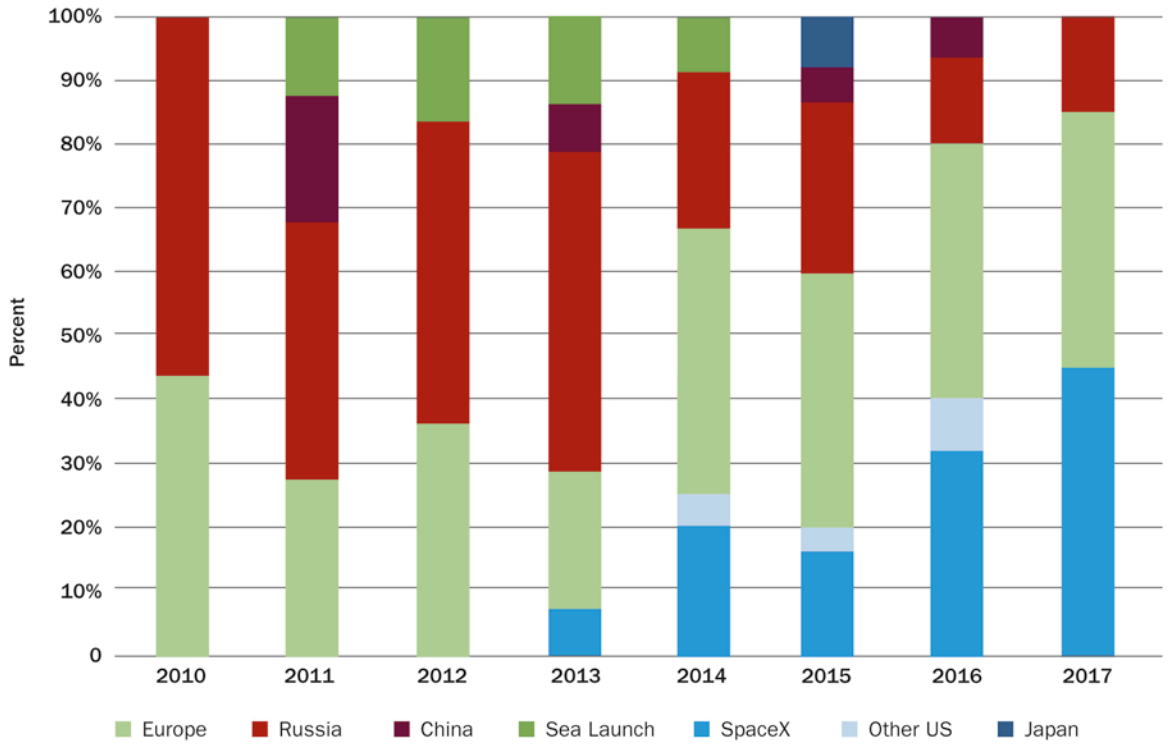




The CBO study can be found at: https://www.cbo.gov/publication/54894

The Reversal of Fortunes for U.S. Aerospace

Market Share for Commercial Global Launch Services



Enter SpaceX

Source: SpaceX

See also an 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 also tweeted in February 2019 that SpaceX captured a 65% market share in 2018: *https://twitter.com/elonmusk/status/1098619793844797441?lang=en*

The Emergence of SpaceX

- The company's innovations have led to substantial cost reductions
- Its flagship rocket, the Falcon 9, is composed of nine smaller engines, each of which achieve high thrust efficiency
- SpaceX employs factory fabrication, and makes use of homemade and non-space-grade components
- It is the only company landing its first stage and recovering components like the fairing
- Assisted in early years by NASA's Commercial Orbital Transportation Services (COTS) program

