DOE Fusion Energy Sciences: A Plan on a Possible Cost Share Program for Fusion Reactor Technologies

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United States Department of Energy
Washington, DC 20585

Message from the Director of the Office of Science

This report presents a plan for a possible cost share program for reactor technologies for the development of fusion energy, including program objectives and eligibility requirements.

If you have any questions or need additional information, please contact me or Ms. Katie Donley, Deputy Director of External Coordination, Office of the Chief Financial Officer, at (202) 586-0176.

Sincerely,

Chris Fall
Director, Office of Science

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EXECUTIVE SUMMARY

This report provides a review of the Department of Energy's (DOE's) analysis of a possible cost share program for reactor technologies for the development of fusion energy. Any effort to initiate such a program at DOE would need to be evaluated as part of future budget formulation processes and be included in a future budget request to Congress; the concepts presented herein are not final and continue to be under consideration within the Department.

The mission of the Fusion Energy Sciences (FES) program, in the Office of Science (SC) at DOE, is to expand the fundamental understanding of matter at very high temperatures and densities and build the scientific foundation needed to develop a fusion energy source. To meet its fusion energy mission, FES utilizes appropriated funds to support a broad portfolio of research efforts across the country at DOE National Laboratories, universities, and private industry.

In parallel with the federally funded programs in fusion, several companies in the United States (U.S.) and overseas have been investing private resources toward the development of fusion reactor concepts focusing on rapid commercialization. Recognizing the recent surge in interest and investments by the private sector in the development of fusion energy, FES has been exploring partnership initiatives to leverage the private sector's basic research efforts, with the objective of accelerating progress toward the realization of fusion energy and solidifying U.S. leadership in this critical energy technology of the future. As a first step, FES launched the Innovation Network for Fusion Energy (INFUSE)[1] program, which provides private-sector fusion companies with access to the expertise and facilities of DOE's National Laboratories to overcome critical scientific and technological hurdles in pursuing development of fusion energy systems.

The Department may also evaluate the value of partnership programs using a performance-based, milestone-driven approach. Such programs could be modeled after successful milestone-driven cost share programs established by other DOE offices or Federal agencies, such as the Gateway for Accelerated Innovation in Nuclear (GAIN) Voucher program of the DOE Office of Nuclear Energy (NE), or the Commercial Orbital Transportation Services (COTS) program of the National Aeronautics and Space Administration (NASA), with appropriate modifications. If deemed suitable, cost effective, and an appropriate use of taxpayer funds, cost share programs could help the U.S. capture the opportunity of working with an evolving fusion industry to develop and demonstrate technologies and devices that could enable a fusion electric power plant, which would have no carbon-based pollutants, no long-lived radioactive waste, and an almost inexhaustible fuel supply. The need for clean energy for the future, coupled with technology innovation in the fusion community and the emergence of private U.S. interests in testing and demonstration of fusion concepts, point to the potential opportunity for collaboration.

Potential activities and outcomes that DOE is evaluating include:

[1] Innovation Network for Fusion Energy, https://infuse.ornl.gov/

- Establishment of multiple Public-Private Partnerships (PPPs) at different levels to begin addressing the most challenging technical gaps, guide us to better technology options, accelerate implementation, and improve economic viability.
- Research and development of viable fusion energy technologies and devices, for eventual deployment in the energy market.
- Growth and maturation of a world-leading U.S. fusion industry and workforce.
- Development of a self-sustaining U.S. fusion industry supply chain.
- Robust and cost-effective U.S. fusion energy research programs at all levels (including individual researchers and laboratory-scale technology development).

FES reviewed best practices from several successful industry partnership programs, including Advanced Research Projects Agency – Energy (ARPA-E), DOE's GAIN[2] and Consortium for Advanced Simulation of Light Water Reactors (CASL)[3] programs and Industry Funding Opportunity Announcements (IFOAs) for fission reactor technology development, and the NASA COTS,[4] Tipping Point solicitations,[5] and Announcement of Collaborative Opportunity solicitations. These range in funding (up to $150M per year) and time scale (up to five years) to fit the scope of the programs under consideration. While not true in all instances, some lessons the Office of Science took from these programs include:

- Competitions include multiple companies and institutions, and multiple technologies are considered at first, especially for larger awards.
- Milestone-driven programmatic models work well.
- Advisory boards consisting of industry representatives, subject matter experts from National Laboratories and universities, and government representatives, are established to generate and review unbiased information to be used in the decision-making process for selection of programs.

While the experience from other programs and agencies offers much valuable information about how cost share programs could be organized to achieve success with the private sector, there are also significant differences that should be kept in mind in the development of similar programs for fusion energy. Most of the existing cost share programs (e.g., those of NE or NASA) focus on technologies at much higher maturity and technology readiness levels (TRLs) and their focus is more to enhance or economically produce systems at scale, rather than enable relevant technologies. Fusion is fundamentally different. So far no concept (private or public) has demonstrated engineering or even scientific breakeven (i.e., when the energy produced by fusion reactions is more than the external energy input into the plasma needed to maintain the fusion reactions), and there remain many challenging scientific and technical issues to be overcome before the goal of putting fusion electricity on the grid can be realized.

