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Introduction

Chairman Williams, Ranking Member Bowman, and distinguished Members of the Subcommittee and Committee, thank you for your longstanding support of fusion energy sciences R&D. As a Senior Advisor and the Lead Fusion Coordinator for the Department of Energy (DOE), it is an honor to provide testimony regarding DOE's efforts over the past year to develop and advance a *Bold Decadal Vision for Commercial Fusion Energy*, which was first unveiled at a White House Summit in March 2022.[1]

A key ambition of the *Bold Decadal Vision* (BDV) is to partner with the private sector to resolve the remaining scientific and technological (S&T) challenges to realize an operating fusion pilot plant[2] (FPP) on a decadal timescale. Equally important, the BDV aims to ensure that fusion energy supports energy and environmental justice and an equitable clean-energy transition, by engaging the public and local communities at the outset of development, demonstration, and deployment.

In September 2022, I testified before the Senate Energy and Natural Resources (SENR) Committee on DOE's initial actions to support fusion commercialization following the White House Summit. In that testimony,[3] upon which the present testimony builds, I emphasized the following points:

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[1] 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.

[2] The DOE defines an FPP based on the National Academies report in footnote 4: an FPP should generate at least 50 megawatts of net electricity for at least 3 continuous hours, with a timely path to 1 full power year and at a capital cost that will attract private investors and commercialization partners.

[3] https://www.energy.senate.gov/hearings/2022/9/full-committee-hearing-to-examine-the-federal-government-s-role-in-supporting-the-commercialization-of-fusion-energy.

1. The profound and positive implications fusion energy may have on humanity and for strengthening U.S. technological leadership, as a potentially clean, on-demand, abundant, and globally scalable energy source;
2. Recommendations by recent consensus expert reports[4] to fundamentally shift the U.S. fusion energy R&D strategy toward an energy-development mission, including greater emphases on public-private partnerships and developing the required materials and enabling technologies for a commercially relevant FPP;
3. The confluence of increasing technical readiness of fusion S&T and significant market interest in fusion energy (as evidenced by more than $4.7 billion of private investment into predominantly U.S. fusion companies); and
4. The need for an updated U.S. strategy for international collaborations, including maximizing the present learnings from ITER to inform domestic efforts, and targeted new collaborative activities with like-minded countries to enable eventual fusion commercialization and global deployment.

In December 2022, thanks to decades of DOE/NNSA investments, a significant fusion event occurred – the achievement of *fusion ignition* and *scientific energy breakeven*[5,6] at the DOE/NNSA Lawrence Livermore National Laboratory's National Ignition Facility (NIF). The NIF achievement was enabled by DOE/NNSA's longstanding support of its inertial confinement fusion program, which led to the scientific, computational, and technological advances needed to reach this milestone. For the DOE/NNSA, this milestone allows scientists to study and further our understanding of physics at extreme conditions, enabling us to build confidence in our nuclear deterrent without nuclear explosive testing.

However, the NIF result also has significant implications for the pursuit of fusion energy. Most importantly, it showed that controlled fusion can be a source of clean energy for humanity and elevates inertial fusion as one of the possible pathways to commercial fusion energy. It is not an exaggeration to compare the achievement of fusion ignition and scientific breakeven to the first sparks leaping from the flint stones of early humans on the way toward our mastery of fire and chemical combustion.[7]

Continued advances in fusion energy sciences and enabling technologies are needed to achieve the energy gains and sustainment durations (or repetition rates in the case of inertial or magneto-inertial fusion) required for an FPP. The foundational research in plasma and fusion sciences, supported by the Fusion Energy Sciences program, is as crucial today as it has been for the many decades leading up to the recent breakthroughs. We must continue to drive discovery and scientific advances in the behavior of both burning fusion plasmas and low-temperature plasmas,

