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THE FEDERAL GOVERNMENT'S ROLE IN SUPPORTING THE COMMERCIALIZATION OF FUSION ENERGY

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED SEVENTEENTH CONGRESS

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THE FEDERAL GOVERNMENT'S ROLE IN SUPPORTING THE COMMERCIALIZATION OF FUSION ENERGY

THURSDAY, SEPTEMBER 15, 2022

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The Committee met, pursuant to notice, at 10:07 a.m. in Room SD–366, Dirksen Senate Office Building, Hon. Joe Manchin III, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. JOE MANCHIN III, U.S. SENATOR FROM WEST VIRGINIA

The CHAIRMAN. Today, we have gathered leaders in fusion energy to discuss the path to commercialization of this potentially transformational energy technology. I want to make a personal note. I had the unbelievable opportunity and some of my staff with me, to go to ITER, in France, and it has kind of changed who I am and what I think that we can do, and as civilization on this earth, what we can, maybe, calm down a little bit and treat each other a little nicer because we are not fighting over something we do not have to fight over anymore, which is energy—so, a lot of promise and hope. This March, as I said, I was fortunate enough to visit the International Thermonuclear Experimental Reactor, located in Southern France, and was graciously provided a tour by Dr. Luce. Thank you for making the effort to be here. We would have made accommodations any way we could to have you on virtual and all that, but you made that effort, and that means—that speaks a lot.

It was my first tour of the fusion facility and it left me profoundly reflective of the potential of the technology to transform our energy future. Touring a facility dedicated to international scientific and engineering collaboration with our geopolitical rivals, including Russia, including China—are they still paying?—and allies, helps restore faith in what we can do together given so much conflict at present. This project was initiated in 1985 during the Cold War between President Reagan and General Secretary Gorbachev to develop fusion energy for peaceful purposes. The promise of technology and the collaborative approach of nations provides a model for technology innovation and competition without conflict by focusing on data transparency and mutual benefits. The visit left me hopeful that we will be able to meet the challenges of climate change and overcome our internal and external political pettiness to improve people's lives at home and abroad.

Domestically, fusion research is at a critical inflection point. Private fusion companies are preparing to demonstrate their technologies. Our national labs have hit significant milestones and private capital has been generously invested in the promise of technology. The Fusion Energy Science Advisory Committee and the National Academies of Sciences, Engineering, and Medicine released reports last year providing a clear set of recommendations for commercialization. The Department of Energy Office of Science and the National Labs continue to advance research to advance computing for predictive and modeling capabilities needed for sustainable fusion while also enhancing existing facilities and planning for the next generation of materials and approaches. The White House Office of Science and Technology Policy has similarly spearheaded a high-level commitment to fusion energy, and our Committee's members and colleagues in the Senate and House have championed historic new legislation and investment in the past four years.

To further support and direct fusion and plasma research and development, Congress passed the Energy Act of 2020, the CHIPS and Science Act of 2022, and the Inflation Reduction Act of 2022. The enactment of these bills provides direction to DOE to fully support the U.S. contribution to ITER, pursue innovative fusion concepts, and establish a milestone-based development program to design and build a pilot fusion plant. In addition, these bills will bring to fruition the experimental capabilities that we need to advance fusion research, including the material plasma exposure experiment facility managed by Oak Ridge National Lab. This facility will help us understand the material capabilities required in high-heat environments. It also provides upgrades to meet research needs for understanding physical and chemical changes to plasmas and fundamental timescales, and exploring new regimes of dense material physics, astrophysics, planetary physics, and short-pulse laser-plasma interactions. Most importantly, $280 million has been made available for fusion science construction in additional funds for science lab infrastructure that will help accelerate projects such as the Princeton Plasma Innovation Center.

The legislative activity this Committee has led is an essential step for the federal stewardship of this vital technology and the many components and materials that make up its supply chain. It is a step made in concert with the research and growing business communities, and it is one made amid increasing competition around the world. For me, fusion provides a vision of and potential pathway toward world peace. So I look forward to hearing from our witnesses on how they are involved in bringing this exciting technology to fruition.

With that, I am going to turn to my friend, Senator Barrasso, for his opening remarks.

OPENING STATEMENT OF HON. JOHN BARRASSO, U.S. SENATOR FROM WYOMING

Senator BARRASSO. Well, thanks so much, Mr. Chairman. Thanks for holding this very important hearing today.

You know, there is that old saying about fusion. They say it is 30 years away and always will be. But I believe that is no longer the case. Innovators are working to move us beyond fusion science, working to demonstrate usable fusion energy. We still have a long way to go, but I believe, Mr. Chairman, we are turning the corner.

In March, the White House hosted a summit on commercial fusion energy. In the wake of the summit, one of our witnesses, Dr. Cowley, was quoted in Newsweek saying, "I believe that we could have fusion electricity by the end of the 2030's." There have also been recent reports highlighting the steps needed to harness fusion energy. These reports included a 2021 study from the National Academy of Sciences titled, "Bringing Fusion to the U.S. Grid." This hearing is going to help us better understand what is needed to commercialize this technology.

We have enjoyed the benefits of nuclear energy for more than half a century. Today's nuclear energy, called nuclear fission, is generated when we split a uranium atom. Nuclear fusion energy takes the opposite approach.

Fusion energy is generated when elements, such as hydrogen, are combined. This is the process that powers the sun. It is also how dozens of elements of the periodic table are created. The English physicist Arthur Eddington first theorized the existence of nuclear fusion over 100 years ago. But unlike nuclear fission, we have not been able to generate electricity from fusion energy.

The Department of Energy leads the Federal Government's efforts to develop nuclear fusion energy. The Fusion Energy Sciences program is managed by the Office of Science. This program remains largely focused on basic scientific research.

The Department's National Nuclear Security Administration supports another type of fusion technology—specifically, the National Ignition Facility, which uses a massive laser to focus enormous amounts of energy on a tiny target. The primary mission of this facility is to support our nuclear weapons program. It is also advancing fusion research. Last year, this facility took a historic step forward by producing heat from fusion reactions. This is an important step toward demonstrating usable fusion energy.

There are 33 private-sector companies developing fusion energy systems right now. Backed by over $4.7 billion in private investment, these fusion companies are making progress. They are eager to partner with the Department of Energy to move beyond fundamental scientific research. At the same time, they are outpacing the Department by developing technologies that are smaller and cheaper. Private-sector companies may demonstrate the ability to generate net energy production before the Federal Government achieves this milestone. Commonwealth Fusion Systems is one such company. To support these private-sector efforts, Congress authorized the Department of Energy to establish a milestone-based, fusion development program in the Energy Act of 2020. The Department has been slow to implement the program. And I understand that Dr. Hsu was recently brought in to lead this effort. I look forward to hearing how the Department is preparing to work with the private sector to transition from fusion science to commercial fusion energy.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Barrasso, I appreciate the opening remarks, and now we are going to introduce the panel and then we will start our testimonies. So I want to turn, basically, and say thank you to all of you.

Dr. Scott Hsu is the DOE Lead Fusion Coordinator in the Office of the Undersecretary of Science and Innovation. Thank you for being here.

We have Professor Steven Cowley, Director of Princeton Plasma Physics Laboratory. Thank you.

Dr. Tim Luce, the Chief Scientist at the International Thermonuclear Experimental Reactor in France. Thank you.

And Dr. Robert Mumgaard, CEO of Commonwealth Fusion Systems.

So we will start with Dr. Hsu with your opening remarks, sir.

OPENING STATEMENT OF DR. SCOTT HSU, LEAD FUSION COORDINATOR, OFFICE OF THE UNDERSECRETARY FOR SCIENCE AND INNOVATION, U.S. DEPARTMENT OF ENERGY

Dr. HSU. Thank you, Chairman Manchin, Ranking Member Barrasso, and distinguished members of the Committee, for your longstanding support of fusion energy research, including the visionary fusion authorizations in the Energy Act of 2020 and the CHIPS and Science Act, as well as your support for fusion in the Inflation Reduction Act. It is an honor to appear before you today as Lead Fusion Coordinator for the Department of Energy to provide testimony regarding federal support for fusion commercialization.

Fusion holds the promise of being an on-demand, safe, abundant source of carbon-free primary energy and electricity with the potential to transform the way humans generate and use energy. However, much work remains to realize this promise. Fusion may also enable new defense and space capabilities, meaning that the race to fusion is a race for future global leadership. Through recent consensus expert reports, the U.S. fusion R&D community declared that they are ready to take on an energy development mission. This will require a fundamental shift in the U.S. fusion energy strategy. Firstly, a greater emphasis on developing the needed enabling materials and technologies for a fusion pilot plant. And secondly, a greater focus on public-private partnerships to ensure commercial relevance and better harness the large amounts of private capital being invested into predominately U.S.-based fusion companies.

In March of this year, the White House Office of Science and Technology Policy and DOE co-hosted a White House summit entitled, “Developing a Bold Decadal Vision for Commercial Fusion Energy,” which aims to seize the opportunity enabled by private capital to translate U.S. leadership in fusion science into a U.S.-led commercial fusion industry. This entails building a strong partnership between DOE and the private sector to resolve the remaining scientific and technological challenges this decade with the goals of a fusion pilot plant and first commercial deployments in the 2030’s. In parallel, we must prepare the path broadly for fusion commercialization, as discussed at the White House summit.

Following the summit, DOE hosted a workshop in June entitled, “Fusion Energy Development via Public-Private Partnerships” where a broad set of fusion stakeholders had inclusive conversations about the Bold Decadal Vision. A key piece of this vision is a milestone-based fusion development program, as first authorized in the Energy Act of 2020. This program, expected to be announced imminently, will support for-profit entities to pursue applied R&D in partnership with national laboratories and universities toward one or more viable fusion pilot plant designs. DOE has also formed a fusion crosscut team to coordinate fusion-relevant activities across the Office of Science, ARPA-E, NNSA, Nuclear Energy, Economic Impact and Diversity, and Environmental Management. To realize an operating fusion pilot plant on a decadal time scale requires increased funding as well as attention to investment strategies that can amplify federal funding. For example, ARPA-E's fusion portfolio has, to date, received follow-on private funding six times the original federal funding.

Let me turn to the role of ITER in the Bold Decadal Vision. While I defer to Dr. Luce to speak to ITER's mission and updates, I emphasize that there are opportunities to maximize ITER's benefits for the Bold Decadal Vision starting immediately. Examples include placing more Americans on the ground at ITER and enabling streamlined access by U.S. fusion stakeholders to ITER's data and vast experiences with such a large and complex project. A recent DOE-sponsored ITER research-needs workshop discussed these opportunities. Regarding international collaborations, more generally, governments and private companies from around the world have expressed interest in collaborating with our Bold Decadal Vision. Collaborative opportunities could include securing startup tritium, sharing test facilities, and developing robust supply chains, just to name a few examples. There is an active Fusion Energy Sciences Advisory Committee charge to assess mutually beneficial international collaborations.

Chairman Manchin, Ranking Member Barrasso, members of the Committee, thank you again for the opportunity to testify. As your Committee considers further how to support fusion commercialization, DOE continues to be guided by the visionary authorizations you and your House colleagues have already provided, and the incredibly hard work that the fusion R&D community put into the recent consensus reports declaring that the U.S. is ready for a fusion energy development mission. Thank you.

[The prepared statement of Dr. Hsu follows:]

Testimony of
Dr. Scott C. Hsu
Lead Fusion Coordinator
Office of the Undersecretary for Science and Innovation
U.S. Department of Energy

Before the U.S. Senate Committee on Energy and Natural Resources
September 15, 2022

Introduction
Thank you, Chairman Manchin, Ranking Member Barrasso, and distinguished Members of the Committee for your longstanding support of fusion energy R&D, including the visionary fusion energy authorizations in the Energy Act of 2020 and the CHIPS and Science Act, and your support for fusion R&D infrastructure in the Inflation Reduction Act. It is an honor to join you today as Lead Fusion Coordinator for the Department of Energy (DOE) to provide testimony regarding Federal support for the commercialization of fusion energy. While I now coordinate fusion-energy activities across multiple DOE program offices, I do not represent those offices. Thus, I may not be able to answer detailed questions about activities of particular program offices but would be pleased to provide written responses and ongoing collaboration with the Committee.

As this committee knows, the potential benefits of fusion energy are enormous. Fusion holds the promise of being an on-demand, safe, and abundant source of carbon-free primary energy and electricity. Fusion may completely transform the way humans generate and use energy, providing immense economic opportunities beyond commercial energy. In addition, fusion may enable new defense and space capabilities,[1,2] with profound impacts for national security. Together, this means that the race to fusion is also a race for future global leadership. While fusion has long enjoyed international collaboration and should continue to do so, make no mistake, fusion is now also an international competition. Failure to act now may relegate the U.S. to being importers rather than exporters of fusion technology.

The US fusion R&D community, including both public and private-sector players, has spoken in unison, as manifested in the 2020 Fusion Energy Sciences Advisory Committee (or FESAC) Long-Range Plan[3] and 2021 National Academies report *Bringing Fusion to the U.S. Grid.*[4] They are ready to take on an energy-development mission, which will require a fundamental shift in the US fusion energy R&D strategy: firstly, a greater focus on public-private partnerships to ensure commercial relevance and to better harness the large amounts of private capital being injected into fusion R&D, and secondly, a much greater emphasis on developing and demonstrating the needed enabling materials and technologies for a fusion pilot plant,[5] or FPP.

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[1] https://aerospace.org/article/sizing-compact-fusions-potential.
[2] Dr. Jeff Waksman, Strategic Capabilities Office, Office of the Secretary of Defense (personal communication, 2022).
[3] https://usfusionandplasmas.org.
[4] https://nap.nationalacademies.org/catalog/25991/bringing-fusion-to-the-us-grid.
[5] The National Academies report *Bringing Fusion to the U.S. Grid* (footnote 2) specifies that a fusion pilot plant (FPP) should generate a meaningful amount of net electricity (e.g., more than 50 MWe) for more than 3 continuous hours with a timely path to a full power year, at a capital cost that can attract private funding.

There are two primary reasons why fusion is poised for an energy-development mission. The first is fusion's scientific and technical readiness, as evidenced by multiple once-in-a-decade breakthroughs in the past year alone, for example reaching the cusp of fusion ignition on the National Ignition Facility at DOE's Lawrence Livermore National Laboratory and the demonstration of a fusion-scale magnet at nearly twice the previously available magnetic-field strength by a privately funded US fusion company. The second development is the enormous market pull for an energy technology with the characteristics of fusion energy, as evidenced by the nearly $5B of private capital invested into predominantly US-based fusion companies.[6]

Bold Decadal Vision

In March of this year, the White House Office of Science and Technology Policy and the DOE co-hosted a White House Summit entitled *Developing a Bold Decadal Vision for Commercial Fusion Energy*.[7] The *Bold Decadal Vision* aims to seize the opportunity enabled by private capital, which is now on par with public fusion funding, to translate longstanding US leadership in fusion science into a world-leading US-led commercial fusion industry. This would enable US technological leadership in the 21st century and beyond, provide sustainable global energy security and abundance, and support a just energy transition.

The *Bold Decadal Vision* aims to establish a strong partnership between the DOE and the fusion private sector with the following over-arching objectives: firstly, demonstrate net energy breakeven in the 2020s, by possibly more than one approach, while aggressively developing the enabling materials and technologies needed for an FPP; secondly, achieve at least one credible FPP design by the late 2020s that attracts significant private funding and commercialization partners for FPP construction and operation by the early 2030s; and, finally, enable commercial first-of-a-kind fusion plants by the late 2030s and rapid deployment throughout the 2040s and beyond.

As a foundation to the *Bold Decadal Vision*, we must also prepare the path broadly for fusion commercialization,[8] going well beyond the R&D. This includes public engagement and energy justice, diverse workforce development, a regulatory framework that engenders public trust and supports timely deployment, market identification, attracting investment and commercialization partners, export control, nuclear nonproliferation, cybersecurity, international coordination, building critical supply chains and manufacturing capabilities, and waste disposition.

Since the White House Fusion Summit in March, DOE has engaged in a number of activities to support the development of the *Bold Decadal Vision*. First, DOE hosted a workshop in Washington, DC in June of this year, entitled *Fusion Energy Development via Public-Private Partnerships*,[9] where we brought together a broad set of fusion stakeholders and multiple government agencies to have inclusive conversations about the path forward for the *Bold*

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[6] https://www.fusionindustryassociation.org/copy-of-about-the-fusion-industry.
[7] https://www.whitehouse.gov/ostp/news-updates/2022/04/19/readout-of-the-white-house-summit-on-developing-a-bold-decadal-vision-for-commercial-fusion-energy.
[8] https://www.whitehouse.gov/ostp/news-updates/2022/06/03/parallel-processing-the-path-to-commercialization-of-fusion-energy.
[9] https://science.osti.gov/fes/Community-Resources/Workshop-Reports/Fusion-Energy-Development-via-Public-Private-Partnerships.

Decadal Vision. Secondly, we are working hard to launch a milestone-based fusion development program, as first authorized in the Energy Act of 2020. This program, which is expected to be announced imminently, will support for-profit entities to develop FPP preconceptual designs and technology roadmaps, and to pursue applied R&D in partnership with national laboratories and universities to enable a successful FPP design. This will be a first-of-a-kind DOE program that will use DOE's Other Transactions authority. Third, a DOE Fusion Energy Crosscut Team has been formed with representatives from the Office of Science, ARPA-E, NNSA, Nuclear Energy, Economic Impact and Diversity, and Environmental Management. The crosscut team spans DOE's equities across broad areas of need in fusion energy R&D and commercialization. Going forward, the crosscut team will identify, recommend, and coordinate needed new activities and funding in support of the *Bold Decadal Vision*, including coordination with the interagency and the private sector. Finally, discussions internally at DOE and with external fusion R&D stakeholders are proceeding regarding possible new programs and test facilities aligned with the priorities of the FESAC Long-Range Plan and the technology roadmaps that will be early deliverables of the milestone-based development program. Much planning will need to occur over the next year and beyond so that we are prepared to rapidly implement new programs and initiate construction projects.

To realize an operating FPP on a decadal timescale will require increased funding, as well as attention to investment strategies that can amplify federal funding. ARPA-E has proven that federal investments can be amplified by private funding in its fusion programs, which to-date have garnered a 6-to-1 ratio of private follow-on funding to its fusion portfolio.

Role of ITER and International Collaborations in the Bold Decadal Vision

Change is occurring at ITER. Projection construction for ITER is 76 percent complete to First Plasma. US ITER is now 70 percent complete to First Plasma. ITER Director General Bernard Bigot passed away in May 2022. He was an extraordinarily gifted leader of the ITER Project, and his outstanding service will be remembered with much appreciation around the world. A search is underway to identify and hire the next ITER DG. Pandemic-related delays led to the need to rebaseline the ITER project. The new DG will want the opportunity to comment on the ITER rebaselined cost and schedule prior to approval by the ITER Council. We note that there was a recent Fusion Energy Sciences Basic Research Needs workshop on the US ITER Research Program so that US researchers are prepared to take advantage of the scientific opportunities presented by ITER first plasma and beyond; the draft report is available online.[10]

There are opportunities to maximize ITER benefits to the US and the *Bold Decadal Vision* starting immediately and before first plasma. Examples include placing more US people on the ground at ITER, including from US private industry, and enabling streamlined access by US fusion stakeholders to ITER data and experience with construction, supply chains, costing, systems integration, regulatory engagements, and public engagement.

Let me turn to the topic of international collaborations more generally. Governments and private companies from around the world are paying attention to the development of the *Bold Decadal Vision.* Several have reached out for discussions regarding potential partnerships. These discussions are ongoing but need to be accelerated. International collaborations may provide

[10] https://www.iterresearch.us.

opportunities to accelerate fusion RD&D and reduce costs to the US Government in support of the *Bold Decadal Vision*. Such opportunities may include but are not limited to securing fuel supplies including startup tritium, personnel exchanges, design-code validation, workforce development, sharing of capital-intensive test facilities, regulatory coordination, developing robust supply chains and availability of critical materials, coordination on nuclear and cybersecurity. I note that there is an active FESAC charge to assess targeted and mutually beneficial collaborative activities on overseas facilities as well as the modalities for such collaborations, with a report due in Spring 2023.[11]

Conclusion

Chairman Manchin, Ranking Member Barrasso, and Members of the Committee, thank you again for the opportunity to testify on Federal support for fusion commercialization and the status of the *Bold Decadal Vision.* As the Senate and its colleagues in the House continue to consider how to support the *Bold Decadal Vision for Commercial Fusion Energy*, the DOE is continuing to develop an "all-of-DOE" approach to accelerating fusion energy RD&D in close partnership with the private sector, guided by the visionary authorizations you and your House colleagues have already provided and the incredibly hard work that the fusion R&D community put into the 2020 FESAC Long-Range Plan and the 2021 National Academies report *Bringing Fusion to the U.S. Grid*. I would be happy to take questions.

[11] https://science.osti.gov/-/media/fes/fesac/pdf/2022/FESAC-charge-on-international-benchmarking.pdf.

The CHAIRMAN. Thank you, Dr. Hsu.

Now we are going to turn to Dr. Cowley for his opening remarks.

OPENING STATEMENT OF STEVEN COWLEY, DIRECTOR, PRINCETON PLASMA PHYSICS LABORATORY

Dr. COWLEY. Chairman Manchin, Ranking Member Barrasso, and Committee members, thank you for the invitation to testify today. I am the Director of the Princeton Plasma Physics Lab, as Senator Manchin said, and a professor of Astrophysics at Princeton University. Princeton manages PPPL for the Department of Energy, and it is the lead lab in fusion, and has been since 1951. We are grateful to this Committee for its longstanding commitment to the development of fusion energy. It is indeed an honor to be here today.