The approach in this report, informed by study of lessons learned from other successful industry engagement programs, could be a staged three-tiered one, where targeted technology areas would be described as:

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[2] https://gain.inl.gov/SitePages/Home.aspx
[3] https://www.casl.gov/
[4] https://www.nasa.gov/commercial-orbital-transportation-services-cots/
[5] https://www.nasa.gov/directorates/spacetech/solicitations/tipping_points

- **Tier 1:** Basic science and proof-of-principle research and development (similar to the existing INFUSE program).
- **Tier 2:** Representative scale research development of specific candidate enabling technologies that close gaps for, or enhance the attractiveness of, multiple future fusion reactor concepts.
- **Tier 3:** A milestone-based program to evaluate and demonstrate the commercial viability and potential significance of candidate fusion confinement concepts.

A decision to grow Tier 1, and initiate Tier 2 and 3, would be dependent on successful results from previous program efforts and whether a follow-on investment is appropriate and is a priority. This decision would also involve a determination of where in the Department this effort would fit and how the Department would best execute it.

While, in principle, multiple efforts at each Tier can be supported simultaneously, a staged approach in which an expanded Tier 1 INFUSE program may be augmented by a new Tier 2 activity focusing on reactor enabling technologies, is a possible option, creating the potential for the maximum benefit across the entire public and private fusion enterprise. The efforts supported under the first two Tiers, if pursued, could increase the technical readiness of multiple fusion concepts, reducing risk for concept demonstration projects under Tier 3, if a subsequent budget and policy decision were made to initiate Tier 3.

1. LEGISLATIVE LANGUAGE

This report responds to legislative language set forth within the Explanatory Statement regarding H.R.1865, Further Consolidated Appropriations Act, 2020[6], requesting the Department to provide to the Committees on Appropriations of both Houses of Congress, not later than 180 days after enactment of this Act, a plan on a possible cost share program for reactor technologies:

> "*The agreement does not include funds for the creation of a Fusion Public-Private Partnership Cost Share Program for reactor technologies at this time. The Fusion Energy Sciences Advisory Committee is directed to give full consideration to the establishment of a cost share program for reactor technologies as part of its ongoing long-range strategic planning activity. The Department is directed to provide to the Committees on Appropriations of both Houses of Congress not later than 180 days after enactment of this Act a plan on a possible cost share program for reactor technologies. The plan should include program objectives, eligibility requirements, and a funding profile for future fiscal years*."

This report addresses the second request. The first request is being addressed separately by the Fusion Energy Sciences Advisory Committee (FESAC).

2. INTRODUCTION

This report provides a review of DOE's analysis of a possible cost share program for reactor technologies for the development of fusion energy. Any effort to initiate these activities at DOE would need to be evaluated as part of future budget formulation processes and be included in a future budget request to Congress; the concepts presented herein are not final and continue to be under consideration within the Department.

The mission of the Fusion Energy Sciences (FES) program, in the Office of Science, U.S. Department of Energy, is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source.

To meet its fusion energy mission, FES utilizes appropriated funds to support a broad portfolio of research efforts across the country at DOE National Laboratories, universities, and private industry. These include experimental research at world-leading SC user facilities, such as the DIII-D National Fusion Facility at General Atomics and the National Spherical Torus Experiment-Upgrade at the Princeton Plasma Physics Laboratory; foundational theory and advanced simulations to develop a predictive capability for magnetically confined plasmas; research on the development of novel materials that can withstand the harsh environment of a burning plasma; the development of innovative diagnostic techniques to measure key plasma parameters; and the support of enabling technologies (such as superconducting magnets, fueling

[6] 165 Cong. Record No. 204, H11248 (Dec. 17, 2019)

systems, and plasma heating technologies). In addition, FES supports U.S. scientists to conduct research on international fusion facilities with unique capabilities and supports the U.S. contributions to ITER project, the world's first burning plasma experiment being built in France and scheduled to commence operation in 2025. ITER is designed to demonstrate the scientific and technical feasibility of fusion energy. Public-private partnerships would focus on innovation to reduce size and cost for future fusion reactors.

In addition to SC FES, ARPA-E has also been supporting some early-stage research in innovative fusion concepts. Recently, FES and ARPA-E joined efforts to support projects of common interest and issued a joint Funding Opportunity Announcement (FOA).[7]

Government organizations have employed cost share programs at many levels to incentivize and mature industry capability to fulfill important national strategic needs. Perhaps the most visible example is the NASA COTS program, which led to the development of a U.S.-based launch capability—a service that is now used by multiple government and commercial organizations. With that program, the United States was able to become a world leader in commercial launch capability after having none. It represents a dramatic turnaround for the U.S. space industry.

The highest-level objective of federally funded energy programs is to prepare and position for the physical security and economic interests of the country, whether today or well into the future. With respect to energy, this implies the development of affordable, safe, clean, and U.S.-controlled sources of energy so that energy independence can be maintained while sound environmental stewardship is practiced. The need to reduce dependence on fossil fuels and the possibility of harnessing an essentially inexhaustible supply of carbon-free energy with no long-lived radioactive waste provides strong motivation for a focused pursuit of large-scale fusion energy. Fusion is an element of a long-term, clean, and abundant energy strategy. However, for an industry to be robust, it should not be monolithic. A central goal of a government investment strategy should translate to the development of diverse industry employing multiple technologies.

Public-Private Partnerships (PPPs) could be considered if they serve as the most appropriate mechanism to address challenging technical gaps, guide us to better options, accelerate implementation, or improve economic viability. Each development path could also work to accelerate or improve the approach to commercialization by helping to attract additional private investment and engage market forces. However, it is also true that there are no easy solutions to economically viable fusion technology. The essential question is related to what can be done to improve the fusion development path.

