

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

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Fostering a New Era of Fusion Energy Research and Technology Development
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Chairman Bowman, Ranking Member Weber, and other distinguished members of the Subcommittee, my name is Bob Mumgaard and I am appearing before the Subcommittee today as the CEO of Commonwealth Fusion Systems and as a Board Member of the Fusion Industry Association. I would like to thank the Subcommittee for this opportunity to provide an update on the status and prospects of commercial fusion energy.

I also want to thank the Committee for all its work and support on commercial fusion through its authorizing legislation in the *Energy Act of 2020*, the *Department of Energy Science for the Future Act*, and the *Build Back Better Act* bill currently moving through the Congress which would provide important funding to leverage the unique strengths of both the public and private sectors as we work to bring fusion energy to the grid.

Commercial fusion energy will be a game changer in the clean energy transition. It will provide zero-carbon, safe, and limitless power for the world. Most importantly, it is a solution that can be deployed at the scale of the problem that is climate change and at the speed required for the energy transition. The fusion community has been studying fusion science for decades, understanding its potential as an energy source. But we are at a unique moment in time with the advent of new commercial technologies and private investment of \$2.4 billion flowing into a growing number of commercial fusion companies, all while countries around the world enact bold new programs. I am confident that with the right programs the feasibility of commercial fusion power plants will be demonstrated this decade, followed by commercial fusion power plants on the grid starting in the early 2030s

We are about to enter the era of commercial fusion energy, but there is a global race, and the U.S. is falling behind as other countries are working to progress pathways for a commercial fusion energy sector and outspend the U.S. on programs such as public-private partnerships, enabling technologies, appropriate regulation, and aggressive plans to be first in this energy source. Despite being a historical leader in fusion, the last 10 years have seen the U.S. cede leadership in the publicly funded program to other nations who were willing to enact bold new programs while the U.S. public program has largely stagnated. To regain a leadership position, the U.S. must increase resources and investments into fusion energy. This is done by leveraging the government investment in fusion research at National Laboratories and universities, while also developing new programs that align with developments happening in the private sector. The U.S. Department of Energy Fusion Energy Sciences program, the primary funder of fusion

research, needs to act quickly on plans already developed to match the moment or else the U.S. will irrecoverably cede a fusion industry to other nations. Failing to act means that instead of selling commercial fusion power plants as a large globally important industry, the United States will be buying them from overseas.

We need only to look at the impressive track record of establishing new industry sectors such as space, biotech, and others to know that the U.S. can lead in bringing fusion energy to the world by combining the American entrepreneurial spirit, robust capital markets and full life cycle R&D investment of the private sector with the right support from the U.S. government.

Fusion's role in the global energy transition

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.

Growth of the renewables sector in the past decade, specifically wind and solar has been strong enough that in 2019 more renewable energy was consumed than coal electricity in the U.S.¹ But strong continued growth of intermittent renewables 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 We need a new dispatchable, zero-carbon electricity source that is scalable. To achieve zero-emissions electricity production by 2050 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 fundamentally new energy generation technology.

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

Key attributes of commercial fusion energy:

- *Zero emissions:* no carbon dioxide, other greenhouse gases or pollutant emissions
- *Dispatchable:* can operate constantly and integrate with intermittent sources
- *Scalable:* freely available and inexhaustible fuel supply
- *Safety:* inherently safe with no meltdown or long-lived nuclear waste
- *Siting flexibility:* relatively small footprint and can be built anywhere
- *Robust Domestic Supply Chain:* built of mostly steel and concrete; manufacturable in the U.S. and would not require reimagining supply chains
- *Markets:* in addition to 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

¹ <https://www.eia.gov/todayinenergy/detail.php?id=43895>

² <https://www.iea.org/reports/net-zero-by-2050>

³ <https://link.springer.com/article/10.1007/s10894-021-00306-4>

- *Clean energy jobs*: replace existing energy production facilities and create clean energy, sustainable jobs for the future

The U.S. has an opportunity unlike any before to take a leadership role in fusion research and development by partnering with the private sector on the construction of the first major viable fusion energy demonstration and pilot plant facilities. To do so requires implementing a comprehensive plan.