The COTS Program

- The space shuttle was retiring; NASA needed another means of providing routine access to space and the ISS.
- NASA has noted that in its traditional relationships with industry in the past, it was "obligated to pay the additional cost of unforeseen slips in scheduled development" which could be perceived as giving contractors "the incentive to do more, less-efficient work, as they [knew they would] not be financially responsible for delays and cost overruns."
- A 2004 study proposed the idea of offering payments upon reaching milestones, where any additional work required to complete the mile-stone would be the financial responsibility of the company, not the government. Private companies would propose milestones and associated payments for them, and then NASA would select companies based on an assessment of best value.
- NASA hired a venture capitalist to help design and implement the program.
- NASA received proposals from 20 different companies by March 2006, and downselected to six finalists. Finalists were put through a round of "rigorous interviews and meetings."
- Two winners— SpaceX and RocketPlane Kistler—selected in August of 2006.
- 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.
- After $32M of milestones were achieved, RocketPlane Kistler failed to meet a financing milestone and NASA terminated the agreement and recompeted the money, with Orbital winning.
- Overall, NASA invested $788M in private companies as part of COTS, and those companies invested about $1 billion of their own money.

https://www.nasa.gov/content/cots-final-report

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
	Total of 22 milestone awards (only 14 shown):	$278M	

Note: The completion date is when NASA verified that SpaceX completed the milestone. Only 14 of the original milestones shown here. More milestones (and funds) were added at a later date.
Source: Appendix of “Commercial Orbital Transportation Services,” NASA 2014.

NASA Funded Space Act Agreements

Company	Award Date	Total Value (million$)	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 effect 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 billion

Source: NASA Office of Inspector General, “NASA’s Use of Space Act Agreements,” 2014. Table 1.

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

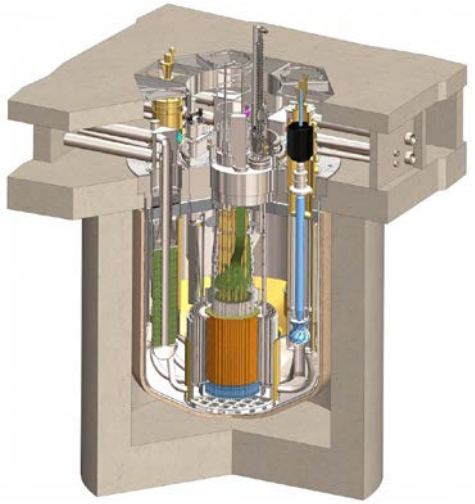
Company	Initial Award Date	Total Value (millions)	Purpose
Orbital ATK	Dec. 2008	$2,889	CRS-1: Transportation of supplies to the International Space Station
SpaceX	Dec. 2008	$3,042	
Orbital ATK	Jan. 2016	$639	CRS-2: Continuation of CRS-1
Sierra Nevada	Jan. 2016	$893	
SpaceX	Jan. 2016	$1,074	
Boeing	Dec. 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	

Note: 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."

Advanced Reactor Companies

As in aerospace, a variety of private companies are trying to commercialize different designs

- Variety of thermal outputs, coolants, coolant temperatures, fuel forms, and targeted markets
- Potential advantages from: building a larger plant from multiple smaller modules, higher conversion efficiencies, operating at near-atmospheric pressure, factory fabrication, greater use of less specialized components, etc.
- Federal legislation passed in December 2020 directed the Secretary of Energy to demonstrate advanced reactor concepts