As a first step, FES launched the Innovation Network for Fusion Energy (INFUSE)[8] program, which provides private-sector fusion companies with access to the expertise and facilities of DOE's National Laboratories to overcome critical scientific and technological hurdles in pursuing development of fusion energy systems. This public-private partnership program is

[7] DE-FOA-0002288: Galvanizing Advances In Market-Aligned Fusion For An Overabundance Of Watts (Gamow): Enabling Technologies For Commercially Attractive Fusion Energy (https://arpa-e-foa.energy.gov/#FoaId7c0cc9b9-16a8-4792-842e-78c05f4736df)
[8] Innovation Network for Fusion Energy, https://infuse.ornl.gov/

modeled after the voucher award program within GAIN and is the first such program in the Office of Science. INFUSE accepts research applications focused on innovation for fusion energy in enabling technologies, materials science, plasma diagnostics, modeling and simulation, and experimental capabilities. In fiscal year (FY) 2019, the first year of the INFUSE program, 22 Requests for Assistance (RFA) were received and 12 awards of up to $200K for one year were made to six companies partnering with six national laboratories. Subsequently, an INFUSE workshop was held in November 2019, with attendees from the ten participating national laboratories, nine private fusion companies, ARPA-E, and the Fusion Industry Association, to discuss lessons learned and possible changes. In FY 2020, the INFUSE program expanded eligibility to foreign companies whose participation is beneficial to the U.S., raised the funding level and award duration to $500K and up to two years, and relaxed the limit on the number of proposals per topical area. Two rounds of RFA will be held. The 20 percent cost share from participating companies continues. In the first RFA in FY 2020, 25 applications were received and ten awards were made. Although it has been less than a year since the INFUSE program was launched, evidence of its promise is emerging. So far, 22 awards have been made to six DOE labs to address the scientific challenges of ten private fusion companies. An additional 25 RFA proposals are currently under review. Two publications based on research supported by INFUSE have already been accepted by a leading plasma physics journal and more are under preparation. In addition, one company credits its INFUSE award for securing additional private-sector funding and for increasing its collaborations with academia and DOE laboratories.

This report considers elements that can form an effective PPP for the development of fusion energy, structured into three tiers. These tiers range from smaller programs like the existing FES program INFUSE, which resembles the GAIN voucher program; to mid-scale programs that close gaps for essential fusion technologies; to larger cost share initiatives that would more closely resemble the NASA COTS program, the NASA Tipping Point program, and the DOE Advanced Reactor Concepts awards. A strong PPP is not based on a single program but is the result of many interactions occurring across a wide variety of challenges at different levels of maturity and technological readiness. Addressing these challenges in collaboration across the private and public sectors can lead to a synergy that accelerates the realization of fusion energy. Information provided in this document was obtained through a series of interviews and discussions with stakeholders within the fusion community, and within other cost share programs. In this report, DOE describes a possible cost share program plan based on the successful features of those programs but adapted to the characteristics of fusion energy development.

In parallel, FES published a Request for Information (RFI) seeking stakeholder input on the establishment of cost share partnerships with the private sector.[9] The RFI input will be a valuable resource for FES if such a program were to be launched in the future.

[9] Cost-Sharing Partnerships with the Private Sector in Fusion Energy, 85 FR 21842, 21842 (April 20, 2020)

3. EXAMPLE PROGRAMS

Smaller cost share opportunities are routinely available through programs such as ARPA-E. Each of these programs can have varying degrees of industrial partner cost-sharing. Continuing programs have periodic calls that are quite specific in technical scope, and taken as a whole, they are broad programs with the flexibility to move into new and promising areas as needed. Projects within these programs are usually modest in terms of funding and duration; funding is typically on the order of a few million dollars for performance periods of two to three years. By and large, selected projects are designed to show whether a new principle is sound.

Programs such as ARPA-E are more generally incubators for initiatives that might be adopted by a government program, or spun off to private companies, if the early stage development and demonstration efforts are successful.

3.1 NUCLEAR ENERGY PROGRAMS

In 2016, DOE initiated a program to engage and support industry in the area of advanced fission reactor technology development. The Gateway for Accelerated Innovation in Nuclear (GAIN) in the Office of Nuclear Energy (NE) thus serves as a recent and direct example of a public-private partnership approach. Various PPP programs within NE are described in this section.

GAIN NE Voucher Program: One of the programs within GAIN, this program provides vouchers to national laboratories for joint research and development (R&D) projects with private industry. Awards for GAIN vouchers can range up to approximately $500K with occasional awards slightly above that threshold in compelling cases. The GAIN NE Voucher program provided a useful paradigm for the first-step fusion energy PPP pilot program called INFUSE, described earlier.

IFOAs: DOE also administers larger IFOAs for fission reactor technology development. Two awards were granted under the Advanced Reactor Concepts program in fiscal year FY 2015. The two awards each committed approximately $40M to five-year projects that are managed by private organizations and supported by national laboratories.