Senator Barrasso gave us a very good explanation of what fusion is. I will back that up a little bit. It is the power source of the sun and all the stars in the universe. It is the process of fusing small atoms to make bigger atoms—small atoms like hydrogen to make bigger atoms like helium. Indeed, that is what the sun is doing and has been doing for 4.6 billion years. Fusion is, in many ways, the perfect energy source. It is safe and clean. It has no greenhouse gas emissions and no long-term radioactive waste. The fuel we need for fusion is extracted from sea water. It is abundant and sustainable for millions of years. But fusion requires unbelievable conditions—astonishing temperatures of over 100 million degrees. So is it even possible to do fusion on Earth? The answer is clearly, yes. As far back as 1994, we made over ten million watts of fusion power at PPPL in a device that used powerful magnets to contain and control a 250-million-degree fuel.

Fusion research took another major leap forward in 2021 with two remarkable results. First, the National Ignition Facility at Lawrence Livermore National Laboratory achieved the first self-sustained fusion burn from a pellet ignited by the world's most powerful laser. That same year, the Joint European Torus, in the UK, sustained fusion conditions to release 59 megajoules of fusion energy. The question, therefore, is not whether we can do it, but whether we can make fusion electricity at a cost that the consumer wants to pay. I am optimistic that we can, clearly, but only if we both harness the private sector to drive down cost and utilize the public sector—the nation's national laboratories and universities—to propel the science and innovation forward. Neither sector is sufficient alone.

What should the Federal Government do now to hasten the arrival of commercial fusion and meet the Administration's decadal vision that Dr. Hsu describes? I will highlight some immediate actions. The National Academies of Sciences, Engineering and Medicine, last year, published a report bringing fusion to the U.S. grid. That report recommends a clear and ambitious goal: "the Department of Energy and the private sector should produce net electricity in a fusion plant in the United States in the 2035 to 2040 time frame." The first step toward this is contained in the report's second recommendation: "the Department of Energy should move forward now to foster the creation of national teams, including public-private partnerships that will develop conceptual pilot plant designs and technology roadmaps that will lead to an engineering design of a pilot plant that will bring fusion to commercial viability." This is essential. We must urgently form those teams and develop these conceptual designs. I am delighted that the CHIPS and Science Act authorizes the Office of Science to establish not less than two national teams that shall develop conceptual pilot plant designs and technology roadmaps. We are ready to go.

My optimism about fusion's commercial prospects is not only rooted in last year's impressive results, but also in recent step-changes in our scientific understanding. Notably, advances in theory, algorithms, and high-performance computing have finally made it possible to predict the turbulence and instabilities that dominate all fusion experiments and have frustrated progress. These advances have been validated by beautiful experiments on the DIII-D tokamak at General Atomics and on NSTX at PPPL. Those experiments must continue if we are to improve our predictive capability. The solution to the fiendishly difficult turbulence problem is a triumph of the DOE-funded program. It is not just an intellectual breakthrough. It is now possible to design and optimize fusion systems on the computer. With industry and university partners, PPPL is addressing the need by combining virtual engineering and the latest fusion science to innovate computationally. This plays into the Department of Energy's leadership in computational science that for many years has dominated the world in this area.

These powerful new tools and their potential to shorten the time to fusion electricity are also recognized in the CHIPS and Science Act, in which the Secretary is authorized to establish and operate a national high-performance computing for fusion innovation center. This, too, is essential. Finally, we need to address the crucial fusion technologies that were set aside while we mastered the containment of the hot fuel—technologies like materials, and how to actually convert neutrons into electricity. Fortunately, the national labs and universities have extensive experience and expertise in related technologies. I am thinking, for example, of the tritium capability at Savannah National Laboratory and the nuclear technology and design expertise at Idaho National Lab and the materials expertise at Oak Ridge National Lab. These are exciting times as we progress towards fusion commercialization. The number of applicants for our fusion Ph.D. programs has nearly tripled, as students sign up to deliver the perfect energy source. It will take immense private, public, and international efforts, but I am convinced we are in the end game. Thank you again for your support and I look forward to your questions.

[The prepared statement of Dr. Cowley follows:]

Testimony of Professor Steven Cowley, Director, Princeton Plasma Physics Laboratory
U.S. Senate Committee on Energy and Natural Resources
"The Federal Government's Role in Supporting the Commercialization of Fusion Energy"

September 15, 2022

Chairman Manchin, Ranking Member Barrasso, and Committee members,

Thank you for the invitation to testify today. I am the Director of the Princeton Plasma Physics Laboratory (PPPL) and a professor of astrophysics at Princeton University. Princeton manages PPPL, which is the lead Department of Energy National Laboratory for fusion research and plasma physics. The entire fusion community is deeply grateful to this Committee for its long-standing commitment to the development of fusion energy. It is an honor to appear before you.

First, what is fusion energy? It is the power source of our sun and, indeed, all the stars of the universe. It is the process of fusing small atoms, like hydrogen, to make bigger atoms and release energy. Indeed, the sun has shined for 4.6 billion years powered in its core from the fusion of hydrogen to make helium.

Fusion is, in many ways, the "*perfect energy source*." It is safe and clean (it has no greenhouse gas emissions and no long-term radioactive waste). The fuel we need for fusion is extracted from sea water. It is abundant and sustainable for millions of years. But fusion requires extreme conditions – astonishing temperatures above 100 million degrees centigrade.

So, *is it even possible to do fusion on earth?* The answer is clearly, "yes." As far back as 1994, we made over 10 million watts of fusion power at PPPL in a device that used powerful magnets to contain and control 250-million-degree fuel. Fusion research took another major leap forward in 2021 with two remarkable results. First, the National Ignition Facility at Lawrence Livermore National Laboratory achieved the first self-sustained fusion burn from a pellet ignited by the world's most powerful laser. That same year, the Joint European Torus in the UK sustained fusion conditions to release 59 megajoules of fusion energy. Dr. Luce will explain why we are confident that ITER will generate a self-sustaining reaction for long timescales.

The question therefore is not whether we can do it, but *whether we can make fusion electricity at a cost that consumers want to pay*. I am optimistic that we can, but only if we both harness the private sector to drive down cost and utilize the public sector – the Nation's National Labs and Universities – to propel the science and innovation forward. Neither sector is sufficient alone.

What should the Federal Government do now to hasten the arrival of commercial fusion and meet the administration's decadal vision that Dr. Hsu described? I will highlight some immediate actions. The National Academy of Sciences, Engineering and Medicine last year published a report *Bringing Fusion to the U.S. Grid*.[1] That report recommends a clear ambitious goal: *"the Department of Energy and the private sector should produce net electricity in a fusion plant in the United States in the 2035-2040 timeframe."* The first step towards this is contained in the report's second recommendation: *"The Department of Energy should move forward now*

[1] https://www.nap.edu/catalog/25991/bringing-fusion-to-the-us-grid

to foster the creation of national teams, including public-private partnerships, that will develop conceptual pilot plant designs and technology roadmaps that will lead to an engineering design of a pilot plant that will bring fusion to commercial viability." This is essential: we must urgently form these teams and develop these conceptual designs. I am delighted that the "CHIPS and Science Act" authorizes the Office of Science to: "*establish not less than 2 national teams that shall develop conceptual pilot plant designs and technology roadmaps*." We are ready to go.

My optimism about fusion's commercial prospects is not only rooted in last year's impressive results, but also in the recent step-change in our scientific understanding. Notably, advances in theory, algorithms, and high-performance computing have finally made it possible to predict the turbulence and instabilities that dominate all fusion experiments and have frustrated progress. These advances have been validated by beautiful experiments on DIII-D at General Atomics and NSTX at PPPL. Those experiments must continue as we continue to improve our predictive capability.

The solution of the fiendishly difficult turbulence problem is a triumph of the DOE-funded program. It is not just an intellectual breakthrough; it is now possible to design and optimize fusion systems *on the computer*. This is a critical advance since all fusion reactor designs require innovations to make them viable candidates for the first generation of fusion plants. With industry and university partners, PPPL is addressing the need by combining modern virtual engineering and the latest fusion science to innovate *computationally*. These powerful new tools and their potential to shorten the time to fusion electricity are also recognized in the "CHIPS and Science Act" in which the Secretary is authorized to *"establish and operate a national High-Performance Computing for Fusion Innovation Center."* This is essential.

Finally, we need to address the crucial fusion technologies that had been set aside while we mastered the containment of the hot fuel. Fortunately, the National Labs and Universities have extensive expertise that can be adapted to provide those solutions. I am thinking, for example, of the tritium capability at Savannah River National Laboratory and the nuclear technology design expertise at Idaho National Laboratory.

These are exciting times as we progress towards fusion commercialization. The number of applicants to our fusion PhD programs has nearly tripled as students sign up to help deliver the *"perfect energy source."* It will take immense private, public, and international efforts, but I am convinced we are in the end game.

Thank you again for your support, and I look forward to your questions.

The CHAIRMAN. Thank you, Dr. Cowley.

And now, visiting us from France, we have Dr. Luce.

OPENING STATEMENT OF DR. TIM LUCE, CHIEF SCIENTIST, ITER ORGANIZATION

Dr. LUCE. Thank you to the Chair, Senator Manchin, Ranking Member, Senator Barrasso, and members of the Committee, for the opportunity to discuss fusion energy. As introduced, I am Tim Luce. I am presently the Head of Science and Operations Domain, and Chief Scientist for the ITER Organization. The ITER Organization is responsible for the coordination of the design, assembly, commissioning, and operation of the ITER tokamak with the goal of demonstration of fusion power production at the power plant scale.

The world needs reliable energy in sufficient quantity to support the development of society without adverse impact on our environment. To address this need, multiple solutions, both for the near-term and in the future should be explored. As has been stated already, fusion energy is not yet at the stage to satisfy the need for abundant clean energy. However, we know that fusion has the potential to supply this energy for millennia. Fusion can be realized around the globe, enabling ready access to energy, which should reduce one source of conflict among nations. But the potential of fusion remains to be demonstrated at the scales required for energy production for the planet. ITER plays an essential role in this demonstration. While proper conditions for fusion power have been demonstrated in laboratories around the world for seconds at a time, the challenge remains to produce megawatts of power with substantially greater output than input.

A fundamental element of the ITER mission is to validate our physics understanding that is it is possible to produce a burning or self-heated plasma at the power plant scale. Our goal is 500 megawatts output at ten times the input power. A second key element is to test some of the essential technologies to bring fusion into the energy economy. Now under assembly, ITER is more than 75 percent complete for the infrastructure and components needed for first plasma operations. As a member of the ITER agreement, the U.S. plays an essential role. About 85 percent of the capital investment in ITER is supplied by in-kind contributions. For the U.S., this is the responsibility of the ITER Project Office in Oak Ridge, under the direction of the Department of Energy, and it continues to deliver a range of systems necessary for ITER mission success. Through the research enabled through the Office of Fusion Energy Sciences, the U.S. fusion program has been a leader in the physics understanding that led to the ITER design and continues this leadership with physics R&D directed toward the optimization of the ITER research plan. And finally, the ITER organization consists of staff from all the members, and the U.S. staff play a vital role in all facets of the work going on at the ITER project.

The ITER organization cannot advocate for any specific proposals to member governments, but we wholeheartedly support the development of roadmaps to fusion energy by the members. Preparing to build on the success of ITER will bring the maximum return on the ITER investment. In this light, we note positively the recent

National Academies of Sciences, Engineering and Medicine report. The title, "Bringing Fusion to the U.S. Grid," places the focus on fusion playing a role in the energy supply economy, which is our fervent hope as we work toward accomplishing the ITER mission. And it is appropriate to note here specific places where ITER has contributed or will contribute to a fusion energy roadmap. First, ITER will demonstrate our scientific understanding of fusion plasmas and inform designers of future fusion pilot plants and power plants regarding tradeoffs among key design features, such as pulsed versus steady-state operation. Second, ITER is providing us with practical experience in licensing a fusion facility under nuclear safety regulations. Third, the in-kind supply model for ITER components has made and should continue to make a positive impact on industry, resulting in the development of a new global fusion supply chain and workforce. These are essential steps that will support the design and construction of a fusion pilot plant, and eventually, a fusion economy.

ITER is a prudent investment as part of a fusion energy strategy. For a fraction of the total investment, which minimizes the individual risk to the members, each of the members receives 100 percent of the ITER science, technology, and associated intellectual property. Continued U.S. support for ITER is essential for the path to fusion energy and provides important experience for a fusion pilot plant. The ITER Organization is grateful for the support for fusion by this Committee and its counterpart in the House and by individual Members of Congress. We acknowledge the support from the Department of Energy through the Office of Science and the engagement of many U.S. companies contributing to ITER. Finally, we are indebted to the individual U.S. researchers, engineers, and those in other disciplines in the national laboratories, universities, and industry who have made fusion their goal and their passion, whether directly toward ITER, or in parallel. This passion is necessary to realize our common goal of seeing fusion energy take its place in the energy economy.

I thank you for your interest and I welcome any questions you may have.

[The prepared statement of Dr. Luce follows:]

Statement of Tim Luce
Head of Science and Operations Domain
ITER Organization

Before the Committee on Energy and Natural Resources
United States Senate

September 22, 2022

Hearing on the Federal Government's Role in Supporting the Commercialization of Fusion Energy

Thank you to the Chair, Senator Manchin, Ranking Member Barrasso and Members of the Committee, for this opportunity to discuss fusion energy.

I am Tim Luce, and I am presently the Head of the Science and Operations Domain and Chief Scientist for the ITER Organization. The ITER Organization is responsible for coordination of the design, assembly, commissioning, and operation of the ITER tokamak, with the goal of demonstration of fusion power production at the power plant scale.

The world needs reliable energy in sufficient quantity to support the development of society without adverse impact on our environment. To address this need, multiple solutions both for the near-term and in the future should be explored.

Fusion energy is not yet at the stage to satisfy the need for abundant clean energy. However, we know that fusion has the potential to provide that energy for millennia. Fusion can be realized around the globe, enabling a global access to energy, which should reduce one source of conflict among nations. But this potential of fusion remains to be fully demonstrated at the scales required for energy production for the planet.

ITER plays an essential role in this demonstration. While proper conditions for fusion power have been demonstrated in research laboratories around the world for a few seconds at a time, the challenge remains to produce fusion reactions that produce megawatts of power with substantially greater output than input. A fundamental element of the ITER mission is to validate our physics understanding that it is possible to produce a burning (or self-heating) plasma at the power plant scale of 500 MW output, 10 times the input power. A second key element is to test some of the essential technologies to bring fusion into the energy economy.

Now under assembly, ITER is more than 75% complete for infrastructure and components needed for first plasma operations. As a Member of the ITER Agreement, the U.S. plays an essential role. About 85% of the capital investment in ITER is supplied by in-kind contributions. For the U.S., this is the responsibility of the ITER Project Office in Oak Ridge under the direction of the Department of Energy, which continues to deliver a range of high-tech systems necessary for mission success, including the central solenoid magnet at the heart of the ITER tokamak. Through the research enabled through the Office of Fusion Energy Sciences, the U.S.

fusion program has been a leader in the physics understanding that led to the ITER design and continues this leadership with physics R&D directed toward optimization of the ITER Research Plan. Finally, the ITER Organization consists of staff from all the Members, and U.S. staff play a vital role in all facets of the work ongoing in the ITER Project.

While the ITER Organization cannot advocate for any specific proposals to Member governments, we wholeheartedly support the development of roadmaps to fusion energy by the Members. Preparing to build on the success of ITER will bring the maximum return on the ITER investment.

In this light, we note positively the recent National Academies of Science, Engineering and Medicine report. The title, *Bringing Fusion to the U.S. Grid*, places the focus on fusion playing a role in the energy supply economy, which is our fervent hope as we work toward accomplishing the ITER mission.

The above referenced National Academies report states that "technology and research results from U.S. investments in ITER, coupled with a strong foundation of research funded by the Department of Energy (DOE), position the United States to begin planning for its first fusion pilot plant…. [and] much of the experience gained through the ITER process is relevant to a pilot plant regardless of its configuration." It is appropriate to note here specific places where ITER has contributed or will contribute to a fusion energy roadmap.

First, ITER will demonstrate our scientific understanding of fusion plasmas and inform designers of future fusion pilot plants and power plants regarding trade-offs among key design features such as pulsed versus steady-state operation.

Second, ITER is providing us with practical experience in designing, manufacturing, assembling, and operating a fusion facility that can be licensed under nuclear safety regulations. Independent of the ultimate details of future facilities, the basic nuclear safety objectives of confinement of radiological materials and protection of the public and workers will be constant. Satisfying regulatory oversight is one of many areas in which lessons can already be learned from the ITER experience.

Third, the in-kind supply model for ITER components has made and should continue to make a positive impact on industry, resulting in the development of a new global fusion supply chain and workforce. These are essential steps that will support the design and construction of a fusion pilot plant and eventually a fusion economy.

ITER is a prudent investment as part of a fusion energy strategy. For a fraction of the total investment, which minimizes the risk, each of the ITER Members receives 100 percent of ITER science, technology and associated intellectual property. Specifically for the U.S., a contribution of ~9 percent toward construction and ~13 percent toward operations provides all of the return. I would emphasize here that 'know-how' is both the most important and the most difficult intellectual property to capture. We encourage all of the ITER Members to take full advantage of ITER through aiding in staff recruitment and taking advantage of the new Long-Term Assignment program that will be introduced in the coming year. To form and execute an effective roadmap, 'know-how' is vital and can only be gained by direct experience. As for all Members, ITER is thus an invaluable resource for the emerging U.S. fusion industry.

Continued U.S. support for ITER is essential for the path to fusion energy and provides important experience for a fusion pilot plant. The ITER Organization is grateful for the support for fusion by this committee and its counterpart in the House, and by individual Members of Congress. We also acknowledge the support from the Department of Energy through the Office of Science, especially the Office of Fusion Energy Sciences, the U.S. ITER Project Office, and the many U.S. supplier companies contributing to ITER. Finally, we are very grateful to the individual U.S. researchers, engineers, and those in other disciplines in the National Laboratories, universities, and industry who have made fusion their goal and passion, whether directly toward ITER or in parallel. This passion is necessary to realize our common goal of seeing fusion energy take its place in the energy economy.

Thank you for your interest. I welcome any questions you may have.

The CHAIRMAN. Thank you, Dr. Luce.

Finally, we have Dr. Mumgaard.

OPENING STATEMENT OF DR. BOB MUMGAARD, CEO AND CO-FOUNDER, COMMONWEALTH FUSION SYSTEMS

Dr. MUMGAARD. Thank you, Chairman Manchin, Ranking Member Barrasso, and esteemed members of the Committee, especially for the longstanding support for fusion. I think that has led us to where we are today. I am Bob Mumgaard. I am the CEO and Co-Founder of Commonwealth Fusion Systems. What is that? That is a fusion company. The company is four years old, with 300 people. It is backed by private investment from people like Bill Gates and large energy investors who believe in the potential of fusion. I am here also representing the Fusion Industry Association, which is over 30 members, and I am a founding board member there.

My role in this, Committee, is a bit different because my esteemed colleagues here have already explained what fusion is, where the science is, and how far we have come, and they are exactly right. And really, I am here to talk about the next step, where we are investing, and that is, how do we get to fusion commercialization? And this is where fusion makes an impact in the world because we go from a world about resources, you know, under us or shining on us, to a world about resources that are what we can do—what our people can do, human resources—to take a technology and bring it to scale. And it is widely agreed, I think, seen here, that fusion is at an inflection point where we are going from the science to energy and we are thinking about what that looks like. This has been seen by the private markets who have put $4.7 billion in, much of that recently. And that is into developing technologies that could scale. And this represents, you know, actually, more money invested in fusion than in advanced nuclear reactors, for instance.

And of course, other nations also see that inflection point and they are acting. They are acting fast. They are acting bold. And we at CFS regularly get inquiries from other governments about where to build the first fusion power plant, where to use what test facilities. And the U.S., long a leader in fusion science, risks not leading, but buying fusion energy from elsewhere. We are in a race to put that fusion on the grid as soon as possible—in the 30s. And the consequences of not winning are substantial. And today, we are not where we want to be in that race. But I think we are seeing a big change, that the key word here is—bold. We are seeing a Bold Decadal Vision. And there are some policies that are already underway that I think are really going to be supportive. We already have a lot of the elements that are bold in the fusion industry itself. So you can see pictures of people putting hardware in the ground, building things—building things and trying things. And that is very exciting. The public programs are now also figuring out how to support that.

And so, where can they help? First, we should note that much of what needs to be done is already authorized. We have already gone through this. We have looked at it. We have looked at the plans. We have passed the things that we need to pass. I think about it in four different buckets. So, first, there is an alignment activity that needs to happen, which is aligning the existing strong programs with an energy mission. And as pointed out in the National Academies' report, the DOE should focus on a domestic fusion energy industry and all the technologies that feed that. To do that, we need the DOE national labs and the universities to focus on their core strengths, which are scientific computing, innovation of the basic science, materials, et cetera, while the private sector focuses on its core strengths, which are deploying technologies, building things, engineering, market assessments, understanding what is attractive. And together, we are going to get there faster than we would individually. Second, we need to build things. We need to build test stands. Those have been identified in the National Academies' report, the FESAC report, and we should start doing those right now because other nations are doing things in metal that we have only looked at on paper for the last couple of years. Those are authorized.

