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Fusion Industry Association: Igniting the Future of Clean Energy

"Today, fusion is more than just a science experiment – commercial fusion is an engineering challenge similar to putting a man on the moon; it is an economic opportunity even greater than the California gold rush of 1849, and it is a legislative opportunity as consequential to our nation as was the Louisiana Purchase or the Marshall Plan. I would like to introduce the topic and focus of today's hearing in a very personal way. I want to tell you of my own journey from being a fusion-skeptic just a few months ago, to a fusion-optimist today..."

— US Congressman Brandon Williams; Energy Subcommittee June 16, 2023[1]

As Andrew Holland, the CEO of the Fusion Industry Association (FIA), listened to Congressman Williams' opening remarks, he was proud to hear such importance and optimism being placed on the prospect of fusion energy. Shortly he would be providing formal testimony to Congress about the state of the industry. This hearing, titled "From Theory to Reality: The Limitless Potential of Fusion Energy," was a new signal to Holland that real progress was happening.

Following a series of technical breakthroughs and an unprecedented wave of private capital pouring into startups, commercial fusion energy was on the cusp of transitioning from academic science project to a geopolitically critical industry. The race was now on. Fusion companies were competing to be the first to test and scale their technologies, and governments were competing to host the initial commercial plants while debating alternative approaches to regulations. At the helm of the FIA, Holland worked to maintain a clear view of these different happenings. He found himself working with executives, engineers, advocates, and legislators with a mission of shepherding fusion into the next commercial (and competitive) phases of development. Many, including Congressman Williams, had become convinced of fusion energy's potential. But many still remained skeptical.

The FIA had grown to nearly forty member companies, the most advanced of which had raised billions of dollars in venture capital in recent years. In addition to these few highly funded startup companies, FIA's membership also included incumbents from the fission energy sector, as well as a host of smaller startups with a diverse set of expertise that might play a role in the commercialization of fusion. To-date, the eclectic mix of FIA members had worked well together with a common mission of moving fusion energy forward. However, Holland knew plenty of new challenges lay ahead, and it

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was unlikely that all of FIA's members would be able to overcome those challenges. "The nature of a new industry is that not everybody succeeds, whether it's because of technical or scientific reasons or because they just can't raise the money in the next year or two," noted Holland.

In addition to the evolving regulatory landscape, the capital markets, especially private funding for startups, were also undergoing massive changes. The positive trends for fusion funding were fueled by a historic surge of venture capital and private equity funding in the past several years. But with the central banks steadily increasing interest rates starting in January 2022, startups were facing a tighter funding environment with reduced company valuations and less patient investors. Holland wondered how the FIA could help members navigate this turbulence: "what happens when wells are dry for fusion companies?"

To date, Holland had primarily focused his efforts on US federal policies related to the federal funding of fusion science and the regulation of (eventual) commercial efforts. Now, his list of potential objectives was quickly expanding to include issues related to educating consumers, global supply chains, international regulations, geopolitics, and the broader financial landscape. Critics often claimed that "fusion energy is always thirty years away," but Holland was determined to ensure that, in less than thirty years, fusion energy was not just here, but a fundamental component of the global energy industry.

The First 80 Years of Fusion Energy

In the process of atomic fusion, matter is energized to the point that the nuclei of atoms collide at very high temperatures, creating a single atom and releasing a tremendous amount of energy. This reaction fuels the stars and involves plasma (the fourth form of matter) often exceeding 100 million degrees Celsius. Fusion is performed using light elements (often but not exclusively isotopes of hydrogen like deuterium and tritium), which merge to create heavier elements (like helium), along with fast neutrons and energy. For comparison, atomic fission involves the splitting of a single, heavy isotope (e.g., uranium-235) after collision with a neutron to release multiple lighter atoms (e.g., xenon-133 and cesium-133), neutrons, other particles (e.g., beta-particles, gamma-rays), and energy.

The amount of energy needed to cause a fusion reaction is vast, but scientists understand that the amount of potential energy that can be released is even larger. This is why fusion enthusiasts celebrated its "limitless" potential. The ratio of energy released from a fusion reaction relative to the energy put into it is referred to as the *energy gain factor* or Q for shorthand. For companies in the fusion race, developing commercial systems capable of achieving a factor of $Q > 1$ (i.e., net energy gain) is the goal. Scientific progress towards net energy gain occurred at a rapid clip in the 1970s and 1980s, then seemingly stalled for many years, before recently picking up again (see **Exhibit 1**). In 2022, the fusion device at the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory very temporarily achieved 3.15 mega-joules of energy output from 2.05 mega-joules of input (Q=1.54).[2]

However, sustaining an environment that facilitates fusion, one that mimics the interior of a star, was still a challenge. Thus, one of the main technical hurdles of commercial fusion systems was designing structures that could contain the fusion reaction for extended periods and prevent the external environment from disrupting the plasma. The best way to approach this problem was still far from clear. The most popular approach relied on magnets to confine the plasma, and recent advances in High Temperature Superconductor (HTS) magnets had led to some dramatic improvements. But many companies were making bets on alternative approaches such as laser inertial confinement, which was the method underlying NIF's device.

Since the early days of fusion energy science, most research was funded by public sources. One of the most important funders over this period, the US Department of Energy (DoE), invested in fusion primarily through two large strategic initiatives: NIF and the International Thermonuclear Experimental Reactor (ITER). NIF and ITER represented the largest-scale efforts based on the two leading fusion device designs, inertial confinement (NIF) and magnetic confinement (ITER). The DoE was effectively the sole funder of NIF since it was based at a US national laboratory. NIF was a 10-story building the size of three football fields, which housed 192 lasers that could focus more than 1 million joules of energy in billionth-of-a-second pulses onto a target about the size of a pencil eraser.[3] The NIF took over a decade to construct (nearly 5 years behind schedule), and its final costs of construction were approximately $3.5 billion (nearly 4 times initial projections) with annual operational costs on the scale of $300 million.[4] ITER represented a much more expansive, global effort with investment, technology, and management coming from 35 countries including the US, South Korea, Russia, Japan, India, the European Union, and China. ITER had faced considerable project challenges. Original plans were for production costs to be roughly $5.6 billion with the first plasma being heated in 2022, and full-scale fusion reactions occurring in 2023.[5] These initial estimates turned out to be wildly optimistic. By 2020, the project timeline appeared to be anywhere from five to ten years behind schedule and the budget forecast had swollen to about $20 billion.[6] Except for those directly engaged with ITER, sentiment surrounding the epic project had fallen to new lows.

