ASSESSMENT OF INDUSTRY PARTICIPATION IN U.S. DEPARTMENT OF ENERGY USER FACILITIES AND PROPOSED MARKETING EFFORTS TO INCREASE ENGAGEMENT WITH THE FUSION ENERGY INDUSTRY

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ABSTRACT OF THE THESIS

Assessment of Industry Participation in U.S. Department of Energy
User Facilities and Proposed Marketing Efforts to Increase Engagement
with the Fusion Energy Industry
by
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The U.S. Department of Energy, Office of Science operates a fleet of User Facilities that provide unique research capabilities to all interested parties. These User Facilities provide for participation by commercial entities, i.e., industry, through multiple mechanisms. In some instances, industry participants can significantly reduce their capital costs by utilizing resources and capabilities of User Facilities. A study of publicly available User Facility data shows that industrial participation is generally low. A detailed case study focused on the area of fusion energy development finds that industry participation is particularly low. Feedback from the fusion energy industry is collected through interviews and professional engagements, as well as a survey that measures the level of awareness of industry researchers with User Facilities. The fusion energy industry case suggests a series of adjustments to User Facility operation that would accelerate the commercialization of related technologies. These specific fusion energy industry needs, and a set of general communications adjustments applicable to all User Facilities, are proposed as ways to improve industry participation in User Facilities, thereby increasing the national benefit derived from publicly-supported research and development.

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First and foremost, I am grateful to my family for helping me to complete this part-time student, full-time employed, MBA journey over the past 3.5 years. Lea Pace provided immense support, not least by caring for Marlo and Austin two nights each week while I was attending classes. I promise never to try to learn anything again!

I also wish to extend gratitude to Professor Claudiu Dimofte for serving as the Thesis Chairperson. I especially appreciate his patience in affording me the time to explain how a fusion energy research focus has any relationship to business practices, and then again as we navigated the administrative requirements for pursuing a Masters Thesis.

Consistent with full disclosure, I note that I am professionally involved in both fusion energy research and its associated industry. During the preparation of this thesis, I was employed as the Deputy Director of the DIII-D National Fusion Facility, one of the two User Facilities supported by the U.S. Department of Energy, Office of Science, Fusion Energy Sciences program. I serve in this role as an employee of General Atomics, which has overall management responsibility for the facility and is also a participant in the commercialization of fusion energy technologies. This role was disclosed to all those who provided input for this project. It is definitely true that I have a deeply personal interest in seeing fusion energy succeed in becoming a sustainable global energy source. Coordinating a discussion between industry and academic researchers, as this thesis aims, provides great professional satisfaction, but not any financial gain.

CHAPTER 1
INTRODUCTION

1.1 Benefits of Publicly Funded Scientific Research

The national benefits of publicly funded research and development program are well documented. These include benefits related to economic growth, internal energy sources, environmental sustainability, public health, and national security [14]. Nearly all of these benefits are realized through either the commercialization of a technology, or the scaled production/distribution of a technology. In both cases, industrial partners are highly likely to participate. For this reason, there is typically great concern over the relationship between industry (specifically, for-profit firms) and government agencies that make funding decisions.

A common assessment is that science is, or can be, kept separate from technology [25]. Science is then defined as basic research, which is best left to funding sources that do not require returns (i.e., government-funded), while technology is meant to be sold on the open market. Technology development is, therefore, advanced according to which items provide the best returns for the investors. The resulting conflict is best described by Eisenberg and Nelson [25]:

"The challenge for public policy is to devise arrangements that preserve the great advantages of an open system for basic science while still preserving profit incentives for the creation of valuable new products."

The nuance in this description is that the balance of public vs. private funding for research and development should be driven according to how the greatest benefit is achieved for the host country. In some cases, the public funding is best applied as an addition to on-going private investments. As a contemporary example, the field of climate change and sustainability science is densely populated with both private and public investments. Greater national benefit arises from ensuring that the results of these investigations, regardless of source, are accessible to a wide audience of researchers [36]. A natural conclusion would be that there is a place for public funding to ensure that these data are more widely available.

1.2 Deriving Commercial Benefits through Public Funding Mechanisms

Actions to increase the realization of commercial applications derived from federally funded research have been consistently taken over the past few decades. One of the most influential legal actions is the Bayh-Dole act,[1] which grants small businesses and non-profit entities the ability to retain intellectual property rights for inventions resulting through federally funded research. Prior to the act, invention rights were not assured, and the specific funding agencies had considerable leeway in determining whether it was in the interests of the public good to grant rights to the relevant organizations. Following its enactment, the act has led to a proliferation of patent generation from universities, the largest benefactors of government research funding.

Universities have largely used the creation of "technology transfer offices" to facilitate their commercialization of research outcomes. This is now a worldwide phenomenon as many international legislative units have enacted laws similar in effect to the Bayh-Dole act. Entrepreneurship from faculty is desirable to universities because it increases their access to resources, which improves the experience of their students and the ultimate success of the institution. Universities facilitate the productivity of their faculty in this regard by creating hubs for relevant activity, sometimes called "science parks" or "innovation labs." This increases the ability of industry to participate, and it improves the likelihood that people with the relevant experience, capabilities, and resources will meet and engage [1].

While universities are not part of industry, they are able to engage with industrial partners to advance common interests. Bringing together industry and university partners in science parks is considered one of the most effective methods for commercial firms to survive the so-called valley of death [3]. The valley of death is the time period of financial losses during which a firm is overcoming the risk factors associated with their products or services. The U.S. takes a bottom-up approach to the entrepreneurial ecosystem, meaning that the government acts as a facilitator and prefers to realize economic gains through market processes. One indirect support mechanism for the government is to assist in the funding of research and development that features higher risk for the industrial firms. A second type of government assistance occurs when procurement requirements incentivize firms to provide specific products, for example, the Department of Defense driving strong reductions in ozone-depleting chemical consumption through procurement rules that made production of new, alternative products more profitable to vendors [6].

[1] https://uscode.house.gov/view.xhtml?path=/prelim@title35/part2/chapter18&edition=prelim

Commercial benefits derived from public research funding are therefore most strongly related to the increased engagement of university partners. Additional benefits result from the acceleration of technological development. Specific examples related to workforce development and technology are presented here in the case studies focused on the area of nuclear fusion energy commercialization.

1.3 Marketing Considerations for Publicly Funded Research

The driving goal of this work is to identify a marketing approach that improves the engagement of for-profit industry with U.S. Department of Energy User Facilities (defined in Section 1.4.1). Fundamentally, the application of marketing principles to the non-profit sector is most relevant.

Marketing principles as applied to non-profit organizations is most strongly influenced by the concept of New Public Management (NPM) [37]. New Public Management is a trend, largely established by now, of incorporating private-sector management techniques to public-sector organizations and efforts. NPM often involves bringing increased accountability (e.g., metric performance measures) and more competition to non-profit entities, including government offices and programs. Interest in NPM is spurred, in part, by a desire to realize private-sector efficiencies in the exercise of public works. When applied to government programs, a criticism of NPM notes that government projects have explicit and implicit expectations of equity, which is not necessarily a priority or even a consideration in profit-focused approaches.

Through the lens of NPM, non-profit organizations should understand the importance of a professional marketing approach in the execution of their processes. In practice, however, non-profits typically do not employ a comprehensive marketing strategy and are rarely staffed by trained marketing professionals [2]. Personnel working in the public non-profit sector typically learn marketing on-the-job [23]. Higher education institutions are known to employ marketing professionals, even as they remain largely unable to provide compensation that is competitive with the for-profit sector. Those marketing professionals report accepting lower compensation for the sake of working in higher education and achieving a higher quality of life (presumably, by working a more reasonable number of hours compared to alternative employment). As shown throughout the case study, the selected research facilities do not employ marketing teams or marketing strategies, and they typically collect "customer" feedback from the researchers themselves.

As Blery, Katseli, and Tsara [8] note, "Most non-profit organizations are not selling products, they are selling their organization's mission, their ideas, their programs and their services.” For a museum or an institution of higher education, their ideas, programs, and services can be described succinctly. That leads to another challenge of marketing, namely that the institution is prone to developing a belief that their approach is fundamentally correct, and that customers or users do not drive the definition of the services offered [10]. This is more common for charities that have engaged communities in a particular way for many years. With an established federal research program, the concern is that emerging needs from the wider research community may be marginalized.

With these broad concerns in mind, detailed marketing concerns specific to the case study and focus area are presented in Chapter 4.

1.4 Areas for Improvement of Industrial Participation in National Research Efforts

Taking the value of industry engagement with publicly (federally) funded research in the United States as well demonstrated, the focus of the present work is to determine the extent to which select existing Federal facilities are presently used by industrial organizations. Following that, an assessment of changes or new approaches that would improve this situation are proposed. A Federal facility is any institution fully directed through an office of the U.S. government. In some cases, these institutions are operationally managed by academic institutions or some other non-government entity, but the continued existence of the facilities remains determined by the relevant agency or the U.S. Congress (through budget action).

The whole of industry is vocal, through its lobbyists and professional support organizations, about its desire to work more closely with the resources of national facilities. In 2020 testimony before the U.S. House of Representatives Budget Committee [17], Deborah Wince-Smith, President and CEO of the Council on Competitiveness stated,

“In addition, our crown jewel national laboratories are hamstrung by Federal policies, and a lack of resources both to fulfill their missions and to optimize their contribution in support of U.S. industry and innovators seeking access to a shared national innovation infrastructure. The national laboratories turn away hundreds of promising start-ups and innovators every year due to these constraints and authorization concerns.”

This provides the motivation of the questions in the present work:

- To what extent are federally funded research institutions engaging industry?
- What are the factors that limit this level of engagement?

- How might the engagement be improved?

1.4.1 Areas of Focus

To investigate the questions above, some amount of focus is required. First, Federal facilities are limited to designated User Facilities of the Department of Energy, Office of Science as described in Chapter 2. The Office of Science is the largest supporter of basic scientific research in the U.S., and its portfolio extends across a wide range of areas from physics to genomics. The User Facilities of the Office of Science are specifically charged with providing unique research capabilities to both academia and industry. There is clear motivation for the User Facilities to make themselves attractive and useful to industry, and for industry to utilize available capabilities in order to reduce their own capital investments.