Third, we need to enable pilot plants. Now, these are plants that put power on the grid and importantly, in a commercially relevant way. That is really important for the companies because that is part of their business plan, to show they can do that, and then do that repeatedly as an industry. Fortunately, we have examples about how to do that well in other areas of science and technology in the United States. We have, for instance, the NASA COTS program, which worked with SpaceX to be able to go up to the International Space Station and provide a new capability that could then be used commercially, and now it dominates the launch market. And that was enabled because Congress saw that, you know, stable funding, being bold, they put up $500 million for the NASA COTS program in year one to fund for five years. Everyone could see where that was going to go and could go there quickly together. That milestone program in fusion is already authorized and waiting to be funded and waiting to be actually put in implementation. Fourth, we need to ensure regulatory clarity. We have a process in place with the NRC right now, and it is actually near its conclusion. And so, hopefully, that goes well, but Congress should continue to monitor that.

You know, I am pretty confident that a Bold Decadal plan that hits these four things: working together, building the necessary test stands, enabling a milestone program for a pilot plant, and doing regulatory certainty, will be able to put the U.S. into the lead, and it will show that this commercialization activity is indeed now, and could result in an industry in not the second half of the century, but hopefully, in the 30s. So with that, thank you for the invitation. I look forward to answering questions.

[The prepared statement of Dr. Mumgaard follows:]

Written Testimony of Bob Mumgaard, Ph.D.
CEO, Commonwealth Fusion Systems

Senate Committee on Energy & Natural Resources
United States Senate

The Federal Government's Role in Supporting the Commercialization of Fusion Energy

September 15, 2022

Chairman Manchin, Ranking Member Barrasso, and members of the Committee, my name is Bob Mumgaard and I am the CEO of Commonwealth Fusion Systems (CFS), a fusion energy company that spun out of the MIT Plasma Science & Fusion Center in 2018, and a Board Member of the Fusion Industry Association, which advocates for the commercial fusion industry here in Washington, DC. I would like to thank the Committee for holding today's hearing on the Federal government's role in supporting the commercialization of fusion energy.

I want to start by also thanking the Committee for your efforts to support commercial fusion through the passage of recent legislation, including the *Energy Act of 2020* and the *CHIPS and Science Act of 2022*, and by providing critical funding through the annual appropriations process and the recently enacted *Inflation Reduction Act*.

We are at a unique moment in time with the advent of new commercial technologies, a dramatic change of fusion's commercialization timelines and significant private investment of $4.7 billion flowing into over 20 commercial fusion companies in the U.S., and at least 35 worldwide, all while countries around the world enact new fusion programs and supportive policies in their attempt to lead in this sector. At CFS, we are confident that, with the right collaboration between the public and private sectors and sufficient funding, the feasibility of net-energy (i.e., the ability to generate more power out than it takes to start the fusion process, which is the most critical next step for the viable commercialization of fusion energy) will be demonstrated and improved upon within this decade. From there, we believe we have a real shot at commercial fusion power plants on the grid starting in the early 2030s. This confidence is shared with the Fusion Industry Association and increasingly with foreign governments.

Commercial fusion energy will be a game changer in the energy sector. It will provide zero-carbon, safe, affordable, and limitless power for the world. Most importantly, it is a solution that can be deployed at scale to improve our energy security and at the speed required for the clean energy transition to achieve our decarbonization goals by mid-century.

Despite being a historical leader in fusion, the last 20 years have seen the U.S. cede that leadership in the publicly funded programs to other nations who were willing to enact bold new programs. These countries are moving aggressively to be first to commercialize this transformational energy source and will outspend the U.S. on publicly funded programs, such as critical R&D and enabling technologies, as well as developing appropriate licensing and siting regulations to support this technology and encourage the industry. As an American, I want to see the U.S. win this race. But as a fusion company, we have a responsibility to go where the best environment is to quickly build this new industry to prevent future impacts of climate change and to meet the growing global demand for clean energy.

For the U.S. to succeed, it should exploit its significant advantages in innovation relative to other countries by leveraging the U.S. private sector to create a commercial fusion product. This requires two things. First, the U.S. must increase public resources and investments in targeted fusion energy R&D. Second, we must ensure better coordination between the Department of Energy (DOE) and the private sector in those R&D efforts. Better public-private collaboration means programs to facilitate publicly funded scientists to continue their research and learn as much as possible from newly built private fusion facilities, private company contributions and access to publicly funded capabilities and results, and public facilities and fusion test stands participating in de-risking private commercialization endeavors on the private sector's timeline. In short, we need a realignment of federal R&D efforts to match the direction and current timeline of the U.S. private sector, and need sufficient funding for those R&D efforts and other already authorized fusion programs to bring this technology to market as quickly as possible.

Collaboration is not going to be sufficient to win, we also need a renewed focus by DOE on a commercialization pathway of this promising technology.. The U.S. has an opportunity unlike any time before to accelerate fusion research and development by partnering with the private sector to de–risk certain technological gaps and building out important R&D facilities and test stands identified in the 2020 Fusion Energy Sciences Advisory Committee (FESAC) recommendations to DOE[1]. To do so requires implementing a comprehensive plan, such as the *Bold Decadal Vision for Commercial Fusion Energy,* on the timeline that the private industry is currently working on, which includes funding key programs, such as the milestone fusion development program and developing a fusion industry.

But capturing a first-mover advantage will require Congress, the Administration, federal and state regulators to take concrete steps now to enable a thriving domestic fusion energy industry here in the United States. If the U.S. does not act in a timely manner, there is a real risk of private companies investing and constructing their fusion power plants elsewhere in the world. Failing to act means that instead of selling commercial fusion power plants as a large globally important industry, the United States could be buying them from overseas.

[1] FESAC_Report_2020_Powering_the_Future.pdf

Fusion's role in the global energy transition

From clean energy policies across the world, to transitions already underway in the global economy, and the mounting costs of extreme weather, we need deep decarbonization at a global scale that can support continued global economic growth and prosperity, while at the same time achieving the stated U.S. goal of a net-zero economy by no later than 2050. Members of this Committee are all aware of the progress the U.S. has made in reducing our emissions through fuel switching and the rapid growth of the renewables sector in the past decade, specifically wind and solar. But strong continued growth of intermittent resources, like wind and solar, alone cannot get us to net-zero emissions in a time frame that matters given renewables have been shown to have unfavorable cost scaling above 50% share[23]. To achieve our net-zero goals, we need a new dispatchable, zero-carbon electricity source that is scalable. To achieve this midcentury net-zero goal, we will need one of the largest industrial transformations in history, with replacement plus expansion rates of ~100GW in new power plants. This is the largest problem and opportunity facing humanity and to solve it the market needs a fundamentally new energy generation technology.

Fusion can be that technology. Fusion is a zero-emission, firm, dispatchable energy source that will be economically competitive and can scale-up rapidly.

Key attributes of commercial fusion energy:

- **Zero emissions**: no greenhouse gas or pollutant emissions
- **Dispatchable**: can operate constantly, 24/7 and integrate with intermittent sources
- **Scalable**: freely available and inexhaustible fuel supply
- **Safe**: inherently safe with no meltdown or long-lived nuclear waste
- **Siting flexibility**: relatively small footprint and can be built anywhere, close to load centers
- **Robust domestic supply chain**: built of mostly steel and concrete with some high technology components; manufacturable in the U.S. and would not require reimagining supply chains
- **Markets**: beyond producing electricity, fusion is also a dispatchable source of high-quality heat that can unlock other hard-to-decarbonize markets (e.g., hydrogen production, industrial process heat, green fuels, district heating, direct air capture of carbon dioxide, desalination, and others)
- **Jobs**: creates and supports good paying clean energy jobs

2 https://www.iea.org/reports/net-zero-by-2050
3 https://link.springer.com/article/10.1007/s10894-021-00306-4

A growing fusion industry

For decades, the goals of the U.S. fusion program have been, broadly, to understand the scientific basis of fusion, and to pursue fusion as a viable energy source. However, in the U.S. the advent of the private fusion industry has always been understood to be an inevitable stage on the pathway to the widespread deployment of fusion power to the grid, as highlighted in the 2020 FESAC report as well as a 2021 National Academies of Science (NAS) report, *Bringing Fusion to the U.S. Grid*[4]. I believe that we are now at that stage and I am not alone in that view.

According to a recent survey conducted by the Fusion Industry Association (FIA)[5], there are now at least 35 global fusion companies and, of those surveyed, 52% were founded in the last 5 years alone. The report also indicated that of the 29 companies surveyed, of which 57% were U.S. companies, nearly $4.7 billion of private capital has been raised for commercial fusion energy, a 139% increase since the 2021 report. Of that amount, more than $4.1 billion went to American companies. All indications are that this investment trajectory is likely to continue. The vast majority of fusion innovation is focused on electricity generation, and a majority (93%) of the companies that responded to the survey stated they believe the world will see fusion power on the grid in the 2030s or earlier. By contrast, a purely government-led effort would likely put commercial fusion on the grid in the 2040-2050 time horizon.

It is recognized that the private sector builds on the previous successes of fusion energy achieved at laboratory scale around the world. Now scientists, investors, and business leaders believe that net gain or net energy (that is more energy output than input or Q>1) from fusion is within reach. The growing fusion market is showing encouraging signs of diversity in technological approach which increases the likelihood of overall sectoral success. Private companies are exploring numerous approaches to achieve fusion, including:

- *Magnetic Confinement Fusion*: Confining hot plasma fuel within a chamber with new types of magnets;
- *Inertial Confinement Fusion*: Compressing and heating the fuel so fast that fusion takes place prior to the central fuel interacting with surrounding materials; and
- *Magneto-inertial Confinement Fusion*: Combining aspects of magnetic and inertial confinement to contain the hydrogen plasma fuel.

This rapid growth in the private sector demonstrates the need for a significant shift in the priorities of the government-funded public programs if they are to remain relevant and engaged in the deployment of fusion power plants here in the U.S.

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[4] https://nap.nationalacademies.org/read/25991/chapter/2
[5] https://www.fusionindustryassociation.org/about-fusion-industry

The need for a bold decadal vision for commercial fusion energy

In order to maintain U.S. leadership in fusion energy and center this rapidly growing industry here, it will require a *Bold Decadal Vision for Commercial Fusion Energy* as announced at a White House event this past March[6]. There are several pillars to achieving this vision.

a. *Shifting Priorities of current Government-funded Programs*

Executing on a *Bold Decadal Vision for Commercial Fusion* will require executing a consensus view that we must shift the priorities of current government-funded public programs to focus on helping the private sector and expedite the deployment of fusion power plants in the United States . Previously, public programs were focused on the plasma physics architecture and the only major new fusion devices resided at international and national laboratories. However, the private industry's progress and results no longer justify this approach. To use an example, rather than NASA building and designing every aspect of a commercial aviation industry, from testing and understanding the science of flight to designing and building the airplanes themselves, the government focuses on what it does best, the R&D (e.g., aerodynamics research), the infrastructure (e.g., the wind tunnel), while industry utilizes those R&D resources and expertise to build the products themselves (e.g., the planes) and as aligned with what the end-users need and want. The system works together towards a common goal (e.g., a leading aviation industry and corresponding jobs and technologies) faster than any one element alone could.

A recent report by the National Academies of Science made a similar point in their 2021 report, *Bringing Fusion to the U.S. Grid*[7]; The NAS report stated: “A great deal of scientific and technological progress has been made, but significant remaining technical and scientific issues must be addressed in parallel with developing a successful pilot plant design that would enable an economically attractive power plant. There is increased risk associated with this approach, as compared to solving technical and scientific issues prior to designing a pilot plant, but urgency in clean energy needs, coupled with the promise of fusion energy, motivates this approach.”

As a result, if the U.S. is to win this race for the commercialization of fusion energy, there must be a collaborative partnership between the public and private sectors, who need to work together, divide and conquer, and focus on their corresponding strengths. To achieve this, we need clear roles and responsibilities.

Private fusion is proving its ability to execute large hardware projects, including integrated fusion device demonstrators, and enabling technologies such as high-field magnets, at speeds many times faster than possible in public programs. CFS is doing that right now with the

[6] Readout of the WH Summit on Developing a Bold Decadal Vision for Commercial Fusion Energy
[7] https://nap.nationalacademies.org/catalog/25991/bringing-fusion-to-the-us-grid

construction of our demonstration device, SPARC, in Devens, Mass (Figure 2). Helion Energy is building their fusion generator, called Polaris, in Everett, Washington and TAE Technologies have announced their plans to construct its next fusion research facility, Copernicus, in Irvine, California. More importantly, the private sector is engaging with end customers, bringing market relevance and the ability to speed up development of customer-driven solutions for fusion power systems. Having private investors and customer involvement in commercial entities can prevent dreaded white elephant projects.

On the other hand, we need DOE, the National Laboratories and universities to de-risk outstanding research and technological gaps. Rather than building their own fusion pilot plants, as some countries are doing, U.S. taxpayer dollars and government resources would be better spent by focusing on science and technology towards commercially relevant implementation. Specifically, DOE should follow the FESAC recommendations and move quickly to building important R&D facilities and test stands that align with our best, fastest opportunities for commercialization, including:

- Fusion Prototypic Neutron Source (FPNS), which will provide unique material irradiation capabilities;
- Material Plasma Exposure eXperiment (MPEX) and high-heat-flux testing experiments, which will enable solutions for the plasma-facing materials;
- Blanket research and the associated Blanket Component Test Facility (BCTF), which will provide the scientific understanding and basis to qualify fusion power system blankets for a fusion pilot plant.

These new facilities, and the researchers who use them, the scientists who develop the understanding, the computer simulations that incorporate the results are all a powerful package that the U.S. National Labs and Universities know how to execute. These are widely endorsed but not yet completed and in some cases not yet started. We know what to do, we need to do it.

b. Leveraging Public-Private Partnerships to Maintain U.S. Leadership

This shift in roles in fusion energy development also brings new relevance to, and enhanced need for, public-private partnership (PPP) initiatives. In 2019, the DOE launched the INFUSE program to connect private fusion enterprises with National Labs, supported by DOE's Office of Science's Fusion Energy Science (FES) program. The program offers funding opportunities for projects with awards of $50,000 to $200,000 each and a 20 percent cost-share for private industry partners. While this is a helpful government funded program for the commercialization of fusion energy, INFUSE continues to be funded at a much lower percentage compared to other fusion science programs and relative to the private industries other efforts or programs overseas.

Likewise, the DOE Advanced Research Projects Agency-Energy (ARPA-E) program has funded over $80 million in fusion research at both public and private organizations since 2015 and is currently executing another round of funding expected to support $29 million in programs through 2025. It's worth noting the ARPA-E fusion projects leveraged tremendous amounts of private sector funding with relatively modest funds from American taxpayers. For example, $30 million invested in ALPHA leveraged $570 million in private funds and $40 million in BETHE has already leveraged $200 million in private funds. I believe this serves as a useful model for how the U.S. government can partner with the private sector to bring this disruptive technology to market on a timeline our energy security and changing climate demand.

By contrast, DOE is partnering at scale with the private sector on advanced fission pilot plants. Through DOE's Advanced Reactor Demonstration Program, DOE is putting up $2 billion for implementation of an advanced nuclear pilot plant program such as TerraPower's Natrium reactor in Kemmerer, Wyoming. This is the type of scale and level of commitment the commercial fusion industry could utilize as the U.S. government looks to maintain a leadership role in deploying new clean, firm power sources.

We appreciate the U.S. government's - and this Committee's - support of the private fusion industry to date, however, current federal appropriations for helpful programs such as authorized public private partnership programs are simply not sufficient for the U.S. to gain global leadership position in fusion energy, nor to retain, attract or meaningfully support commercial fusion companies capable of building a domestic fusion energy sector. Indeed, the described ARPA-E programs are one-time, and the only annually recurring fusion public-private partnership program, INFUSE, is currently supported at just $6 million per year. By comparison, the private fusion industry is poised to construct over $2 billion of new integrated fusion demonstration facilities over the next couple of years. It is critical that PPP programs for fusion scale up to remain relevant with the planned private sector investments and accelerated timelines.

c. Maximizing federal resources and funding

Industry's central organizing goal is to put commercial fusion energy on the grid in the early 2030s, a current goal among 92% of the fusion companies that participated in the earlier mentioned survey conducted by the FIA.

The pathway to achieving this goal does not only require us to shift the current priorities of already funded programs, but also to maximize federal resources and funding and make every dollar from the public go further. Thanks to this Committee's leadership, the programmatic architecture for achieving a *Bold Decadal Vision for Commercial Fusion Energy* already exists through current and recently authorized DOE programs and we have successful PPP case studies to point to and emulate to achieve the goals of the Vision. What is needed from Congress and the

Administration is robust and sustained funding through the decade to match the billions in private funding already flowing into this sector.

As an example, a promising development for the fusion industry has been the milestone-based fusion development program, as established by Congress through the *Energy Act of 2020*. Under this new program, companies would accept the bulk of the risk by funding their activities until agreed upon milestones are achieved and verified at which point the company would be reimbursed at an agreed upon fixed price. This is a highly leveraged and ideal option for government investment in fusion with the private sector carrying the risk of schedule and cost overruns and the government supporting companies that have skin in the game by covering a meaningful cost of the program. This type of public-private model has proven successful in other sectors and unleashed an abundance of societal benefits in a short period of time.

The milestone-based fusion development program is modeled after the successful National Aeronautics and Space Administration (NASA) Commercial Orbital Transportation System (COTS) program demonstrated to great success with SpaceX and Orbital[8][9], a program Congress played a key role in establishing several years ago. The COTS program provided NASA with a 10x reduction in launch vehicle program costs, as well as a 2.5x reduction in management costs and has directly contributed to a thriving commercial space industry.

This Committee had the foresight to authorize the fusion milestone program in the *Energy Act of 2020*, and Congress provided the first tranche of funding for the program - $45 million - in FY22. DOE is in the process of standing up this new program and we expect a Funding Opportunity Announcement (FOA) soon, perhaps by the end of this month. We are grateful for this funding and look forward to working closely with Congress, DOE, and others in the private sector to move quickly and put these dollars to work to advance critical commercial fusion energy technology. However, we fear the funding that has been provided for the milestone program in FY22 and what's been proposed for FY23 falls short of the COTS model in order to replicate its success. COTS was successful, in part, because NASA was provided a significant, upfront appropriation of $500 million spent over five years[10]. This level of funding did two things: 1) it provided the private sector a level of confidence that the public sector funding would be there to drive investments in the private sector; and 2) it gave the NASA the ability to plan over a longer time horizon (five years vs a single fiscal year) and de-risk multiple barriers to faster deployment of commercial space, at scale. In short, it enabled the U.S. to move fast.

In order to achieve the *Bold Decadal Vision for Commercial Fusion Energy* and replicate the tremendous success of the NASA COTS model, it's critical that funding levels for the DOE milestone-based fusion development program align with the full, authorized amounts. This will,

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[8] NASA Commercial Orbital Transportation Services (COTS) Program
[9] https://www.nasa.gov/content/cots-final-report
[10] https://www.nasa.gov/commercial-orbital-transportation-services-cots

in turn, unleash millions more in private sector funding, helping to drive deployment of commercial fusion in this country. If the fusion milestone program is successful, it will lead to new privately constructed fusion facilities testing key aspects for commercial fusion energy and possibly one or more net-energy fusion systems deployed in the U.S. The time to put fusion energy on the grid would be reduced dramatically and the potential net savings for the taxpayer (versus a fully government funded approach) would be profound.

We are at an inflection point for fusion energy. The DOE's FES program needs to act quickly on already developed plans and utilize existing and new programs that support private industry's accelerated timelines. If we are to be successful in maintaining U.S. leadership in fusion energy, we need the following:

1. Full funding for the DOE FES program, as recently increased in the *CHIPS and Science Act* from $713 million/year to $1 billion/year;
2. Direct better alignment between the FES program and the private fusion industry to advance critical R&D necessary to deploy fusion energy commercially, in line with industry's technology pathways and timelines;
3. Full funding for critical DOE R&D facilities and fusion test stands, such as: Fusion Prototypic Neutron Source (FPNS), Material Plasma Exposure eXperiment (MPEX) and high-heat-flux testing experiments, and the Blanket research and the associated Blanket Component Test Facility (BCTF); and
4. Full funding for the DOE milestone-based fusion program, *INFUSE*, and ARPA-E fusion projects to help achieve the goals of the *Bold Decadal Vision for Commercial Fusion Energy*.

By making the best use of existing and recently authorized fusion R&D funding, better aligning those DOE R&D dollars to support a commercialization pathway, and fully funding these important recently authorized DOE programs, I believe the chances of the U.S. being the first nation to put power from fusion energy on the grid in the early 2030s are greatly enhanced.

This achievement would be one of the most significant advances for all mankind, have the potential to re-order geopolitics that center around energy, and provide humanity with a powerful new tool to tackle the climate crisis.

International governments competing for leadership in fusion energy

The U.S. is not alone in its pursuits and other nations are aggressively supporting development of fusion energy. Foreign governments are also making significant investments in public-private efforts to promote a domestic fusion industry. The United Kingdom has committed over $500 million to fusion PPPs[11]. China is spending hundreds of millions per year[12] on their private fusion industry. This compares to $32 million in the U.S. for both the DOE's INFUSE public-private partnership program and the milestone-based program in the FY23 budget request.

The United Kingdom has continued to build new facilities to test the components needed for a fusion power plant. These include facilities to develop the fuel cycle for fusion, to practice maintenance on a fusion power plant, to extract the heat from the fusion components, and to test materials. The U.S. has no such set of test stands or development programs despite the long-identified need for these facilities. Over the last five years, the United Kingdom has built in steel and concrete while the U.S. program has yet to implement the recommendations from expert reports. I would also note that FIA member General Fusion has announced plans to build a Fusion Demonstration Plant (FDP) in the United Kingdom, which will demonstrate their Magnetized Target Fusion (MTF) technology.