M&S and CASL: The Energy Innovation for Modeling and Simulation (M&S) is an example of a government-funded initiative to develop state-of-the-art capability addressing significant technical challenges of the nuclear power industry. The M&S was initiated in FY 2010 to develop computational tools for the advanced simulation of Light Water Reactors (LWRs) and to demonstrate their application to industry-identified operational issues in the existing LWR fleet. The Oak Ridge National Laboratory led a Consortium for Advanced Simulation of Light Water Reactors (CASL) of national laboratories, universities, and industry partners to manage the program. The CASL Hub successfully created a virtual reactor model of an actual Pressurized Water Reactor and the Virtual Environment for Reactor Applications (VERA) tool set was successfully used to analyze and understand key challenges to the safety and economics of reactor operations. With the successful completion of the Hub's initial work scope, the Hub was brought to a closure and the VERA research activities were consolidated into the NE Advanced Modeling & Simulation program in FY 2018. The Hub was funded originally for five years with an option to extend the program five additional years. Overall, approximately $25M was funded, per year, over the ten-year program.

ATF: DOE NE initiated the Accident Tolerant Fuels (ATF) program to help enable industry's development of advanced fuels that could be used in existing LWRs. The program is currently funding early-stage, cost-shared R&D with three industry awardees[10] to develop and test unique concepts based on their own proprietary technology.

3.2 NASA PUBLIC-PRIVATE PARTNERSHIPS AND PROGRAMS

Tipping Point Solicitations

NASA has many different public-private partnership opportunities. One example, NASA's Tipping Point solicitations, is managed by the Space Technology Mission Directorate, which states that "*A technology is considered at the tipping point if an investment in a demonstration of its capabilities would result in a significant advancement of the technology's maturation, high likelihood of infusion into a commercial space application, and significant improvement in the ability to successfully bring the technology to market.*"

NASA's Tipping Point solicitations began in 2015, and are targeted toward technologies at mid-range maturity levels. In its first year, nine projects were selected for participation, all of which required cost-sharing. The nine projects were distributed among four distinct technical areas. The cost share awards were executed through fixed-price contracts with milestone payments. A minimum of 25 percent corporate cost share was required. Contracts ranged from $2M to $20M and had a performance period of up to two years with a targeted goal of a system-level demonstration of a technology. The annual budget for Tipping Points was on the order of $80-120M per year, subject to the availability of appropriated funding. In its early years, NASA targeted multiple smaller cost share awards (~$2M to $10M). Tipping Point was recently modified to consider larger awards (multiple awards totaling $250M, spanning three to five years in duration), with the cost share fraction depending on the size of the company (10 percent for businesses with 500 or fewer employees and 25 percent for businesses with more than 500 employees).

Announcement of Collaboration Opportunity Solicitations

The Announcement of Collaboration Opportunity (ACO) also began in 2015. ACO focuses on industry-developed space technologies (TRL 3 or higher) that can advance the commercial space sector and benefit future NASA missions. ACO awards result in Non-Reimbursable Space Act Agreements (no funds exchanged with industry), such that NASA provides technical expertise, test facilities, hardware, and software at no cost to industry to accelerate the development and availability of commercial technologies and reduce costs. In November 2015, NASA selected 13 ACO projects, covering four technical areas. The selected ACO projects are on the order of approximately $1M each. The annual budget for ACO is approximately $20M, subject to the availability of appropriated funding.

[10] https://www.energy.gov/ne/articles/doe-awards-111-million-us-vendors-develop-accident-tolerant-nuclear-fuels

COTS Program

Larger projects often focus on commercializing more mature technology. The COTS program was specifically funded to produce a U.S. commercial launch capability after the retirement of the space shuttle program. The technology was well understood, but there were major industrial barriers to the affordable engineering and manufacturing of systems because of inefficiencies in the market. A hallmark of the successful public-private partnerships was that the government would incentivize competition among multiple providers and, rather than manage development, government would only set high-level requirements. Industry led the design, engineering, test, and flight of the systems.

SpaceX made the first commercial resupply flight to the international space station in May 2012. Orbital ATK, now part Northrup Grumman, successfully completed its maiden resupply mission in January 2014.

The COTS program was a competitively awarded program in which participants attempted to pass through pre-negotiated milestones in a fixed-price cost share arrangement. Once a milestone was successfully met, government funding was made available to work toward the next milestone. Key features that marked its success included the following.

- Multiple companies were involved and were allowed to work to individual timescales and milestone objectives.
- Partnerships with unsuccessful companies were terminated and funds were redirected to partnerships with new entrants to maintain competition.
- The program effectively leveraged support of government expertise and capability but was not unduly constrained by the direct management requirements associated with government-funded cost-plus programs.
- Incentives were aligned so that companies profited off of successful missions, rather than development.
- The program took advantage of nontraditional acquisition strategies allowed under the Other Transaction Authority created by NASA's organic statute, which streamlined the process and reduced compliance overhead.

NASA has other incentive programs, some of which are cost shared and others which are not. If a technology is less mature, but is promising for space use, NASA uses a range of tools including research grants, prizes, funded or unfunded agreements to use NASA staff or facility resources, and milestone-driven programmatic models similar to the COTS program to assess the technology. Projects are targeted in scope such that multiple technology options are demonstrated to meet a specific functional need in progressively representative use environments. Multiple projects using different technologies can occur simultaneously but independently. The goal is to mature technologies to the point where they can be considered for a flight program, and multiple technologies are pursued as risk mitigation in the event that a promising option is not successful.

4. FUSION TECHNOLOGY BUSINESS OPPORTUNITIES

A growing commercial interest in fusion power has attracted private investment, estimated at more than $1B, to several dozen fusion technology companies. These companies range from small ventures focused on a specific aspect of fusion technology to more established engineering firms employing up to 100 employees working on advanced concept demonstrations. These companies believe that fusion can be more rapidly advanced with the successful demonstration of their ideas, and that they can create a self-supported private fusion industry ecosystem.