A further focus is implemented by examining the area of nuclear fusion energy development in Chapter 2.6. Fusion energy is a nuclear technology in which lower atomic number atoms are combined (i.e., fused) to create higher atomic number elements in a process that releases energy. The fuel for fusion may be simple elements such as hydrogen isotopes or boron, and the energy production is inherently sustainable and does not directly produce greenhouse gases. As such, fusion energy is considered to be a major component, or requirement, in order to maintain global populations with environmentally sound energy production. Creating these reactions is challenging, however, as the fusion energy program began shortly after World War II and has spent decades building a series of international devices that stepped ever closer to the required parameter regimes. In the past decade, the science foundation for much of fusion energy has solidified sufficiently to allow the creation and growth of a fusion industry. For a nascent industry with such clear ties to federally funded research, an investigation to determine improved interactions between the industrial partners and User Facilities is particularly interesting, and possibly beneficial to the enterprise.

An assessment of needs provided by original data collected from the fusion industry is outlined in Chapter 3. Finally, proposed implementations that would accelerate the commercialization of fusion energy are presented in Chapter 4.

1.4.2 Data Collection

Data and other information is collected from both primary and secondary sources. Much of the information related to User Facilities is publicly available, for example, annual budget levels and participation of researchers as a function of their home institution. There is less publicly available information related to the fusion industry, as the vast majority of those organizations are privately-held. There are, however, related fusion industry support and lobbying organizations, and those do provide relevant information that is cited as used.

Primary data sources include interviews and a survey. Twelve formal interviews were conducted with personnel representing the fusion industry and government offices that support related research efforts. Informal input was collected from researchers and staff through professional engagements such as conference participation. The anonymity of the contributors is maintained in this work for two reasons. One reason is that the fusion industry, while growing rapidly, remains centralized by a tightly connected group of individuals. An investigation into ways to improve government support of a growing industry is naturally going to identify criticisms of past performance, and the industry respondents would be limited in their input if their statements might be attributed to them. The second reason is that both this work itself, and the input from government representatives, is much more difficult to produce if attribution is required. Given that the identities of the contributors is not material to the feedback provided, their participation remains anonymous.

A survey is also used to collect primary data. The survey is directed at individual researchers employed by organizations within the fusion energy industry. It investigates the extent to which these organizations are aware of opportunities to engage User Facilities outside of traditional approaches, e.g., proprietary work through cost recovery. The goal of the survey is to quantify the extent to which fusion-relevant User Facilities are being utilized to advance the industry. For that reason, more than one respondent from any single organization is desired. In actuality, however, the 22 survey responses represent nearly 22 distinct organizations. The respondents and their organizations are afforded anonymity consistent with the previous description.

CHAPTER 2

USER FACILITY PROGRAM OF THE U.S. DEPARTMENT OF ENERGY

2.1 About the User Facility Program

Located within the U.S. Department of Energy, the Office of Science (SC) is the largest supporter of fundamental physical science research in the United States [67]. In fiscal years 2020 and 2021, the enacted budgets of SC were $7B [68]. There are six science programs within SC, and each of these science programs operates a number of User Facilities, as detailed in Table 2.1. These programs cover a wide range of research areas, extending from fundamental particle physics, to energy science, to advanced computational methods that apply to many other fields.

The User Facility system is the mechanism by which the SC defines, constructs, and operates major research facilities. Formally defined in a memorandum from SC in 2012 [21], some key aspects of a User Facility are:

- interested users are welcome to participate in research, regardless of their “nationality or institutional affiliation”
- non-proprietary participation does not incur any usage fees
- proprietary use is allowed with cost recovery
- facility capabilities are not allowed to compete with available private sector capabilities

By their very definition, User Facilities provide unique capabilities in high-technology and advanced scientific fields. Furthermore, interested parties are able to participate in the work of the facility, or their own preferred project using facility resources, without fees (these parties must fund their own expenses). The mode of operation for these facilities varies from a service-oriented role to a research stewardship role. As an example on the service side, the Advanced Photon Source (APS)[1] creates high energy x-rays and researchers bring their “targets” for irradiation. As discussed in the detailed study later, the National Spherical Torus Experiment-Upgrade (NSTX-U)[2] engages it user base to define an annual set of experiments, thereby acting as a steward

[1] https://www.aps.anl.gov/

[2] https://www.pppl.gov/research/nstx-u

of the relevant research community. In that research plan, both the local team and the collaborator user base work together to complete each experiment, sharing responsibilities and publication rights.

2.2 Scale of Overall Participation

The Office of Science (SC) sets reporting requirements for the User Facilities in order to quantify and track the associated user bases. The resulting datasets are distributed publicly on the SC website [69] and a summary report was last published in 2015 [70]. For the present analysis, all available data has been collected and reviewed. The data set covers fiscal years 2013 through 2020. These reports are submitted by each User Facility following the completion of the fiscal year on September 30. The data for fiscal year 2021 was submitted to SC by November 2021 and is not yet publicly available. As with many other research endeavors, the data from 2020 is influenced by the global COVID-19 pandemic in some ways that may not yet be apparent. Any appreciable deviations in behavior driven by 2020 data will need to be considered separately.

An important note for the following analysis is that these reports qualify "users" as people who have consumed facility resources for the purpose of research and associated innovation. A user is an individual, not an organization, so there must be a separation of the institutional usage from this data set. Of similar concern, an organization could theoretically assign official facility interactions to a single person, meaning that the number of people indirectly using facility resources may be larger than reported. One motivation for engaging in this manner is that it reduces the overhead for the organization since User Facilities have onboarding and annual update processes for their users.

These user counts do not include the support teams of the facilities themselves, except in the cases where those personnel also engage in research activities. For example, the following roles may be employed at the facility, but would not themselves be counted as users: department specialists, administrative assistants, management, technicians, and information technology service providers. For the purposes of this investigation, the user definition is relevant because it allows for quantification of the extent to which industry is using facility resources (as a counter example, if all team members were reported, then this data might more simply indicate the size of the facility instead of its true user base).

Figure 2.1 indicates the number of User Facilities, along with their user bases. The total user count is remarkably stable across this eight year time frame, remaining between 30,000 and just over 36,000 users. With the exception of a reduction in 2020, the average number of users per facility demonstrates a consistent increase over the rest of the period. While the total number of facilities is fairly constant, the closure of even a single facility could lead to a significant reduction in users for a single year.

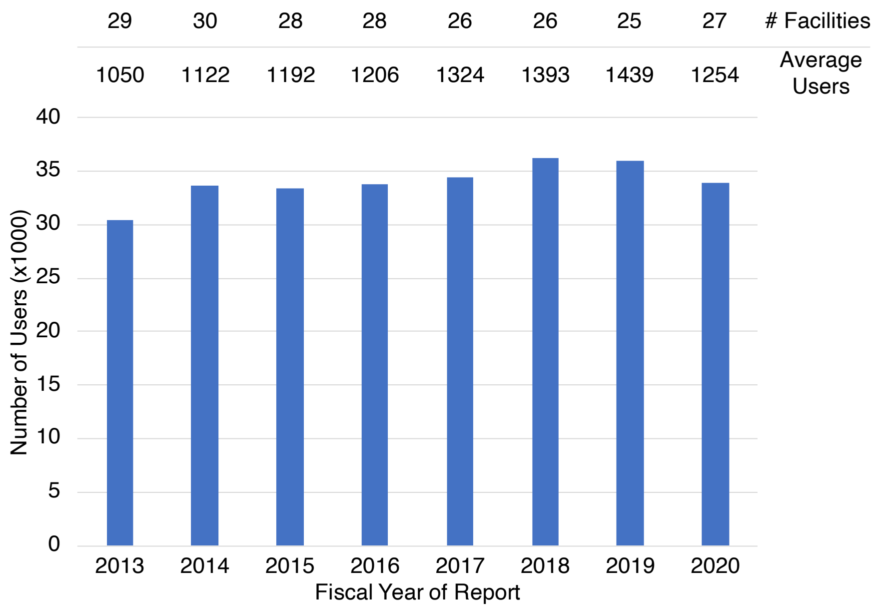

Figure 2.1. Total number of reported users across all User Facilities through fiscal years 2013 through 2020. Top annotations indicate the number of reporting User Facilities and the resulting average number of reported users per facility.

The wide variety of research topics, coupled with the different modes of operation for the User Facilities, results in large differences in scale. Distributions of the total user count for reporting years 2019 and 2020 is provided in Figure 2.2. The majority of facilities report fewer than 4000 users, with two of the 27 facilities operating in 2020 surpassing that count. In summary, the typical User Facility serves on the order of 1000 users. The largest user base belongs to the National Energy Research Scientific Computing Center (NERSC)[3], which reported 8329 users in 2020, and has maintained the largest user base since 2014. NERSC provides access to supercomputing capability for its users. Given the applicability of supercomputing to nearly all known fields of research, this is an expected outcome.

[3]https://www.nersc.gov/

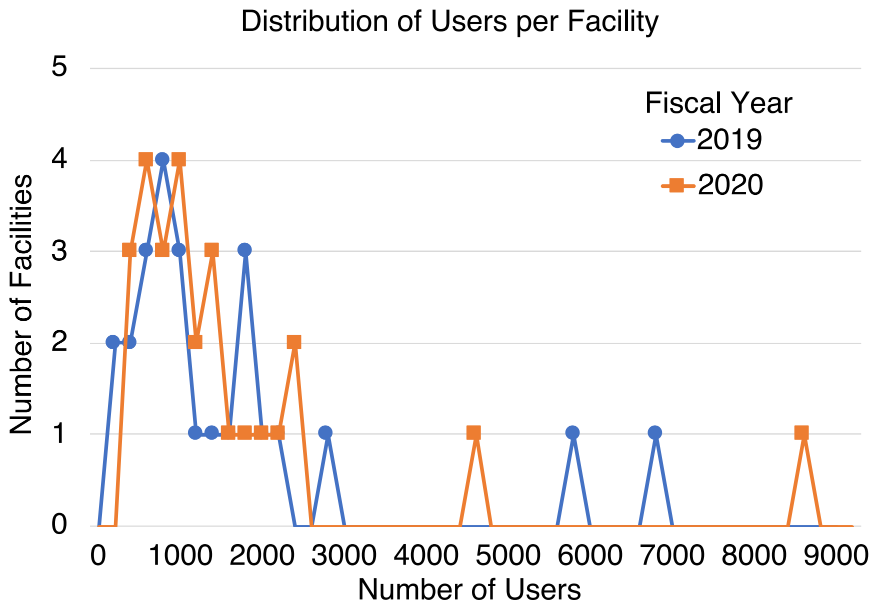

Figure 2.2. Distribution of user count across User Facilities for the 2019 and 2020 reporting years.