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[4] *Powering the Future: Fusion and Plasmas*, report of the Fusion Energy Sciences Advisory Committee (2020), https://usfusionandplasmas.org; *Bringing Fusion to the U.S. Grid*, report of the National Academies of Science, Engineering, and Medicine (2021); https://nap.nationalacademies.org/catalog/25991/bringing-fusion-to-the-us-grid.
[5] https://www.energy.gov/articles/doe-national-laboratory-makes-history-achieving-fusion-ignition.
[6] *Fusion ignition* is when the instantaneous energy being released from fusion reactions exceeds all instantaneous energy losses from the fuel. *Scientific energy breakeven* is when the fusion energy released in a fusion experiment exceeds the input energy delivered into the vacuum vessel of the experiment (e.g., the laser energy on NIF).
[7] "The Significance of the Achievement of Scientific Energy Gain at the National Ignition Facility," ARPA-E Blog Post (2022); https://arpa-e.energy.gov/news-and-media/blog-posts/significance-achievement-scientific-energy-gain-national-ignition.

advance the discovery of materials that can be sustainably deployed in a commercially relevant fusion environment, and pursue grand challenges in high-energy-density plasma science. These use-inspired areas of fundamental research must be sustained to ensure that we have the scientific underpinnings, tools, and expertise to overcome challenges in pursuit of the BDV and to ensure that we have solutions to continue to drive down costs of commercial fusion energy after it is demonstrated and initially deployed.

That said, the achievement of ignition and scientific breakeven on NIF shows that the state of fusion science has reached a suitably mature level to support the premise of the BDV to pivot toward applied R&D and engineering development of a commercially relevant fusion pilot plant. Practical fusion energy may now be less a matter of time than of collective societal will.

Advancing the *Bold Decadal Vision for Commercial Fusion Energy*

Over the past year, DOE led or collaborated on several new activities in support of the BDV, as described below in more detail.

Milestone-Based Fusion Development Program

This is a major new public-private-partnership (PPP) program, launched by the Office of Science (SC), that was first authorized in the Energy Act of 2020 (Sec. 2008) and re-authorized in the CHIPS and Science Act of 2022 (Sec. 10105). This 5-year program is a centerpiece of the BDV, enabling and encouraging the private sector to work together with national laboratories, universities, and other partners on the applied R&D and stakeholder engagements required to realize a preliminary engineering design for a commercially relevant FPP. The deliverables for all selectees within 18 months include FPP pre-conceptual designs and technology roadmaps. The 5-year deliverable is either a successful preliminary engineering design review for an FPP, or a significant performance improvement of a team's FPP concept as defined by the applicant. Participants will contribute more than 50% of total project costs via non-Federal sources.

Notably, the authorization language for the program[8] specified that the program shall be established using "Other Transactions" (OT) authority,[9] i.e., transactions other than contracts, cooperative agreements, and grants, and that projects must "meet particular technical milestones before a participant is awarded funds by the Department." Since its inception in 2018,[10] the Fusion Industry Association (FIA) had advocated for this type of program, with the goal of negotiating industry-friendly terms on intellectual-property and data rights and avoiding onerous federal procurement rules and cost-accounting requirements, in exchange for taking on substantial financial risk (i.e., greater than 50% of the total project cost). A dedicated Integrated Project Team (IPT) was formed by SC in June 2022, combining contracting, legal, program/technical, and commercialization expertise from SC, GC, the Office of the Under Secretary for Science and Innovation (S4), ARPA-E, Economic Impact and Diversity, and EERE. The IPT worked through the summer of 2022 and charted a solution that fulfilled the

[8] 42 U.S.C. 18645(i)(1).
[9] 42 U.S.C. 7256(g). DOE implements its OT authority through Technology Investment Agreements (10 C.F.R. 603).
[10] https://www.fusionindustryassociation.org/fusion-industry-association-announces-launch.

program's authorization language and all pertinent statutes. DOE SC released the funding opportunity announcement (FOA) in September 2022.[11]

The Milestone Program aims in part to implement the key recommendation of the National Academies report *Bringing Fusion to the U.S. Grid* of realizing an FPP via PPPs, and was informed by (1) the NASA Commercial Orbital Transportation Services (COTS) program that led to the commercial space launch industry[12] and many conversations between Milestone IPT members and COTS program leaders/staff; (2) responses to a Request-for-Information in 2020 on *Cost-Sharing Partnerships with the Private Sector in Fusion Energy*;[13] and (3) a DOE *Workshop on Fusion Energy Development via Public-Private Partnership* in June 2022.[14] Milestone IPT members also received useful input from DOE Nuclear Energy staff regarding their experiences with formulating and implementing the Advanced Reactor Demonstration Program.