The United Kingdom and China are targeting having a fusion pilot plant operational by the late 2030s. The UK will soon announce their site selection for their STEP fusion pilot plant[13], and China has shared their plans[14] for a fusion pilot plant. However, neither of these timelines are where the U.S. private sector is today and the U.S. could beat these other countries to market by pursuing a PPP model for de-risking R&D and industry development which complement the private sector's plans to build their own pilot plants. Many FIA member companies are planning on operational plants in the early 2030s. In the case of CFS, we are already building our demonstration facility, SPARC, and in the siting process for our first commercial-scale facility, ARC, to support a construction time of being operational in the early 2030s.

If the U.S. wishes to take an international leadership role in fusion, then it needs to accelerate the timeline for a fusion pilot plant to be ahead of its peers by aligning itself with private industry commercialization goals and leveraging the best of DOE and private industry strengths and resources.

Regulatory landscape

While not the jurisdiction of this Committee, I would be remiss if I didn't briefly discuss the importance of having a predictable licensing and regulatory framework to support the growth of fusion energy. In addition to other nations investing significant public funds to develop

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[11] https://www.neimagazine.com/features/featurefusion-projects-make-progress-in-2020-8492724/
[12] https://www.neimagazine.com/features/featurefusion-projects-make-progress-in-2020-8492724/
[13] https://www.gov.uk/government/news/step-closer-to-naming-site-of-first-fusion-energy-power-plant
[14] http://firefusionpower.org/FPA21-2_CN_ASIPP_Fusion_Song.pdf

commercially viable fusion energy, they are also moving quickly to develop a regulatory framework that provides certainty to companies and investors.

For instance, the United Kingdom is leading in the development of a regulatory framework for commercial fusion that recognizes the significantly lower risk profile that fusion presents compared to fission. The United Kingdom government established a commercial fusion regulatory framework and earlier this year published its response to a public consultation, and confirmed that current UK regulators of fusion R&D facilities, the Environment Agency (EA) and Health & Safety Executive (HSE), will retain responsibility for future commercial fusion facilities[15]; and the government will legislate to make the regulatory treatment of fusion energy clear in law. From a risk perspective, fusion energy facilities are much more like particle accelerator facilities that one would find in a hospital, and it makes sense to regulate them in a similar manner, rather than impose the more onerous and wholly inapplicable requirements developed for fission reactors which simply do not match the risk and safety profile of a fusion system.

In the U.S., the Nuclear Regulatory Commission (NRC) is laying the foundations now for the licensing and regulatory approach of fusion energy. We support this work, which began over two years ago, and appreciate the careful and attentive approach the NRC and its staff are taking in its development. It is our hope the NRC designs a framework that aligns with the risk and safety profile of fusion energy (which is quite different from fission), instills public confidence, and provides industry with the certainty it needs to invest and meet our 2030 deployment goals. We believe the NRC already has the authority it needs to regulate fusion energy under 10 Code of Federal Regulations Part 30, Rules of General Applicability to Domestic Licensing of Byproduct Materials. The NRC staff is scheduled to release their draft recommendations for the regulatory framework for fusion energy next week and we look forward to continuing working with them in this process.

Commonwealth Fusion Systems - Our path to commercial fusion energy

Commonwealth Fusion Systems (CFS) is among the many start-ups we have seen emerge and join the private sector over the past 5 years. In 2018, CFS was spun out of Massachusetts Institute of Technology (MIT) Plasma Science and Fusion Center after many years of DOE funding of MIT's long-standing fusion program. At that same time, new high temperature superconductors were becoming commercially available. The MIT team that would become CFS co-founders were exploring how this new material could be used to build a novel design for magnets that would be the strongest fusion magnets of its kind in the world. Magnets are the key technology in a fusion machine called a tokamak, the most widely studied machine for the magnetic confinement fusion approach described above. If we were able to build

[15] https://www.world-nuclear-news.org/Articles/UK-developing-regulatory-framework-for-fusion

high-temperature superconducting (HTS) magnets, we knew that we could build smaller, faster, and less expensive fusion devices that would achieve net energy and become commercial power plants. It meant that we could provide economical fusion power, supplying humanity with abundant clean energy.

CFS set out on an aggressive timeline for bringing fusion power to the grid. As a first step, with with the backing of private capital and by attracting top talent, the company and its funded collaborators at MIT delivered on its commitment to build and successfully test a first-of-a-kind high-field large-bore HTS magnet (Figure 1) in September 2021. It is the largest HTS magnet in the world with a magnetic field of 20 Tesla.[16] The HTS magnet enabled smaller fusion devices than previous magnet technology. The demonstration was what was needed to start construction on SPARC, a tokamak fusion device, that will be 1/40th the size of the International Thermonuclear Experimental Reactor (ITER).

As mentioned earlier, CFS is currently building our magnet factory and SPARC (Figure 2), our fusion device in Devens, Massachusetts. The plasma physics for SPARC was validated in a series of seven peer-reviewed papers published in the Journal of Plasma Physics[17]. The papers show, point-by-point, using the absolute best simulations, physics, and tools - all built from previous world-wide fusion science - that if SPARC is built according to its design, it will work and achieve a net energy gain of Q>10, which is on par with ITER. Gains of Q>10 would serve as the basis for the design of an economical fusion power plant, which we call ARC.

[16] Figure 1 - 20-Tesla HTS Magnet
[17] Status of the SPARC Physics Basis

Figure 2

The SPARC facility is aimed at the same basic physics questions of the ITER facility and uses the same scientific and technology advances that underpin ITER. However, the reduction in scale afforded by the HTS magnets means that it can be constructed in a fraction of the time and cost. This puts a burning plasma – a long sought scientific goal – in a much-accelerated time frame. In fact, SPARC is expected to become operational in 2025 and reach net energy from fusion for the first time in history in the following year with burning plasmas soon after that. This is the power of innovation and commercialization. This is a domestic facility, built by a U.S. company, backed by private capital, creating a leadership opportunity for U.S. science, engineering, and industry creation. I would note that despite our best efforts to engage, without a comprehensive plan for public private partnerships, there is no readily apparent pathway for the DOE to engage at the scale needed to take advantage of this advancement in the sector.

Following the SPARC demonstration in 2025, CFS plans to construct the world's first commercial-scale fusion power plant, ARC, and put electricity on the grid in the early 2030s. In parallel with the construction of SPARC, we are already conducting a global search for the site of the first ARC such that we can achieve our ambitious goals, in what I believe are achievable timelines.

ARC will further demonstrate the science and technology required for economically competitive, mass production of fusion energy. It will pave the way for fusion systems that will provide carbon-free, safe, virtually limitless power for the world. However, the current publicly funded program's roadmap for developing the required technologies is not at the scale, timeline, or technology choices the private sector requires, thus companies could be forced to duplicatively develop technologies themselves. It is for this reason, the U.S. should move quickly to develop and fund a *Bold Decadal Vision for Commercial Fusion Energy*.

At CFS, we are building a company with the know-how and capabilities to achieve these timelines. We are hiring the best talent to bring this technology to market as quickly as possible and then scale. We also recognize the value in continued collaboration with DOE, the National Laboratories and universities for science research that can support and accelerate development in the fusion private sector. We look forward to growing existing and developing new public sector partnerships that put the U.S. on the fastest path to fusion energy on the grid.

I thank the Committee for holding today's hearing and look forward to working with you to ensure the U.S. will remain at the forefront of this rapidly changing landscape.

Executive Summary of Recommendations to Secure U.S. leadership in Fusion Energy

- Expanded support from the federal government for fusion energy programs is necessary to keep the center of the private fusion industry based in the U.S. To achieve this goal, the U.S. should develop and fund a *Bold Decadal Vision for Commercial Fusion Energy* that leverages the strengths of existing Department of Energy (DOE) programs and National Laboratories and those of the private sector.

- If the U.S. does not scale the public sector efforts and does not align them with the private sector, it may fall behind other nations, like the United Kingdom or China, and miss the opportunity to be a leader in a large-scale energy transition to fusion power.

- The private sector is moving quickly with nearly 35 companies having raised $4.7 billion in private funds and driving towards commercial fusion in the 2030s. Now is the time to make the necessary changes to align DOE resources and funding to partner with the private sector to drive innovation and leadership in fusion energy.

- We need better alignment between the DOE, National Laboratories, universities, and the private sector to work collaboratively towards a common-objective of deploying commercially viable, fusion energy in the early 2030s. Specifically, the DOE and National Labs should focus on their core strengths, such as building out important R&D facilities, test stands and focusing on the science, while the private sector brings its capital, market insights, engineering and execution expertise to move more efficiently towards power plants.

- Congress and the Administration should move quickly to implement a *Bold Decadal Vision for Commercial Fusion Energy* by fully funding existing and newly authorized DOE fusion programs and by leveraging milestone-based, public-private partnerships in order to rapidly deploy commercial-scale fusion energy. Specifically, Congress and the Administration should:
    - Provide full funding for the DOE FES program, as recently increased in the *CHIPS and Science Act* from $713 million/year to $1 billion/year;
    - Direct better alignment between the FES program and the private fusion industry to advance critical R&D necessary to deploy fusion energy commercially, in line with industry's technology pathways and timelines;
    - Move quickly to fund and build important fusion R&D facilities and test stands, including, in line with Fusion Energy Sciences Advisory Committee (FESAC) recommendations:
        - Fusion Prototypic Neutron Source (FPNS), which will provide unique material irradiation capabilities;

        - Material Plasma Exposure eXperiment (MPEX) and high-heat-flux testing experiments, which will enable solutions for the plasma-facing materials;
        - Blanket research and the associated Blanket Component Test Facility (BCTF), which will provide the scientific understanding and basis to qualify fusion power system blankets for a fusion pilot plant.;
    - Provide full funding for the DOE milestone-based fusion development program, *INFUSE,* and *ARPA-E* fusion energy projects.

- Fund and implement the DOE milestone-based fusion program to emulate the successful NASA Commercial Orbital Transportation System (COTS) program model, demonstrated by great success with SpaceX, which provided significant upfront funding ($500 million over five years) to move quickly and drive innovation in a strategically important sector.

- Implement a predictable, reliable licensing and regulatory approach from the Nuclear Regulatory Commission (NRC) that aligns with the risk and safety profile of fusion energy, instills confidence with the public in the technology, and provides the industry with the certainty it needs to invest and meet our early 2030s deployment goals.

The CHAIRMAN. Thank you very much to all of you. I appreciate very much your opening remarks and you all making the effort to be here.

I will start the questions out, if you will.

Dr. Luce, first, I want to thank you for traveling so far to be with us today. I enjoyed my visit to ITER. My entire staff did. You all were very gracious, and we learned a tremendous amount, and it was very impressive. It is a remarkable effort to the international collaboration scientifically—ingenuity and engineering that will demonstrate the commercial viability of fusion energy, and it opened my eyes, more than any, I believe, to those possibilities available to not only the collaboration between nations that are not on the best terms and not getting any better since I was there, of course, the impact of harnessing fusion. So can you describe how the ITER demonstration will assist the effort to commercialize fusion energy technology and all, like in the United States, I am sure other countries, they all have variations of what they are trying to achieve and still belonging to that? Are other countries duplicating what we are doing? Spending more money and just taking time to do what has already been done or more effort into ITER that can give them a technology?

Dr. LUCE. Thank you, Senator.

As I pointed out in my opening remarks, the primary mission is to remove uncertainty from the scientific point of view, and as Steve said, we have made great progress in predictive, but in the end, we need to validate that predictive capability with an actual demonstration. And we believe ITER will perform that demonstration in a variety of operating scenarios. So this enables others to take that information and apply it to design of pilot plants or power plants. It can go in parallel or it can go in series. It is a matter of a decision from the individual member governments how rapidly they want to progress.

The CHAIRMAN. Let me ask simply this, in layman's terms. What you are doing at ITER at a mammoth scale—and I was just blown away with the scale—but fusion has been around for a while. People have been working for this for some time. All of you have been involved in one way or another. What is ITER doing differently than what has already been done, and is there anyone else that has done something on a smaller scale that gives ITER more of a direction and a pathway?

Dr. LUCE. So indeed, the JET tokamak, operated by the European Union, has recently operated at tens of megawatts of fusion power, but not yet at gain. So there is a——

The CHAIRMAN. So it takes as much to put as much in and take it out——

Dr. LUCE. Correct, slightly more.

The CHAIRMAN. So there is no net. Slightly more.

Dr. LUCE. Correct.

The CHAIRMAN. Okay.

Dr. LUCE. Yes. So we need to go to the frontier where the dominant heating source is from the fusion reactions themselves. That has not been accomplished and it needs to be accomplished somewhere. It is a vital first step.

The CHAIRMAN. And that is what the demonstration that we saw at ITER has the capability of doing?

Dr. LUCE. Correct.

The CHAIRMAN. Is there anything else in the world that has that capability?

Dr. LUCE. There are plans. I think Dr. Mumgaard will tell you about their plan to demonstrate that type of capability. I will let him talk about what——

The CHAIRMAN. Let me just say this—why would we be investing in ITER or investing in that if we are already invested in ITER and you are doing something on a much larger scale?

Dr. LUCE. I think we are doing things that are complementary. And so, it is a way of advancing the program, minimizing the risk, and focusing on things that ITER cannot do. What Dr. Mumgaard mentioned is absolutely true. The technologies you need for a fusion economy are not going to be demonstrated properly in ITER. And so, facilities that can come along in parallel of that, both in special laboratories or in unit demonstrations, are essential.

The CHAIRMAN. Let me go to Dr. Hsu.

Dr. Hsu, basically, the Energy Act of 2020 and the CHIPS and Science Act of 2022 provided the Department of Energy with direction to aggressively pursue the development of fusion research and technology development. It calls for DOE to provide a 10-year strategic plan on and on and on. In April, the White House held a summit on developing a Bold Decadal Vision for Commercial Fusion Energy, which resulted in three new initiatives. The first was the announcement of the Department of Energy agency-wide fusion initiative to accelerate the viability of commercial fusion. The second was naming you, Dr. Hsu, as the Lead Fusion Coordinator, and the last was making available $50 million for advancing a fusion pilot plant.

So first of all, I would ask, can you provide the Committee with an update on what is going on and where the Bold Decadal Vision of Commercial Fusion lies, and how are you spending the $50 million?

Dr. HSU. Absolutely, thank you, Senator Manchin.

So the DOE, right now, is, you know, formulating and developing its plan for the Bold Decadal Vision. As I outlined in my opening remarks, you know, central to that is, as Dr. Mumgaard said, aligning the efforts between the public and private sector activities. And really, we are focused on resolving the remaining scientific and technological challenges in order to enable that vision of operating a pilot plant.

The CHAIRMAN. If I may ask, is it redundant to what is being done at ITER? Are you duplicating what ITER has already done? Are you trying to do something different than ITER needs you to do so it helps them?

Dr. HSU. It is both. ITER is going to be a scientific tool, going forward, where we can do research that cannot be done on any single private-sector facility. But on the other hand, ITER is not going to do everything that will bring us to commercial viability either. For example, we need to really accelerate efforts in, let's say, the fuel cycle, as an example, right? Tritium breeding. These are areas that the Bold Decadal Vision really needs to focus on to accelerate in order to meet the time scales.

The CHAIRMAN. I got you.

Now, we will turn to Senator Barrasso for his questions.

Senator BARRASSO. Well, thanks so much, Mr. Chairman.

Dr. Luce, the Chairman testified that in the last month he went to France and it changed his life.

[Laughter.]

Senator BARRASSO. Last month, my staff went to Massachusetts and they brought me some pictures.

[Laughter.]

Senator BARRASSO. Dr. Mumgaard, they went to your facility and were very impressed. Private fusion companies have now raised $4.7 billion, [including from investors like] Bill Gates and some others. Can you talk about why they are so confident about the prospects of commercial fusion energy? And then, specifically, what types of metrics have these investors established to assess the company's performance?

Dr. MUMGAARD. Right, so, first, when you think about what the private investors are looking at, they are looking at this type of panel, what the science has done so far. The statement of conviction of something like ITER that fusion is worth doing and can be done is a huge factor for them putting in private capital to do the next step. That foundation cannot be underestimated.

They are also looking at the quality of the science and the predictive capabilities—that we can actually do experiments faster and cheaper, that we don't need to guess and check. That is key for developing a technology. They are also looking at the market pull. You cannot underestimate how big of a problem energy security, abundance, and sustainability is. That is a trilemma that needs to be solved. And when we solve that, they will build a massive industry. Whether that industry is in some other energy source or fusion, it is up and open for grabs right now.

And so, they are looking across those [fusion companies] and they are saying fusion is serious, and there are serious people who are taking fusion seriously with serious dollars.

Senator BARRASSO. So then——

Dr. MUMGAARD. Then looking at the different companies, and they see a variety of approaches, which means that more than one might work. And so, a portfolio approach can work. And so, now they are asking the question, what can we do together to make the likelihood of one of those working soon and scalable higher?

Senator BARRASSO. So, what metrics are they using, specifically? Because you had talked about a plan to demonstrate net energy production by 2025, and you know, that is a decade earlier than the Department of Energy's international fusion demonstration project. I am wondering, should we be reprioritizing our investments in fusion research?

Dr. MUMGAARD. The two big headline metrics are, can you push a button and make more power out from the plasma than what went in? Break-even energy. Above that, there is burning plasma, which burning plasma is also very important scientifically, but maybe not big headline. The next big headline is electricity on the grid. And the decadal plan actually breaks that out, and says that's on the goal, electricity on the grid, and the National Academies also say those are the two big phases of a pilot plant—net energy and power on the grid.

And so, they are looking to see that, but of course, they need to see intermediate milestones before to know that we are on track. And so, they are tracking not just what the private companies are doing, but what the labs—like JET—and others are doing as well to indicate are we on track? The key thing is time. If we wait, we lose. And that is because the market window is really, really, sensitive on time.

Senator BARRASSO. Dr. Hsu, in your testimony, I was struck by the fact that when you talked about fusion research, you said it has profound impacts for national security. How is the Department protecting fusion research from Russia and China? I saw yesterday that Presidents Putin and Xi were going to meet together.

Dr. HSU. Thank you, Senator, that is a very important question. Our crosscut team has members on it from NNSA, especially because we want to tackle this question more seriously. Furthermore, we are also working with the White House. They are looking into offering cybersecurity training and resources for our private fusion industry. Those are starts, but we know we have to pay careful attention.

Senator BARRASSO. So Dr. Luce, as I see Russia and China being bad actors along the way, should they be allowed to continue participating in international fusion projects?

Dr. LUCE. So historically, fusion has been a bridge to have conversations with various political entities with which we do not necessarily share the same world view. This goes back to Khrushchev visiting the UK in 1957. There is no weaponization potential for magnetic confinement fusion, and for the ITER agreement, itself, it is a treaty-level agreement. We have chosen to work together, and I think it is a realization both of the good investment, they get everything from a small amount, but also from a common need. If we can reduce one source of friction among us, this is a plus.

Senator BARRASSO. Dr. Cowley, if I could ask you—last week, Newsweek published an article highlighting how South Korean researchers sustained a stable fusion reaction for 30 seconds. Who are America's main competitors right now in fusion research?

Dr. COWLEY. Well, the biggest investment is clearly coming from China. And China has a plan to get a pilot plant together on a slightly accelerated time scale, even compared to ours. Interestingly, they just announced a second machine to try and rival what Commonwealth Fusion is doing and go that route, which is the more compact route. They are pouring in dollars and you know, if you ask what a global competitor is, certainly China.

The other one is obviously Europe and the UK. I should not talk too much about the UK, but——

[Laughter.]

Dr. COWLEY. But there is a plan in the UK to push forward the spherical tokamak concept, which is what the machine that Princeton is innovating on towards a reactor on a similar time scale—to the end of the 2030s—that we are talking about. I think China is looking at us and trying to copy the different steps that we are taking and it is very interesting that they have made a step to copy what Commonwealth Fusion Systems is doing. Whether they will move as fast as the private sector in the U.S., I have my doubts.

Senator BARRASSO. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator.

Senator Hirono.

Senator HIRONO. Thank you, Mr. Chairman.

For Dr. Hsu: as you may know, Hawaii's State Constitution requires a two-thirds vote of the legislature in order to site a nuclear fission plant in the state, and this provision was added in 1978 reflecting public concern about the safety of nuclear power and the radioactive waste it generates. Today, we are talking about fusion, not fission, so can you describe some of the safety issues we need to take into consideration with fusion and compare them to the safety concerns associated with the fission reactors used in the nuclear plants today? In plain English.

[Laughter.]

Dr. HSU. Thank you, Senator. This is indeed a very, very important question you ask. So let me start by saying that the safety profile of fusion is one of its potential benefits. That is why people are excited about it, especially this panel. For example, there is no inherent risk for runaway or meltdown as you hear about in nuclear energy, and fusion does not need any special nuclear materials, for example, plutonium or enriched uranium, and it doesn't produce high-level radioactive waste. So these are great, great advantages of fusion, both for safety and for licensing.

But we must seriously take into consideration the potential safety issues that are specific to fusion. You know, these include kilogram or more quantities of radioactive tritium, which is one of the fuels for fusion, and that must be securely contained. And then the safe handling and disposition of potentially large volumes of low-level waste. And fusion, of course, will also have hazards associated with any large industrial facility.

Senator HIRONO. So since fusion does create some waste, what concerns should we have regarding the containment and disposal of the waste produced under the fusion process?

Dr. HSU. We have to take this seriously and treat it carefully. We think we can do it. And in fact, our crosscut team in DOE has environmental management as a team member. We will leverage our knowledge and capabilities across the agency to come up with the right solutions. And I think Dr. Cowley seems like he wants to jump in here.

[Laughter.]