At the other end of the spectrum, the Energy Sciences Network (ESnet)[4] User Facility provides high-speed network access connecting energy-related research groups across the world. This includes more than simple internet access, for example, ESnet maintains a *Science DMZ* that facilitates research data transfer and access internationally, thereby enabling efforts that would otherwise be severely limited by public-facing network capabilities. ESnet reports 76 users in 2020, even though its network services are provided to thousands of active researchers, especially through the other User Facilities. Since the user definition includes only those involved in innovative research, but not the provision of the facility, the ESnet user base is considerably smaller than the number of people who benefit from the facility.

2.3 Participation of Industrial Institutions

The user reports indicate whether the host institution of each use is an industrial organization. For reference, this essentially means for-profit organizations, though it is possible for a non-profit organization to exist within industry (trade groups, lobbying associations, etc.). Considering the types of institutions that utilize resources from User Facilities, the academic (colleges and universities) and governmental (national laboratories, regulatory agencies, etc.) institutions represent both the bulk of participation and the non-industry segment.

[4] https://www.es.net/

In this analysis, the institutions are counted, not the number of qualifying individuals from each institution. For example, if an industrial organization has 30 recognized users of a facility, that organization is still only counted once in the analysis below. The reasoning is that the number of industrial partners is a better reflection of private-sector utilization than the number of distinct individuals.

There is a cautionary note concerning the use of the industry classification by the User Facilities. While the column data is reported as "Industry?" with a Yes/No value, there is no indication of how the industrial classification is determined. There are many instances of universities being listed as industry institutions, that is, marked with a Yes value. Within the reports from 2014, for instance, the University of California, Davis (UC Davis) appears as both an industry institution and a non-industry institution. When marked as an industry institution, its "Institution Type" is listed as "For-Profit Organization (Other than Small Business)." All of the other instances of UC Davis list its type as "University/Educational Institution."

These discrepancies suggest that the individual User Facilities, which prepare and submit their User Reports to the Office of Science, are not necessarily using equivalent assessment criteria in determining whether participating organizations are members of industry. It may be in the interests of the Office of Science to require that User Facilities identify institutions according to a third-party database that provides uniformity, such as the Research Organization Registry[5]. No attempts are made here to correct the reported statuses from each User Facility.

Figure 2.3 shows the time history of reported industry institutions supporting users engaged with User Facilities. The number of industry institutions is consistently between 400 and 600, with an apparent steady value near 500 across the past five reporting periods. The number of reporting facilities and the resulting average number of industry institutions also indicates a fairly steady population of nearly 20 institutions, on average, per User Facility. In this representation, the same institution will be counted each time it appears in the report from a different User Facility.

The number of unique industry institutions is plotted in Figure 2.4. Here, each industrial institution is counted a single time per year, that is, a single organization is counted once per year that it had personnel engaging any of the User Facilities. As with the other counts, the number of organizations is fairly constant over the reporting periods, averaging approximately 400 institutions. This number is likely erroneously larger than reality due to the mis-identification of universities as industry organizations instead of educational institutions.

[5]https://ror.org/

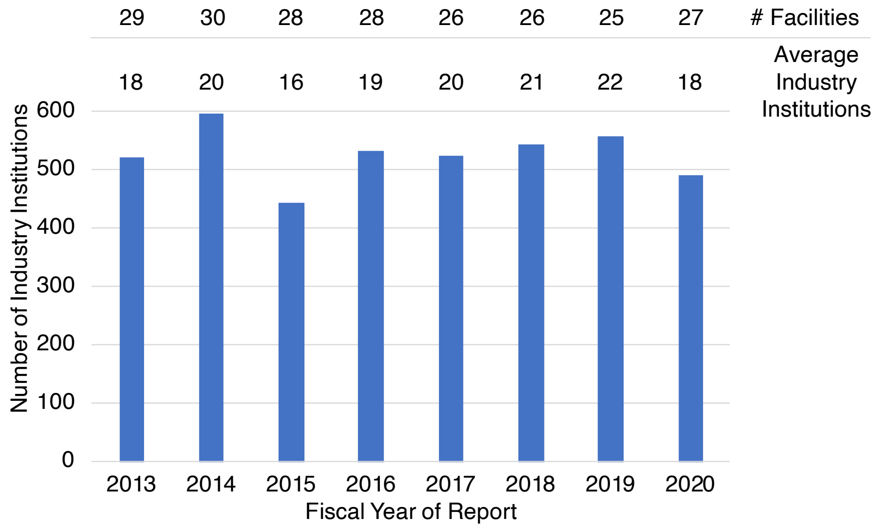

Figure 2.3. Total number of reported industrial institutions who supported users across all User Facilities through fiscal years 2013 through 2020. Top annotations indicate the number of reporting User Facilities and the resulting average number of industry-identified user institutions per facility.

It is a reasonable assessment that the less than 400 industrial organizations utilizing the resources of the User Facilities is extremely low. The User Facilities are accessible to researchers and companies worldwide. To provide context, and to simplify by focusing only on U.S. companies, consider the following National Science Foundation analysis by Wolfe [75], which analyzed research and development (R&D) spending of U.S. firms. This report identified 1.1M companies in the U.S. that funded R&D, had more than 10 employees, and were for-profit, but not farm-related. While it is certainly true that not all of these 1.1M companies have technical development needs that overlap with resources and capabilities of User Facilities, this still suggests that the pool of potential industrial user organizations is orders of magnitude larger than the actual number observed.

2.4 Small Business Engagement

The User Facility data distinguishes participating institutions according to whether they qualify as a small business (these organizations would also be counted as industry participants). This designation is extremely important from the perspective of the participating business. As discussed in Section 1.2, an organization that is recognized as a small business automatically retains intellectual property rights to inventions resulting from its execution of publicly funded research. Given the potential

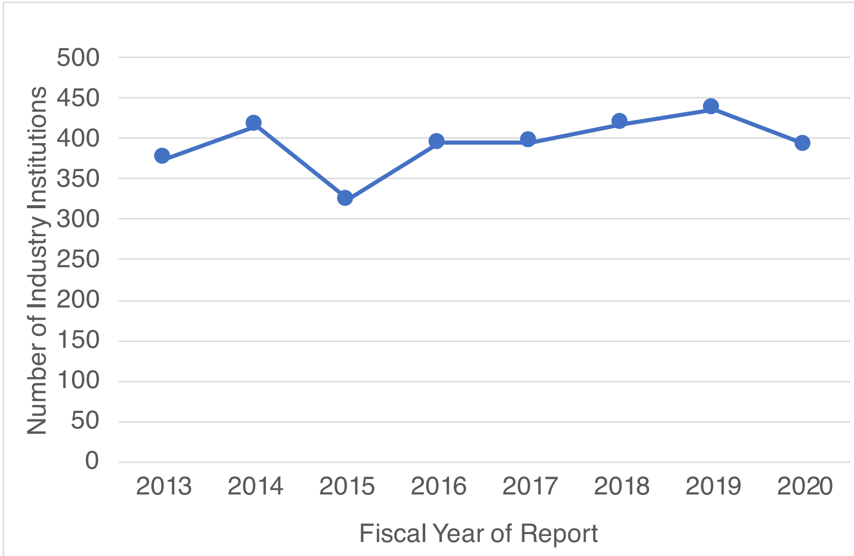

Figure 2.4. Annual number of unique industrial institutions participating in User Facility research.

repercussions of such a designation, the federal government provides multiple options for definitively determining this classification. The U.S. Small Business Administration and its Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs provide webpages to confirm this status[6].

As with the industry identification caution in Section 2.3, there are some apparent inconsistencies in the small business data. For example, Amazon.com is identified as a small business in the 2015 report. As publications from that year show, however, Amazon was already the established leader in e-commerce [56] and had individual business units with revenue in billions of dollars per year [51]. The size of the workforce would surely have been above any stated guidelines at that time. Using third-party databases to identify institutions and companies might provide the User Facility User Reports with greater accuracy. Corrections are not attempted in the present work.

Figure 2.5 shows the time evolution of reported small business participants. This is a user base for which there is clear growth (approximately 25%) over the past five years. The average number of small business institutions per User Facility has grown similarly. Impressively, the level of small business participation remained essentially constant in 2020, while total user base (Fig. 2.1) and industrial user base (Fig. 2.3) both decreased in that COVID-19 pandemic year. It might have been expected that small business participation would drop more significantly than the others because both

[6]https://www.sba.gov/document/support--table-size-standards
https://www.sbir.gov/sbirsearch/firm/all

academic users and larger business industry users have greater capital pools to sustain them across such shocks.

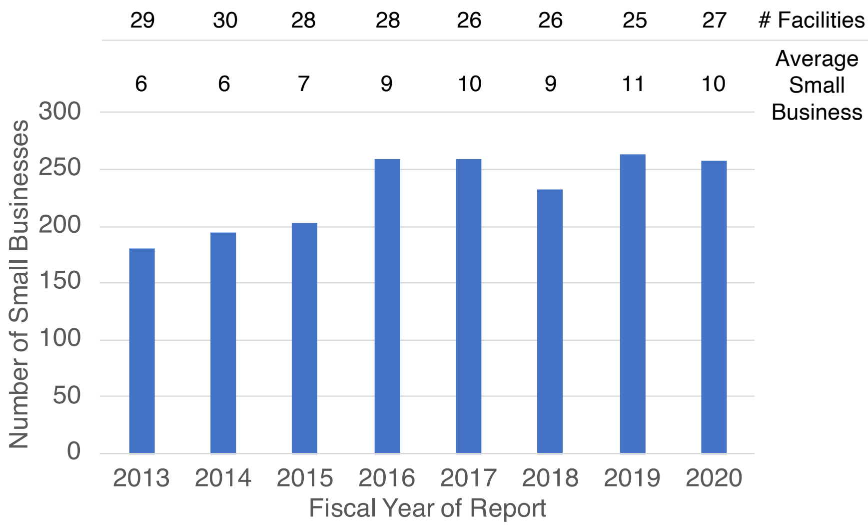

Figure 2.5. Total number of reported small businesses engaged across all User Facilities through fiscal years 2013 to 2020. Top annotations indicate the number of reporting User Facilities and the resulting average number of small business participating institutions per facility.