Amidst these enormous public investments, there had been a recent surge in private sector investment. Some of the key companies were young, such as Commonwealth Fusion Systems (CFS), while others such as TAE Technologies and Helion Energy had been pursuing alternative energy sources for a decade or more.[7] In 2021, CFS alone raised a record-setting $1.8 billion in its Series B funding round.[8]

Birth of the FIA

A White Paper and a Spark at ARPA-E

In 2013, Andrew Holland was working at The American Security Project, a think tank in Washington, DC. Like many of his peers, Holland produced "white papers" on a range of topics relating to the energy sector in hopes of steering policymakers towards specific solutions. One particular white paper he co-authored was titled "Fusion Power: A Ten-Year Plan for American Energy Security."[9] The paper imagined a bold, decade-long plan to harness fusion power as one of the primary sources of base load power for the economy.[10]

Two years later, the Advanced Research Projects Agency at the DoE (ARPA-E) launched a program to start a new investigation into the possibility of commercial-scale fusion energy: the Accelerating Low-cost Plasma Heating and Assembly (ALPHA) program. Led by ARPA-E Program Director Patrick McGrath and his colleague Scott Hsu, the ALPHA program provided funding to nine fusion startups, universities, and national labs to explore alternative fusion pathways with a focus on reducing the size and costs of key technologies. Beyond the funding, the ALPHA program provided a basis for a new community of fusion enthusiasts to convene. It hosted a bi-annual conference to foster collaborations between scientists, government program managers, energy industry incumbents, entrepreneurs, and lobbyists.[11] McGrath saw his mission as ensuring that a diversity of approaches to fusion devices were pursued and de-risked by public funding to help spark private funding:

> At the end of the day, I have no dog in the fight. Whether we get one winner or five competitors, as long as fusion could be a part of the energy mix by midcentury, I will be extraordinarily happy. But I do think there is a risk in what is happening with ITER. They might have "down-selected" too soon. I think it is important to keep the path open for

> more development because there are still ideas out there that are not as mature. Some of them are way aggressive on the physics, like muon catalyzed fusion. It is one of these things that's way too risky for private dollars to go into. But more research should be going into that.

Holland always attended the ALPHA conferences and the ten-year plan in his white paper had garnered him a reputation of being ambitious on the technological front of fusion, but pragmatic on the regulatory front. He started to receive a recurring request from attendees: "Andrew, you're one of us, but you have a unique background. Could you assist in organizing and establishing a structured platform for us?" Together, McGrath, Holland, and others decided that the ALPHA program was a promising start, but its ability to influence large-scale public funding efforts and to advocate for particular regulatory pathways was limited.

Tyler Ellis, an early investor and advisor for Commonwealth Fusion Systems, remarked on this time: "We had identified some big priorities that weren't company specific but were for the betterment of the industry, so I talked to some of the other major companies that had raised substantial capital and we decided it would be worthwhile to each contribute some money for these joint efforts." They decided that the formation of an industry association was in order, and so the Fusion Industry Association (FIA), was born.

Formation, Governance, and Stakeholders

Established in 2018, the FIA began with fifteen founding member companies. The Chief Executive Officer of TAE Technologies remarked in a press release at the time, "With continual breakthroughs in recent years, the time is right for diverse approaches in this industry to come together, identify common priorities, and advance shared goals. Today makes an important step forward toward that vision."[12] FIA's three goals were as follows (quoted directly from the FIA's first press release)[13]:

> (1) <u>Partner with Governments for Applied Fusion Research</u>: The private sector should have access to the pathbreaking research that governments have pursued for decades. Likewise, the public sector should be able to benefit from exchanges with private scientists working on fusion.
>
> (2) <u>Drive Financial Support</u>: Sustained financing is needed to accelerate fusion from early-stage research to demonstration levels of energy production. Public-Private Partnerships that include government support can multiply private financial support by reducing risk.
>
> (3) <u>Ensure Regulatory Certainty</u>: Fusion research, development, and deployment should be subject to appropriate regulation when experiments are built and sited.

Initially, funding for the group was sought from philanthropies and other non-governmental organizations (NGOs) with stated interests in fusion energy. However, these efforts were mostly unsuccessful. Further, the venture capitalists who had invested in the member companies expressed reservations about the members allocating some of their funding to the FIA when technical roadblocks seemed much more pressing than anything related to the happenings in Washington, D.C. Recognizing the need for action, Holland convened a meeting with his board members in 2021 to rally support and determine a financing plan.

As the CEO, Holland reported to board members, the primary decision-makers, who often used voting processes to determine the organization's course of action. While FIA had various membership tiers, only companies who contributed a significant amount were granted a seat on the board. FIA's organizational structure also included committees (which included non-board members) focused on issues such as government relations, regulations, and international affairs. Much of the detailed policy work took place at the committee-level, while any controversial or high-level strategic questions normally went to Holland and the board for a vote.

FIA was registered as a non-profit with 501(c)6 status, which was a designation for organizations created for the improvement of business conditions, and the standard structure used by industry associations across most sectors. Membership dues accounted for essentially all of FIA's revenues, FIA spent roughly $650,000 in 2022, with roughly a 40/60 split between compensation and other expenses.[14]

FIA served as a focal point for private fusion companies, policymakers, and other players in the fusion energy ecosystem. Holland maintained an "influencer file" that ranked his stakeholders based on their attitudes towards fusion as well as the degree to which they could influence different aspects of the ecosystem (e.g., regulations, funding, etc.). While Congressional champions played an especially crucial role as they could facilitate valuable legislative support, there were few champions among the hundreds of congresspeople. Beyond legislators, there were numerous initiatives across the executive branch (e.g., the White House, the Department of State, the National Security Council) that had direct, short-run effects and/or indirect, long-run effects on the future of the fusion sector. While the association very rarely faced vocal opposition to fusion as a technology per se, the close connection to fission (which had suffered a range of political setbacks) and slow pace of technical progress had led to a significant amount of skepticism amongst many policymakers.

But Holland and the FIA were increasingly involved in many key discussions and had achieved some notable successes. The number of fusion companies and amount of private investment was growing, with these companies pursuing a variety of diverse technologies and designs, hiring a workforce with a mix of science, engineering, and managerial skills, and exploring a range of potential markets beyond the obvious delivery of electricity to the grid (see **Exhibit 2**).