Dr. COWLEY. The total level of radioactive waste from a typical fusion power station will be about a thousand times lower than from a fission station, and the half-life of that radioactivity, most of it, is less than 10 years. And so, by 200 years after the end of the reactor's lifetime, all of that waste can be remanufactured into new fusion plants.

Senator HIRONO. So would you say that the Hawaii Constitution's reference to fission, that that would not prohibit the development of a fusion plant in Hawaii?

Dr. COWLEY. We believe so.

Senator HIRONO. Okay.

Dr. COWLEY. I am not a lawyer.

Senator HIRONO. Yes.

[Laughter.]

Senator HIRONO. Dr. Hsu, you noted that the pathway to fusion energy goes well beyond technological challenges, and including, among other priorities, "public engagement and energy justice." I very much appreciate your reference to energy justice. Can you explain a little bit about what you mean by energy justice, and how does DOE plan to engage the public on fusion energy and energy justice and other challenges you described?

Dr. HSU. Yes, thank you again for a wonderful question.

So these are indeed a high priority of the Bold Decadal Vision. We humbly seek to learn from the deployment experiences of other technologies—energy and otherwise—in engaging with the public and energy justice communities. You know, not only are these the right actions to take, but working toward these goals will actually help accelerate fusion deployment when the technology is ready.

Senator HIRONO. What do you mean by energy justice?

Dr. HSU. We want to address how energy technologies have harmed particular communities in the past and make sure not only that we restore, but also make sure that we do not perpetuate those harms.

Senator HIRONO. Thank you. I was particularly taken by that concern that you raise and I appreciate that.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator.

Now we have Senator Cassidy.

Senator CASSIDY. Thank you, sir.

Dr. Luce, now if you all have covered this, I apologize. But there seems to be a little bit of tension, as my staff whispered in my ear. Democrats are going to want to support the public programs and Republicans are going to want to support the private initiatives. And you will diplomatically say that we are going to work together. But I want to explore that a little bit. So Dr. Luce, we have heard today that the private sector has been making great progress in conjunction with the public sector writ large, but that ITER is progressing slowly and increasing in cost. So if I had to defend continued investment in ITER, in 30 seconds, what would be the elevator speech that would allow me to defend the continued investment when it seems as if the private sector is racing ahead?

Dr. LUCE. So two key points. For an investment of around 10 percent, you get 100 percent. So your risk exposure is less in terms of cost.

Senator CASSIDY. You lost me there. I am going to give you another 10 seconds, if you don't mind. So go ahead.

Dr. LUCE. So the model for the ITER cost is that, for example, the U.S. pays nine percent of the construction.

Senator CASSIDY. I got it.

Dr. LUCE. Thirteen percent of operations. They get 100 percent of the outcome.

Senator CASSIDY. Got it.

Dr. LUCE. So if they were to do that themselves, they would have to pay 100 percent. So it is a prudent investment.

The second thing is, it is already in progress. So you have learned, already, lessons that need to be integrated into things going on in parallel. As we said before that it is largely a scientific removal of doubt and beginning the technology journey. Other places, like Dr. Mumgaard said, are focusing on the technology journey. This is what industry does the best. In terms of public-private, I would have an observation. The one place where the U.S. Government has worked on technology development is national security. To me, it is clear that energy security is national security.

Senator CASSIDY. I accept that.

Now, going back to establishing certainty, it seemed like there is $4.7 billion in private investment, which seems to be pretty assured. So I am just making that observation.

Dr. Mumgaard, you point out how NASA used to be the one that sent all the all the rockets into space, and now, we rely upon private companies to do it. They do it faster and cheaper. And it was clear in context you were drawing an analogy here. Knowing that you have to probably be a little diplomatic, but frankly, I hope you are not.

[Laughter.]

Senator CASSIDY. How would you give a 30-second speech in response to the question which I ask?

Dr. MUMGAARD. Yes, just because we have Boeing doesn't mean we stop building wind tunnels in the public program. You have to keep innovating on the science. You have to keep pushing that forward. And if we are right, and we build a giant fusion industry, something like ITER makes a whole lot of sense, right? Because it is going to continue to be a center of excellence to try new things that are too risky for the private programs to try. And if we are right, we have a commercial fusion industry that allows the public program to focus on the next step. And so, when NASA no longer goes to low-Earth orbit, and instead has commercial entities to do that, that frees NASA to go and do the really cool stuff like go to Europa, because they don't have the baggage of running a technology and industry.

And so, this is analogous here, where we are trying to build a science——

Senator CASSIDY. I get your point.

Dr. Hsu and Dr. Cowley, you all are kind of disinterested, in my mind at least. I am going to let you arbitrate. Okay, now I don't know the capabilities of what ITER has because I have a sense that it is trying to prove in concept the process by which you would do this. It is going to show that you can have sustained increase of temperature to a sufficient degree that this reaction can occur. But in putting that much investment into hard structures, you cannot really say, well now we want to do this. You know, way back when I was taking biochemistry and chemistry, we would say, oh, now we want to make this reaction, not that. And we would rearrange a few things and boom, we were blowing up the lab another way.

This is going to be billions sunk into capital projects, and it is hard for me to think that you are going to be able to rearrange everything and see how it works differently. So if Dr. Mumgaard is suggesting that there is going to be a basic level of pushing the ball forward on science, how much flexibility will this newly built infrastructure give to try different things?

Dr. Cowley, you are outside the government, so I am going to ask you first, okay?

Dr. COWLEY. I think there is a key thing that ITER is going to do, which is, it is an experiment. So they are going to study what is going on inside the reaction. When Commonwealth Fusion or one of the other private companies actually demonstrates fusion, they are going to move forward and try and make electricity. But one of the things that has gotten us to where we are is by understanding the science of containment of the 100-million-degree plasmas.

Senator CASSIDY. Isn't that the baseline of what they are attempting to do, and once that is established, you have established the understanding?

Dr. COWLEY. No, because, in fact, we contain it with magnetic fields that push it in and take it off the walls. And there is turbulence that brings the heat from the middle to the outside. And if we can reduce that turbulence, we can make the whole system smaller. And in fact, pound for pound, the highest performing experiment in the world is really General Atomics DIII-D in San Diego. They have managed to reduce the turbulence to much smaller levels than any of the other machines in the world, and that is by understanding what is going on. And therefore, they get higher performance. And in the end, it is going to be a question of, is the performance good enough to make the electricity cheap enough? We do not know the answer to that yet.

Senator CASSIDY. And Mr. Chairman, could I ask Dr. Hsu just to weigh in if he has anything to add?

The CHAIRMAN. Absolutely.

Senator CASSIDY. Dr. Hsu.

[Laughter.]

Dr. HSU. Thank you, Senator.

Well, I will not repeat what has been said, but I will add a few points. I think the international engagements aspects of ITER have a lot of spillover of benefits and we would be happy to go into those a bit more, maybe in written responses, in the interest of time.

Maybe I will just mention one, international coordination on things like regulatory is very important, if the U.S. wants to export fusion as a global product, for example.

I also want to point to the Office of Nuclear Energy example. We have deployed nuclear energy for decades and decades, but we still have need for test reactors and other facilities to continue optimizing the industry. So that is one example where ITER could continue to help, regardless of the private-sector time scale.

And finally, at this very moment, you know, I sincerely hope Dr. Mumgaard proves us wrong, but ITER is the surest path to a burning plasma at this point in time. And of course, we all should continue to reassess based on global developments in fusion development.

Senator CASSIDY. Okay. Thank you all.

The CHAIRMAN. Thank you very much.

Now we have Senator Hickenlooper.

Senator HICKENLOOPER. Great. Thank you very much, and thank you all for your time, your commitment, and all the work you are doing. It is—and the Chair has said this before—what you are doing has the direct potential to change life on Earth as we know it and so many of the challenges we face.

I want to start with Dr. Mumgaard. Leading fusion companies and efforts, the pathways of progress, are getting millions of dollars in investment, very exciting for the industry. However, there are many smaller companies just starting up like you were a few years ago that are—we have several of them in Colorado, of course. The newer companies are smaller, do not have the track record, attract less funding and attention. They struggle to get any federal dollars because of the hurdles, like high cost-share requirements and milestone-based funding. What should we be thinking about to try and lower barriers and direct capital toward the innovative, nascent fusion companies?

Dr. MUMGAARD. Yes, great question.

We think of it as a ladder. So you have at one level, grants like ARPA-E, which are how most of these companies get started. That is a grant. But then you also have things like, well, if you had access to the labs, so that the science, that running supercomputer time, that you could not afford to do as a small company, you get access, not just to stuff, but to people's minds. So lowering the barrier to collaboration between the labs and the companies. And then that means you get results, and those results mean that maybe you are in an innovation program by tech-to-market from DOE to help find connections of people that might invest.

And so, you get up and up on the ladder and you know, the big scale, maybe it is a milestone program, but after that, maybe it is the tax incentives and subsidies that we do for any energy system. So it is important that we have a ladder that doesn't have gaps. And that means it has to be a holistic look at it.

Senator HICKENLOOPER. Great. And I could not agree more, and that is part of our job, but we need your input to make sure we do that properly, and that there are not missing rungs, gaps, that get in the way.

Dr. Luce, let me turn to you. It is always great to see a lasting international collaborative effort. It is so important for so many reasons, but especially for such an important energy innovation. At the same time, it is a global race, which obviously will at some point hopefully have important energy security consequences. Some of the major players in the fusion space, like the United Kingdom and Canada, do not participate in ITER. And again, as we have seen with Dr. Cowley, that British accent does create a sense of real knowing. All the movies we have seen about these frontiers.

[Laughter.]

Senator HICKENLOOPER. They have an advantage that we should recognize.

How do we balance the collaboration and competition to ensure that the U.S. stays ahead of the curve, but also works together with our allies to make progress on fusion?

Dr. LUCE. Well, I think you have almost answered your own question—that engagement is essential. If you are engaged with what the world is doing, then your investments will return more because you participate and then you choose what you can do best or what you want to focus on, and that enhances the investment, basically.

Senator HICKENLOOPER. Yes, that makes a lot of sense.

Just as a follow-up, any of you can answer—what are some of the things we should be learning from other countries, not necessarily about a specific scientific innovation, but process or approach, if there is something that you should be sharing with the Senate?

You can look at it like Jeopardy, just push the button and say "me."

[Laughter.]

Dr. LUCE. Well, one thing, one of the reasons why ITER is in France is because it has a unique nuclear regulatory regime that is demonstration based. So this has challenges in terms of certainty for industry if they are using a proven technology, but it allows for innovation. So there is room for consideration of how to do regulation that enables innovation.

Senator HICKENLOOPER. Got it. I like that, yes.

Dr. MUMGAARD. The UK. So the UK is in the middle of executing a very good transition from focusing on plasma science to enabling technology development, and building test stands that other people are going to come use, and they have, you know, grown an entire technology cohort of people in doing so. So in terms of the pivot, the UK has done a very good job.

Senator HICKENLOOPER. Interesting, really good.

Anything else? Yes, go ahead.

Dr. COWLEY. I was going to make that point, actually, but——

[Laughter.]

Dr. COWLEY. But again, so is China. And China is putting a lot of money into the technology aspect, the materials, how to handle the fuel cycle, that is, you know, processing the fuels and bringing them in. The turning neutrons into electricity, this is something the U.S. program has put aside for a period of time and needs to really focus back on, and the decadal plan and the National Academies have all focused on saying that if we are serious about electricity, that is what we have to do. And the Europeans are doing it. The British are doing it—very well—and the Chinese are doing it.

Senator HICKENLOOPER. Great, perfect. Thank you very much.

Dr. Hsu, anything?

Dr. HSU. Just to hammer that point. What I said in my opening remarks is that we are ready for an energy development mission for fusion and that requires a fundamentally different strategy.

Senator HICKENLOOPER. Right. A point well taken.

Thank you all. I yield back to the Chair.

The CHAIRMAN. Thanks, Senator. Thank you.

Senator Hoeven.

Senator HOEVEN. Thank you, Mr. Chairman. Thanks to all of you for being here today.

So in a nutshell for each of you: why fusion? I mean, we went the nuclear fission route. Obviously, not only in weapons, but then utilizing it for energy. That has seemed to have fallen to disfavor for a variety of reasons now. There is some effort, I think, to return to it. And then I also remember the Super Collider days back in Texas. We were putting billions into that when billions was a lot of money, right? And that didn't seem to actually happen. So is this really going to happen? And why do you think so, and why should it? In layman's terms now so that the public actually goes, gosh, we want that, right? Because that is a big part of any of this, particularly with the massive investment that is required. So, I don't know, Dr. Hsu, if you want to start?

Dr. HSU. Sure, thank you. It is always good to ask the questions right from the basics, so I appreciate that. I think a couple of things. One is, fusion has a lot of implications for not only energy security, but national security and global leadership. So it is a race for future global leadership. That is one point.

The second point is energy abundance. We will need a lot and a lot of carbon-free, primary energy going forward, for multiple reasons, and we hope we can get there. And fusion is kind of the ideal way to do it. It is dense in energy. The fuel is theoretically limitless and it can be deployed anywhere. You do not rely on weather or climate, et cetera. And so, there are many reasons why it would be good to have in our back pocket as something for civilization. I will turn it over to my colleagues.

Dr. COWLEY. At the PCAST hearing, around December, Jesse Jenkins, my colleague from Princeton, talked about what was missing in the suite of technologies in order to decarbonize America's supply. This is the Net-Zero America project that he leads from Princeton. And the key thing that is missing is what is now termed "the firm energy sources." These are ones you can turn on when the wind doesn't blow and the sun doesn't shine, and you can supply energy in all kinds of places. And his point was that we do not have enough options in that space. At this point, they are basing it on doing an extension of nuclear and using carbon capture and storage. And both of those have, at this point, unless we develop advanced nuclear, they have finite lifetimes, you know, decades possibly they can be used for, then we will have used up their potential. And therefore, we have to have a firm energy source that goes into that space. And that is fusion.

Dr. LUCE [holding up a bottle of water]. This contains fusion fuel. This makes it easy. If we used deuterium and tritium, everybody has this. It is safe. Our byproduct is helium. It is an inert gas. The reactor has in it one gram of fuel at any time. It cannot run away. We have demonstrated scientific understanding to manipulate, as Steve has said, to optimize. Where we need the next frontier is technology. And that is where the mystery is and that is where the investment needs to be. We do not have the same predictive capability for metals, for other things that we have for the plasma physics, which is tremendously hard science, but we have really attacked it and we have largely solved that problem. We have to show that, but it is solved. Now we need to address the technology.

Dr. MUMGAARD. In terms of layman, I go to like the most layman thing I can think of—fusion is the energy source that is in all the science fiction. It is in all the comic books. Why? It's because it is a fundamentally different relationship between humanity and energy because it is energy without fuel, without consumption. If you have a machine, you have energy, full stop, forever, no one can take it away from you, no one can stop you from doing it, you have energy. Not only do you have energy, you have energy that is 99.9999999 percent the energy of the universe. We just saw [the launch of the] James Webb [telescope]. That was a very fancy camera in space to take a picture of fusion power plants, ancient ones. It is the thing of the stars. So it's like a very fundamental difference. And it manifests itself in all these different practical ways we talk about of energy security, but it is very different.

Senator HOEVEN. Are we really going to get there? Is this the fuel of the future and always will be? You mentioned General Atomics. I do a lot of work with General Atomics. So I was intrigued when you said they have been doing some really good work. I think they are really good about actually getting a result. They have to be, they are private sector and so forth. So they do not have limitless funding, even on the scale of some of the really big companies.

So if you will indulge me for just a minute, Mr. Chair?

The CHAIRMAN. Sure.

Senator HOEVEN. I will come back to you, Professor Cowley. Why is it not always going to be the fuel of the future? Are we actually going to get there, and when? And if you want to work in a little bit on General Atomics that would be good, what they are doing because it sounded like you thought they were actually getting to something.

Dr. COWLEY. Yes, they have done some beautiful experiments at General Atomics that have reduced the loss of heat from the experiment so that you can, therefore, make the experiment smaller and in the future, make fusion reactors smaller. But the reason I am actually optimistic about fusion is we have actually done some. We have actually made the fusion reaction happen, and last year was a record-breaking year. The experiments at Lawrence Livermore Lab actually got a fusion burn. So we know that fusion is possible. We now have to apply all the power of the private sector in order to drive down the costs so that it is then at a cost that the consumer wants to pay.

Senator HOEVEN. So it is technologically possible, maybe not yet commercially viable? I mean, you actually can do it?

Dr. COWLEY. Exactly. That is a good way to say it.

Senator HOEVEN. That is very interesting. Thank you.

Thank you, Mr. Chair.

The CHAIRMAN. Thank you.

And now, by the graciousness of Senator Cortez Masto, Senator Kelly.

Senator KELLY. Thank you, Mr. Chairman and thank you, Senator Cortez Masto.

Dr. Luce, I want to just follow up a little bit—you said for ITER, nine percent of the investment, 100 percent of the outcome. Do you mean we just get 100 percent of the results and the technology and the intellectual property? Is that what the 100 percent is?

Dr. LUCE. Indeed, but also, as has been pointed out, I think by Scott before, if we are engaged, you get the know-how, and know-how is a critical intellectual property that is very challenging to capture. You do not want a chef that has read a cookbook, you want to chef that is actually been in a kitchen.

Senator KELLY. Yes, it is the reason why other countries have a hard time manufacturing jet engines, even though they can get a jet engine and look at it, but they might not be able to make it. So yes, I understand that.

And Dr. Luce, I also want to follow up on the fuel issue. You know, mentioning that we have, you know, holding up the water and you know, tritium or helium-3 being our fuel that would go into a fusion reaction. What is the processing to turn this [the Senator holds up a bottle of water] into tritium?

Dr. LUCE. Well, not into tritium. There is deuterium here directly.

Senator KELLY. Right.

Dr. LUCE. So it is a distillation process, a mass separation. The important thing that needs to be done for fusion is closing the fuel cycle. Tritium has a decay lifetime of only about 12 and a half years. So it doesn't exist naturally. We need a startup——

Senator KELLY. Well, it doesn't exist naturally on Earth.

Dr. LUCE. Correct, but we need to make it within the fusion power plant. So we need the blanket technology to make the tritium fuel and return it, not just to that plant, but to the next plants also.

Senator KELLY. We often hear these—I spent 15 years at NASA—and as we talk about going back to the moon, often the whole thing comes up about well, there is tritium on the moon. We could bring that back and use it in the fusion power plants. Is that a realistic source of tritium?

Dr. LUCE. So I think you are thinking of helium-3. There is a reaction between deuterium and helium-3, but it is more difficult to get it to go than it is the deuterium/tritium. So in terms of optimization and advance, I would see that as similar as to when you mentioned jet engines. It is like the jet engine to the right flyer and there is a progression you might go through on a fusion economy. And so, yes, that might be a future fuel, but it is not the optimum way to start.

Senator KELLY. Okay, so you do not feel like fuel is going to be an issue once we have the technology developed?

Dr. LUCE. We have to do it, but yes, there is a known way to do this, known processes, and we just have to demonstrate the industrialization of them.

Senator KELLY. Dr. Hsu, when I think about this, and I cannot remember who mentioned this, but we were, you know, talking about when the wind is not blowing and the sun is not shining you have a ready source of power. Is it true that if batteries became more dense and more efficient that at some point this becomes a race between fusion technology and battery technology?

Dr. HSU. Yes, I will take that. Thank you very much, Senator.

If I may, I want to just go back to the fuel question for one second. I think as part of our Bold Decadal Vision, we want to be very, very transparent about fusion with the public. It is important to mention that in order to breed tritium, we need lithium. So lithium and deuterium actually are the input fuels for a DT fusion system. Fortunately, we do not need huge, huge amounts of lithium because of how energy-dense fusion is, but that is very important and it is something that we have to tackle. But we think we know how to do it, as Dr. Luce says.

In terms of a race, so I don't like to look at it as a race. I think, right now, we need as many energy technologies, and to deploy them and to develop new ones so that we have the best chance of meeting our decarbonization goals and finding a way forward sustainably. Fusion, though, however, as Dr. Cowley said, does have, because it is an on-demand source, it will help the overall energy system be lower cost and more reliable.

Senator KELLY. So you are not concerned? Let's say we are able to get battery efficiency up by another 20 percent and more dense, that at some point, when you look at the cost to generate power that the solar modules have become so cheap that you deploy more solar, you store the energy in a battery and then you have them, you solve the problem for when the sun is not shining or the wind is not blowing.

Dr. HSU. So I came from ARPA-E before this, where we looked at every energy technology in existence and what I keep coming back to is that we need more than 500, 600 exajoules of carbon-free energy per year by mid-century.

Senator KELLY. Okay.

Dr. HSU. Frankly, I don't know how we are going to supply that without multiple——

Senator KELLY. With what we have.

Dr. HSU. Yes.

Senator KELLY. And I agree. And I am supportive of funding, you know, this technology. I think it would be an incredible breakthrough for our country. We want to lead on this technology because if we do not, somebody else is going to, and it does go a long way to solving a lot of issues, what you just mentioned, but also, you know, issues surrounding climate. And in Arizona, we have hotter days every year. We are looking at the potential of, if we continue on the business-as-usual plan, at the end of the century there are going to be a lot more days over 100 degrees. That means more wildfires, more drought. So I want to see this move forward.

Thank you.

The CHAIRMAN. Thank you, Senator.

Senator Cortez Masto.

Senator CORTEZ MASTO. Thank you, Mr. Chairman.

I am always so impressed with the diverse perspectives on this panel. Here I am going to be talking about critical minerals and how we mine those here in the state. We have an astronaut talking about bringing them from the moon. I think it is just so impressive. So I am always pleased to listen to my colleague from Arizona and the perspectives that he brings.