The sustainment of the small business user base is further demonstrated by the time evolution of unique participation shown in Figure 2.6. In this representation, each small business that participated in any User Facility project is counted only once. This, therefore, shows the number of unique small businesses participating in research at one or more User Facilities. The growth in this population is also shown here, proving that the growth is truly an increase in the number of small business participants (as opposed to small businesses extending their present engagement to additional User Facilities).

In 2020, the number of unique small businesses reported by User Facilities was 213. Of these small businesses, 44 conducted work at more than one User Facility (21%). This is similar to the rate for industry overall, which in 2020 reported 99 organizations performing research at more than one User Facility, out of a total of 393 (25%). The majority of industry and/or small business participants in User Facilities are engaged with a single facility.

2.5 Scale of Proprietary-use at User Facilities

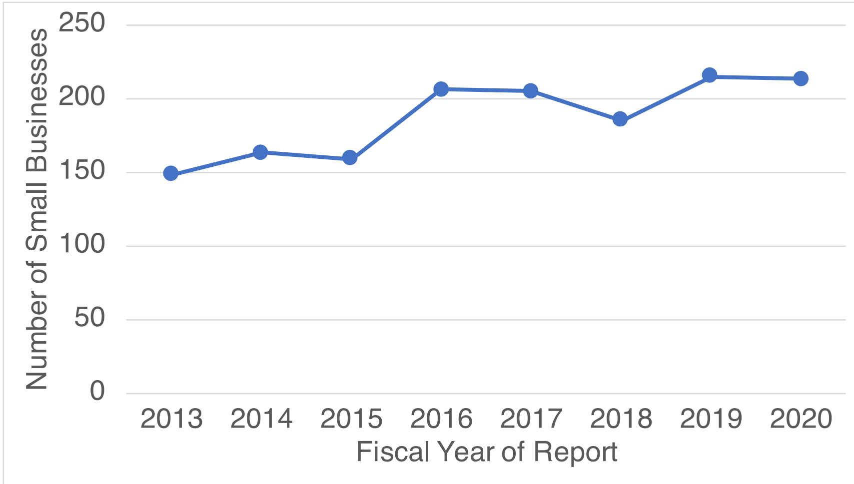

Figure 2.6. Annual number of unique small businesses participating in User Facility research.

A business-related, yet distinct, issue related to User Facility usage is that one's participation can be either non-proprietary or proprietary. These classifications can apply to any institution, that is, a non-profit research organization can still engage in a proprietary use case. Similarly, a for-profit organization can participate in a User Facility's research program under a non-proprietary agreement. The U.S. Department of Energy defines [71] proprietary use of a User Facility as that usage for which the requesting organization pays full cost recovery, and in return is allowed to keep as proprietary any data generated, as well as keeping the rights to any resulting inventions.

This creates an important assessment on the part of the industry user: whether or not to pursue proprietary usage. Qualifying small businesses are granted rights to inventions automatically, so they may actually find it more cost-effective to engage through non-proprietary agreements in which the User Facility provides its capabilities free of charge. Even larger businesses may prefer to reap the cost reduction by performing non-proprietary work. If the particular technology presents a high barrier to entry for other commercial firms, then there might not be much competitive advantage to keeping the data protected (recall that in non-proprietary work, the data produced by the User Facility must be accessible to all participants, regardless of whether those participants were engaged in the particular research). With this situation in mind, there are limits to the conclusions that may be drawn from the levels of reported proprietary work.

At present, there is no uniformity in the availability of proprietary work at User Facilities. The most recent formal announcement of this option is from 2015 [72], which appears to indicate that 25 of the 27 User Facilities provide the option for proprietary research. Reporting on proprietary usage began in 2015 and extends through the 2020 reporting period. This designation occurs at the project level, not the user level, so in one year any single user (or institution) could engage in both proprietary and non-proprietary projects at a User Facility.

The counts represent the number of projects that were performed under proprietary procedures. Each User Facility has its own process for determining project or experiment identification. This creates some inconsistencies in the data. A few examples are taken from the 2018 reports. Multiple projects may have been in service of one particular effort, for example, the following are recorded as separate projects,

- Characterization Of High Volumetric Energy Density Battery Materials (#7)
- Characterization Of High Volumetric Energy Density Battery Materials (#8)

but could reasonably be interpreted to represent a continuation of a project guided by the same user goal. Some projects clearly identify an industry partner as the driving force, for example,

- Pfizer Data Collection At Imca-Cat 2018-1
- Gsk Data Collection Of Protein / Drug Complexes
- Genentech'S Remote Data Collection At Ne-Cat

where Pfizer, GSK, and Genentech are all for-profit businesses. Finally, other project titles provide little indication of the goal, for example,

- Physics
- Atlas
- Cloud Study

Counts of users engaging in proprietary projects are shown in Figure 2.7. The usage levels are mostly constant, except for a large decrease in 2018. That decrease is primarily due to reduced proprietary usages at the two User Facilities: the Advanced Photon Source (APS)[7] and the Stanford Synchrotron Radiation Light Source (SSRL)[8]. The APS and SSRL regularly produce the largest number of proprietary users, averaging 215 and 42 such users each year.

The number of distinct projects that were classified as proprietary is shown in Figure 2.8. Outside of the 2019 extreme, there is a weakly increasing trend over the reported time period. The 2019 spike is due entirely to an massive increase in reported proprietary projects from the Atmospheric Radiation Measurement Climate Research

[7] https://www.aps.anl.gov/
[8] https://www-ssrl.slac.stanford.edu/content/

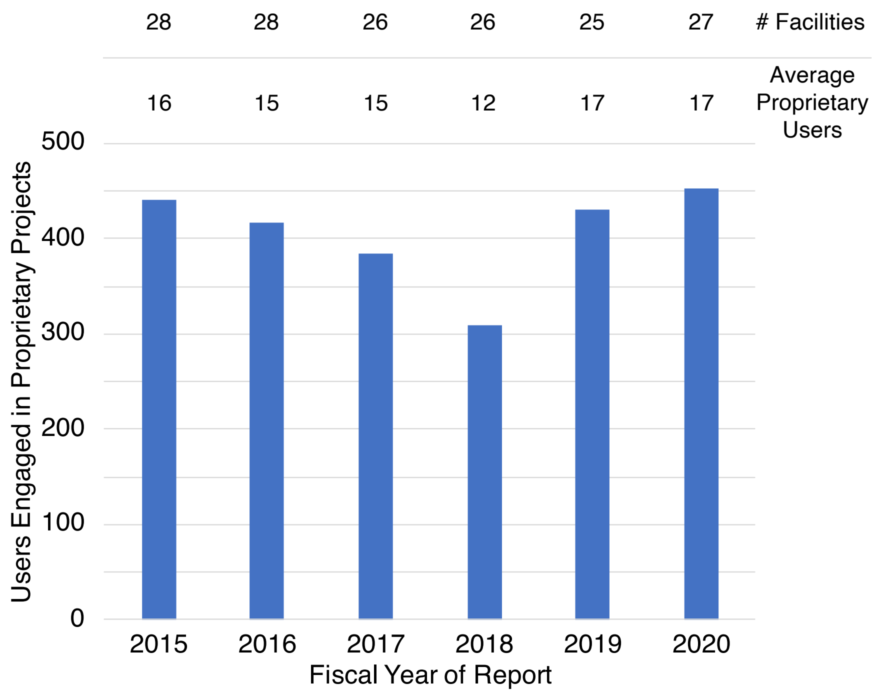

Figure 2.7. Total number of reported users who engaged in proprietary projects across all User Facilities through fiscal years 2015 to 2020. Top annotations indicate the number of reporting User Facilities and the resulting average number of users performing proprietary projects per facility.

Facility (ARM)[9] averaged 12 users working on proprietary projects for each year except for 2019, in which it reports 102. Each proprietary project has only one user associated with it, with that person typically coming from an academic institution and the funding source being either from the user's home institution or a government (including outside the U.S.) agency. There are no indications that 2019 was a unique year for the facility, leading to a reasonable conclusion that there may be an error in the reporting.

Notes on specific ARM projects do not provide any indication that they were proprietary in nature. For example, the Macquarie Island Cloud and Radiation Experiment (MICRE)[10] project is listed as proprietary, yet considerable information about it is publicly available. Furthermore, the data appears to be available to members of the ARM team. Membership as a team member (user) of User Facilities is open to any interested person, with only minimal user agreement required (see Sec. 2.1).