Early Wins

Public Funding

In the early years of the FIA, Holland and the FIA membership had lobbied for the DoE to create a "milestone" program that would allocate approximately $500 million in a staged funding to companies that demonstrated clear progress towards an operational fusion pilot plant on the scale of five-to-ten years. This milestone program idea was inspired by NASA's Commercial Orbital Transportation Services (COTS) program, which played a key role in the successful relationship between NASA and SpaceX.[15] Under COTS, NASA selected multiple commercial companies to develop cargo transportation services for low-earth orbit, then awarded fixed-price milestone payments to those participants only after they achieved well-defined performance objectives. This model starkly contrasted the traditional "cost-plus" government procurement contracts in which the government selected a single supplier to deliver a finished product and paid all costs plus a set profit margin. The ex-post payment structure of COTS required participating companies to independently raise capital to fund their efforts. But in exchange for this additional risk, the COTS participants had much more management and design freedom as well as potentially larger upsides if they achieved the performance milestones efficiently.[16]

In late 2022, the DoE announced its own version of a milestone-based program, a "public-private partnerships program" that would award up to $50 million to firms as a part of a milestone-based program. And by mid-2023, the DoE announced $46 million would be allocated over the following 18 months to eight different companies.[17]

Clearly, this program was much smaller than FIA's ambitions and was almost trivial compared to the billions in venture capital that the largest fusion companies had recently raised. "Would we have wanted more?" remarked Holland, "Sure, but it's just the nature of an annual budgeting cycle. You can't take a new program up to hundreds of millions right from the start. But maybe you can take a program that's $25 million up to $150 million one year after and so on." While these initial funding amounts were small, Holland saw these steps as important for putting funding channels in place that could be useful in the future if politicians could be convinced to scale funding further. Holland's hypothesis was that "politics follows a winner," and he wanted to have mechanisms in place to capture the value of any political momentum FIA might eventually help generate.

Code of Federal Regulations: Reactor or Particle Accelerator

A key regulator of fusion energy was the Nuclear Regulatory Commission. The stated goal of the NRC was "to ensure the safe use of radioactive materials for beneficial civilian purposes while protecting people and the environment."[18] Regulators at the NRC were becoming increasingly aware of the progress towards commercial fusion. In 2018, Congress passed the Nuclear Energy Innovation and Modernization Act, which required the NRC to develop a regulatory pathway for "Advanced Nuclear Technologies," which, per Congress' definition, included fusion.[19] And so, debates began as to the specific legal framework that should be applied to regulate fusion energy.

As was often the case, the regulators looked to existing frameworks for the best analogue. One view was to use regulations that applied to nuclear fission reactors as specified in 10 Code of Federal Regulations (CFR) 50/52. The requirements of this particular framework were driven by the perceived risks of fission reactions, and often cited as one of the chief reasons why constructing new fission plants was so slow and costly.[20]

Another path would be to integrate fusion into the ongoing development of the proposed 10 CFR 53, which was a new regulatory pathway being designed in hopes of facilitating advances in small and modular nuclear fission reactors. Tyler Ellis, the investor and advisor, had cautioned against including fusion in this regulation path: "I was against that, because creating a new part of the CFR is at least a ten-year endeavor. So, you're not going to get the regulatory certainty any time soon. 10 CFR 53 was being developed for fission reactors, which have a higher risk profile than fusion power plants. Starting with more onerous regulations and then trying to scale back certain requirements that don't apply is likely to lead to an overly burdensome regulatory framework."

An alternative view was to use regulations that applied to particle accelerators, such as those contained within medical imaging machines as specified in 10 CFR 30. Particle accelerators and related devices had much lower level of risk. The costs and timelines these regulations would impose on the development of fusion devices was estimated to be an order of magnitude smaller as compared to the regulations governing fission reactors. The true risks of full-scale fusion devices were far from certain, so some legal experts steeped in the fission-oriented regulations were weary to support a push towards the different framework. Ultimately, by consensus, FIA's members decided to lobby in the direction of being included in 10 CFR 30.

In April of 2023, after years of effort, the FIA finally had a regulatory win to celebrate when the five commissioners of the NRC unanimously voted to move forward with 10 CFR 30 as the focal framework for fusion.[21] Holland and Ellis believed that early engagement with the NRC with a unified front from all the leading fusion companies was key to the NRC's relatively swift movement towards the alternative regulatory framework. Perhaps surprisingly, this move had been met with very little resistance or opposition. Ellis reflected on the arc of the regulatory process:

> Initially, a lot of the government stakeholders were saying things such as, "There's this interesting new fusion thing. How are we going to go about regulating it?" The industry showed we were all in on the particular position of 10 CFR 30 at the first public meeting, while the government was just starting to think about it. That early work by the industry changed the nature of the discussion away from fission-based regulations [e.g., Parts 50/52 or 53] being the inevitable outcome to the regulators saying, effectively, "Ok, let's have a discussion between 30 and 53 and let's see what makes the most sense." That early stake in the ground was pretty impactful.

Ellis and Holland both viewed the regulatory decision as a success, with helpful engagement from the NRC. However, many of the details still remained unsettled. Ellis noted that the next steps would be to engage in the "limited rulemaking" process to codify the details into regulation. Next, the NRC would issue a regulatory guide that would instruct fusion companies on how to apply for regulatory approval. FIA constituents knew that it was one thing for regulations to be agreed upon, but the specifics of how the regulations would be enacted were still far from being finalized.

Ongoing Debates

A Missing Counterpart?

Frequently, industry associations (across many sectors) have a counterpart organization that represents the interests of stakeholders on the consumer side of the market. For example, in the US pharmaceutical sector, the Pharmaceutical Research and Manufacturers of America (PhRMA) represents businesses' interests while a range of organizations represented patients' interests (e.g., the American Cancer Society, American Heart Association, Alzheimer's' Association, or the Juvenile Diabetes Research Foundation). Similarly, consumer-oriented groups could be found in the automotive sector (e.g., the Center for Auto Safety) and the telecommunications sector (e.g., the Electronic Frontier Foundation).

However, FIA had no clear counterpart of this sort. There were many advocacy groups with overlapping interests in combatting climate change, promoting the use of clean energy technologies, or the availability of low-cost, reliable energy for consumers. But the fusion community did have one other notable nonprofit group, the University Fusion Association (UFA), an older group representing university students and professional researchers studying plasma fusion science. The UFA primarily took on issues related to research funding and student educational opportunities in fusion science.[22] Still, no entity had the explicit goal of educating consumers or representing energy consumers' objectives as it pertains to fusion energy specifically. The degree to which such an organization would complement FIA's objectives and amplify its impact, as opposed to generating new points of contention, was unclear. Should the FIA expand its mission to take on this important area given the importance of consumer education and engagement?