So that is my next question. So just to open it up to the panel, nearly everyone on today's panel has discussed the need to develop a domestic supply chain in order for fusion energy deployment to be successful. What is the potential for domestic production of the minerals that are necessary for the deployment of fusion energy projects, and how does that fit into this panel or this Committee's discussion on identifying our current critical mineral domestic manufacturing needs and capabilities?

I am going to open it up to the panel, if anybody would like to start. Yes, Dr. Mumgaard.

Dr. MUMGAARD. Yes, so we look at this from a commercialization standpoint and we try to get ahead of the supply chain. You know, one thing to remember is that because there is not a fuel—that the fuel is tritium or sorry, deuterium and some lithium—that is not really what we are talking about. We are talking about what it takes to build the machine, right? That machine is made out of a lot of steel, so like, high quality steel. So you have to have that supply chain in place, including all the manufacturing and forging. There are some unique materials that go into it, like lithium. You need lithium. You do not need a lot of lithium, but you need lithium, you know, at a scale that is a fraction of the EV market. So domestic lithium is important. There are some rare earths that are not a lot, like much less than say, a full-out, built-out wind market, but you still need those as well—things like yttrium. There is some niobium sometimes that you need to have, but they are in amounts that are—build a machine and then have it for many, many years, not a continual consumption.

There is a manufacturing problem as well. So, like, you need people that can machine things. People that can put complicated machines together. Things that kind of look like aerospace. People that can construct plants, iron workers, et cetera, because you are building an industrial plant.

Senator CORTEZ MASTO. Okay. Anyone else?

So let me jump then to the discussion of fiscal resources. I was here earlier and I had to run to the Banking Committee, but as you were talking with Senator Barrasso, you were talking about the need for public-private, really, partnerships to validate the demonstration project to move us forward. But what is the fiscal funding that is necessary? There is a lot of private funding that we are seeing coming in and we want to continue that, but is there a role for us at the federal level? Should we be looking at more of a fiscal investment here? And I am just curious, your thoughts on that, maybe, Professor Cowley?

Dr. COWLEY. I think what has been authorized in various places is——

Senator CORTEZ MASTO. Is enough? What we have already authorized through the current appropriations and legislation?

Dr. COWLEY. What has been authorized is not what has been appropriated, right?

Senator CORTEZ MASTO. Okay.

Dr. COWLEY. What has been authorized is over a billion for the federally funded part of the program, a year, and we are at about $730 million at this point.

Senator CORTEZ MASTO. Okay.

Dr. COWLEY. I think what is authorized, actually, is quite good in outlining what should be done by the public sector in order to support the private sector. We need the private sector to drive down cost.

Senator CORTEZ MASTO. Right.

Dr. COWLEY. That is not what we are good at, right? But we do need the public sector to, for instance, help develop the new materials. We need the public sector to continue to innovate the containment so that we can make these things smaller and more efficient and we can get to market with something that really is cost effective. And so, I think what was authorized is actually pretty perceptive about what we need right now.

Senator CORTEZ MASTO. You are saying that Congress was perceptive? Is that on the record? That is what you just said?

[Laughter.]

Dr. COWLEY. Yes.

Senator CORTEZ MASTO. All right, just checking. Thank you. I appreciate it.

Anybody else?

I appreciate this conversation today. Thank you very much.

Senator BARRASSO [presiding]. Senator King.

Senator KING. Dr. Cowley, we particularly appreciate your comment because like most Americans, I attribute about 20 points of IQ to the British accent, additional IQ that is, incrementally.

[Laughter.]

Senator KING. My father, who grew up in Alexandria, used to say that the Pentagon was the only building in the world where you drive straight at it and it keeps getting further and further away. I feel like that is where fusion is. I have been hearing about fusion for 25 years. It keeps getting further and further away.

A variation of Senator Hoeven's question, Dr. Hsu, will it ever work? Is it real or is this a WPA project for scientists?

Dr. HSU. Thank you, Senator.

This is the question that is always on the mind for fusion, but yes, I think the answer is yes. Dr. Cowley earlier explained why we think fusion will work. In fact, fusion does work. It is about getting it to a point where it can be economically attractive and competitive. I also want to say there was a quote to a Russian scientist that said, you know, when will fusion be ready? And he said, "when society needs it." And I think we may be at a point where society needs fusion.

Senator KING. Dr. Mumgaard, talk to me about when. When?

Dr. MUMGAARD. Yes, it is always very hard to predict when technologies will happen. I think if you look at the history of technology development, the argument that well, it is always, we have always talked about it and it is not here yet. We had that argument days before the Wright Brothers flew. We had that argument about AI, and look at what AI has done. So it is very difficult to predict, but you can look at some indicators, right? The diversity——

Senator KING. The private sector is putting money into it.

Dr. MUMGAARD. Right. You have the diversity of approaches, you have the diversity of stakeholders who are getting involved in it, from investors, from other corporations that are starting fusion divisions in oil and gas companies. So there are a lot of indicators that say that we are close. We haven't yet seen the flight, but we have seen people gliding. We have seen people doing wind tunnel experiments and it does feel like we are on the precipice of something. And we know that it can be made to work. We have experiments like JET and others, and also, of course, we look at the——

Senator KING. It is theoretically feasible.

Dr. MUMGAARD. Theoretically feasible, done on earth in specialized machines, not quite at the right performance, but getting close and then proving historically faster than Moore's law within a factor of a few away. And so, feels good.

Senator KING. Well, let me go on the assumption that it is possible and then the question is, how do we get there and how do we get there as soon as possible?

Dr. Luce, this strikes me as a world-saving technology. This is not just a U.S. technology. And we are used to thinking, in fact, in this hearing people have talked about a race—we are in a race, you know, with other countries. Shouldn't this be a straight-up, international effort? I mean, if we have adequate, non-fossil fuel energy in China, that is a good thing. They have not won a race. They are helping the environment. So I see this as an opportunity for an unprecedented worldwide collaboration on a technology that could literally save the planet.

Dr. LUCE. So we are proving that that is beneficial through the ITER project, and it has, as I said before, it is a common need. Everyone will need energy for their civilization to develop, no matter what choices they make. However, I think there has to be national investment too, to have energy security.

Senator KING. Oh, I agree with that. I am talking about the mechanics of carrying it out. I think everybody has to be invested, but should it, is it, can it be an international collaboration as we work through this?

Dr. LUCE. I believe that is effective, but it is not complete. So yes, I have spent most of my personal—I have spent a lot of my career working internationally. I worked on 11 different fusion facilities, nine of which were not in the U.S. So I have seen the benefits from this and those benefits were brought back into the U.S. program and now I am with the ITER program, again, working internationally. We get the best of the best by collaborating, but then you have to take advantage of it. We have known for a long time the potential of fusion. I think, as Dr. Mumgaard said in his initial comments, the investment of the public sector enables people to take a little bit more risk with private money and move forward.

Senator KING. That gets into my final question. If it will work, if it has the enormous potential that you all have testified to, are we doing enough? Shouldn't this be an international Manhattan Project rather than—you mentioned a billion dollars that has been authorized. If this has the promise that we all think it does, then it seems to me this ought to be an even larger investment, both by this country and other countries, and maybe it could be a matching proposition. We will put up this much money if Germany, Great Britain, China, and Japan put up an equivalent amount or some portion of that, but if it is that good, this ought to be urgent instead of a, you know, a moving-along science project.

You are nodding. Nodding doesn't go into the record.

Dr. COWLEY. We would love to see something like that. But I have to say I am impressed with how the private companies, driven by the competitive spirit, are moving very, very quickly in this space. Energy industries, $8 trillion a year. You get a small percentage of $8 trillion a year, it is a pretty good business. And so, you know, when investors look at this and say, if this is what it is promised to be, the payoff is just so enormous that we are going to see people come in and compete on it.

So I like this sort of dual program where we have a very cooperative program on ITER, but then we have a very competitive set of startups that are trying to innovate in it. I think, actually, you know, that might be an ideal way to go forward.

Senator KING. Other thoughts? Dr. Mumgaard?

Dr. MUMGAARD. Yes, I would echo that, that, you know, competition is good for some things, but not usually for understanding science, right?

Senator KING. Yes.

Dr. MUMGAARD. Science is——

Senator KING. Basic science——

Dr. MUMGAARD. Competition is great for demonstration, for developing supply chains, for doing the technology commercialization activities, for a variety of solving the customer's needs, right? We are not going to invent the right fusion power plant without talking to the people that use it, but if we have lots of companies that talk to lots of people, that is going to be an ecosystem that is going to sort it out as it goes. But I agree with the idea that you could have competitive companies and cooperative international science. And we do that all the time in human health where we build pharmaceutical companies that deliver drugs to patients. We also do research and we share that research widely—internationally, and public and private. And so, I see that ecosystem being where this is headed.

Senator KING. Final point. I just hope that if you all have further thoughts about what our response should be, what we could do to further this research and whether it should be more money or directed in a different way, please let the Committee know. We would be very anxious to work with you on that.

Thank you. Thank you.

The CHAIRMAN [presiding]. Thank you, Senator, I appreciate it. It is quite interesting, all this discussion. I want to thank you all again.

We are going to finish up, but I just have one thing.

We all know the fusion reactors require strong magnets, very cold temperatures, achieve a liquid helium and vast computational power. Many of the technologies that we have developed have required entirely new fields—new fields and materials, science processes achieved, and design specification needs for action. So we will start, Dr. Mumgaard, with you, and I want to go right down the line here. Do you all have examples or do you know of any examples of the major advances that fusion researchers brought in related materials and supply chains in the market today?

Dr. MUMGAARD. Yes, your observation that fusion is sort of like at the top of the technology chain that uses lots of things is spot-on. And so, when you think about the superconducting magnets, fusion is always the first to use big magnets, and those have ended up in MRI. And then this next generation of magnets is likely to impact that as well, wind turbines, MRI, other things.

Dr. LUCE. Supercomputers—energy research, and specifically, fusion energy research in the U.S. was one of the drivers for the development of supercomputers for non-defense uses.

The CHAIRMAN. Great.

Dr. COWLEY. I hope I can get to it quickly.

[Laughter.]

The CHAIRMAN. You can try.

Dr. COWLEY. The first one is, 46 percent of the steps in making a computer chip are made in plasma reactors that bombard the surface and cut the circuits into the chip and lay down the whole thing. The whole microchip industry is based on plasma processing. That came as a spin-out, partly from the fusion program and partly from, you know, Bell Labs in the 1990s.

The CHAIRMAN. Yes.

Dr. COWLEY. And it is what drives forward innovation in microelectronics. And we are hoping with the Micro Act that there again will be support, too, for this kind of research for the next generation of microelectronics.

The CHAIRMAN. Great.

Dr. COWLEY. One more thing, very briefly. When two black holes collide, as we have seen with the LIGO gravitational wave detector.

The CHAIRMAN. Right.

Dr. COWLEY. Around them is a plasma and it is emitting all kinds of gamma rays and x-rays, et cetera. The codes that solve what happens inside a fusion reactor are now being applied to what happens when two black holes collide.

The CHAIRMAN. Wonderful.

Dr. Hsu.

Dr. HSU. I will add one more, related to microelectronics processing, but something that came out of the inertial confinement fusion program in laser technology is what allows the etching of chips at five nanometers. So like, your latest smart phones are actually enabled by something that came out of the inertial confinement fusion program.

The CHAIRMAN. Wonderful.

I am going to go to Senator Barrasso real quick and I am going to have Senator Cantwell finish up for us.

Senator BARRASSO. Well, I am going to follow up, Mr. Chairman, on something that Senator King was asking about. Dr. Hsu, and I am going to also ask Dr. Mumgaard to comment on it.

So how does the Department plan to execute initiatives focused on commercialization of fusion technology, because as Senator King asked, how do we carry this out? And does it make sense for the Department to execute these activities?

Dr. HSU. Yes, thank you, Senator.

So I mentioned earlier, well, many of us mentioned the milestone-based program. That is a key component, not the only component, but that is an organizing program that tries to align the public and private sector activities and to develop the plans going toward a fusion pilot plant. But of course, the public sector programs, we are in discussion in DOE on many of these other needs, for example, growing enabling technologies and materials programs. We would be happy to work with your Committee to, you know, in going forward with those plans.

Senator BARRASSO. Dr. Mumgaard.

Dr. MUMGAARD. The milestone program is really important because that allows certainty. It allows the pilot program to say hey, we have got your back, go build these things and we are going to help you figure them out and we are going to learn a lot from them. So that one is really important. But it is not the only thing, but also things like what happens after that. So the Loan Program Office, like someday there will be a fusion application in the Loan Program Office. There will be investment tax credits, things like that, that do on the upside, and then earlier than say, a milestone program, doing things like an expanded infused program, which allows access back and forth is really important, and ARPA-E, which has been a huge driver of new innovations.

Senator BARRASSO. Thank you.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator.

Senator Cantwell.

Senator CANTWELL. Thank you, Mr. Chairman. Thank you for having such an important hearing. I really, really appreciate it. I wanted to reiterate my open invitation for you to come to the Pacific Northwest.

The CHAIRMAN. I am coming. I am coming.

Senator CANTWELL. To go to the national laboratories there and to see all the innovation that is happening, particularly the fusion innovation that is happening. I think about 90 percent of the commercial, private-sector investment has been made in the tri-cities area. So we are very excited about that private capital investment and the continued research that can happen.

I wanted to—I have been listening in and out as I have been at other places in the legislative buildings today, but you are getting really to the heart of the matter, which is that we passed this CHIPS and Science bill. We put a lot of money on the table. We did not see in the larger bill that was signed by the President, fusion as a qualifying technology. Do we need to rectify that? What specifically—I heard many of you talking about the next steps for manufacturing—what is it that we need to do, Dr. Hsu? Senator Wyden worked on this, but we need to get, I think, qualifying tax credits, but Senator Manchin and I definitely made sure the R&D investment was at DOE for this next generation technology.

So what kind of test beds do we need to do? What kind of things do we need to do to get the manufacturing focus, thinking about this from a demonstration perspective? So I just want to go down the line.

Dr. HSU. Thank you, Senator. I can start. And first, let me just say that I and Undersecretary Richmond are planning to attend Seattle Fusion Week and we are very excited about that.

Senator CANTWELL. Great.

Dr. HSU. We stood up a crosscut team in DOE exactly to bring in multiple program equities, including on topics like this, manufacturing, and supply chains. These are things that fusion science has not focused on as much. And so, we are formulating our plans and priorities here. So I cannot say much here, but be assured that this is on our radar.

Dr. COWLEY. I think one of the things that has just really changed a lot is that high performance computing is now being used to optimize the way forward, just in the way it is being used in the new space industry, et cetera. And we need to actually take all the tools that we need for fusion reactors, integrate them and start innovating in the computer. We just had a—there is a young woman at Princeton who has just designed a new shape for a fusion reactor that is really pretty interesting and it came just from the computer and she started optimizing things on the computer and it is really going to be one of the ways in which we accelerate the pace of innovation, right? This is the great strength of a huge part of the DOE system, is computation.

Senator CANTWELL. Okay, so more dollars to high-performance computing analysis of reactors?

Dr. COWLEY. Of fusion systems, yes.

Senator CANTWELL. Of fusion systems, yes, okay.

Dr. LUCE. So for me, I would note that the U.S. is not participating in the test blanket system program in ITER, which is how you close the fuel cycle and generate the fusion fuel. So the U.S. will need to supplement that in some way if they want to be a leader in the fusion economy. The other area, which I think requires less investment initially, is materials. And as has been said, the materials that can stand the radiation environment at very high temperatures so that we get very good efficiency of the electricity generation is very important, but also, the materials that have to face the plasma itself. And there, you can start in the small scale, at universities, national labs and with computational capabilities in parallel with it, then you can move to industrialize it very rapidly. And so, this is a key place where I see that investment worldwide is needed to make progress in fusion.

Senator CANTWELL. Is there anybody leading that right now in the materials science side?

Dr. LUCE. There is work ongoing in the UK, certainly. There is work in Europe that I know about, but in the U.S. the funding has been quite short, is my experience.

Senator CANTWELL. Okay. So since we are very familiar with this, creating a tech center, tech hub, in materials science, specifically focused on fusion.

Dr. COWLEY. There is a key part there, which they are having a meeting of EPRI about next week, which is to produce a neutron source that mimics a fusion reactor called a point neutron source in order to test the materials, and there is a meeting, I think it is at Oak Ridge, but I am not quite sure where the meeting is. I will be joining via Zoom. I think pushing that forward, and it was made a priority in the plan that the National Academies put forward to make that test facility.

Senator CANTWELL. Okay.

Dr. Mumgaard.

Dr. MUMGAARD. On the manufacturing front, I just would like to point out in the pictures here, the two big boxes are actually new factories—Helion in the Pacific Northwest, this one in the Commonwealth of Massachusetts, to make fusion components. So actual factories to make pieces. But, you know, those are the components we know how to make today. We also need to develop the components for tomorrow. And to the point about the test stands, the idea of let's build the test stands so we can make new materials, things like the neutron source, but let's also get the people that are going to take those results and turn it into an industrial fabrication in that pipeline, let's get them involved. So those are the metal makers, the foundries, et cetera. So that they have a seat at the table when we are figuring out what the materials are and they can take it immediately from the test stand to scale. So this goes to the idea of cooperation, not just the test stand, not just the manufacturing, they have to work together. And we think the materials, particularly, that is a ripe spot for the U.S. to lead.

Senator CANTWELL. Great. I agree, because we were just at PNNL and saw some of the groundbreaking work that they are doing on new metals. The terminology, I cannot think of it right now, but it is pretty breakthrough, that is making for, you know, mold injecting technology that is being used by the auto industry and others, just a very cost-effective way to build strong metal for manufacturing.

How do you do this industrial pipeline for fabrication? What is the framework? How do you create that, is what I am saying. How—what—who needs to do something that so, again, do we take—is that a center of excellence, is that a university leading the way in collaboration with the private sector, is it Department of Commerce?

Dr. MUMGAARD. Yes, so from our point of view at CFS, we have been very successful by going to adjacencies. So like, we assemble magnets. Well, people that assemble cars can be taught how to assemble magnets and robots that make cars can make magnets. And so, you don't want to, I don't think, start from a blank slate. I think you want to go and say, hey, where are there people that do things that are similar? Let's get them all in a room together, figure out what we need to do and then go and have the resources to try it at some scale that is relevant because if it just ends up as a paper report, we do not advance. So a center of excellence or using a national lab or building a hub, those, I think, come after you actually know what you want to do.

Senator CANTWELL. So this is the experimentation part.

Yes, Professor Cowley.

Dr. COWLEY. Sorry, I wasn't nodding my head to say something, but there is a very interesting thing here which is sort of one of those valleys of death from development to materials, which is that people in universities and small labs make little pieces of material, but actually what you want to know is that in a foundry, you can make steel, for instance, that is what we call low-activation steel for fusion devices—a special kind of steel, right? And to do that, you have to do things at probably a national lab type scale, the kind of thing that is going on at PNNL, for those kinds of materials.

Senator CANTWELL. Well, the Chairman was very clear about this, that he wanted to see, and I think the Ranking Member too, that they wanted to see the innovation at the labs who have been successful in some of these things in the past lead the charge. So we are going to look to that.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator.

Let me just tell all of you that we have been almost two hours. You can tell the interest and the quality of this hearing that you all have brought to us and we appreciate it very much. We probably could go on for another couple hours, but we have to go vote. And let me just say, we thank you again and we look forward to working with you in the future.

Members will have until close of business tomorrow to submit additional questions for the record.

The Committee stands adjourned.
[Whereupon, at 11:51 a.m., the committee was adjourned.]

APPENDIX MATERIAL SUBMITTED

U.S. Senate Committee on Energy and Natural Resources
September 15, 2022 Hearing
The Federal Government's Role in Supporting the Commercialization of Fusion Energy
Questions for the Record Submitted to Dr. Scott Hsu

QUESTION FROM RANKING MEMBER JOHN BARRASSO

Q1. The Office of Science's Fusion Energy Science (FES) program primarily focuses on basic scientific research. Expanding this program's mission could detract from this important function. Should FES have the responsibility to oversee demonstration activities, or does it make more sense to move such activities to another part of the Department, such as the Office of Clean Energy Demonstrations?

A1. FES has responsibility for supporting basic and applied R&D in plasma and fusion sciences, including resolving scientific and technological issues for fusion energy. The Department is committed to maintaining FES' scientific research mission, while also assessing whether future fusion energy demonstration activities should be the responsibility of an applied or deployment-focused office, such as the Office of Clean Energy Demonstrations (OCED), in coordination with other Departmental elements including the Office of Science. Such a transition, if deemed appropriate, would require coordination between the Office of Science and the appropriate applied/deployment office starting several years in advance. The Department's new crosscutting approach to the development of fusion energy positions it well as technology develops.

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QUESTION FROM SENATOR JAMES E. RISCH

Q1. There appear to be similarities in the use of public-private partnerships to commercialize fission energy systems through such programs as the Advanced Reactor Demonstration Program and the establishment of the National Reactor Innovation Center at INL. Can you discuss how the experience with PPP with fission nuclear system can be utilized to commercialize fusion energy and how the National Reactor Innovation Center can be used to support commercial fusion developing including demonstrations?

A1. The Advanced Reactor Demonstration Program (ARDP) and the National Reactor Innovation Center (NRIC) managed by the Office of Nuclear Energy (NE) have both served as models in discussions and planning for new PPP programs for fusion managed by the Office of Fusion Energy Sciences (FES). For example, ARDP's inclusion of multiple technical "tiers," based on technical readiness level, has been adopted in the recently announced Milestone-Based Fusion Development Program. The Innovation Network for Fusion Energy (INFUSE) program of SC FES is modeled after NE's GAIN voucher program. NE has a representative on the newly formed DOE Fusion Crosscut Team, which will leverage experiences, capabilities, and learnings from NE, NRIC, and the Idaho National Laboratory in developing and managing fusion PPP programs.