Turning to the issue of funding sources for this work (proprietary projects provide cost-recovery to the User Facility), the 2020 reports indicate 453 users

[9] https://www.arm.gov/

[10] https://www.arm.gov/research/campaigns/osc2016micre

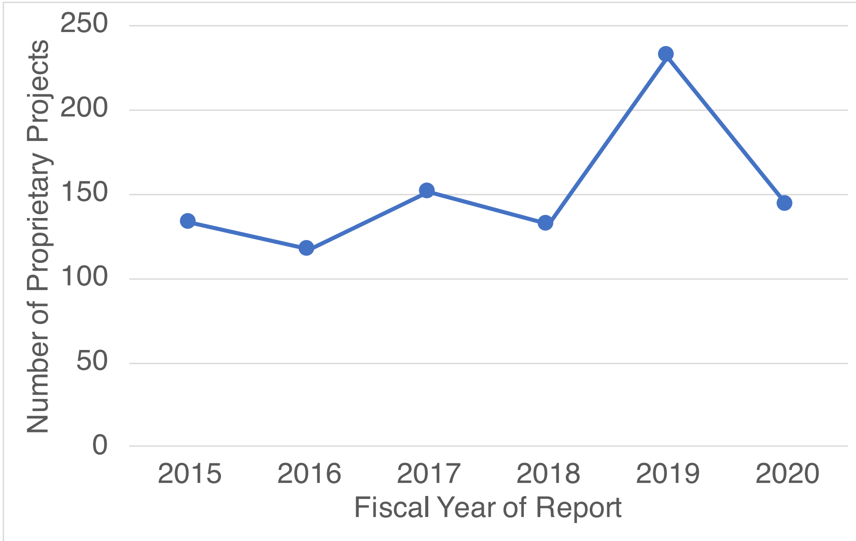

Figure 2.8. Annual number of unique projects classified as proprietary use by User Facilities.

supported to work on proprietary projects. The funding sources for those users is shown in Figure 2.9. Note that these sources represent the source of funding that supported the person performing the work, but there is no known record of how the institution fulfilled its cost recovery obligation to the User Facility. The majority of personnel who performed this type of research were funded by industry, with a smaller proportion coming from the U.S. government. This confirms that the interest in proprietary research at User Facilities is driven by industry.

There is a lack of available data concerning how cost recovery is provided to User Facilities. Each User Facility generates its own proprietary usage agreement, for example, see the documentation from the SSRL [58]. As the SSRL agreement states, an early step in the preparation of a proprietary experiment is for the requester (user) and the User Facility to cooperate in the generation of a cost estimate. Given the highly unique and custom nature of fundamental and high-technology research, it seems reasonable that “flat rates” or some type of catalog of services are not available.

2.6 Case Study On User Facilities Within Fusion Energy Sciences

The preceding sections introduced the full complement of User Facilities within the U.S. Department of Energy, Office of Science portfolio. The breadth of research areas covered by this collection of 28 User Facilities is very wide. Industry needs across all of the areas vary considerably, and a single marketing strategy is unlikely to properly address that entire potential user base. For this reason, a case study is

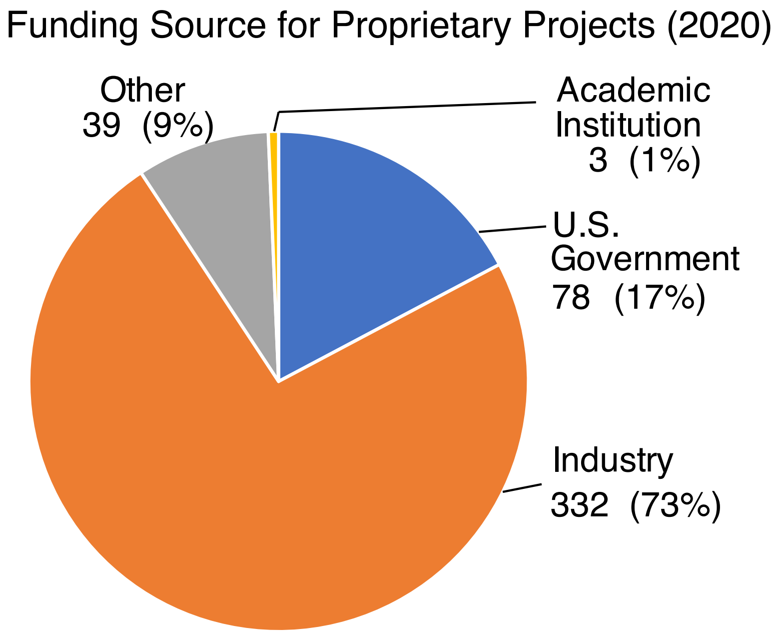

Figure 2.9. Funding sources for users working on proprietary projects (one report of "unfunded" is not included in this graphic).

performed on the research area of fusion energy and its associated DOE programs and industry. In the following sections, the research field is described and then the User Facilities within this field are detailed.

2.6.1 Fusion Energy

Two forms of nuclear energy exist: fission and fusion. Fission processes involves atoms of larger atomic number (i.e., higher number of protons in the nucleus) decaying into atoms of lower atomic number. That process releases energy in the form of heat, typically along with other particles. All existing nuclear power plants are fission plants. The U.S. Department of Energy, including in its previous existence as other U.S. agencies, has worked with fission energy since the time of World War II and the development of the first atomic weapons [45].

Fusion involves combining two atoms such that they form a new element. This process releases energy similar to fission. The energy density of the fusion process is actually greater than that of fission, and the process provides some other fundamental advantages. One such advantage is that fusion reactions cannot runaway, that is, the process of fusion ceases through natural mechanisms should various containment systems fail. The disadvantage of fusion is that is is significantly more difficult to achieve compared to fission.

A sufficiently large pile of uranium will spontaneously decay (through fission) and increase in temperature. By comparison, atoms cannot be fused until they are pressed together with sufficient force to overcome the electrical repulsion of the positively charged nuclei. The energy required to compress, or slam, these atoms into each other with sufficient force is immense. The only naturally occurring fusion process occurs in stars, which achieve the compression through the collection of massive amount of matter. It is common to describe the process of developing fusion energy as "bringing a star to Earth," as done in many historical reviews of the field, or projections for its future [63, 15, 11, 16, 54].

Given the inability to literally bring stellar mass to Earth, there are two leading mechanisms for producing fusion: inertial and magnetic confinement. Inertial fusion involves compressing the atoms until they fuse. Among the many ways of performing this compression, extremely high powered lasers are fired upon mm-scale targets. The lasers impart such a force on the outer shell of these targets that the material is crushed sufficiently to generate fusion reactions. The National Ignition Facility (NIF) [11] performs this type of research within the U.S.. This work is relevant to stewardship of the national nuclear weapon stockpile, however, and the NIF is not a User Facility even though it is managed within the Department of Energy. Figure 2.10 from NIF [43] shows an example target within a housing irradiated by lasers (in this particular setup, the lasers strike the housing, which then emits x-rays all around the target to compress it evenly).

The other common approach to fusion energy is magnetic confinement. In this approach, a vacuum vessel is surrounded by electromagnets. These create a magnetic field inside the vessel. Gas is then introduced into the vessel and superheated such that it fully ionizes, that is, the electrons separate from the atoms, allowing the negatively charged electrons and the positively charged nuclei to travel independently throughout the vessel. These charged particles gyrate about the magnetic field, even as they are heated such that they reach energies (velocities) sufficient to fuse with other atoms when they collide. These vessels are typically toroidal, or donut-shaped, so that the particles are better contained. While this basic concept provides flexibility for many different designs, the implementation that currently features the best fusion performance is known as the tokamak [74]. Figure 2.11 shows a conceptual drawing [39] and an internal photo from DIII-D tokamak [60].

[11] https://lasers.llnl.gov/

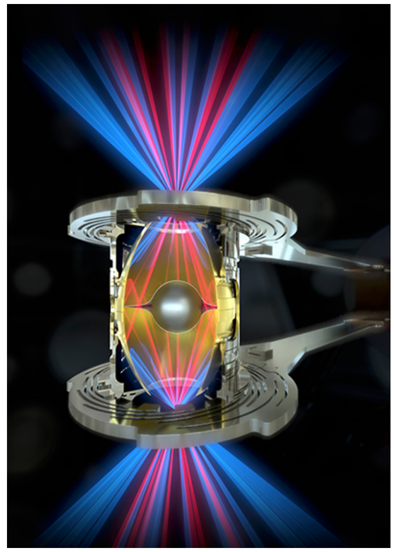

Figure 2.10. Lasers striking a target in inertial fusion. Image taken from, National Ignition Facility, Image Credit to Jacob Long. "Pursuing Fusion Ignition," https://lasers.llnl.gov/science/pursuit-of-ignition.

2.6.2 Background and Funding Levels

Fusion Energy Sciences (FES) is one of the six U.S. Department of Energy, Office of Science programs that manages User Facilities. As stated in its mission statement (see Table 2.1), FES supports research into basic understanding of matter at high temperatures and densities, and also supports fusion energy development.

The funding level of FES is described by the three panels in Figure 2.12. This data comes from the FES Budget archive[12]. These budget values represent the enacted levels, which are typically reported (finalized) near the end of the fiscal year as a consequence of the U.S. government's budgeting processes. Figure 2.12(a) compares the total FES budget with the total of its User Facilities. Both the total FES budget and the amount allocated to FES User Facilities have risen faster than inflation since 2013. Comparing the 2013 and 2021 enacted levels, the FES budget has increased the equivalent of 7.5% annually, and the share to User Facilities has increased the equivalent of 6.5% annually. In actuality, the decline leading up to 2017 has been overcome by the steady increases since that year.

[12] https://science.osti.gov/fes/About/FES-Budget

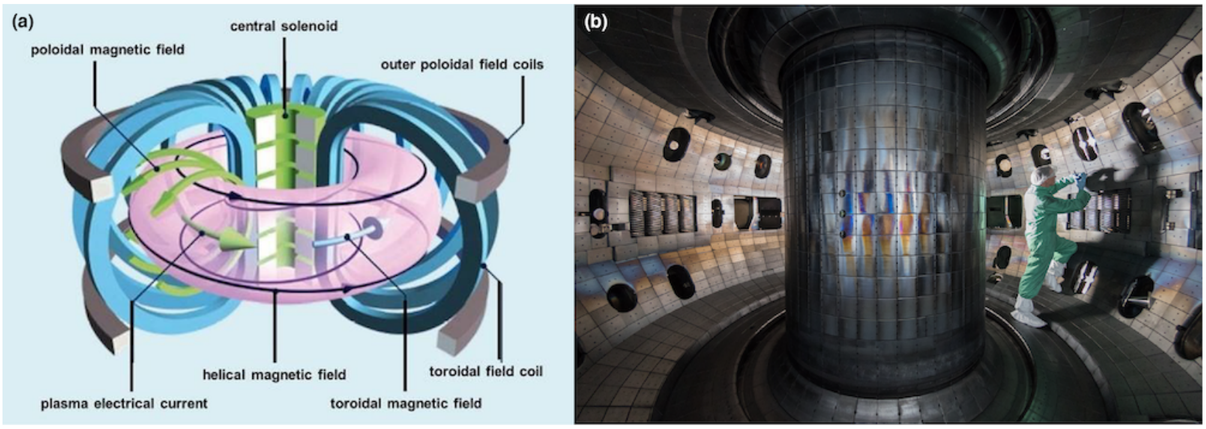

Figure 2.11. (a) Tokamak concept indicating primary coils and resulting magnet fields. Taken from, M. Lanctot, "Doe explains...tokamaks". Image courtesy of EUROfusion, https://www.energy.gov/science/doe-explainstokamaks. (b) Interior of the DIII-D tokamak. Taken from, Tokamak Photo, available through Wikimedia Commons, https://commons.wikimedia.org/wiki/ File:2017_TOCAMAC_Fusion_Chamber_N0689.jpg.