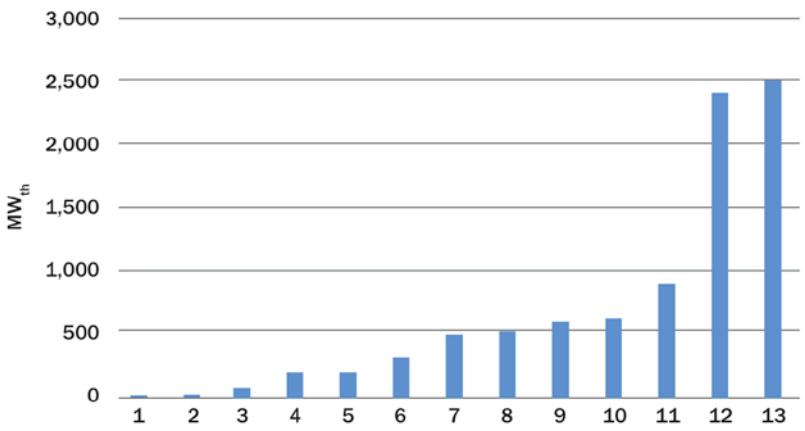


Advanced Reactor Survey from NIA Report

Highlighted responses from 12 companies on 13 designs

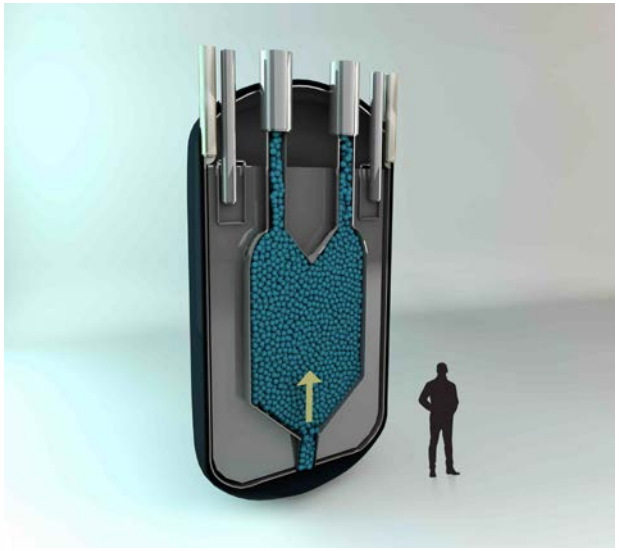
- 50/50 split on demo being commercial-scale vs. smaller
- Licensing pathways: Part 52, Part 50 (w/ and w/o use of NRC prototype provisions), non-power/medical isotope licenses, and undecided
- Estimated design, licensing, FOAK engineering costs ranged from $50M to $1600M (average of $720M)
- Estimated construction cost for demos: $100M to $3B (average: $1.2B)
- Many different suggestions for what would help companies meet 2028 timeline in congressional legislation
  - Loan guarantees, PTC, PPA, cost-share
- One relevant suggestion for improvement
  - "Milestone-based set of payments that do not rely upon submission and audit of paid invoices and payroll accounting systems."

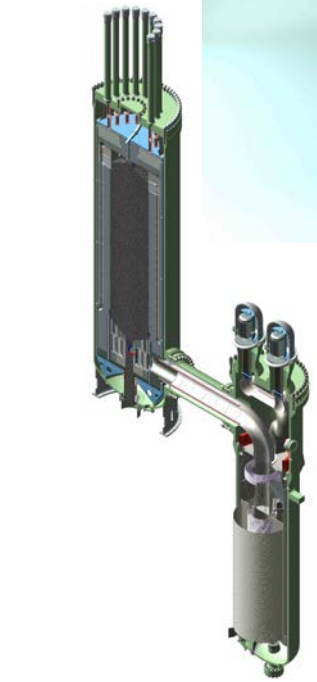
Commercial Reactor Module Power Outputs



A Similar Approach to NASA COTS could be used for Advanced Reactor Demonstration

- DOE could issue an “Announcement for Proposals” with reactor companies submitting milestones & payments followed by evaluation and downselect
- Multi-stage series over the next decade+; likely billions of dollars in total investment
- Possible procurement prong: federal power purchase agreements
  - Esp. for deployments at or near DOE sites
  - E.g., DOE issued a notice of intent to procure power from NuScale project at INL (link below)
  - Two studies from Kutak Rock/Scully Capital on federal power purchase agreements and how they could work at INL and ORNL in particular: “Purchasing Power Produced by Small Modular Reactors: Federal Agency Options” and “Small Modular Reactors: Adding to Resilience at Federal Facilities.”





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

How Do Recent DOE Advanced Reactor Awards Change the Picture?

In October/December of 2020, DOE announced several awards

- "[DOE] approved a multi-year… award… that could provide up to $1.4 billion to help demonstrate and deploy a 12-module NuScale power plant located at Idaho National Laboratory. The agreement serves as a funding vehicle and *is subject to future appropriations* by Congress."
- "DOE is awarding TerraPower… and X-energy... $80 million each in initial funding to build two advanced nuclear reactors that can be operational within seven years...The Department will invest a total of $3.2 billion over seven years, *subject to the availability of future appropriations*, with our industry partners providing matching funds."
- Risk Reduction for Future Demonstration Projects. $30 million in initial funding (potentially $600 million over seven years) to 5 companies: Kairos Power, WEC, BWXT, Holtec, and Southern Company
- ARC-20. $20 million in initial funding (potentially $56 million over four years) to 3 entities: ARC, General Atomics, and MIT