Supply Chains, International Regulation, and Geopolitics

As of 2022, the vast majority of fusion companies (~80%) reported that they relied on specialty materials and complicated components to conduct their research and construct their devices. Furthermore, since there was still a wide range of device designs in play (e.g., magnetic confinement, inertial confinement, hybrids), it was difficult to characterize the industry-wide supply chain. As Holland noted, "the problem is the fusion supply chain is not one supply chain. There are six or seven different supply chains and it's really diverse among all of the companies. Some of the companies use tritium, some don't, some need lasers, some don't, all this sort of stuff." The demand for specialized suppliers and a more robust fusion industry supply chain was growing. While 20% of fusion firms reported relying entirely on commodity components and materials, roughly 60% reported some reliance on suppliers who specialized in fusion inputs, and another 20% reported a heavy reliance on fusion-specific suppliers (see **Exhibit 3** for more on companies' spending).[23]

Projections suggested that fusion companies' demand on their supply chains would increase by as much as fourteen-fold in the next decade and could feasibly grow to be hundreds of times larger if the industry achieved the scale it hoped was possible.[24] While FIA members expressed a willingness to make joint investments, standardize certain components, and share early risks with their supply chain to ensure scalability, the specifics of how exactly this all might be done remained unclear.

Other dimensions of complexity were the national security and geopolitical issues that were starting to emerge. The national defense community had a growing concern that individual countries might intentionally, or unintentionally, monopolize the production of critical fusion device components in the name of national competitiveness.

In these early stages, national governments appeared quite eager to implement business-friendly environments for fusion-related companies. "There is a certain competitiveness aspect to this," Holland noted, "the first countries that can set up an appropriate regulatory regime for fusion might be the ones that attract the early pilot plants."[25] But there was a concern that countries would race to attract fusion-focused investments and, in the process, enact regulations with unintended consequences. While these concerns had not yet manifested in a tangible way, Holland and the FIA began discussions about lobbying for government support to diversify the supplier base and to find ways of sharing risks inherent to the supply chain.

Uncertain Industrial Organization

Even if the FIA could perfectly predict and control the regulatory environment and consumer sentiment, many structural uncertainties about the fusion industry remained.

One primary source of uncertainty was the variety of competing reactor designs; should the industry start to converge on one design? If so, which one? While the donut-shaped magnetic confinement "tokamak" design was the most well-established, the FIA was comprised of a number of companies developing alternative designs. These alternatives included variants such as the stellarator design, laser-pulsed inertial confinement systems (like the one at Livermore's NIF), and hybrid designs that combine magnetic confinement of plasma with pulsed collisions to ignite the fusion reaction (see **Exhibit 4** for some images).

One possibility was that a dominant design would emerge and become the de-facto industry standard.[26] The history of new technologies was full of such convergence or "lock-in" as some called it: Direct Current (DC) versus Alternating Current (AC) electricity in the 1880s; electric-powered versus gasoline-powered automobiles at the turn of the 20th century; and Betamax versus VHS film devices in the 1970s. In the context of nuclear fission, pressurized light water reactors eventually won out over heavy water and gas graphite designs. This occurred in spite of the significant technological advantages of the latter designs, which likely due to entrenchment in the industry that was driven by the adoption of light water reactors by the US Navy.[27,28]

Holland thought it was too early to clearly forecast how the design competition would play out. He also noted the possibility that the emerging designs from smaller industry players might prove relevant for differentiated applications beyond servicing the grid. From marine shipping to space propulsion, smaller fusion energy systems had potentially massive commercial markets. Holland believed the FIA should support fusion companies representing all design types, and help the industry avoid any detrimental, premature lock-in effects.

Beyond the technical designs, another source of uncertainty was the ideal number and size of fusion companies. At this early stage of evolution, the fusion industry was composed of a few extraordinarily well-funded startups, a few large incumbents with legacy experience from nuclear fission, and numerous less funded and smaller startups. But it was still unclear what the optimal size and scope of the industry should be in order to maximize the chances of successfully commercializing fusion energy writ large. Would a few, large vertically integrated companies lead to a better outcome than an ecosystem of many smaller companies with specialized offerings? Holland noted the tradeoffs of consolidation. On one hand, it could lead to a productive concentration of human talent and capital. On the other hand, it could lead to suboptimal levels of diversity and fewer points of failure: "some companies are going to be winners, but we have to manage what that may look like, because if we get a fusion bubble that bursts, those sorts of narratives can be challenging."

Mega-funding

Initially, it was unclear whether private capital markets would provide the large investments necessary to design and build fusion devices. But then Commonwealth Fusion Systems closed a $1.8 billion Series B round, TAE Technologies raised $1.3 billion, and Helion Energy received close to $600 million. These unprecedented levels of investment were supplied by a mixture of venture capital firms, impact investing funds, philanthropic-motivated billionaires, large technology companies, energy and oil incumbents and sovereign wealth funds. By 2023, a total of $6.2 billion had poured into the fusion sector,[29] With about half of that funding went to companies pursuing designs other than magnetic confinement in tokamaks. Despite this surge of capital, Holland was hearing from his members that funding was still one of the chief points of concern in the near term (see **Exhibit 5**).

Meeting the milestones mapped out in FIA's own reports would require many more billions of dollars in the very near term. But while some companies targeted commercial launch dates as early as 2028, most timelines put the first plants online no sooner than the early 2030s, still at least ten years out (see **Exhibit 5**). Typically, venture capital funding cycles largely operated on timescales of five to ten years. While these initial investments signaled that some venture capitalists and strategic investors were willing to make large, long-term bets on fusion companies, the broader appetite of financiers was still unclear. And the willingness of traditional governmental funding programs to engage with these timescales and magnitudes was also unclear. Even some of the most long-term oriented public programs aimed at growing emerging technological industries (e.g., NASA's COTS program) involved timescales of roughly eight years.

There was a growing sense amongst FIA members that securing the funding necessary would require engagement with new groups of investors and novel financial vehicles. Further complicating this was the reality that traditional institutional investors and debt-based financiers rarely financed projects with first-of-a-kind technologies involved. This posed a series of financial puzzles. Could fusion companies go public via IPOs before building their first commercial facilities? Would governments step up their direct support of leading fusion power projects in a "moonshot"-style race for this strategic technology? What other capital could be lured into funding the scale up and commercial deployment of the most promising fusion designs?