There are numerous reports and experts closely examining how to accelerate putting fusion power on the grid. This includes the 2020 report “*Powering the Future: Fusion & Plasmas*”⁴ from the Fusion Energy Sciences Advisory Committee that advised focusing on establishing the scientific and technical basis for a fusion pilot plant and the February 2021 National Academies’ report “*Bringing Fusion to the U.S. Grid*”⁵ which presented a strategic plan for a fusion pilot plant with the goal of producing electricity in the 2035-2040 timeframe. On October 19, 2021, the President’s Council of Advisors on Science and Technology (PCAST) hosted a public discussion on “*The Potential for Integrating Fusion into the U.S. Energy Grid*”⁶. The U.S. Intelligence Community recognized the potential of the fusion private sector to address climate change in the *National Intelligence Estimate*.⁷ The estimate suggests that a breakthrough in fusion via a startup company would alter the Intelligence Community’s assessment of the likelihood of the world meeting the 1.5 degrees C goal. But capturing a first-mover advantage will require the U.S. Congress, the executive branch, the U.S. Nuclear Regulatory Commission (NRC), and state regulators to take concrete steps to enable a thriving domestic fusion energy industry.

If the U.S. does not act now, there is a risk that private companies will invest and construct their fusion power plants elsewhere in the world.

A growing fusion industry

U.S. government support for fusion research extends back to 1951 and has cumulatively totaled \$32.5 billion⁸. 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. It was not always clear when this private industry would appear, but it is now evident that the private industry ramp is underway.

According to a recent survey conducted by the Fusion Industry Association (FIA) and the UK Atomic Energy Agency (UKAEA)⁹, there are now at least 35 global fusion companies and of those surveyed 52% were founded in the last 5 years alone. With increased capital now flowing into the private sector, we are seeing a shift that will lead to an acceleration of development in

⁴ https://science.osti.gov/-/media/fes/fesac/pdf/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf

⁵ <https://www.nap.edu/catalog/25991/bringing-fusion-to-the-us-grid>

⁶ <https://www.whitehouse.gov/pcast/meetings/>

⁷ <https://www.dni.gov/index.php/newsroom/reports-publications/reports-publications-2021/item/2253-national-intelligence-estimate-on-climate-change>

⁸ https://www.everycrsreport.com/files/20000131_RL30417_3fe121b74567d1e4bdb7c55100dd800ef5c67640.pdf

⁹ <https://www.fusionindustryassociation.org/about-fusion-industry>

fusion energy technologies. By leveraging prior publicly funded work, private investments in fusion will enable more research and innovation at a much faster pace.

The report also indicated that of the 23 companies surveyed, of which 57% were U.S. companies, nearly \$1.9 billion of private capital has been raised for commercial fusion energy, and this is now \$2.4 billion with another funding announcement since the report was released a few weeks ago¹⁰. 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 (83%) 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.

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 are convinced that net gain (more energy output than input) from fusion is within reach. Private companies are exploring numerous approaches to achieving net energy fusion, including:

- *Magnetic Confinement Fusion*: Confining hot plasma fuel within a chamber with magnetism;
- *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 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. Public programs were previously responsible for every aspect of fusion device design, engineering, construction and operations. However, private industry progress frees them to focus on their core capabilities. 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. More importantly, the private sector will be engaging with end customers, bringing market relevance and the ability to speed up development of customer-driven solutions for fusion power systems.

This shift in roles in fusion energy development also brings new relevance to public-private partnership (PPP) initiatives. In 2019, the Department of Energy (DOE) launched the INFUSE program to connect private fusion enterprises with National Labs, supported by the Office of Science's Fusion Energy Sciences (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. The Advanced Research Projects Agency — Energy (ARPA-E) within the DOE has funded over \$80 million in fusion research at both public and private organizations

¹⁰ <https://www.helionenergy.com/articles/helion-raises-500m/>

since 2015 and is currently executing another round of funding expected to support \$29 million in programs through 2025.