In 2021, approximately one third of the FES budget was allocated to support of its two User Facilities, which are detailed in Secs. 2.6.5 and 2.6.6. This situation arises because FES funds many fusion-related activities in addition to the research performed at the User Facilities. For example, U.S. contributions to the international project known as ITER[13] come from within the FES budget. These contributions are in-kind, meaning that the U.S. provides hardware and software for the ITER device (a tokamak), not simply cash. Budgeted funds for these contributions are largely spent on activities conducted within the U.S., such as the construction of the central solenoid by General Atomics near San Diego, CA[14].

Figure 2.12(b) shows the enacted funding for three FES User Facilities along with a total for "Direct Industry" funding, which is the total of the data shown in Figure 2.12(c). The User Facility funding plot includes that for Alcator C-Mod[15], which was shut down during this period and last received funding in fiscal year 2016. The other two User Facilities, the DIII-D National Fusion Facility (DIII-D) and National Spherical Tokamak Experiment-Upgrade (NSTX-U) remain active and supported. Support levels for NSTX-U are complicated by the fact that the facility experienced a major failure shortly after completing its upgrade from NSTX to NSTX-U. After completing 10-weeks of experiments, the NSTX-U device suffered a coil failure from which is has not yet recovered. While initial estimates from 2016 suggested that the

[13] https://www.iter.org/
[14] https://www.ga.com/iter-cs-fabrication
[15] https://www.psfc.mit.edu/research/topics/alcator-c-mod-tokamak

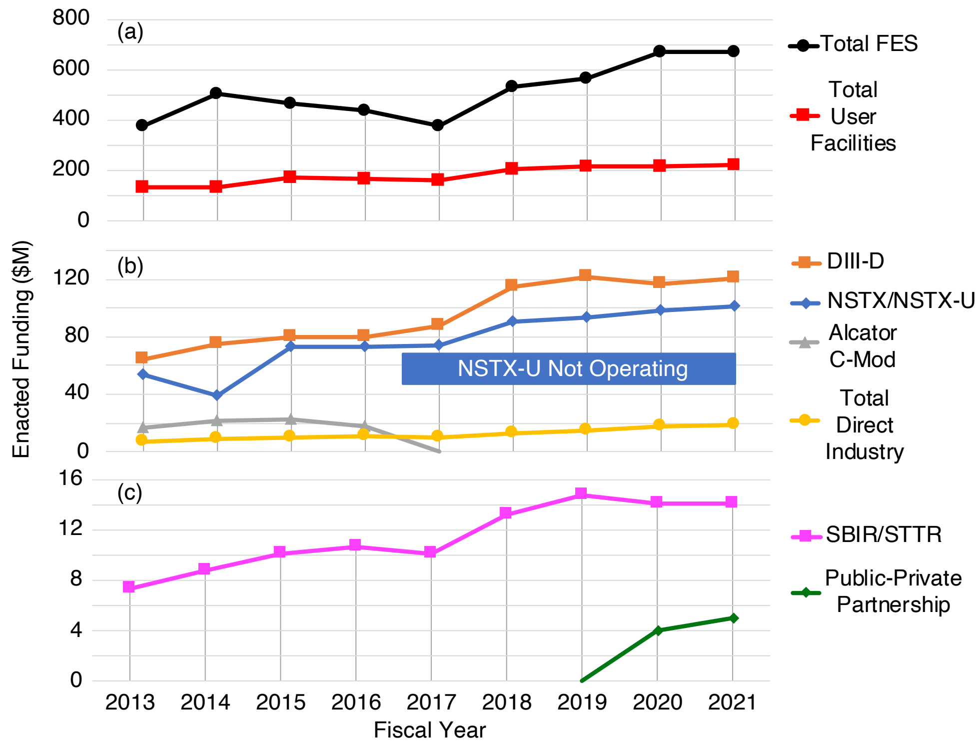

Figure 2.12. Enacted budgets for FES (a) in-total, (b) specific to User Facilities, and (c) specifically catered to industry development.

downtime might last a single year [61], and in 2018 there was new optimism [46], as of 2022 the device has not completed repairs and remains inoperable. The increasing budget level for NSTX-U may be reasonably interpreted as necessary to support the design and execution of repairs following a detailed analysis and review period, but it does not directly represent research output.

The DIII-D budget level demonstrates the same growth trend of that of NSTX-U. The facility has engaged in research operations during this period. For both DIII-D and NSTX-U, the budget level includes support outside of that going directly to the facilities. The enacted support levels for FES User Facilities includes both the operation of the facility, and a selection of researchers from institutions other than the managing organizations. The Department of Energy provides opportunities for researchers to apply for funding of fusion research to be conducted at DIII-D or NSTX-U, for example, Funding Opportunity Announcement Number DE-FOA-0002562 [65], and selected award winners receive funds that were originally included in the total budget for the relevant User Facility. In this regard, it is not possible to immediately determine a changing budget level's effect on facility operations compared to expansions or contractions of the user base. The FES budget archive files through fiscal year 2021 separated out User Facility operations and research, while the 2022 release did not.

Finally, Figure 2.12(c) separates out the FES budget categories that are considered direct support of industry. The funding opportunities referenced as SBIR and STTR, discussed in Sec. 2.4, target recognized small businesses. The amounts shown here represent the FES funding that was allocated to those programs. The level of support generally follows the trend of the total FES budget, though the recent emergence of a new sub-program may affect this level into the future. As shown, a new FES sub-program called the "Public-Private Partnership" began in fiscal year 2020 and continued into 2021.

The public-private partnership sub-program is executed by FES as the Innovation Network for Fusion Energy (INFUSE)[16]. As stated on its website, "The objective of INFUSE is to accelerate basic research to develop cost-effective, innovative fusion energy technologies in the private sector." The INFUSE program does not provide direct funding to the industrial firms, rather, selected winners receive support through new funding provided to national laboratories to perform the work. In essence, winning an INFUSE grant provides resources to existing FES national laboratory researchers and other staff to enable them to work with the selected industry partner. The industry organization is required to provide a cost share in the amount of 20% of the full project cost. The INFUSE program provides access to university staff who are associated with FES grants. While the FES User Facilities are not connected to the INFUSE program, the Princeton Plasma Physics Laboratory, which hosts NSTX-U, is a participating organization.

The INFUSE program, with its direct tie-in to industry focused organizations, should be expected to generate much better information concerning the ability of fusion research output to advance commercial enterprise. Further investigation into the general class of public-private partnerships and the unique implementations relevant to the fusion industry is provided in Sec. 3.2.

2.6.3 FES Perspectives on Industrial Role

A collection of public documents and various statements made by Fusion Energy Sciences personnel (at conferences, etc.) provide input on the FES approach to supporting the fusion energy industry. The primary industry engagement occurs through the solicitation of proposals for direct funding. These award opportunities are generally open to for-profit organizations and the announcements are made publicly through government websites. There is also an FES-specific website[17] that announces all open competitions.

[16]https://infuse.ornl.gov/what-is-infuse/
[17]https://science.osti.gov/fes/Funding-Opportunities

The FES program is aware that some fusion industry organizations have experienced difficulties becoming engaged with the fusion-specific User Facilities (industry comments to this effect are included in Chapter 3). In response, FES initiated a project to classify the DIII-D National Fusion Facility as a designated non-proprietary User Facility. When complete, this designation actually allows both non-proprietary and proprietary uses of the Facility according to the prospective user's preference. The goal is to enable users to participate in research at the Facility regardless of whether they have any FES funding. The project was initiated in 2021 and is expected to be finalized in 2023, though the first user to join the Facility under this program has already arrived.

Initiation of this DIII-D adjustment is a recognition of the low level of industry participation in the User Facility. The Material Plasma Exposure eXperiment (MPEX)[18], scheduled to begin construction in 2023, will not operate as a formal User Facility, but is including industry participants in the creation of its research plans [50].

2.6.4 Technologies Associated with Fusion Energy Development

A wide range of high-technology applications are required in fusion energy research. The tokamak environment (which, again, is not the sole device to study fusion, but does represent most of the technology requirements that exist across the wider field) features high vacuum, magnetic fields, radiation, and pulsed power. Development of these devices over many decades has led to spin-off products used outside of fusion. The research community and the Department of Energy have sponsored assessments of these derivative technologies to varying degrees of detail [5, 7, 29].

The most detailed assessment of technology spin-offs from fusion research in the U.S. was performed at the request of the Department of Energy (DOE) through a charge[19] to the Fusion Energy Sciences Advisory Committee (FESAC). The final report [29] identified many areas in which DOE-supported fusion research contributed to commercial developments. Since this included all derivatives from any DOE-FES supported efforts, it extends beyond contributions arising directly from operation of FES-directed User Facilities. Some key examples cited in the report include:

[18] https://www.ornl.gov/mpex

[19] https://sc.osti.gov/-/media/fes/fesac/pdf/2015/signed_Non_Fusion_Application_Charge.pdf

- High-power microwave generators developed for heating fusion plasmas are being explored by the U.S. National Aeronautics and Space Administration (NASA)[20] for use in rocket or satellite propulsion.
- Radio-frequency generators developed for generating plasmas are being further developed by the Ad Astra Rocket Company[21] for use in space propulsion.
- Development of nuclear grade silicon carbide that enables the next generation of accident-tolerant reactor cores for fission reactors.
- Development of cast stainless steel, which, compared to equivalents, is stronger and amenable to advanced production techniques that improve manufacturing efficiency.