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QUESTIONS FROM SENATOR MARIA CANTWELL

While the Energy Act of 2020, the CHIPS and Science Bill, and the Inflation Reduction Act (IRA) all provided key authorizations and funding for certain aspects of fusion research, development, and deployment, explicit federal incentives to spur and ensure domestic manufacturing of the components needed for deploying fusion (such as specialized capacitors and vacuum vessels) has not yet been enacted.

Q1. What more could the federal government be doing to specifically incentivize and support the domestic manufacturing of components to support fusion deployment at scale?

A1. The newly formed DOE Fusion Crosscut Team plans to assess critical supply chains for fusion technologies and identify domestic manufacturing gaps and opportunities. Eventual fusion energy deployment at scale could also be supported by relevant tax credits to support manufacturing and supply chains where eligible. DOE looks forward to working with you on this important topic.

Q2. Do you believe there is the potential for most, if not all of the critical component supply chain for domestic deployment of fusion at scale to be developed in the United States?

A2. There is a potential for many or most of the critical component supply chains to be developed in the United States. Some of the raw materials needed for these components, e.g., lithium and other rare-earth elements, are currently available predominantly from foreign entities. A full list of critical materials and supply chains for fusion energy is being developed and assessed as part of DOE's Fusion Crosscut activities. DOE would be happy to collaborate with you on this important topic.

Q3. Fusion was left out as being explicitly enumerated as a qualifying technology for the 48C clean energy manufacturing credit in the IRA. Do you believe that fact will present an issue for the Treasury Department's interpretation in guidance regarding fusion qualifying for 48C? Fusion was also not included in the 45X advanced manufacturing tax credit in the IRA, which requires specific components to be enumerated to qualify. Do you support adding fusion components to the list of qualifying components? Do you believe that making fusion eligible for these two manufacturing tax credits, in parity with other clean energy technologies, will help spur the domestic growth of the industry? Please elaborate.

A3. The 48C tax credit in IRA allows the Department of Treasury to make a designation of eligibility for other components and equipment to be included in "advanced energy property." DOE will continue to work with Treasury on implementation of the IRA.

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QUESTIONS FROM SENATOR STEVE DAINES

Q1. Now that the CHIPS and Science Act has been signed into law we must ensure that the Federal Government and this administration follows the congressional intent of the bill and prioritizes the advancements in science, manufacturing and innovation that the bill focuses on. One of those was the development and commercialization of fusion energy. As a supporter and sponsor of the bill it is important to me that the Department of Energy closely follows congressional intent. Since passage what specific actions has the Department of Energy taken to implement the bill?

A1. A Milestone-Based Fusion Development Program, as re-authorized in the CHIPS and Science Act, was announced by the Department of Energy in September 2022. This program, led by the Office of Fusion Energy Sciences (FES), is a key component of the *Bold Decadal Vision for Commercial Fusion Energy* announced in March 2022, and will support a partnership between DOE and the private fusion industry to work toward preliminary designs for a fusion pilot plant. Other programs authorized in the CHIPS and Science Act, e.g., inertial fusion energy and high-performance computing initiatives for fusion energy, are under discussion and consideration. Their implementation is contingent upon receiving corresponding appropriations.

Q2. The CHIPS and Science Act authorized the creation of a High-Performance Computing for Fusion Center. When do you expect that center to be established and what process will the Department of Energy take to choose the location for the center?

A2. The establishment of a High-Performance Computing for Fusion center and the process for choosing a location for the center are under discussion. The Department welcomes the opportunity to provide an update when we have more information to share.

Q3. The CHIPS and Science Act authorized two national teams for pilot plant designs. When do you expect those to be named, and what process will the Department of Energy take to choose those teams?

A3. The establishment of national teams to develop pilot-plant designs is under discussion, and the expectation is that they will be selected as awardees of the Milestone-Based Fusion Development Program in FY 2023.

Q4. What can the Department of Energy do to expand public-private partnerships for fusion and other technologies to speed up development and commercializing of NextGen energy technology?

A4. DOE has formed a new Fusion Crosscut Team to explore this very question. The Team will make recommendations to Department leadership and coordinate activities and budgets across DOE program offices working on fusion-energy-related R&D. The recently announced Milestone-Based Fusion Development Program, managed by the Office of Fusion Energy Sciences within the Office of Science, is an example of an expanded public-private partnership for fusion.

Q5. Has the Department of Energy begun to identify or consider energy-friendly states to create a fusion pilot plant within?

A5. No. However, DOE plans to partner with the private sector in supporting their siting activities for fusion pilot plants and public engagements as part of the Department's Milestone-Based Fusion Development Program.

Q6. What are the most important attributes for locations that might hold a future pilot plant?

A6. Economic incentives for the developer and opportunities/benefits to local communities, especially those harmed by legacy energy activities and/or displaced by the ongoing energy transition, are among the most important attributes in determining the site of future fusion pilot plants. There are also potential technical considerations, including the availability of grid interconnects, cooling water, and existing infrastructure that could be repurposed.

Q7. Montana has always been an energy rich state, with a diverse portfolio of production. It also has existing infrastructure, transmission and a trained workforce for energy production. What steps has the Department of Energy taken to work with Montana to bring a fusion or other energy project to the state.

A7. To date, no steps have been taken to work with specific states on siting of future fusion energy projects. DOE looks forward to working with states, including Montana, the private sector, and local communities to identify siting possibilities for a fusion pilot plant.

Q8. Will you commit to work with me to ensure Montana has a seat at the table for any existing or future energy pilot projects, including for fusion, SMR, or other nuclear energy source?

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A8. DOE will work to ensure that all interested parties and states, including Montana, are aware of and have an opportunity to compete for future energy pilot projects, including fusion, SMR, or other nuclear energy source.

Q9. The Administration has called for ambitious timelines for fusion, however recent budget requests have been less than the amounts authorized in a bipartisan way by this Committee. Does the Administration plan to bring parity between budget requests and proposed fusion goals?

A9. DOE is grateful for the bipartisan support from this Committee for fusion energy R&D. Within our current appropriations, we have launched new, authorized initiatives in support of the ambitious timelines for fusion energy described in the *Bold Decadal Vision* announced in March 2022. The Department recognizes the strong funding authorization levels that have been provided for fusion energy, including in the CHIPS and Science Act (P.L. 117-167), and is committed to meeting, to the extent possible within budget constraints, the aggressive timeline outlined in the *Bold Decadal Vision*. We look forward to working with Congress on support for fusion energy RD&D activities at DOE.

Q10. What other countries are leading in fusion development?

A10. The United Kingdom, China, and European Union are very aggressive with declared, nationally funded missions toward pilot demonstrations of fusion energy. Notably, the United Kingdom, China, and the European Union are ahead of the United States on design activities for pilot or demonstration-scale fusion facilities and the required enabling materials and technologies.

Q11. How important is it for the United States to be the global leaders in fusion energy?

A11. Fusion energy could be a disruptive technology not just for energy but also for defense and space applications. The nations that lead in the development of fusion energy are poised to realize substantial economic benefits as global providers of fusion systems and their key enabling technologies.

Q12. Are there national security concerns with Russia, China or other countries being the first to commercialize fusion energy?

A12. Yes. Fusion could provide energy security and abundance, with positive impacts on the economic might of nations. Fusion could have defense and space applications with strong implications for national security. Finally, the commercialization of fusion energy will also provide dual-use benefits of fusion's enabling technologies.

Q13. Which crucial fusion technologies are you anticipating to become your highest priorities?

A13. To diversify scientific and engineering risk and to access a range of energy markets, it is important to support the development of multiple fusion approaches, as is the intent under the Milestone-Based Fusion Development Program. The National Academies of Sciences, Engineering, and Medicine report, "Bringing Fusion to the U.S. Grid" identified the key innovations required to develop fusion. DOE will support broadly applicable research on fusion science and enabling materials/technologies, while setting meaningful technical and commercialization metrics for prioritizing R&D toward a viable design for a fusion pilot plant. The Fusion Energy Sciences Advisory Committee (FESAC) Long-Range Plan recommends growth in R&D support for fusion materials, as well as tritium breeding blankets and processing technologies.

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QUESTION FROM SENATOR ANGUS S. KING, JR.

Q1. Please lay out concrete policy steps that Congress and the Administration could take to accelerate the commercial deployment of fusion reactors.

A1. The *Bold Decadal Vision for Commercial Fusion Energy* to realize a fusion pilot plant has three necessary pillars: (1) build and sustain innovative public-private partnerships, such as the Milestone-Based Fusion Development Program, to accelerate the RD&D required to realize an operating fusion pilot plant on a decadal timescale; (2) increase the level of national R&D efforts in the priority scientific and technological (S&T) areas as laid out in the 2020 Fusion Energy Sciences Advisory Committee (FESAC) Long-Range Plan (including the science of achieving and sustaining a burning plasma, substantial growth in the enabling materials and technologies needed for a fusion pilot plant, and construction of priority test facilities such as a Fusion Prototypic Neutron Source and others); and (3) prepare the path broadly for fusion commercialization (including but not limited to public/community engagements, developing a regulatory framework, addressing nuclear security/nonproliferation, building a diverse fusion workforce, building critical supply chains and manufacturing capabilities, addressing the Department's equity and justice priorities, and appropriate federal financial assistance such as loan guarantees and tax incentives for demonstrations and early deployments).

Concrete policy steps to support the above could include, but are not limited to:

- Provide appropriations at the authorized levels in the CHIPS and Science Act for the Office of Science Fusion Energy Sciences. Such funding would enable DOE to initiate meaningful new efforts to support the above three pillars, including public-private partnerships, priority public-sector R&D activities, and the design and construction of new test facilities (e.g., the Fusion Prototypic Neutron Source);
- Formally authorize a fusion energy development and demonstration mission within the DOE alongside the present fusion science mission;
- Ensure that fusion energy activities are eligible for tax credits and other Federal economic incentives that support clean energy RD&D and associated equity and energy justice priorities;
- Ensure timely regulatory certainty for licensing fusion plants that both engenders public trust and enables timely deployment;

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- Explore the range of actions that could be taken to enable the U.S. to legally export fusion designs/systems developed by U.S. companies; such systems will likely include presently export-controlled technologies (e.g., tritium handling systems) and possibly other materials and/or components and that do or may fall under export-control rules;
- Address the establishment of an international nuclear non-proliferation and security framework for commercial fusion energy, which does not presently exist;
- Provide means to stimulate domestic supply chains and (advanced) manufacturing capacity/capabilities that are needed for a rapid build-out of commercial fusion energy. One concerning example is the manufacture of high-temperature-superconducting (HTS) tape for fusion magnets, where Chinese and Russian companies are outpacing U.S. companies in manufacturing capacity.

DOE welcomes the opportunity to collaborate with you and this committee on identifying specific needs and opportunities when we are ready to share a more detailed and comprehensive assessment of the challenges to accelerating fusion energy RD&D.

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QUESTION FROM SENATOR JOHN W. HICKENLOOPER

Q1. Once we're able to harness fusion energy reliably, we'll want to scale it up as quickly as possible. This will require a build-out of manufacturing of specialized materials, equipment, and facilities for fusion, many of which are currently outsourced. How can the government, via policy or public-private partnerships, support fusion-related supply chains and manufacturing to ensure a swift build-out when the time comes?

A1. Fusion-pilot-plant technology roadmaps to be developed under the Milestone-Based Fusion Development Program will better define supply-chain and manufacturing issues/needs in support of rapid deployment of commercial fusion systems. The DOE Fusion Crosscut Team will work to identify and recommend needed actions by the U.S. Government and private industry to be prepared for a swift build-out when the technology is ready. DOE welcomes the opportunity to collaborate with you and this committee on identifying specific needs and opportunities when we are ready to share a more detailed and comprehensive assessment of the challenges to accelerating fusion energy RD&D.

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Question from Ranking Member John Barrasso

Question: The Office of Science's Fusion Energy Science (FES) program primarily focuses on basic scientific research. Expanding this program's mission could detract from this important function. Should FES have the responsibility to oversee demonstration activities, or does it make more sense to move such activities to another part of the Department, such as the Office of Clean Energy Demonstrations?

FES has been very successful in developing the scientific basis of fusion from the basic plasma science to the current machine design. While predictive capability has improved dramatically in the last decade, it is not complete. Driving the development of commercial fusion through computer simulation, optimization, and virtual engineering requires further scientific research — FES's mission is not finished. Nonetheless, it is prudent to ask how best to oversee demonstration activities and to explore with the Department of Energy the best options, both now and in the future.

Questions from Senator Maria Cantwell

While the Energy Act of 2020, the CHIPS and Science Bill, and the Inflation Reduction Act (IRA) all provided key authorizations and funding for certain aspects of fusion research, development, and deployment, explicit federal incentives to spur and ensure domestic manufacturing of the components needed for deploying fusion (such as specialized capacitors and vacuum vessels) has not yet been enacted.

Question 1: What more could the federal government be doing to specifically incentivize and support the domestic manufacturing of components to support fusion deployment at scale?

This is an interesting question that needs an in-depth study. I believe that some of the mechanisms used in the Department of Defense to incentivize the supply chain could be very helpful. Several key components will require industry to scale up manufacturing by large factors. For example, superconducting magnet technology is critical to many fusion concepts, but the current production of superconducting strand is far below the projected need. Incentivizing the production of low activation steels is also something that should be considered. The ITER program has enabled U.S. companies to develop specific skills and capabilities. For example, General Atomics has unique skills derived from their manufacture of the ITER central solenoid. While further science and innovation are needed to develop and optimize the "plasma heart" of a Fusion Pilot Plant, the balance of the system will dominate the cost (and perhaps the complexity). As the technology roadmaps become clear, federal programs to preemptively attract U.S. manufacturing may be important. Along those same lines, pipeline programs to attract, train, and retain top talent to further develop the science and innovation will be critical. Future iterations of DOE's public-private partnership milestone program could address some of these issues.

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Question 2: Do you believe there is the potential for most, if not all of the critical component supply chain for domestic deployment of fusion at scale to be developed in the United States?

The United States has all the capabilities to supply the critical components, and it also has the opportunity to do so. Similar to manufacturing of other high-tech products, however, optimizing the source and supply of key raw materials may require additional attention.

Question 3: Fusion was left out as being explicitly enumerated as a qualifying technology for the 48C clean energy manufacturing credit in the IRA. Do you believe that fact will present an issue for the Treasury Department's interpretation in guidance regarding fusion qualifying for 48C? Fusion was also not included in the 45X advanced manufacturing tax credit in the IRA, which requires specific components to be enumerated to qualify. Do you support adding fusion components to the list of qualifying components? Do you believe that making fusion eligible for these two manufacturing tax credits, in parity with other clean energy technologies, will help spur the domestic growth of the industry? Please elaborate.

I agree this mechanism should be investigated to both stimulate the supply chain and to help drive domestic growth of the fusion industry. However, I believe that an in-depth study of the supply-chain needs and the best methods to stimulate production would be prudent. For instance, such an analysis could assess which components are common across the portfolio of technical approaches as well as which manufacturing sectors are most likely to launch component production lines "at risk" before a formal, commercial fusion-energy market is fully established.

Question from Senator Angus S. King, Jr.

Question: Please lay out concrete policy steps that Congress and the Administration ccould take to accelerate the commercial deployment of fusion reactors.

The National Academies' 2021 report *Bringing Fusion to the Grid* lays out steps to Pilot Plants in the 2035-40 range. Following that blueprint, as well as the program direction and authorizations included in the recent *CHIPS and Science Act*, I believe the immediate steps are:

1. Continue to fund FES and the development of fusion science, ensuring continued U.S. leadership in plasma and fusion science. This includes ITER and the domestic fusion experiments NSTX-U at the Princeton Plasma Physics Laboratory and DIII-D at General Atomics, which are all world-class facilities with rich international collaboration and will provide critical data for the Pilot Plant designs.
2. Fund the scientific and technological development of fusion materials, including test facilities at the national laboratories.
3. Expand the milestone-based program after the initial phase (in which technology road maps are to be delivered) to develop Pilot Plants.
4. Fund a High-Performance Computing for Fusion Innovation Center to drive the optimization of fusion concepts through computer simulation and virtual engineering. Such a center, as outlined in the *CHIPS and Science Act*, would help the knowledge transfer to industry from the FES program.

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Question from Senator John W. Hickenlooper

Question: You mentioned the importance of high-performance computing in your testimony and some of the computational work the Princeton Plasma Physics lab is doing. As a former geologist, I can understand the value of performing work computationally before ever having to test out the real thing. I wish my industry had had that in the 80s! For something as complex as fusion, the ability to run experiments computationally is critical to accelerating research and development, and eventually commercialization. How would a purpose-built fusion computation center, like that authorized in the CHIPS and Science Act, promote the commercialization of fusion?

Thank you for a thoughtful question. One of the most impactful contributions of DOE to U.S. scientific and industrial competitiveness has been the development of high-performance computing, including the provision of supercomputers and now exascale computing. Computing allows us to anticipate challenges that frustrate progress and prototype solutions in the virtual environment. A dedicated High-Performance Computing for Fusion Innovation Center and an associated high-performance computation collaborative research program would advance the tools (software) and provide the computational resources to meet the need both in physics simulation and virtual engineering. This focus on a specific application area (fusion energy) and including the engineering, integration, and manufacturability considerations would make the Center unique and extremely impactful. It should draw in commercial partners from industries that already use extensive virtual engineering and prototyping. PPPL is already working with tech companies (e.g. Microsoft) to incorporate machine learning (ML) and artificial intelligence (AI) methods to optimize fusion systems. This approach promises to shorten the time to commercial fusion by large factors, but it requires a strong public program with an intimate connection to the fusion industry, the virtual engineering industry, and the AI/ML leaders. The privately funded fusion industry has limited capability in computation and is reaching out to the national laboratories and universities to help optimize machine designs and scenarios (for instance, through the DOE INFUSE program). While these collaborations are already successful, additional investment in high performance computing will undoubtedly boost public-private partnerships and dramatically shorten the time it will take to achieve fusion electricity.

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Question from Ranking Member John Barrasso

Question: In his testimony, Dr. Hsu noted the need to rebaseline the cost and schedule for ITER, given pandemic-related delays. What is the baseline timeline and cost now, and when can we expect to know the new estimate for full cost and timeline for ITER? How does this compare with the original cost and timeline estimates when Congress first authorized ITER funding over a decade ago?

Answer: The present baseline for the ITER Project is in place since 2016. The Overall Project Schedule (OPS) has the key milestones of First Plasma, which is a demonstration of the core tokamak components and their required supporting systems, by the end of 2025 and the start of the first operating period using deuterium-tritium fuel, which allows the production of substantial fusion power, by the end of 2035. The Overall Project Cost (OPC) has a total value of just over 20 billion Euro (using the 2021 conversion value). It is important to recall two key points with respect to the OPS and OPC. First, the OPS is the 'fastest technically achievable' schedule and the OPC contains no cost contingency; in other words, the baseline is formally both perfectly formulated and perfectly executed. This method of baselining was decided by the ITER Council, the governing body of the ITER Project, as the preferred method against which to judge actual cost and schedule performance. Second, the OPC includes the in-kind contributions comprising about 85% of the capital equipment for the ITER Project; however, the OPC includes only the assigned value at the beginning of the ITER Project (escalated for inflation) and not the actual cost to the ITER Members. This costing choice was part of the ITER Agreement itself. This method chosen for baselining the ITER Project is very different from the method applied by the U.S. Department of Energy to its own projects, and therefore comparisons to execution of domestic projects need to take this difference into account.

At the end of 2021, the ITER Council requested to ITER Organization to make a proposal for an updated baseline, which it did in 2022. The process is still in progress and is expected to complete no earlier than the end of 2023.

With regard to the original cost and timeline estimates, the Final Report of Negotiations on ITER Joint Implementation in April 2006 contained an OPC of just under 15 billion Euro (using the 2021 conversion value) and the OPS had a First Plasma date of 10 years from establishment of the ITER Organization as a Legal Entity, which occurred at the end of 2006. Therefore, the First Plasma was estimated to occur by the end of 2016. The OPS expected that the major goals of the ITER Project as defined in the Project Specification would be achieved without extension of the ITER Agreement, which is possible for up to 10 years. Using the present basis of estimate for ITER operations cost in the OPC, the cost to achieve the Project Specification would be between 20-24 billion Euro (using the 2021 conversion value), depending on the duration of extension to the ITER Agreement agreed by the Members. The ITER Council has not provided for any extension of the ITER Agreement in the baseline OPS and OPC.

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Question from Senator Angus S. King, Jr.

Question: Please lay out concrete policy steps that Congress and the Administration could take to accelerate the commercial deployment of fusion reactors.

Answer: As noted in the written testimony submitted, the ITER Organization should not advocate any specific policy position to be taken by its Member governments, but supports preparations to move ahead using the information already learned from the ITER Project and anticipating that to come. In that spirit, I can offer some considerations on what the policy might address. To be effective, a specific and quantitative technical objective and target date are needed to formulate the policy; for example, a specified fraction of U.S. electrical generation from fusion power by a given date. A realistic view of the total investment and the expectation for the fraction of public and private contributions to the total would be needed, in light of the perspective of energy security discussed during the hearing. In determining these expectations, consideration of what is the technical readiness level of the key technologies and which have use other than fusion (and thereby may prove easier to attract private investment) should be made. If the policy target has a longer time horizon, then a means to convince the private investors of the stability of the public commitment may be needed, such as a public-private corporation that can assure stability of strategy and funding through the variations of appropriation and private investment cycles. Finally, the ownership of the generated intellectual property will need to be carefully considered in advance. I believe the existence and enactment of a public policy that realistically addresses these points will be an effective accelerant to the commercialization of fusion energy.