We appreciate the U.S. government's support of the private fusion industry to date. However, current federal investment amounts are simply not sufficient for the U.S. to regain its global leadership position in fusion energy, nor to attract or meaningfully support commercial fusion companies capable of building a domestic fusion energy sector. The described ARPA-E programs are one-time, and the only annually recurring fusion public-private partnership program, INFUSE, is currently supported at just \$4 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.

New private public partnerships to advance commercial fusion energy

A promising development for the fusion industry has been the milestone-based approach for a fusion cost-share program, as established by Congress through the Energy Act of 2020. Under this program industry would accept the bulk of the risk by funding its activities until milestone achievement, at which point the government would reimburse industry for its share of the costs (no more than 50%). This is a highly leveraged option for government investment in fusion with the private sector carrying the risk of schedule and cost overruns.

The cost-share program is modeled after the National Aeronautics and Space Administration (NASA) successful Commercial Orbital Transportation System (COTS) program, a program this Committee 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.

In May 2020, DOE issued a Request for Information to gather input on the fusion cost-share program about the topical areas, program objectives, eligibility requirements, program organization and structure, public and private roles and responsibilities, funding modalities, and assessment criteria of a cost share public-private partnership program. While the program has been authorized, no funds have been appropriated. Maintaining the funding for the cost-share program included in the text for the Build Back Better Act currently progressing through Congress will be critical for DOE to move forward on implementing the program. If the fusion cost-share program is successful it would 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.

We are at an inflection point for fusion energy. The DOE's Fusion Energy Science program needs to act quickly on already developed plans and additions to existing and new programs that support private industry's accelerated timelines are critical. Additional opportunities could be identified through ongoing dialogue between the public and private sector, so we encourage the U.S. government to continue to explore how they can support the private sector and establish U.S. leadership in putting fusion energy on the grid in a time frame that matters for climate change.

Shift in fusion program emphasis

At the behest of Congress and DOE, the fusion community has laid out via a multi-year planning exercise the technology program that is required for the successful development of practical fusion power. This has been adopted by the FESAC panel as the recommendation to the FES program. This closely resembles the recommendations in two NAS panels. The key elements of this plan are a switch in mission from understanding plasmas to developing a fusion power industry, a switch in focus of the publicly funded program from plasma confinement physics to fusion technology development, and the construction of new facilities and test stands to solve the challenges of harnessing fusion power. This includes the construction of the fusion prototypical neutron source test stand, development of heat exhaust solutions, test stands for the tritium fuel cycle, and an increased emphasis on the material science for next generation fusion materials. Many of these programs are authorized in the Energy Act of 2020. If rapidly started and accelerated, this set of new programs would benefit the entire developing fusion industry.

Despite the comprehensiveness of this plan, direction from Congress, and authorization of programs, there are no current new programs in this space nor in their budget proposals. The time is now to rectify this. Such a change in direction would be a large but necessary change, particularly on aspects of interfacing with the private sector.

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 a half billion dollars to fusion PPPs.¹¹ China is spending hundreds of millions per year¹² on their private fusion industry. This compares to \$6 million for the DOE's INFUSE public-private partnership program proposed in the FY2022 budget.

The United Kingdom and China are targeting having a fusion pilot plant operational by the late 2030s and have kicked off a search for the site of that facility, while at present the U.S. programs are considering longer timelines culminating in a pilot plant in the 2040s. 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. The U.S. could accomplish this by aligning with and supporting the private fusion industry's goals to have a fusion pilot plant operational by the early 2030s.

In addition, 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 has indicated that future fusion energy facilities will be regulated in a similar manner to the Joint European Torus facility, rather than by agencies which oversee fission systems. From a risk perspective, fusion energy facilities are

¹¹ <https://www.neimagazine.com/features/featurefusion-projects-make-progress-in-2020-8492724/>

¹² <https://www.fusionindustryassociation.org/post/chinese-fusion-energy-programs-are-a-growing-competitor-in-the-global-race-to-fusion-power>

much more like 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 technologies. These forward-looking regulatory strategies make the United Kingdom an attractive place for nascent fusion companies.

Furthermore, 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. This technology focus will raise the readiness of all of the fusion entities working, both public and private entities. 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.