Technologies, industries, and supporting programs differ in the maturity of their underlying technology, the timelines to expected implementation, and the scope and scale of demonstrations that would be considered representative and impactful. The degree of difficulty in working with a technology is also a differentiating characteristic. Technologies can be categorized as: (1) the technology is known and understood, so the goal of incentive programs is to establish an industry around that technology, or (2) the technology is less mature and requires considerable investment to identify and resolve technical challenges. Nuclear fission is well understood. The challenge for fission is to reconfigure the industry to make it economically viable in an existing, changing, private energy market. Fusion energy has enormous potential to provide environmentally attractive sustainable energy, but it requires further basic research and technology development before it can feasibly be ready for commercial deployment. Fusion research has developed the underlying science by focusing on a limited number of options selected for large-scale demonstration, such as tokamaks and stellarators. Other magnetic confinement configurations and confinement concepts spanning the range between magnetic and inertial confinement are being explored, mostly by private industry.

Important questions for the fusion community to consider relate to defining realistic schedules to market entry and identifying opportunities to accelerate deployment by successful demonstration of viable technology options.

Nuclear energy demonstrations, including fusion energy, require specialized expertise and authorizations. Representative demonstrations for fusion, if pursued, would require significant funding and time. An important objective of a fusion industry engagement program is to evaluate alternative concepts, but not detract from options already under development. Incentivized investment programs should either: (1) attempt to resolve a known, existing technical challenge, or (2) provide evidence of an alternate and better path to success.

In order to better understand the needs of an expanded fusion PPP from an industry perspective, an ORNL team of subject matter experts, assisting FES in the preparation of this report, conducted interviews with a variety of stakeholders. Private interests were engaged through community organizations and directly. The Fusion Industry Association[11] was engaged through a videoconference and provided profiles of their current members, as well as their vision for fusion PPPs in follow up exchanges. Several private fusion ventures were also engaged independently. Discussions were held with Commonwealth Fusion Systems,[12] General Fusion,[13]

[11] https://www.fusionindustryassociation.org/
[12] https://cfs.energy/
[13] https://generalfusion.com/

and TAE Technologies.[14] Additional understanding of public fusion interests was developed through engagement with ARPA-E. Through these interactions, an assessment of the expectations for a viable and useful PPP program was developed.

5. POTENTIAL OPTIONS FOR FUSION PPP

A high-value program that best matches the needs of the federally funded fusion program and industrial communities could be achieved in part by a PPP as outlined below. A healthy program will accelerate the most important technologies that can potentially lead to sustainable business models. Technologies can generally be categorized as enabling or enhancing. Enabling is defined as necessary for implementation. Enhancing is understood as improving performance. For example, having a material that performs a critical function is enabling. Being able to produce that material at lower cost to improve plant economics could be either enabling or enhancing, depending on whether the cost difference is a deciding economic factor for viability. Programs that are less mature typically focus on enabling research, and to do this they look at the critical technical gaps and apply resources to address them. Thus, an industry engagement program could target generally agreed-upon technical issues according to where they fall within a prioritization list and the ability to effectively address them within available resources. Initial investments can be modest and occur on a short timescale. Scoping studies that involve analysis or preliminary materials exposure tests typically fall into this category. If a concept appears to have merit, it can be successively explored with later, more systematic efforts. Once a concept is proven at the smaller scale, it is potentially a candidate for demonstration.

Technology demonstrations are typically the first time a system or component is being demonstrated at scale. The number of demonstrations in any technical area is inherently limited by the time and funding required. Decisions on which demonstrations to fund can influence direction and progress for decades and must be thoughtfully considered. NASA relies on the science community to identify and prioritize leading-edge scientific questions and the work required to answer them, through the use of Decadal Surveys. NASA's Science Mission Directorate engages the science community through the National Academy of Sciences[15], which conducts studies and surveys to generate independent community "consensus" of issues, needs, and direction. Reports are generated every ten years and provide an opportunity for the science community to look to the future and state where they think they could be. The surveys are then used to inform decisions on investments toward those goals.

An industry engagement program and a federally funded program should be integrated and complementary and balance the needs and the goals of a broader development strategy. An important outcome of an industry engagement program is the development of a true partnership, as was achieved with the NASA COTS program. Experience with cost share programs point to some concerns that should be carefully considered. The engagement program should not exist to keep industry partners in business; rather, it should help companies become self-supporting.

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[14] https://tae.com/

[15] National Research Council, 2011. *Vision and Voyages for Planetary Science in the Decade 2013-2022,* Washington DC: The National Academies Press. https://doi.org/10.17226/12117.

Care should be taken (especially in Tier 3) so that the government is not designing or creating new concepts for an industry partner. Either the industry partners should be coming to the program to test and evaluate their ideas, or industry should be developing capability at the behest of the government. The progression of government commitment should follow the success of previous efforts. Clear technical success criteria must be developed, and a robust process must be established to decide whether or not an activity is to continue.