On May 31, 2023, after a comprehensive merit-review process including evaluation by external subject-matter experts of scientific/technical, business/financial, commercialization, and community-benefits aspects of the applications, DOE publicly announced eight selectees for the Milestone Program.[15] The virtual event featured remarks by DOE and OSTP leadership and a panel discussion of program selectees, partners, and stakeholders moderated by Office of Science Director Asmeret Asefaw Berhe. DOE is now in the process of post-selection negotiations of milestones and terms and conditions, and intends to finalize agreements with the selectees in the near future.

DOE selected a larger number of companies with smaller amounts of Federal funding allocated to each selectee. DOE's rationale considered that (1) the technical, business, and commercialization risks are all relatively high, and thus it is impossible to predict at this stage which team(s) may ultimately succeed or fail, and for what reasons; (2) the program aims to amplify private funding, and thus selecting more credible teams can grow the total amount of funding for fusion development; and (3) related to (1) above, it is anticipated that some teams may drop out partway through this 5-year program due to inability to meet milestones, and having more teams at the outset improves the chances of at least 1–2 teams fulfilling the 5-year objectives of the program.

The eight selectees represent a diversified portfolio of companies, fusion concepts/approaches (tokamak, stellarator, laser inertial fusion, z-pinch, and mirror), and commercialization pathways (e.g., grid electricity or industrial heat). They span a range of scientific maturity in the fusion performance of their concept, as well as a range of likely engineering/technological and eventual commercialization/market challenges. All the selectees indicated in their applications that they would collaborate with multiple DOE National Laboratories.

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[11] https://www.energy.gov/science/articles/department-energy-announces-50-million-milestone-based-fusion-development-program.
[12] https://www.nasa.gov/commercial-orbital-transportation-services-cots.
[13] https://www.federalregister.gov/documents/2020/04/20/2020-08312/cost-sharing-partnerships-with-the-private-sector-in-fusion-energy.
[14] https://science.osti.gov/fes/Community-Resources/Workshop-Reports/Fusion-Energy-Development-via-Public-Private-Partnerships.
[15] https://www.energy.gov/articles/doe-announces-46-million-commercial-fusion-energy-development.

The Milestone Program is also intended to fulfill the objectives in the authorization language for "Fusion Reactor System Design" in the CHIPS and Science Act of 2022.[16]

DOE Fusion Crosscut Team and New Initiatives

At the White House Fusion Summit in March 2022, Secretary of Energy Jennifer Granholm announced that the DOE would pursue an "all-of-DOE" approach to accelerating fusion energy R&D. Over the next few months, as requested by Under Secretary for Science and Innovation Geraldine Richmond and as the new DOE Lead Fusion Coordinator, I formed a DOE *Fusion Crosscut Team* with the primary objective of coordinating and leveraging equities across DOE program offices to accelerate R&D toward the realization of an operating FPP on a decadal timescale, by partnering closely with privately funded fusion companies and coordinating efforts across key DOE program offices. The crosscut team is also coordinating a broad set of new activities to support eventual fusion commercialization. Presently, the crosscut team includes representation from ten DOE program offices: SC (Fusion Energy Sciences, Basic Energy Sciences, Advanced Scientific Computing Research, and Isotope R&D and Production), ARPA-E, NNSA (Office of Experimental Sciences and Defense Nuclear Nonproliferation), Environmental Management, Economic Impact and Diversity, and Nuclear Energy. Next is a summary of *new* initiatives over the past year in support of the crosscut.