Andrew Lo, a professor at MIT, had a bold proposition: a fusion mega-fund. The core idea was simple – diversify the risks inherent to a single fusion company by offering investment in a collection of diverse fusion companies. Therefore, this collection of companies would likely include the very largest fusion players, including every one of FIA's members. Analogous to index funds that track entire markets, the fusion mega-fund would be tied to the whole energy sector. In theory, this could shield investors from the idiosyncratic risks of a specific company or technology. And while it might, in turn, yield a lower expected rate of return than venture investment in a single successful company, the mega-fund would be able to offer a risk-return ratio in line with the appetite of many more investors and move the entire fusion industry forward.[30]

Beyond this pooling approach, Lo incorporated other unique structures into the mega-fund idea. One feature would be to offer multiple avenues for investing in the fund depending on the investors risk-appetite and source of capital. Another was the notion of "first-loss protection," where some early investors in high-risk aspects of the fund would only partly be exposed to losses, which would be muted by sharing these losses with the fusion companies themselves. The fund might also pay a regular dividend to attract investors who might otherwise be turned off by the long fusion development timelines. The fund would ideally attract both private and public capital, and possibly include the government announcing a new "fusion energy bond" tied to the fund. Lo was aware of how extreme the mega-fund idea might seem:

> We're not suggesting that you should deploy $20 billion today, but the point is that if you announce a mega-fund, if the government announced a fusion bond issue, what that does is it changes the way people think about the industry, about the opportunities, and it draws an incredible amount of talent.
>
> In finance, we generally don't think about scale. We think about portfolio theory. We all think in terms of percentages of holdings. But sometimes there is a critical point of total size that you need to achieve. It's kind of like building a parking lot versus building a bridge. If you build half a parking lot, you'll get half the revenues of the cars that you can park there. If you build half a bridge, you're not getting half the benefits of a bridge. In the case of fusion, we're talking about building multiple bridges.

Lo was also aware of the complexity of appropriately managing this sort of financial vehicle, "I want to be careful about getting too excited because of course that thinking is what gave us Fannie Mae and Freddie Mac. But the only way to increase the chances of success is to have a large number of participants that are constantly generating lots of independent ideas."

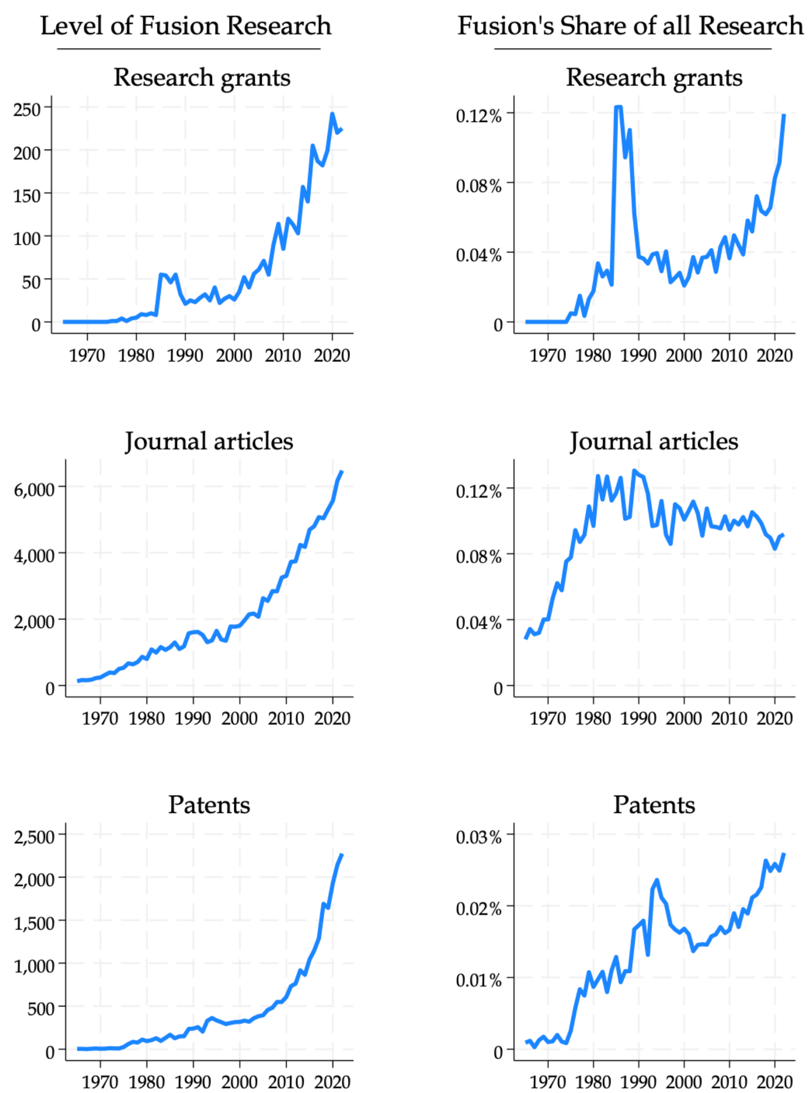
Prioritizing for the Future

Critics of fusion energy often lamented that it was "always thirty years away, every year." But these next thirty years were starting to seem different. Holland and FIA's early wins gave him optimism; but optimism was rarely in short supply amongst those inside the industry. It was newcomers to the world of fusion who needed to be compelled. Regulators, politicians, investors, energy sector incumbents, consumers—they all had much to learn about fusion, and their reactions and priorities were hard to predict.

Even amongst fusion industry insiders, there were still significant uncertainties. Which device designs would prove most effective when built at full scale? Would there be enough investors to provide the large scale and different types of funding necessary? How would fully operating commercial fusion plants compare to other "clean" electricity sources—from solar panels to new nuclear fission plans? What should the fusion energy supply chain look like? How would international fusion regulations evolve? Which nations would place large bets on fusion as an important source of long-term energy production?

Holland knew that he and the FIA could play many different roles in answering each of these questions, and more. But how should he prioritize his time and the limited resources of the FIA to achieve the reality of fusion power in the next decade?