Commonwealth Fusion Systems strategy for a fast path to fusion energy

Commonwealth Fusion Systems (CFS) is among the many start-ups we have seen emerge and joined 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 DOE's cuts to funding for 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 described above. If we were able to build high-temperature superconducting (HTS) magnets, we knew that we could build smaller, faster, and less expensive fusion devices that would achieve net energy. 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 the backing of private capital and attracting top talent, the company and its collaborators at MIT delivered on its commitment to build and successfully test a first-of-a-kind high-field large-bore HTS magnet in September 2021. It is the largest HTS magnet in the world with a magnetic field of 20 tesla. The HTS magnet will allow for smaller devices than previous magnet technology. It will allow for SPARC, a tokamak device that will be 1/40th the size of the International Thermonuclear Experimental Reactor (ITER). SPARC is an important step to accelerate the development of commercial fusion energy. The compact configuration enables the team to rapidly incorporate innovations and provide time sensitive answers to questions surrounding both fusion science and technology.

CFS is currently building SPARC in Devens, Massachusetts (*Figure 1*), a device that will achieve commercially relevant net energy from fusion for the first time in history. The plasma physics for SPARC was validated in a series of seven peer-reviewed papers published in the *Journal of Plasma Physics*¹³. The papers show, point-by-point, using the absolute best simulations, physics, and tools, that if SPARC is built according to its design, it will work and

¹³ <https://www.cambridge.org/core/journals/journal-of-plasma-physics/collections/status-of-the-sparc-physics-basis>

achieve a net energy gain of $Q > 10^{14}$. Gains of that level would serve as the basis for the design of an economical fusion power plant.

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. This puts a burning plasma -- a long sought scientific goal-- in a much-accelerated time



Figure 1: Commonwealth Fusion Systems construction site in Devens, MA (11/09/21)

frame. SPARC is expected to become operational in 2025 and reach net energy fusion in the following year with burning plasmas soon after that. This timeline is nearly a decade faster to the scientific goals as ITER at less than 1/10th of the cost. This is the power of innovation and commercialization. This is a domestic facility, built by a U.S. entity, backed by private capital, creating a leadership opportunity for U.S. science, engineering, and industry creation.

This will require a meaningful and systematic collaboration between CFS and DOE that does not currently exist. This type of facility requires large scale programs, such as a milestone-based cost share program with U.S. publicly funded scientists obtaining burning plasma data earlier.

Following the SPARC demonstration in 2025, CFS plans to construct the world's first fusion power plant, ARC, and put electricity on the grid in the early 2030s. This 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.

At CFS, we are building a company with the know-how and capabilities to achieve these timelines. We also recognize the value in continued collaboration with 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.

¹⁴ $Q = (\text{fusion power out}) / (\text{Heating power in})$; net energy

Summary of recommendations to secure U.S. leadership in fusion energy

Expanded support for fusion energy programs is necessary to keep the center of the private fusion industry based in the U.S.

- The private sector is driving towards commercial fusion in the 2030s. Now is the time to make the necessary changes to align the public resources and funding to drive innovation and leadership in fusion energy. If the U.S. does not scale the public sector efforts and align them with the private sector, it may fall behind and miss the opportunity to be a leader in a large-scale energy transition to fusion power.
- Congress and DOE should quickly move to fully fund and implement the milestone-based fusion cost-share development program and support the funding for it and other fusion programs within the Build Back Better Act currently moving through Congress to ensure the first fusion power plant is built in the U.S, and at the same time continue to identify additional opportunities to enable a thriving private sector capable of rapid deployment of fusion power systems.
- Specifically, Congress and DOE should quickly move to implement the recommendations made in the recent National Academies and FESAC long range planning reports. These recommendations require that DOE pivot and be aligned with energy development for a commercial fusion pilot plant. These plans should be implemented in due haste and accelerated as much as possible as the window where they could create U.S. leadership and help the emerging private industry is quickly closing.

Thank you for the opportunity to share my views on the future of the private fusion industry in the U.S. Both Commonwealth Fusion Systems and the other members of the Fusion Industry Association look forward to the opportunity to continue to work with the committee to bring fusion energy to the grid in a time frame that matters for climate change.