Office of Science

- Fusion Energy Sciences (FES): Launch of the *Milestone-Based Fusion Development Program* (see above); participation in community workshops on updated requirements for a Fusion Prototypic Neutron Source[17] (FPNS) and Fusion Fuel Cycle and Blankets[18] to inform future programs; released an RFI[19] on technology and partnership options for an FPNS, which is the top facility priority in the Fusion Energy Sciences Advisory Committee report (see footnote 4); collaborated with Isotope R&D and Production (see below) on an assessment of fusion fuel supplies; released a $45 million FOA on *Inertial Fusion Energy Science and Technology Accelerated Research*[20] (IFE-STAR)
- Isotope R&D and Production (IP): led an assessment of fusion fuel/isotope (deuterium, tritium, lithium-6, helium-3, boron-11) needs for fusion demonstration and deployment[21]

ARPA-E

- Program development and March 2023 workshop[22] on *Enabling Technologies for Improving Fusion Power Plant Performance and Availability*

[16] Section 10105(j).
[17] Workshop summary: https://www.epri.com/research/products/000000003002023917.
[18] Workshop information: https://www.epri.com/events/A9EE23A5-9B05-4B96-B36B-AEFDB8D08A09.
[19] https://www.federalregister.gov/documents/2023/03/27/2023-06176/fusion-prototypic-neutron-source-fpns.
[20] https://science.osti.gov/-/media/grants/pdf/foas/2023/SC_FOA_0003044.pdf.
[21] K. Myhre and G. Shaw, "Initial Assessment of Fusion Energy Isotope Needs," DOE SC/IP report (2023), available for government distribution only upon request.
[22] https://arpa-e.energy.gov/events/enabling-technologies-improving-fusion-power-plant-performance-availability-workshop.

- Release of a $10 million FOA on May 30, 2023, on an Exploratory Topic, *Novel Superconducting Technologies for Conductors*, to develop novel manufacturing technologies for high-temperature-superconducting tape including for fusion applications.

NNSA

- Office of Experimental Sciences (NA-113): convened a study group of NNSA-supported researchers to assess the use of unclassified inertial confinement fusion (ICF) computer codes by the private sector to support the development of their fusion concepts.
- Defense Nuclear Nonproliferation (NA-20): sponsored a *Fusion Energy and Nonproliferation* workshop[23] (Jan. 25–26, 2023) at Princeton University, with the objective of establishing a community of interest to support the path to fusion commercialization for fusion energy that simultaneously addresses potential proliferation concerns.

Office of Economic Impact and Diversity

- Authored the Community Benefits Plan portion of the Milestone Program FOA and assisted with merit review and finalist interviews of Milestone Program applicants.

The Fiscal Year 2024 President's Budget Request in Direct Support of the BDV

The Fiscal Year (FY) 2024 President's Budget Request includes a record $1.01 billion for SC FES,[24] representing a 32% increase over the FY 2023 enacted budget of $763 million. The FY 2024 budget request shows a commitment to advancing the BDV through the following new investments: (1) $130 million (compared to $25 million in FY 2023) to grow the *Milestone-Based Fusion Development Program*, (2) $120 million (compared to $0 in FY 2023) for new fusion R&D centers to support FPP efforts in the areas of materials, fuel cycle, blanket, enabling technologies, and advanced simulations; (3) $14.7 million (compared to $2 million in FY 2023) for studies on priority test facilities including a neutron source for materials development, and (4) $15 million (compared to $10 million in FY 2023) to grow the program in inertial fusion energy.

Interagency Engagements

As part of the BDV, it is recognized that timely commercialization of fusion energy will not only require accelerated R&D to resolve the remaining S&T challenges but also dedicated whole-of-government efforts on a number of activities to "parallel process" and prepare the path to fusion commercialization.[25] These include but are not limited to assessing the international competitive landscape, market development, developing appropriate regulatory frameworks, building out supply chains, inclusive workforce development, ensuring energy and environmental justice, ensuring viable waste-disposition and recycling pathways, and public engagement. Many of these issues require international coordination as well.