The report identifies some key motivations for the present investigation. To begin, the report identifies that the economic impact of fusion spin-offs is poorly known. The most recent quantifications of this information were produced 10 - 15 years before the report (putting them now 17 - 23 years in the past). Present research into this question produces no newer relevant data. Connections between advanced research conducted with FES funding and eventual commercial applications appear to be produced through investigations after the fact, as opposed to monitored through the work itself. It is therefore worthwhile to engage industry to determine their assessment of the value that resources and capabilities from FES User Facilities provide. More importantly, it is valuable to engage industry to identify the ways in which FES User Facilities can provide better opportunities for transporting fusion developments from the laboratory to the public.

A second issue with the report is that this information was compiled by surveying the FES-supported researchers. In essence, those performing the research are asked to list out the assorted commercial achievements of their work. The quality and accuracy of this input is determined by the level of engagement of these researchers with their industry partners. Analysis from Section 2.3 shows that industrial engagement through the User Facilities is low, so there is reason to suspect that this survey approach leaves some connections uncovered, and others misrepresented. The following two examples illustrate the large difference in commercial success of the two space propulsion items noted in the list above.

The radio-frequency generators developed with FES support represent a successful technology transition. Ad Astra Rocket Company is an incorporated and privately held firm. They exercise intellectual property control over the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) and publicly attribute the

[20] https://www.nasa.gov/
[21] https://www.adastrarocket.com/

importance of NASA and DOE contributions to its development[22]. The Chief Executive Officer, Dr. Franklin Chang Diaz, completed his doctorate within the Plasma Science and Fusion Institute[23], an FES-supported entity. The firm has won NASA contracts to support additional commercial development of the VASIMR [53]. This is a clear example of a development that has made great progress in crossing the valley of death.

Compared to the wealth of information related to the VASIMR development, there is no indication of further commercially relevant work conducted on the gyrotron-powered rockets. The FESAC report was released in 2015. In 2018, researchers in Japan used a MW-class gyrotron to impart thrust on a target [27], another academic test involving universities. Most recently, a 2021 research project (from different universities in Japan) returned to lower power test gyrotrons citing their reasoning as [59] (emphasis added), "However, the flight demonstration requires an over-MW-class continuous-wave microwave source, which is *hard to procure and difficult to use* in this level of concept study." It is reasonable that gyrotrons might not have decreased in price appreciably in six years time, but the lack of direction from industry (including the absence of any obvious industry representative) suggests that this is not a viable spin-off. The conclusion is that gyrotron development has not advanced sufficiently to make large-scale commercial impact as a space propulsion mechanism, that this technology has not crossed the valley of death, and that fusion researchers should not be expected to report on the efforts of industrial partners with whom they may have little interaction.

2.6.5 DIII-D National Fusion Facility

The DIII-D National Fusion Facility is a tokamak device managed by the private, for-profit firm General Atomics. Located in San Diego, CA, the DIII-D device was commissioned on March 3, 1986. The concept of User Facilities emerged later, and DIII-D was recognized as such in fiscal year 2012 [21]. The Department of Energy, Office of Science, Fusion Energy Sciences program funds the facility and retains ownership of all hardware. General Atomics provides overall management of the facility, including the establishment and maintaining of access to all interested researchers as required for all User Facilities. A wide photograph of the facility is shown in Figure 2.13, taken from a press release [44].

User data from DIII-D is shown in Figure 2.14. The total reported research user count is given in Figure 2.14(a). This indicates a steady increase in user base since 2017,

[22] https://www.adastrarocket.com/our-engine/
[23] https://www.psfc.mit.edu/

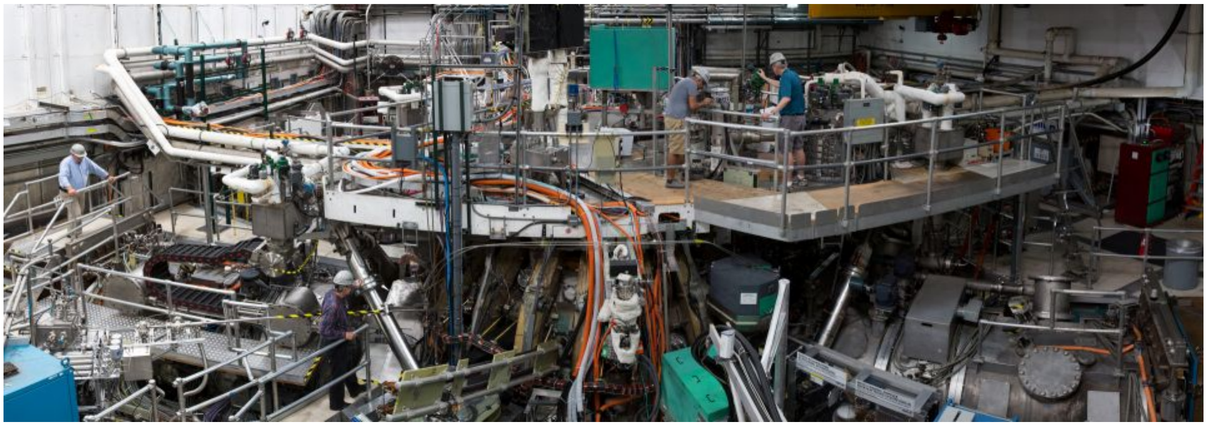

Figure 2.13. Panoramic photo of the DIII-D National Fusion Facility. Most of the device is located below the photo boundary. Photo taken from Nuclear Newswire, "General Atomics' compact fusion design shows net-electric potential," American Nuclear Society, April 6, 2021.

which corresponds to both an increasing funding level for the facility, and the period during which the other fusion User Facility has not been operational (see Figure 2.12).

Industrial user organizations are shown in Figure 2.14(b). Of the 19 industry organizations that provided users to DIII-D in fiscal year 2020, one of them is General Atomics, the organization that provides management oversight of the facility. Of the remaining 18 industry organizations, 14 are classified as small businesses. The four that are not classified as small businesses appear to be incorrectly categorized or included. These firms are listed in Table 2.2. Both Alphawave Research and Palomar Scientific Instruments appear to qualify as small businesses. The other two, Convergint Technologies and Peak Technical Staffing are international firms with a large number of locations, but they provide information technology services and staffing services, respectively. The two personnel associated with these two firms are listed as performing "Engineering" projects, which is an insufficient description to clearly determine their possible contributions to innovative fusion research.

For the sake of this analysis, it seems reasonable to treat all 18 industry organizations as small business. Among the larger of the reported firms, Commonwealth Fusion Systems (CFS)[24] was also classified as a small business. In that year, CFS had already raised $200M in capital [18] and was rapidly adding staff. It is correctly classified as a small business, however, because it fits within standards published by the U.S. Small Business Administration (SBA)[25]. Reviewing requirements

[24]https://cfs.energy/
[25]https://www.sba.gov/size-standards

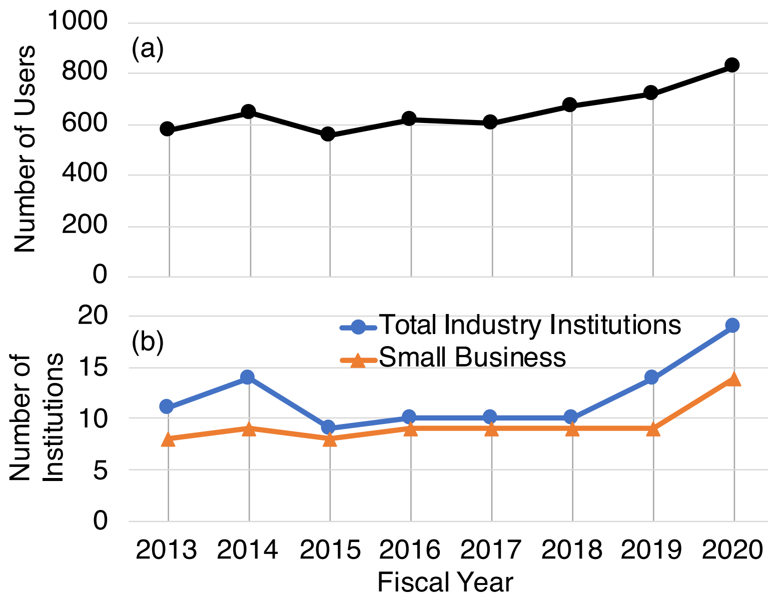

Figure 2.14. (a) Reported number of research users of the DIII-D National Fusion Facility. (b) Total number of research user institutions identified as being part of industry, and the sub-category of those organizations that further qualify as small businesses.

from the SBA, a North American Industry Classification System (NAICS)[26] value of 541715, corresponding to the industry of "Research and Development in the Physical, Engineering, and Life Sciences (except Nanotechnology and Biotechnology)," states that any firm with fewer than 1,000 employees qualifies as a small business. All of the firms engaged in research at DIII-D have fewer than 1,000 employees.

Analyzing the number of DIII-D users per industry-identified institution shows that twelve of the 18 institutions provided a single user. As noted in Section 2.2, the number of users per institution is not necessarily indicative of the level of engagement. Still, given that all of these organizations are small businesses, and that access to facility data requires being recorded as a user, it is likely that these 12 organizations interact with the program through a single individual.

The largest industry participant in the DIII-D program is its managing firm, General Atomics. While General Atomics is a privately held company, it reports a labor base of over 15,000 employees working in various defense and technology sectors, including fusion energy development research, across the globe[27]. User data indicates that General Atomics personnel participate in areas that relate to facility operations

[26]https://www.census.gov/naics/
[27]https://www.ga.com/about

("Engineering") and also those directly related to fusion research ("MHD/Disruptions" where MHD stands for magnetohydrodynamics, a fundamental research area in magnetic confinement fusion). General Atomics does not generate many patents in the areas related to fusion technologies (details on fusion industry patenting appear in Chapter 3), indicating that commercial developments from participation in DIII-D efforts are either minimal, or indirect. Indirect developments would include staff learning about fusion science and technology from work in the DIII-D program, and then separately executing commercially-supported research and development leading to business contracts.

The DIII-D facility does not provide proprietary usage as an option. All industry organization participation (and all other research) falls under the non-proprietary use category, with all resulting data being available to the entire DIII-D user base. Internal presentations to the user base in 2021/2022 indicate that new facility policies and processes will enable proprietary use of DIII-D in the near future (details being developed through 2022).