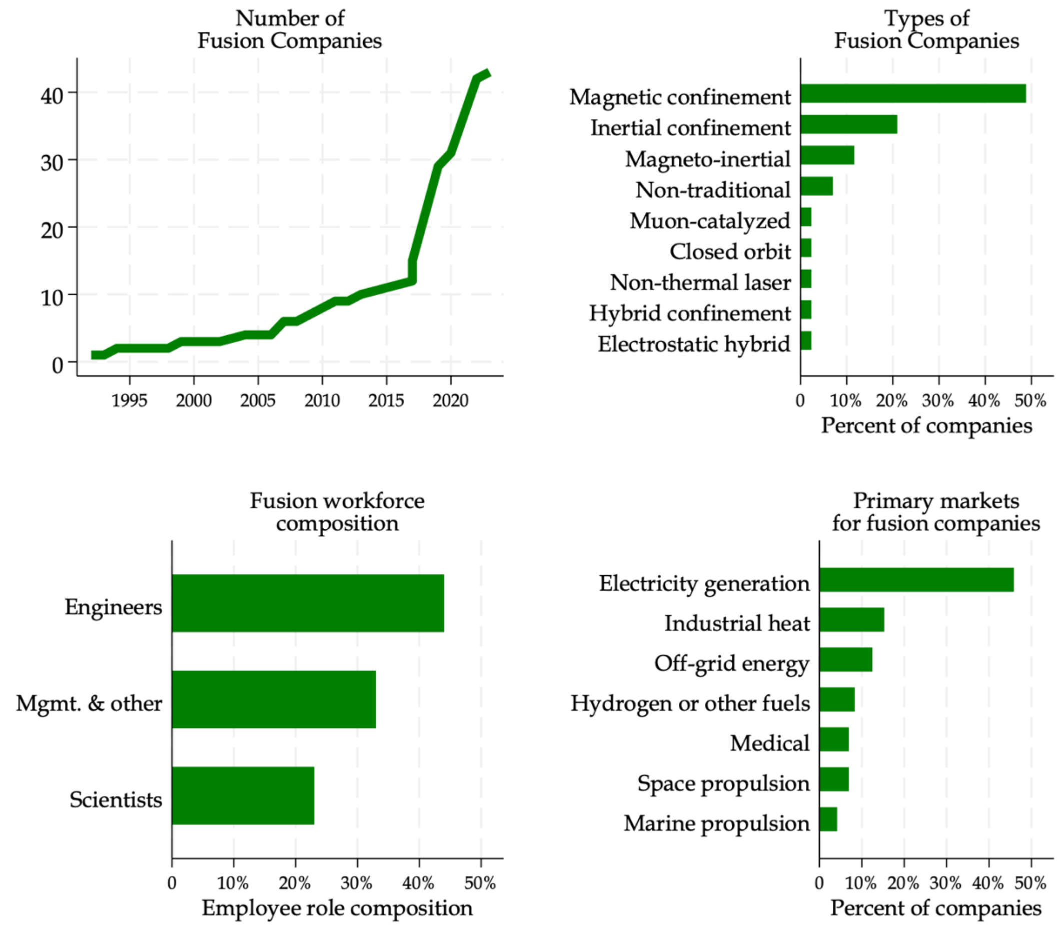
Exhibit 1 Global Trends in Fusion Science



Source: Authors' calculations. Data from: Digital Science (2018-) Dimensions [Software] available from https://app.dimensions.ai. Accessed on November 15, 2022, under license agreement.

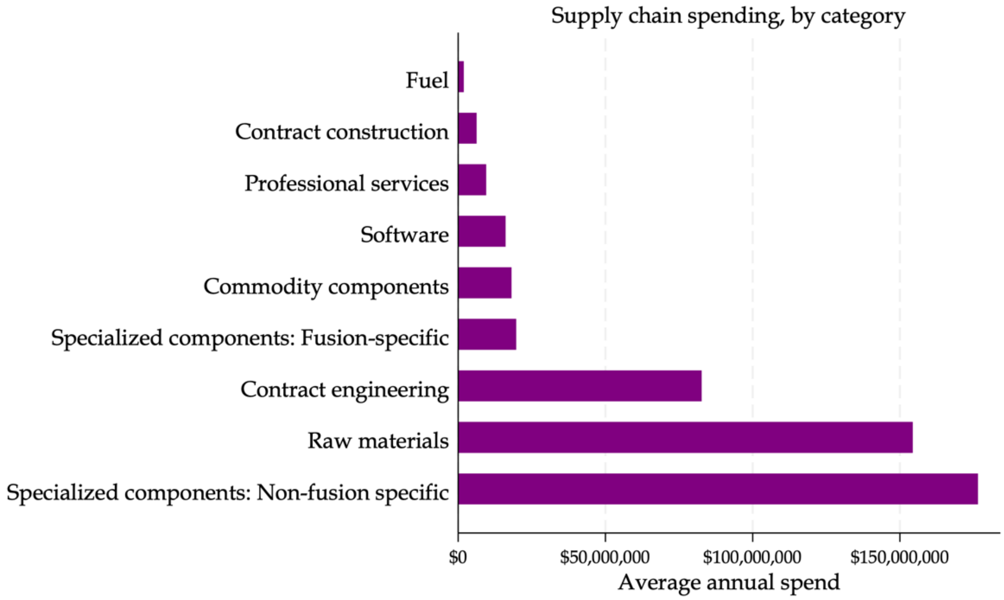
Note: Global trends in counts of public research grants, scientific articles, and patents related to fusion energy sourced from authors' data, using keywords "Nuclear fusion", "fusion energy", or "fusion power" and restricted to be in at least one of the following categories: Engineering; Physical Sciences; Chemical Sciences. Shares are the levels divided by the total number of documents in each category (e.g., the patent share plots the share of all patents that are related to fusion energy).

Exhibit 2 Fusion Industry Companies, 2023 Survey



Source: Company document: 2023 Fusion Industry Association report, "The Global Fusion Industry in 2023: Fusion Companies Survey by the Fusion Industry Association." Available at: https://www.fusionindustryassociation.org/fusion-industry-reports/.

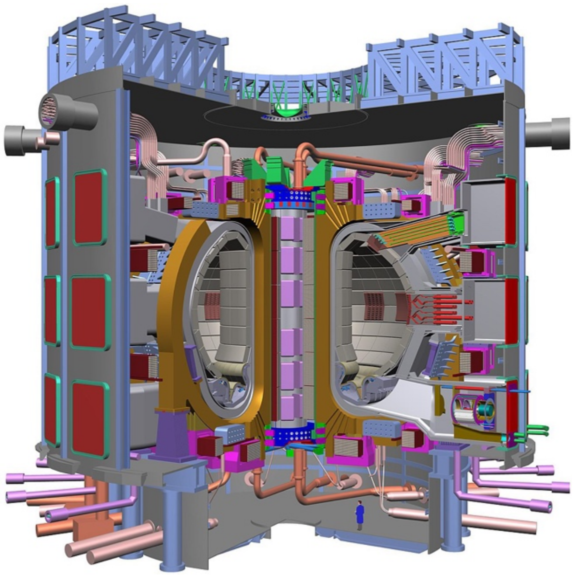
Exhibit 3 Fusion Companies and their Supply Chains



Source: Company document: "The Fusion Industry Supply Chain: Opportunities and Challenges." Available at: https://www.fusionindustryassociation.org/wp-content/uploads/2023/08/FIA-Supply-Chain-2023-FINAL.pdf.