[23] https://sites.google.com/pppl.gov/nonproliferationworkshop/home; workshop report available for download.
[24] https://www.energy.gov/sites/default/files/2023-03/FY2024-PresidentsRequest-FES-Final-1.pdf.
[25] https://www.whitehouse.gov/ostp/news-updates/2022/06/03/parallel-processing-the-path-to-commercialization-of-fusion-energy.

To support these efforts, DOE has engaged with the interagency under the leadership of the White House, which has been leading multiple interagency working groups in support of parallel processing the path to fusion commercialization. One of these working groups is the *Net-Zero Game Changers* (NZGC) *Initiative*,[26] in which "Fusion Energy at Scale" is one of the Administration's five priorities.

For the NZGC Initiative, DOE is leading a planning activity to summarize fusion-energy R&D priorities and system-level commercialization needs and to develop an action plan, with multi-agency contributions. The output is aligned with the BDV and many of the fusion-crosscut initiatives outlined above. The NZGC Initiative recognizes that fusion energy is at the nexus of climate, energy, and national security, and that fusion could be a new paradigm to help the world reach net-zero while providing energy security to nations, minimizing energy-driven geopolitical conflict, fostering energy and environmental justice, and strengthening U.S. technological leadership. As an example of the latter, DoD and NASA expressed interest, as part of the NZGC fusion discussions, in compact/mobile embodiments of fusion energy systems, and this may be an area of future tri-agency collaborations.

Another interagency working group led by the White House aims to develop a whole-of-government roadmap and provide a mechanism for formal interagency collaborations for compressing the time to fusion commercialization. Activities initiated under this working group include: (1) a targeted new international collaboration/engagement strategy to support the BDV; (2) an OSTP assessment of the treatment of fusion-relevant technologies under present export-control regulations with the objective of determining whether additional options are required to enable global deployment of diverse fusion technologies; (3) an assessment of the challenges/gaps of securing a resilient supply chain including critical materials and components;[27] and (4) multi-agency collaboration/outreach with fusion industry stakeholders on protecting their technology from theft, misuse, abuse, or exploitation.

International Engagements

Consistent with the international fusion strategy being co-developed by State and DOE, DOE has been conducting a series of exploratory discussions with like-minded international counterparts on potential new targeted areas of collaboration, focusing on opportunities to benefit BDV strategic priorities: (1) advancing fusion science and enabling technologies of relevance to commercially relevant FPPs in the next decade; (2) access to or shared development of key infrastructure such as test facilities; (3) grow the future fusion marketplace including supply chains and manufacturing capabilities; (4) coordinating with international partners on regulatory-framework harmonization including safety, nonproliferation, export control; (5) diverse workforce development; and (6) public engagement and education. More broadly, our international engagements aim to strengthen energy security and technological leadership of ourselves and our allies. The near-term intent at DOE is to convene bi-lateral and possibly multi-

[26] https://www.whitehouse.gov/briefing-room/statements-releases/2022/11/04/fact-sheet-biden-harris-administration-makes-historic-investment-in-americas-national-labs-announces-net-zero-game-changers-initiative.
[27] The Fusion Industry Association recently released its own supply-chain report: https://www.fusionindustryassociation.org/fusion-industry-association-releases-supply-chain-report.

lateral working-level discussions to identify concrete collaborative proposals to bring to the political leaderships of each country, for their consideration, over the next year.

Conclusion

Chairman Williams, Ranking Member Bowman, and Members of the Subcommittee and Committee, thank you again for the opportunity to testify on DOE's efforts over the past year to advance a *Bold Decadal Vision for Commercial Fusion Energy.* As outlined in my testimony, DOE has been very active in launching new initiatives, setting a new direction for the U.S. fusion energy R&D strategy, and engaging with both the interagency and like-minded international partners in support of the BDV. However, a lot more needs to be done to fulfill the objectives of the BDV and beyond, and the DOE looks forward to continued collaborations with you on enabling the timely delivery of commercial fusion energy.