Last Two Years of Appropriations for Advanced Reactor Demonstration

From Division D – FY21 Joint Explanatory Statement

Budget Line	FY2020 Enacted	FY2021 Enacted
Advanced Small Modular Reactor RD&D	$110M	$115M
Advanced Reactor Technologies	$55M	$46M
Demonstration 1	$80M	$80M
Demonstration 2	$80M	$80M
Risk Reduction for Future Demonstrations	$30M	$40M

Consolidated Appropriations Act, 2021

Division Z – Energy Act of 2020, Title II Nuclear, Section 2003 Nuclear Energy Research, Development, Demonstration and Commercial Application Programs (g) Advanced Reactor Demonstration Program (1)

- "…(b) ESTABLISHMENT.—The Secretary shall establish a program to advance the research, development, demonstration, and commercial application of domestic advanced, affordable, nuclear energy technologies by—
  - "(1) demonstrating a variety of advanced nuclear reactor technologies..

- "…(d) MILESTONE-BASED DEMONSTRATION PROJECTS.—The Secretary may carry out demonstration projects under subsection (c) as a milestone-based demonstration project under section 9005 of the Energy Act of 2020.

- "…(f) AUTHORIZATION OF APPROPRIATIONS.—There are authorized to be appropriated to the Secretary to carry out the program under this subsection—
  - "(1) $405,000,000 for fiscal year 2021;
  - "(2) $405,000,000 for fiscal year 2022;
  - "(3) $420,000,000 for fiscal year 2023;
  - "(4) $455,000,000 for fiscal year 2024; and
  - "(5) $455,000,000 for fiscal year 2025."

Discussion

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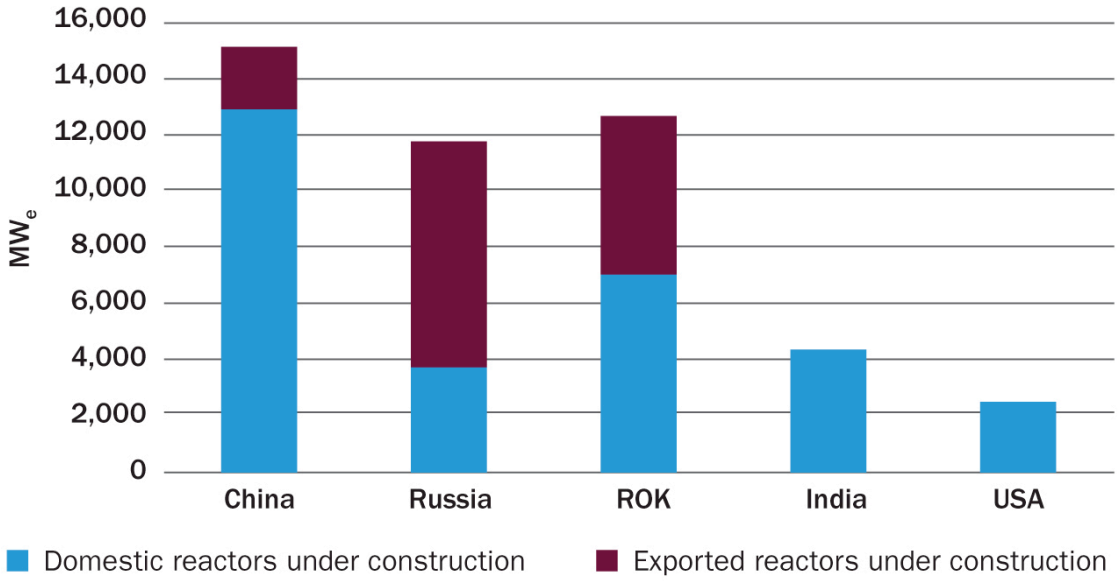
International Nuclear Energy Marketplace

Domestic and Exported Reactors Under Construction for Key Countries



Tsinghua University estimated that China might need to nearly quintuple its nuclear energy generation in order to reach its newly announced target of net zero carbon by 2060.

Source: World Nuclear Association

https://www.bloombergquint.com/onweb/china-s-top-climate-scientists-lay-out-road-map-to-hit-2060-goal