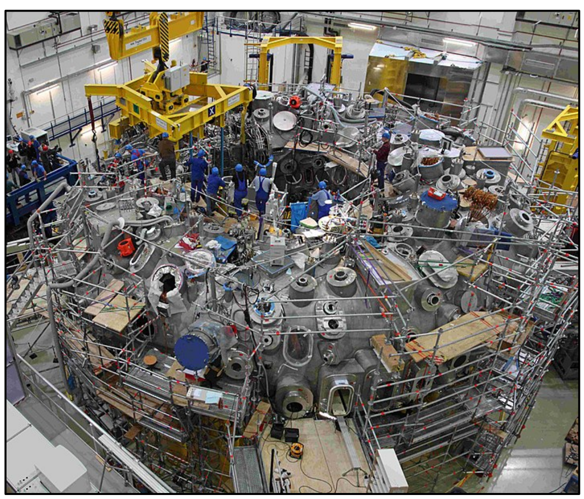
Exhibit 4 Alternative Fusion Device Designs

Diagram of ITER: Magnetic Confinement (Tokamak)



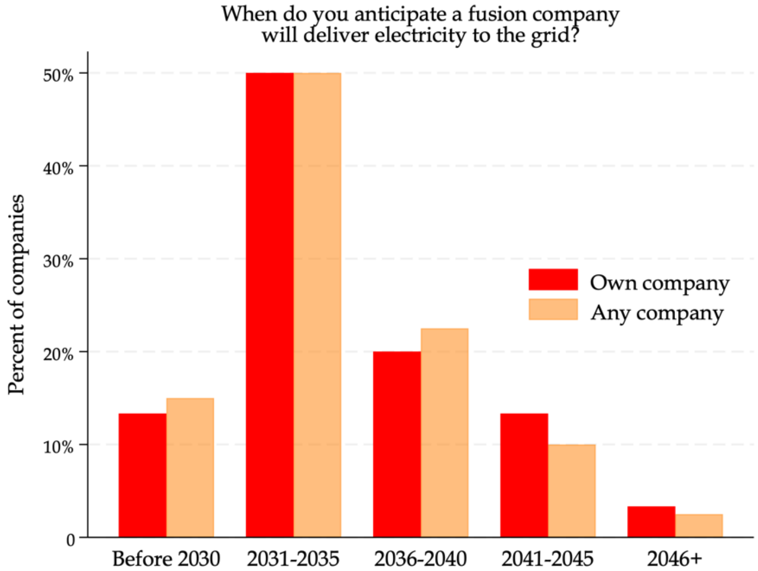
Nova Laser: Inertial Confinement (Linear Colliding Beams)

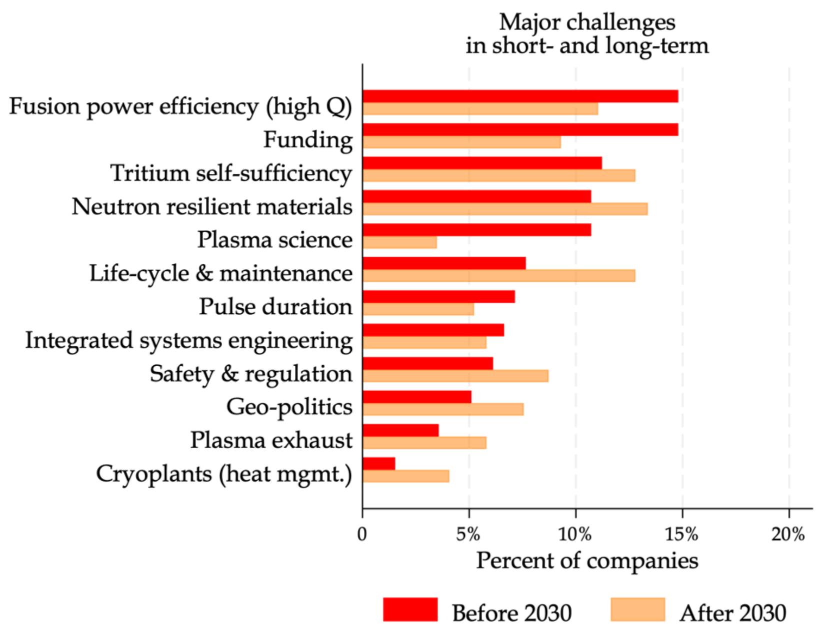
Wendelstein7-X: Stellarator



Source: top left: U.S. Department of Energy, https://commons.wikimedia.org/wiki/File:U.S._Department_of_Energy_-_Science_-_425_003_001_(9786811206).jpg; top right: Lawrence Livermore National Laboratory, scanned from the 1984 Laser Program Annual Report, https://commons.wikimedia.org/wiki/File:NOVA_laser.jpg; bottom: Max-Planck-Institut für Plasmaphysik, Tino Schulz, https://en.wikipedia.org/wiki/File:Wendelstein7-X_Torushall-2011.jpg, licensed under Creative Commons Attribution-ShareAlike 3.0 Unported (CC BY-SA 3.0).

Exhibit 5 Fusion Companies' Beliefs about Timelines and Risks





Source: Company document: 2023 Fusion Industry Association report, "The Global Fusion Industry in 2023: Fusion Companies Survey by the Fusion Industry Association." Available at: https://www.fusionindustryassociation.org/fusion-industry-reports/.

Endnotes

[1] US House Committee on Energy and Commerce, "Energy Subcommittee Chair Brandon Williams Opening Statement at From Theory to Reality: The Limitless Potential of Fusion Energy," 2023, https://science.house.gov/2023/6/energy-subcommittee-chair-brandon-williams, accessed 2023.

[2] This measure of Q for this test ignores the amount of energy used by the National Ignition Facility to power the lasers involved in the demonstration, which was 322 mega-joules. If that energy input is incorporated, the Q of the system is approximately 0.01. Source: Tollefson, J., Gibney, E. "Nuclear-fusion lab achieves `ignition': what does it mean?" Nature News Explainer, 2022, https://www.nature.com/articles/d41586-022-04440-7, accessed 2023.