The following key characteristics are common to successful government-supported industry partnerships:

- It is important to establish consensus on the overall goals and the technical priorities supporting those goals prior to the initiation of the program. NASA used formal studies such as the Decadal Survey to gather input and document the priorities of the space science stakeholder community. The FES program is currently awaiting a report from FESAC, based on community input, for a long-range strategic plan, including the role of PPPs.
- Organizations and individuals external to the government are free to promote their ideas, but the fundamental scientific aspects of concepts and the potential benefits should be well understood prior to award selection. Activities with less probability of success and with limited market potential should have lower funding priority.
- Advisory boards consisting of industry representatives, subject matter experts from National Laboratories and universities, and government representatives are used to generate and review unbiased information to be used in the decision-making process.

5.1 PROGRAM OBJECTIVES

The vision for a potential fusion energy cost share program could be to integrate private and public partners in the basic research and development activities that will underlie the transition of fusion into a viable commercial technology, while supporting the ultimate goal of producing economically competitive energy from fusion. Any such an endeavor would need to be a cooperative effort that may take several decades to complete. Such a program would aim to mature and support private industry to help develop commercially viable fusion technology products, create a self-sustaining fusion industry supply chain, and demonstrate viable fusion energy devices for eventual deployment in the energy market.

5.2 POTENTIAL PROGRAM ORGANIZATION AND STRUCTURE

Projects of interest can be categorized as follows:

- Fundamental research to develop cost-effective, innovative fusion energy technologies in the private sector
- Component technology development that enhances system performance or leads to subsystem development and demonstration
- Subsystem integration and testing for representative-scale demonstration of fusion concepts

A multi-tiered approach may be considered to accommodate the broad mix of industrial partners, the large number of needed technologies, and the widely varying technology maturity levels of interest. Considerable programmatic risk reduction could be achieved through such a phased approach.

Tier 1

Tier 1 work could generally address basic science questions and may not be linked to a commercialization plan. Criteria for industry engagement could be proposed based on an industry partner's technology, or the government can request proposals to investigate technology of interest. In this case, the government would be working with industry to broaden the research base. Tier 1 is represented by the INFUSE program. The INFUSE program would be modified to vary periods of performance and allow the participation of student and early career researchers at universities to address the workforce development needs of the private industry. Work within Tier 1 would generally be funded by the government with a small (up to 20 percent) cost share from industry. Project results would be publicly available after an authorized sequestration period to allow for the protection of IP.

Tier 2

Tier 2 work may be developed as a follow-on to the INFUSE program (Tier 1). Tier 2 would pursue research and development at a larger scale, requiring more time and financial commitment, and they could be set up following a performance-based, milestone-driven approach. Examples of research topics for Tier 2 could include both low- and high-temperature superconducting materials and magnet development, tritium breeding technology development, and neutron source development for materials testing. The need for advances in these topical areas is underlined by the strong response of the U.S. fusion community (including several private companies) to the recent joint ARPA-E/FES FOA on innovative research and development in a range of enabling technologies required for commercially attractive fusion energy. The cost share for Tier 2 awards would vary depending on the maturity of the technology and the perceived market potential of the technology being developed. Results generated within the program would be protected from public release for an authorized period of time to allow a company to secure IP, but after that period the data would be publicly available. Tier 2 funding could go directly to industry and university partners. National laboratory participation would be directly funded through DOE. Tier 2 would be considered as a further expansion of the INFUSE program, and the first awards can potentially be selected from a FOA to allow a quick start to the program.

Tier 3

Tier 3 could be a COTS-like program intended to provide a strategic and sustainable approach to commercially viable fusion concept demonstrations. Such a follow-on program could aim to build and demonstrate individual concepts to assess their commercial viability. Tier 3 would be a multiyear, dynamic, and progressively larger-scale program, and would likely be proposed to be executed independently from the INFUSE program to ensure substantially increased project management requirements due to larger cost, following the model of the DOE CASL and the NASA COTS programs (which, unlike the early stage technology considered here, had well-developed technology bases). A decision to initiate Tier 3 would be dependent on successful results from Tiers 1 and 2. This decision would also involve a determination of where in the Department this effort would fit and how the Department would best execute it.

A third tier of the fusion cost share program could be designed to progressively advance fusion concepts through a series of fundamental questions, such as:

- Will the concept work?
- Can technology developed in Tier 2 be used in components or subsystems of the concept?
- Can the successfully demonstrated concept lead to a commercial fusion energy system?

The pragmatic view of the Tier 3 program is that it would be a trust-but-verify partnership between the government and the industry partner interested in demonstrating commercial viability of a fusion concept. A Tier 3 effort would be a considerably larger engineering effort with additional partnership complexities to consider. The program would require additional expertise in project planning, management, assessment, and controls. In addition to setting up the government-side program administration, project eligibility requirements would include demonstrated technical capability from the industry partner, a credible commercialization plan, and demonstrated financial support and stability.

An important aspect of the Tier 3 partnership would be a consensus on the viability, value, and significance of the technology to be demonstrated. Clearly stated technical criteria must be established for a technology or a concept. Aspects of performance could be validated through computer simulations of both the physics and the engineering. Each activity must have pre-defined consideration of milestone gates.

Cost expectations for each gate must be clearly established. Multiple awards may be considered, and they should not necessarily be considered to be in competition with one another. Individual projects work to a unique set of milestone gates and can have different costs and schedules to each gate. Multiple proposals of significance can be pursued according to available resources. Tier 3 cost share should be weighted toward the company, but also have significant contributions from the government. To fund a demonstration concept, 50 percent cost share from industry should be required.