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Questions from Ranking Member John Barrasso

Question 1: During the hearing, you discussed several key milestones the fusion industry is pursuing.

a. What is your schedule for achieving these milestones?

b. How does your schedule compare to ITER's?

c. How does your schedule compare to the Department's decadal vision?

d. How does your schedule compare to international competitors?

Answer 1:

a. According to a recent survey conducted by the Fusion Industry Association (FIA), industry's central organizing goal is to put commercial fusion energy on the grid in the early 2030s, a goal shared among 92% of the interviewed fusion companies. CFS' demonstration device, SPARC, plans to turn on in 2025 and achieve net energy soon thereafter, proving the viability of fusion as a commercial energy source. We expect our first power plant, ARC, to be operational by the early 2030s in accordance with industry's predictions.

   With respect to the intermediate milestones we will accomplish to achieve our goals, we plan to further discuss these with DOE in the implementation of their Milestone-based fusion development program. The goal of this program is to lead to "applied R&D to resolve scientific and technological issues toward the successful design of a fusion pilot plant (FPP)." The Administration and Congress fully funding this program will support being on the fastest path to achieving this milestone, leading to a successful preliminary design review (PDR) of a commercially-relevant fusion pilot plant that will lay the groundwork for constructing a fusion power plant in the early 2030s. As outlined in the most recent Funding Opportunity Announcement (FOA) for the milestone program from DOE, $50M are expected to cover roughly 18 months in initial deliverables with additional appropriations and funding needed for subsequent milestones over a five year period.

b. With regard to CFS' demonstration fusion facility, SPARC, the project is currently under construction and is expected to be completed in 2024, with first plasma in 2025, and achieving net energy or Q>1 shortly thereafter. It is our understanding of the latest schedule, that ITER is expected to achieve first plasma in late 2025 building towards Q>1 in 2035.

c. We believe our schedule of putting commercial-scale fusion energy on the grid is achievable in the early 2030s, whereas the Administration's Bold Decadal Vision for Commercial Fusion Energy foresees a commercial first-of-a-kind fusion power plant by the late 2030s. The surest and fastest path to achieving this timeline will require better alignment with the DOE Office of Fusion Energy Science (FES) to collaborate on critical R&D that will support ongoing work in commercial fusion, as well as resolving

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outstanding scientific and technical issues necessary for the private sector to build the first fusion power plant. (FPP). Specifically, the DOE, National Labs and Universities should focus on their core strengths, such as building out important R&D facilities, test stands and advancing the science, while partnering with the private sector which brings its capital, market insights, engineering and execution expertise, to move more efficiently towards power plants' construction. A course correction from DOE on aligning existing resources and programs towards a commercial pathway for fusion energy will support an acceleration of the industry's ability to achieve the schedule of the Bold Decadal Vision for Commercial Fusion Energy. Secondly, achieving the Bold Decadal Vision will require a serious commitment from the Administration and Congress to fully fund key programs, leveraged by significant private sector investment. In order to compete with other nations, such as the UK or China, it's critical that DOE's Office of Fusion Energy Science, the Milestone-based fusion development program, INFUSE, and the recently authorized Fusion Reactor System Design program be fully funded.

d. Other nations, such as the UK and China, are moving aggressively in this emerging sector, providing both substantial resources, R&D, and regulatory certainty to put commercial fusion power on the grid in the early 2030s. In 2021, the UK issued their national strategy for commercial fusion, stating their intent "to build a world-leading fusion industry which can export fusion technology around the world"[1], which includes significant funding for ongoing R&D and they announced on October 6, 2022[2] the selection of the location where they plan to build a prototype fusion energy plant by 2040 and funding of $250 million to be ready with a concept design by 2024. China has also announced their intent to lead in fusion energy, announcing on September 15, 2022 they plan to generate fusion power within just six years and their fusion device Z-FFR will be built by 2025 in Chengdu, and then produce power as soon as 2028 before becoming commercially operational by 2035[3].

Question 2: The Office of Science's Fusion Energy Science (FES) program primarily focuses on basic scientific research. Expanding this program's mission could detract from this important function. Should FES have the responsibility to oversee demonstration activities, or does it make more sense to move such activities to another part of the Department, such as the Office of Clean Energy Demonstrations?

Answer 2: We believe there is important work to be done with FES in collaboration with the private sector. As I said in my testimony, the DOE, National Labs and Universities should focus on their core strengths, such as building out important R&D facilities, test stands and advancing the science of fusion energy. As it pertains to addressing scientific issues, FES plays an important role and should better align its own efforts with commercialization pathways as an underlying goal. That said, as fusion technology is rapidly advancing into demonstration activities and later deployment, finding a home for these activities outside the Office of Science

[1] UK's "Toward fusion energy: the UK government's fusion strategy" report - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1022540/towards-fusion-energy-uk-government-fusion-strategy.pdf

[2] https://www.gov.uk/government/news/west-burton-selected-as-home-of-step-fusion-plant

[3] https://www.newsweek.com/nuclear-fusion-china-z-pinch-machine-six-years-1743218 and https://www.scmp.com/news/china/science/article/3192435/chinas-top-weapons-scientist-says-nuclear-fusion-power-6-years

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would be reasonable and prudent as the technology matures and the viability of demonstration fusion power plants comes into focus. We agree that as fusion energy matures, moving from FES to an applied program, such as the Office of Clean Energy Demonstration makes sense. A key milestone will be when SPARC achieves Q>1 in 2025. If commercialization of the technology proves successful, the Administration and Congress should also consider standing up an Applied Office of Fusion Energy.

Question 3: The significant private-sector interest in fusion reminds me of the shift we recently saw in advanced fission energy. Private-sector investments into advanced nuclear fission technology led the Department to transition from focusing on research to partnering with private-sector companies. What can we learn from the Department's recent experiences with advanced fission technology?

Answer 3: We believe one of the more important lessons is that Congress and the Administration recognized the potential and importance of developing advanced fission technology here in the U.S., rather than ceding that leadership to other countries. They did so by providing robust public funding, and utilizing public-private partnerships to drive the technology advances in a manner that is commercially viable. The Milestone-based fusion development program is utilizing the NASA Commercial Orbital Transportation System (COTS) model, whereby the private sector is taking on up front risk to address the "applied R&D to resolve scientific and technological issues toward the successful design of a fusion pilot plant", and only after achieving certain agreed upon milestones that have been verified, will the federal government provide funding. Similar to the DOE's Advanced Reactor Demonstration Program (ARDP) for advanced fission technologies, both programs are cost-share programs.

Question 4: How much energy will a commercial fusion plant produce?

Answer 4: Energy production for each commercial fusion facility will vary, based on technology design, and technology maturity. I can only speak for CFS, but our first generation fusion device, ARC, which is designed to be scalable at >200MW electric, and expected to produce approximately 400MW electric. Other companies are looking at a range of power generation production.

Question 5: What is the expected life of a fusion reactor?

Answer 5: Like power production, life of the fusion device will vary, based on technology design, and technology maturity. It is our goal to have our fusion device ARC have a comparable life to traditional power generation facilities of more than 20 years.

Questions from Senator Maria Cantwell

While the Energy Act of 2020, the CHIPS and Science Bill, and the Inflation Reduction Act (IRA) all provided key authorizations and funding for certain aspects of fusion research, development, and deployment, explicit federal incentives to spur and ensure domestic manufacturing of the components needed for deploying fusion (such as specialized capacitors and vacuum vessels) has not yet been enacted.

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Question 1: What more could the federal government be doing to specifically incentivize and support the domestic manufacturing of components to support fusion deployment at scale?

Answer 1: Among the important things the federal government can do right now to support fusion deployment at scale is to drive R&D to resolve key scientific and technological issues that support the successful design of commercially viable fusion power plants. With respect to manufacturing of the components themselves, I believe Congress has enacted a number of financial incentives in the Inflation Reduction Act, including (but not limited to) expanded funding and loan authority for the DOE Loan Program Office and expansion of the Advanced Manufacturing Tax Credit (48C). CFS and other FIA member companies will be looking to ensure that fusion related technologies can use these programs and incentives as we seek to scale our manufacturing and supply chains.

Question 2: Do you believe there is the potential for most, if not all of the critical component supply chain for domestic deployment of fusion at scale to be developed in the United States?

Answer 2: It depends on where the market is. If the U.S. moves quickly to match the investments other nations are making, such as the UK and China, to bring fusion power to market at scale, then I believe the supply chain will follow here in the U.S. If, however, the U.S. misses this moment, it's entirely possible that we will be importing these technologies and components from other countries. As I said in my testimony, we are at an inflection point. CFS is in the process of building a manufacturing facility for critical components for our fusion devices right now in Devens, Mass. This facility will produce magnets that could be used in the U.S. in commercial fusion facilities and/or exported to other nations and markets. However, as we have seen with other technologies (e.x. semiconductors or solar panels), if the U.S. does not move quickly with supportive policies to support the growth of this technology, we could see near term U.S. leadership in innovation and manufacturing in fusion outsourced to other countries. That is why investments in R&D, a stable and predictable regulatory and licensing framework, workforce development, etc. are all important policies to ensure we can develop this technology and its supply chain in the U.S.

Question 3: Fusion was left out as being explicitly enumerated as a qualifying technology for the 48C clean energy manufacturing credit in the IRA. Do you believe that fact will present an issue for the Treasury Department's interpretation in guidance regarding fusion qualifying for 48C? Fusion was also not included in the 45X advanced manufacturing tax credit in the IRA, which requires specific components to be enumerated to qualify. Do you support adding fusion components to the list of qualifying components? Do you believe that making fusion eligible for these two manufacturing tax credits, in parity with other clean energy technologies, will help spur the domestic growth of the industry? Please elaborate.

Answer 3: As you know, under 48C, the Secretary of the Treasury has the authority to allow fusion to qualify through his/her discretion in determining "other advanced energy property designed to reduce greenhouse gas emissions." While it would have been preferable for Congress to include fusion specifically, as an eligible qualifying manufacturing facility (like solar, wind, geothermal, fuel cells, CCS, etc.), we believe the Treasury has the authority to make fusion eligible for 48C. We look forward to working with other fusion companies, Members of Congress, and other stakeholders supportive of fusion to encourage the Treasury Department to utilize its authorities to allow fusion to qualify for 48C, putting it on an even playing field with other clean energy technologies.

Through the establishment of the new 45X advanced manufacturing production credit, Congress has chosen to incentivize the domestic production of certain clean energy technologies, namely: wind, solar, and batteries. While I understand the policy goals of onshoring these supply chains and driving deployment to meet certain climate change goals, I believe Congress missed an opportunity to take a more holistic view of the production of a broader range of clean energy technologies in the U.S., such as emerging technologies like fusion. I appreciate the care Congress took in restructuring other tax credits in the Inflation Reduction Act to ensure technological parity and avoid picking winners and losers. Adding fusion components to the 45X credit would bring parity to other clean energy technologies and drive deployment of fusion commercially through reduced costs to manufacture and deploy.

Question from Senator Angus S. King, Jr.

Question: Please lay out concrete policy steps that Congress and the Administration could take to accelerate the commercial deployment of fusion reactors.

Answer: Thank you for the question and the ability to expand upon my answer at the hearing. Simply put, we need better alignment between DOE programs and the private sector commercial pathways and schedule and we need Congress and the Administration to fully fund already authorized programs in order to achieve the Bold Decadal Vision for Commercial Fusion and to put fusion power on the grid in the early 2030s. Specifically:

First, we need to **align** the existing programs towards an energy mission. As pointed out in the National Academies report, the DOE should focus on an energy mission with an end goal of establishing a successful domestic fusion industry in the early 2030s. To do this we need to instruct and facilitate the DOE on the cross-cutting efforts to work at the speed of and together with industry. Specifically, the DOE, National Labs and Universities should focus on their core strengths, such as building out important R & D facilities, test stands and advancing the science, while partnering with the private sector bringing its capital, market insights, engineering and execution expertise to move more efficiently towards power plants. Working together will get us there faster.

Second, we need to **build** the test stands needed and identified in the National Academies and FESAC reports including the fusion prototypic neutron source, blanket test stand, and finishing MPEX. DOE needs to do this quickly and flexibly, leveraging public-private partnerships, so that the U.S. can catch up to our international research peers who are producing actual components and facilities the U.S. has had on paper for several years.

Third, enable **pilot plants**, these are plants that put power on the grid in a commercially relevant way and enhance public-private partnerships. The industry is already preparing itself to do this as it is required for a business selling the follow-on power plants. Fortunately, we know how to help new industries and we believe that the milestone-based fusion program is the way to do this. Through the milestone program, private companies accept the bulk of the risk by funding their own activities until agreed upon milestones are achieved and verified, at which point they get reimbursed at an agreed upon fixed price by the government. This type of public-private cost-share model has proven successful in other sectors and unleashed an abundance of societal benefits. A great example is the NASA Commercial Orbital Transportation System (COTS) program which demonstrated great success with SpaceX. This partnership led to a drastic transition in the launch industry. COTS was successful, because as a first step NASA was provided a significant, upfront appropriation of $500 million spent over five years. This provided the private sector a level of confidence in the public sector and it gave NASA the ability to plan over a longer time horizon. In short, it enabled the U.S. to move together quickly. The DOE milestone-based fusion development program is authorized, and initial funding appropriated, let's give it the best shot at success. In order to be successful and emulate COTS' success, we need the program fully funded as authorized ($370M FY22-27). And as has happened with SpaceX, as the commercial sector demonstrates success achieving key milestones in this program, Congress and the Administration should be prepared to provide continued support for the building and commissioning of the first fusion pilot plants starting in the early 2030s, securing a leadership position in fusion energy in the United States.

Fourth, ensure regulatory **clarity**. We need to ensure the regulatory process for the licensing and permitting of fusion power plants in the U.S. is established, risk appropriate, and enables quick commercialization. Fortunately the NRC process is underway. Congress should be ready to support when needed.

Fifth, tax incentives, grants, loans and other forms of financial assistance are always helpful for nascent technologies and industries. We appreciate the focus on tech-neural investment credits in the Inflation Reduction Act where eligibility for credits would no longer be determined by Congress picking "winners" and "losers" but rather on the merits of the underlying technology, such as the ability to produce zero greenhouse gasses. Additionally, funding for workforce development initiatives will be critical to build out a functional fusion industry by the early 2030s.

GENERAL ATOMICS

Statement from General Atomics
For the Record of the Full Committee Hearing to
Examine the Federal Government's Role in Supporting the Commercialization of Fusion Energy
U.S. Senate Committee on Energy and Natural Resources
Thursday, September 15, 2022

Chairman Manchin,
Ranking Member Barrasso,
Members of the Senate Committee on Energy and Natural Resources,
Distinguished Witnesses,

We are pleased to provide this written statement on behalf of General Atomics, to be included in the record of today's important hearing examining the federal government's role in supporting the commercialization of fusion energy. GA is an energy, defense, and diversified technologies company founded in 1955. GA's research and development portfolio includes magnetic and inertial confinement fusion as well as nuclear fission.

GA has over six decades of successful partnership in fusion with the U.S. government and has been an international leader in magnetic fusion research and development since its inception. We are the longest running private-sector participant in fusion energy development and perform both theoretical and experimental fusion research collaboratively with the government and a range of institutions, including national labs, private companies, and universities.

General Atomics serves as the host and operator of the internationally recognized DIII-D National Fusion Facility on behalf of the Department of Energy's (DOE) Office of Science. DIII-D is the largest and only operational magnetic fusion research facility in the United States and is playing a crucial role in the development of solutions to enable the safe and efficient operation of a fusion power plant. The DIII-D National Fusion Facility is also an important proving ground as the United States prepares to take leadership in the international ITER experiment.

As a DOE user facility, DIII-D continues the drive toward practical fusion energy with critical research conducted in collaboration with more than 800 participants supporting the programs and research priorities of over 100 institutions worldwide. DIII-D is also training the next generation of fusion scientists and engineers in the United States. Its high flexibility and world leading measurement systems make it uniquely capable to develop the new techniques necessary for a fusion reactor, and the scientific basis to project them with confidence. With an outstanding scientific and technical team delivering the most operation of any fusion facility in the United States, and its ability to rapidly innovate new approaches, DIII-D is a vital resource for rapidly pioneering the answers needed for the commercialization of fusion energy.

In addition, General Atomics has established the Magnet Technologies Center (MTC), which is the manufacturing and testing site for the ITER Central Solenoid. When completed, the Central Solenoid will be the most powerful pulsed superconducting electromagnet ever built. Often referred to as the heart of ITER, the 5-story, 1,000-ton magnet will drive 15 million amperes of electrical current in ITER's fusion plasma for stabilization.

With renewed interest in commercializing fusion, we are confident that General Atomics will continue to be a reliable partner with government and industry to develop the innovations in fusion and take those solutions to scale. We believe that our demonstrated strategic commitment to fusion will be needed to tackle the significant challenges that remain to be overcome to realize practical fusion power.

General Atomics' vision for fusion takes advantage of the so-called "advanced" tokamak path, which offers the key advantage of inherently steady-state operations for continuous power production. This path is more resilient to transient events that can disrupt plant operation and is designed to minimize cyclic stresses and fatigue. This path was developed through our advances in physics understanding and modeling and new technologies that decrease the size of the facility – thereby reducing the time and capital cost for building a fusion facility. We are confident this approach will provide a viable means to produce fusion-generated electricity and secure our long-term strategic energy needs.

The U.S. fusion community, the Fusion Energy Sciences Advisory Committee (FESAC), and the National Academies have all described plans for realizing fusion powered electricity production through the design and operation of one or more fusion pilot plants (FPPs). This endeavor builds on years of fusion science progress supported through publicly funded programs, the latest understanding of fusion science achieved through theoretical advances and research to optimize the size and cost of a FPP, and on technology breakthroughs developed and learned from ITER and other industries.

In order to successfully commercialize fusion via such FPPs, a well-coordinated effort needs to be undertaken by the public and private programs. There is no single "magic bullet" that will address all the challenges that lie ahead for deploying fusion to the grid, and no singular technology or physics breakthrough that instantly makes fusion economically viable. To have fusion be commercially deployed in a timely manner will require technical expertise and comprehensive software technology that is supported by the public program. The federal government should ensure the continuity and expansion of this very deliberate public program to support the scientific basis, to ensure readiness, and to mitigate risks and delays, of all required technologies for fusion energy.

As such, a new and more broadly structured public fusion program is required, as described in various reports including the 2020 long range plan approved by the FESAC, entitled "Powering the Future: Fusion and Plasmas". This would see substantively new and increased programs in critical areas where federal funding has previously given relatively limited emphasis, including: 1) developing the materials that can withstand the fusion environment, and 2) closing the fusion fuel cycle to inject, breed, process, and store tritium.

In addition, the public fusion program must simultaneously grow in areas where the federal effort has already been historically focused, particularly related to: 1) confinement physics (where studies in the U.S. and Europe continue to show that the largest leverage on the cost of fusion facilities producing electricity is the confinement quality), 2) approaches to improve the heating and current drive techniques to create and sustain the fusion core, and 3) development of instruments and control techniques relevant to a FPP environment.

The public program can also greatly facilitate the commercialization of fusion by continually developing the necessary infrastructure and providing appropriate access to private entities pursuing commercial fusion energy. This requires the: 1) modernization and upgrade of existing facilities, and 2) construction of new facilities and test stands that can tackle these various challenges.

A successful public program will also require completing ITER and establishing a US ITER research team that will do the scientific exploitation of the facility and bring back critical knowledge on operating, sustaining, and controlling a burning plasma at the scale of a fusion power plant. This is of enormous value to fusion deployment, no matter which fusion concept(s) are eventually commercialized.

The public program must provide the private fusion community with access to the intellectual, technical, and financial resources required, and make the public facilities and infrastructure easily accessible, including the advanced computation capabilities that will be needed to simulate all aspects of the fusion power system. In addition, the government should provide phased funding to businesses to encourage development and maturation of their technologies in order to offset the risk and expense of vital research and development, and provide avenues for commercialization of laboratory-developed technologies with industry partners.

As important as the individual programs, a coordinated effort is needed to connect the private and federal programs through teams developing FPP concepts that lead to actual construction of such facilities. By establishing these teams, concepts will have a sound scientific basis and appropriate vetting to ensure that government funds are appropriately deployed when we transition from design to construction.

At the outset of such a FPP design program, it must be recognized that fusion technology has not matured to a level where large-scale cost-shares can be justified, and that doing so would necessarily stifle innovation and limit the number of participants at a time when an "all in" approach is needed. We believe that the DOE should move quickly to fund at least two group efforts to develop designs for FPPs as authorized in the recent *CHIPS and Science Act*. This effort should be considered an R&D effort with a private cost share not to exceed 20%. After at least three years of design activity, the Department could select designs for commercialization that it could fund with a required 50% cost share. This commercialization effort would require multiple times the funding required for the FPP design program.

Given the urgency for fusion to impact plans to decarbonize the electric grid and supply the rapidly growing demand for energy in the U.S. and across the globe, strong government support will continue to play a vital role in maturing fusion energy. Beyond the technical, the government has other key roles to play, including: 1) ensuring there is a suitable and appropriate regulatory framework for fusion in place, 2) establishing the supply chain for critical fusion components and systems, 3) developing the very broad workforce that will be needed to design, site, construct, and operate a fusion power plant, and 4) implementing strategies for social acceptance and deployment with consideration of important societal issues.

General Atomics is optimistic that fusion can be deployed in a timely fashion with the right investments from the federal government and with suitably structured public private partnerships.

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