[3] Lawrence Livermore National Laboratory: National Ignition Facility & Photon Science, "FAQ," https://lasers.llnl.gov/about/faqs, accessed 2023.

[4] Broad, W.J., "So far unfruitful, fusion project faces a frugal Congress," New York Times, Sep. 29, 2012, https://www.nytimes.com/2012/09/30/science/fusion-project-faces-a-frugal-congress.html, accessed 2023.

[5] De Clercq, G., "Nuclear fusion reactor ITER's construction accelerates as cost estimate swells," Reuters, Oct. 7, 2016, https://www.reuters.com/article/us-france-nuclear-iter-idUSKCN1271BC/, accessed 2023.

[6] Ball, S., Guguen, G., "Power from an artificial sun: Fusion reactor project aims to provide clean energy," France 24, July 31, 2020, https://www.france24.com/en/20200731-power-from-an-artificial-sun-fusion-reactor-project-aims-to-provide-clean-energy, accessed 2023.

[7] See: Commonwealth Fusion Systems, https://cfs.energy, accessed 2024; TAE Technologies, https://tae.com, accessed 2024; Helion Energy, https://www.helionenergy.com, accessed 2024.

[8] Source: Commonwealth Fusion Systems, "Commonwealth Fusion Systems Raises $1.8 Billion in Funding to Commercialize Fusion Energy," Dec. 01, 2021, https://cfs.energy/news-and-media/commonwealth-fusion-systems-closes-1-8-billion-series-b-round, accessed 2024.

[9] See: Holland, A., Cunningham, N., "Fusion Power: A Ten-Year Plan for American Energy Security,"American Security Project, 2014, https://www.americansecurityproject.org/wp-content/uploads/2014/07/Ref-0162-Fusion-White-Paper-2014-10-Year-Plan-for-American-Energy-Security.pdf, accessed 2023.

[10] "Base load" refers to the minimum level of demand on an electrical grid over a span of time.

[11] Source: ARPA-E, "Accelerating Low-cost Plasma Heating and Assembly," Aug. 24, 2014, https://arpa-e.energy.gov/technologies/programs/alpha, accessed 2024.

[12] Fusion Industry Association, "Fusion Industry Association Announces Launch," Nov. 9, 2018, https://www.fusionindustryassociation.org/fusion-industry-association-announces-launch/, accessed 2023.

[13] Fusion Industry Association, "Fusion Industry Association Announces Launch," Nov. 9, 2018, https://www.fusionindustryassociation.org/fusion-industry-association-announces-launch/, accessed 2023.

[14] Nonprofit Explorer, "Fusion Industry Association," ProPublica, https://projects.propublica.org/nonprofits/organizations/863094674, accessed 2023.

[15] Wattles, J. "How SpaceX and NASA overcame a bitter culture clash to bring back US astronaut launches," CNN Business, Aug. 10, 2020, https://www.cnn.com/2020/08/09/business/spacex-nasa-astronaut-launch-demo-2-culture-clash-scn/index.html, accessed 2023.

[16] NASA, "Commercial Orbital Transportation Services: A New Era in Spaceflight," https://www.nasa.gov/wp-content/uploads/2016/08/sp-2014-617.pdf, accessed 2023.

[17] US Department of Energy, "DOE Announces $46 million for Commercial Fusion Energy Development," https://www.energy.gov/articles/doe-announces-46-million-commercial-fusion-energy-development, accessed 2023.

[18] US Nuclear Regulatory Commission, "About NRC," https://www.nrc.gov/about-nrc.html, accessed 2023.

[19] Congress.gov, "S.512 - Nuclear Energy Innovation and Modernization Act," https://www.congress.gov/bill/115th-congress/senate-bill/512, accessed 2023.

[20] Current estimates suggest timelines of ten to fifteen years and fixed costs on the scale of five to ten billion dollars. Source: Schlissel, D., Biewald, B., "Nuclear Power Plant Construction Costs," Synapse Energy Economics, Inc., https://www.synapse-energy.com/sites/default/files/SynapsePaper.2008-07.0.Nuclear-Plant-Construction-Costs.A0022_0.pdf, accessed 2023.

[21] Clark, B.P., "Staff Requirements – Secy-23-0001 – Options For Licensing And Regulating Fusion Energy Systems," US Nuclear Regulatory Commission, April 13, 2023, https://www.nrc.gov/docs/ML2310/ML23103A449.pdf.

[22] Clark, B.P., "Staff Requirements – Secy-23-0001 – Options For Licensing And Regulating Fusion Energy Systems," US Nuclear Regulatory Commission, April 13, 2023, https://sites.google.com/site/universityfusionassociation/home, accessed 2023.

[23] Fusion Industry Association, "The Fusion Industry Supply Chain: Opportunities and challenges," 2023, https://www.fusionindustryassociation.org/wp-content/uploads/2023/08/FIA-Supply-Chain-2023-FINAL.pdf, accessed 2023.

[24] Fusion Industry Association, "The Fusion Industry Supply Chain: Opportunities and challenges," 2023, https://www.fusionindustryassociation.org/wp-content/uploads/2023/08/FIA-Supply-Chain-2023-FINAL.pdf, accessed 2023.

[25] Wilson, T., "New nuclear reactor rules ease fusion confusion," Financial Times, Dec. 5, 2023, https://www.ft.com/content/9f4b49c2-8379-4fa0-b18f-1fcb4519d01d, accessed 2023.

[26] Utterback, J.M., Abernathy, W. J., "A dynamic model of process and product innovation," Omega, 3(6), 639–656, https://www.jstor.org/stable/2122817.

[27] Utterback, J.M., Abernathy, W. J., "A dynamic model of process and product innovation," Omega, 3(6), 639–656, https://www.jstor.org/stable/2122817.

[28] World Nuclear Association, "Nuclear Power Reactors," May 2023, https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/nuclear-power-reactors.aspx, accessed 2023.

[29] Fusion Industry Association, "The global fusion industry in 2023," https://www.fusionindustryassociation.org/fusion-industry-reports/, accessed 2023; and Barcel., Y., "Nuclear Fusion May Be Nearer Than You Think," Morningstar, Nov. 1, 2023, https://www.morningstar.ca/ca/news/227636/nuclear-fusion-may-be-nearer-than-you-think.aspx, accessed 2023.

[30] Source: MIT Sloan Office of Communications, "MIT researchers: Megafund approach to attract more private investors to fusion energy," press release, February 28, 2023, https://mitsloan.mit.edu/press/mit-researchers-megafund-approach-to-attract-more-private-investors-to-fusion-energy, accessed 2024.