5.3 PARTICIPATION, ELIGIBILITY, ROLES AND RESPONSIBILITIES

5.3.1 International Participation and Export Control

The following guidelines would apply to all Tiers.

Fusion is an international effort, and detailed guidance on international business interactions must be developed. Recommendations can range from preventing participation by international partners, to funding international partners subject to applicable regulatory and statutory requirements, and with consideration to advancing the interests of U.S. industry. Additionally, the participation of foreign entities or foreign nationals may involve the transfer of export-controlled technology and equipment. Depending on the type of transfer, the activities could be subject to the export control jurisdiction of the Department of Commerce, the Department of Energy, or the Nuclear Regulatory Commission.

5.3.2 Tier 3 Eligibility

Eligibility requirements specifically for Tier 3 must be established for participants. At a base level, the company should:

- Present a plasma or fusion technology concept that meets a base level of performance based on appropriate metrics indicating that the proposed technology has reached a maturity level that merits the investment of Tier 3.
- Bring significant capital to meet the cost share requirements negotiated for the Tier 3 proposal.
- Work with the program to set milestones.
- Present a credible and detailed plan to reach each approaching milestone, as judged by a panel of experts.

5.4 FUNDING CONSIDERATIONS

The proposed three-tier approach allows for substantial flexibility in industry engagement. This section offers some funding considerations. Actual funding amounts would be addressed during the budget formulation process.

Tier 1

Tier 1 activities could be administered by the INFUSE program, which was launched in FY 2019. As of FY 2020, the INFUSE program grants awards up to $500K for up to two years. Consideration should be given to increasing the funding limit for the standard INFUSE award.

Within Tier 1, it is recommended to consider a quick turnaround capability. With quick-turnaround work, industry partners can request assistance for limited technical support. Requests could be for access to specific technical expertise, or for the use of specialized equipment. Quick-turnaround requests would only take a few days to review, and the results could be expected within a few days, or weeks of R&D effort.

In addition to quick turnaround activities, there is a need to consider an intermediate assistance award that lasts more than a few days, but less than a year. The timescale envisioned for these intermediate INFUSE awards is on the order of two to three months of R&D effort. This allows time to more substantially address technical questions.

Tier 2

Tier 2 activities could be larger multi-year research and development awards administered under the INFUSE program. Awards could focus on lab-scale demonstrations that extend beyond basic science, and could perhaps include the first applied demonstrations of an emerging technology. Possible topical areas include both low- and high-temperature superconducting materials and magnet development, tritium breeding technology development, and neutron source development for materials testing.

Tier 1 activities can follow the existing Request for Assistance model in INFUSE. However, Tier 2 activities would likely be funded through FOAs issued by DOE, with direct funding to companies.

Tier 3

Funding for Tier 3 activities could occur in three phases. Periodic calls for proposals could be made and reviewed. Selections could be made according to proposal scores in the areas of technical merit, relevancy, viability and potential significance, and also according to the availability of funding. Potential phases of Tier 3 activities are generally described as follows.

- ***Phase 1***: Proposal evaluation and discussion with the industrial partner. Limited or no funds are exchanged in Phase 1.

- ***Phase 2***: First round of cost share funding in which detailed analysis of a proposed technology or concept is evaluated jointly. A joint report is generated by DOE and the industry partner on the merits and the challenges of a concept. A preliminary project plan is developed in Phase 2 that clearly describes the ultimate goal of the activity and the proposed milestone gates, and provides budget and schedule estimates. Negotiated cost, and period of performance, are based on the complexity of the project, but are generally targeted over a three-month period.

- ***Phase 3***: Phase 3 is the progression through the milestone gates. Funding is awarded at the initiation of an activity, and limited until the next milestone gate is completed. Companies can spend their own resources to complete milestones after federal funds are expended for a period of time, and at their discretion, before permanently exiting the program. Detailed technical reviews are held twice each year. A detailed and documented Record of Decision is made to declare whether a milestone has been achieved, and a second Record of Decision is required to formally begin funding for the next activity. Cost and duration of each activity is negotiated prior to initiation, and is based on the anticipated complexity and availability of funding. Periods of one to two years for funding from the government are anticipated in the early parts of each activity, with increased support during periods of construction and operation. A report should be completed within six months of the final Phase 3 activity.

As noted elsewhere in this report, if work such as that envisioned for Tier 3 were to be proposed, DOE would need to evaluate which program or programs within the Department would be best suited to perform it. In that process, the elements of Tier 3 execution would be revisited as needed.

Funding for Tier 1 and Tier 2 awards could define the program's base funding. Tier 1 would closely resemble the current INFUSE approach where the funding goes directly to National Laboratories and no funds are exchanged with industry. Tier 2 projects could award public funding to private industry, and would tend toward the larger of the Tier 1 funding amounts and performance periods. The current funding level for the INFUSE program is approximately $4M per year, and expansion to include Tier 2 would likely require consideration of additional resources (to be determined during the federal budget formulation process).

By their nature, Tier 3 demonstration activities would be much larger than the lower tier awards and would progress through a series of cost-shared phases over many years. Phase 1 is a no cost proposal activity. Phase 2 could be a modestly funded period to jointly plan the details of awards selected for entry into the program. Phase 3 is the portion of the project in which the milestone gates are achieved.

Tier 3 gate values are expected to increase in cost and commitment through Phase 3, but there would be considerable flexibility in setting the cost and schedule associated with each phase. If the first gate is successfully completed, a series of efforts in detailed design, construction and operation could begin. The cost and duration of each gate element would be project dependent. The final phase of a Tier 3 award would nominally be a two-year effort to shut down the project, decommission equipment and facilities, and produce final reports.

Two fundamental differences between the NASA COTS program and the fusion program are that: (1) the annual NASA budget is much larger (~$20B), and (2) there was an immediately available market for the COTS capability once developed. The current fusion program does not have sufficient funding to engage in a significant demonstration effort unless additional funds were made available and a self-sustaining fusion market were to emerge in the foreseeable future.

The scopes, schedules, and costs of Tier 3 projects may vary widely. The overall cost and duration of the program are dependent on the number of projects funded and their individual costs. The peak annual cost of the program is strongly dependent on the phasing of Tier 3 awards. Proper phasing can create a more sustainable program. Considerable programmatic risk reduction may be attained be provided by initiating Tier 3 awards after sufficient confidence is gained through Tiers 1 and 2 in a phased approach.

5.5 AWARD SELECTION CRITERIA

Demonstration selection relies on factors such as significance, likelihood of success, and allotment of resources required compared with what is available. A demonstration must be technically feasible, but the result should not be certain. A demonstration should inform specific issues concerning the economic viability of the technology. Related to that, both government and industry willingness to invest in an activity are important factors. Industry must believe in their technology and business model, and government must understand and agree with its value.

The basic criterion for award selection could contain the following elements:

- Principles or concepts to be examined must be viable but retain an element of uncertainty.
- The value of a successful demonstration should be well understood and clearly stated.
- If the purpose of the award is to investigate a purely scientific principle, that principle should be of distinct scientific interest to the fusion energy community.

- A credible business strategy must be presented in conjunction with proposed technology demonstrations that aligns with the strategic and economic interests of the United States.

6. RECOMMENDATIONS

The objective of fusion PPPs would be to provide the highest possible value to the nation for its investment and to assist in moving emerging fusion technology toward commercialization. Many activities can be categorized as high risk and high reward investments. In order to maximize the potential of a cost share program, should one be pursued, DOE will seek to clarify the most important issues to be addressed and focus resources on a limited number of long-term objectives.

The following outlines a potential cost share program:

- An overarching three-tier effort will be planned, consisting of an initial staged approach in which Tier 1 (the existing INFUSE program) may be strengthened and a new Tier 2 program may be established as part of the INFUSE program, pending policy and budget priorities. A decision to initiate Tier 3 in the future would be dependent on successful results from Tiers 1 and 2, and a policy decision to prioritize this investment. This decision would also involve a determination of where in the program this effort would fit and how the Department would best execute it. This approach will reduce risk, and increase the readiness of private-sector fusion concepts to maximize their benefit from participating in Tier 3 activities.
- The Tier 2 program could support representative scale research development of specific candidate technologies that close gaps for, or enhance the attractiveness of, multiple fusion reactor concepts. Tier 2 areas should be selected among those with the maximum potential for benefit across the entire public and private fusion enterprise. Examples include low- and high-temperature superconducting materials and magnet development, fusion blanket development, and neutron source development for materials testing.
- As with the current INFUSE (Tier 1) program, foreign companies whose participation is beneficial to the U.S. would be eligible.
- The vital information that is learned from the ITER research activities as foundational for the scientific and technical achievement of burning plasmas will be available to private fusion companies.
- As Tiers 1 and 2 mature, planning activities could be launched to prepare for the establishment of a Tier 3 program.
    - A leadership team with broad representation should be established to administer the program.
    - A team of technical advisors should be established from community stakeholders to generate consensus information as input to the leadership team. This team will clearly characterize and prioritize technology gaps and market opportunities based on their potential significance, urgency, and achievability.

  - Since it will take time to build an effective leadership team and its associated team of technical advisors, these tasks and other Tier 3-specific preparatory activities should be initiated a few years before starting Tier 3 under the recommended staged approach, while Tiers 1 and 2 build confidence in the technologies being pursued by the industry partners.
- A decision to initiate Tier 3 would be dependent on successful results from Tiers 1 and 2. This decision would also involve a determination of where in the program this effort would fit and how the Department would best execute it, as well as resource availability.

- For all three Tiers:
  - Clear and consistent evaluation criteria must be established for each level of award with an emphasis on the development of a detailed work schedule targeted toward well-defined milestones.
  - The program should support a balanced portfolio in terms of both distinct business opportunity areas and the scope and scale of investments within those areas.
  - The program should explore and recommend options for simplified and standardized cost share contracts.
  - Project awardees should provide periodic progress reports and hold detailed project reviews as appropriate.

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APPENDIX

ACRONYMS

ARPA-E	Advanced Research Projects Agency–Energy
CASL	Consortium for Advanced Simulation of Light Water Reactors
COTS	Commercial Orbital Transportation Services
DOE	Department of Energy
FES	Fusion Energy Sciences
GAIN	Gateway for Accelerated Innovation in Nuclear
IFOA	Industry Funding Opportunity Announcement
INFUSE	Innovation Network for Fusion Energy
IP	Intellectual Property
LWR	Light Water Reactor
NASA	National Aeronautics and Space Administration
NE	Office of Nuclear Energy
ORNL	Oak Ridge National Laboratory
OSTI	Office of Scientific and Technical Information
PPP	Public-Private Partnership
SAA	Space Act Agreement
SC	Office of Science