2.6.6 National Spherical Torus Experiment-Upgrade

The National Spherical Torus Experiment-Upgrade is the other User Facility overseen by the Fusion Energy Sciences program within the U.S. Department of Energy, Office of Science. The NSTX-U facility is an upgraded version of the original NSTX, which itself began operations in 1999. The upgrade saw increases in capability that allow NSTX-U to employ stronger magnetic fields and create longer duration plasma pulses. The facility is referred to as NSTX-U in this treatment, even when historical analysis may extend far back enough that the device was actually NSTX. An overview photo of the NSTX-U device is shown in Figure 2.15, where the appearance of stairs and handrails provides size perspective. NSTX-U is located on the campus of the Princeton Plasma Physics Laboratory (PPPL)[28], which is one of the U.S. Department of Energy National Laboratories and is managed by Princeton University.

The analysis that follows is influenced by the lack of experimental operations in NSTX-U since 2016 (see Figure 2.12). Experimental operations have been paused while device repairs progress. It should therefore be expected that the user base would decrease, although the availability of other research avenues may have grown, e.g., theoretical pursuits or the analysis of previously acquired data. The NSTX-U program is of great interest in the context of the fusion industry because it records proprietary

[28] https://www.pppl.gov/

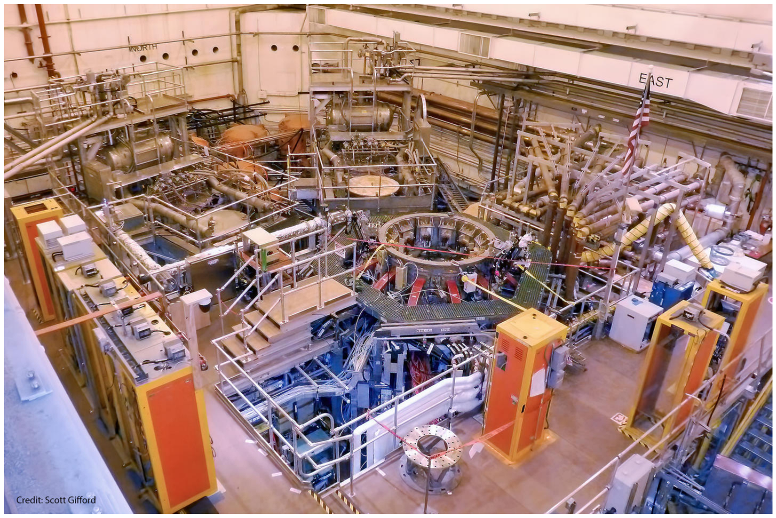

Figure 2.15. Overview photo of the NSTX-U facility. Photo credit: Scott Gifford, https://www.pppl.gov/research/nstx-u

use across its history. While proprietary uses are not the only mechanism by which commercial developments might arise from User Facility research (see Sec. 2.5), the existence of proprietary use still suggests that the acquisition of intellectual property for commercial exploitation was a goal of the effort.

The NSTX-U reported user base history is shown in Figure 2.16. Figure 2.16(a) highlights an incredible growth from 2014 to 2015. The user base size in 2015 more than doubles (244% increase) that of the previous year. This is almost certainly due to the excitement surrounding the beginning of NSTX-U operations (following the upgrade from NSTX) in 2016. While the user base reduced in size following the component failure and pause in NSTX-U operations, it remains above the marks set in the NSTX era. Industry and small business participation is shown in Figure 2.16(b), where almost all industry participants are reported as small businesses. In 2020, in fact, all five industry participants were small businesses. In recent years, the single for-profit organization that was not a small business has been General Atomics, which did not record any NSTX-U users in the 2020 reporting year (hence the lack of non-small businesses in that year).

Proprietary uses of NSTX-U appear in fiscal years 2015 through 2017. A discussion detailing these uses follows, but must be flagged with a caveat: in a series of interviews with personnel knowledgeable about the facility and the works in question, every single person indicated that they believed these proprietary classifications are incorrect. Separately, there are no records of cost recovery for any experiment performed at NSTX-U and there is no publicly-available information concerning how

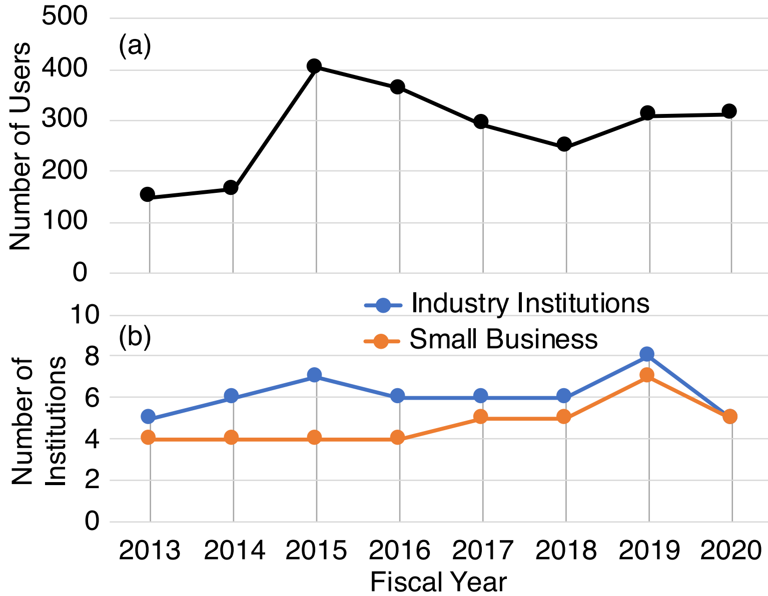

Figure 2.16. (a) Reported number of research users of the National Spherical Torus Experiment-Upgrade. (b) Total number of research user institutions identified as being part of industry, and the sub-category of those organizations that further qualify as small businesses.

cost recovery estimates are generated (that type of information might be available to users who have access to internal documentation). It is therefore likely, but not proven, that proprietary projects have not been performed at NSTX-U.

Table 2.3 lists the organizations and the number of personnel who engaged in proprietary projects during this time. The organizations include universities, U.S. Department of Energy National Laboratories, and private industry (a separate entry for the "University of Tennessee - Knoxville" has been included in the University of Tennessee row). Of the private industry firms, Tokamak Energy[29] is the only one engaged in the development of a complete magnetic confinement approach to energy generation. Tech-X Corporation[30] provides physics simulation software, and Nova Photonics, Inc.[31] provides optical components and ion source technologies. Nova Photonics also specializes in tokamak diagnostic design and operation. In the 2020 report, Tech-X, Seoul National University, and Culham Center for Fusion Energy do not appear as NSTX-U participating institutions. The other organizations do appear, but all project work is classified as non-proprietary.

[29] https://www.tokamakenergy.co.uk/
[30] https://txcorp.com/
[31] http://www.novaphotonics.com/index.html

The funding support for the proprietary work indicated in Table 2.3 is particularly simple. Of the 34 personnel working on proprietary projects over these three reporting years, 28 of them (82%) were funded by the Fusion Energy Sciences (FES) program of the U.S. Department of Energy, Office of Science. The foreign institutions are listed with "Other" as their funding source, which is the standard for non-U.S. sources in the data across all User Facilities.

Details on the requirements for conducting proprietary work through FES (or any other government source) are not readily accessible. The Office of Science provides access to basic information about grants and other awards through the Award Search functionality of their Portfolio Analysis and Management System (PAMS)[32]. In the case of Nova Photonics, the company has three active FES support vehicles (two grants and a cooperative agreement). These indicate a total award to date of $3,053,505.23 since September 2019, which occurs well after the proprietary work indicated in the NSTX-U reports. The titles and abstracts of these in-progress awards indicate that Nova Photonics provides diagnostic services to NSTX-U in addition to other fusion research efforts.

[32] https://pamspublic.science.energy.gov

Table 2.1. Science Programs within the Office of Science

Program	Stated Mission	Number of User Facilities (2021)
Advanced Scientific Computing Research (ASCR)	"to discover, develop, and deploy computational and networking capability to analyze, model, simulate and predict complex phenomena important to the Department of Energy and the advancement of science."	4
Basic Energy Sciences (BES)	"supports fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support DOE missions in energy, environment, and national security."	12
Biological and Environmental Research (BER)	"to support transformative science and scientific user facilities to achieve a predictive understanding of complex biological, earth, and environmental systems for energy and infrastructure security, independence, and prosperity."	3
Fusion Energy Sciences (FES)	"to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source."	2
High Energy Physics (HEP)	"to understand how our universe works at its most fundamental level."	3
Nuclear Physics (NP)	"to discover, explore, and understand all forms of nuclear matter."	4

Table 2.2. Industry Organizations Participating in DIII-D Program and Not Listed as Small Businesses

Organization	Website
Alphawave Research	http://www.alphawaveresearch.com/about.html
Convergint Technologies	https://www.convergint.com/about/about-us/
Palomar Scientific Instruments	http://palomarsci.com/
Peak Technical Staffing	https://www.peaktechnical.com/engineering-staffing/

Table 2.3. Organizations and Number of Personnel Participating in NSTX-U Program through Proprietary Projects, by Fiscal Year

Organization	2015	2016	2017
Culham Center for Fusion Energy	1		
Lawrence Livermore National Laboratory (LLNL)	1	1	
Massachusetts Institute of Technology (MIT)	1	1	
Nova Photonics, Inc	4	4	5
Princeton Plasma Physics Laboratory (PPPL)	2	2	
Seoul National University	1	1	1
Tech-X Corporation	1	1	1
Tokamak Energy	1	1	
University of Tennessee	1	1	2

CHAPTER 3
THE FUSION ENERGY INDUSTRY

3.1 History and Status

To the extent that it is possible for a large group to have a singular goal, the fusion energy industry is essentially focused on *saving humanity* by realizing sustainable energy production through nuclear fusion. A recent industry survey [28] states that 35 for-profit organizations are known to be engaged in this field, with details provided on 23 of them. Twelve of the 23 organizations detailed were founded in 2016 or later. When that survey was released, four of these organizations held 85% of the $1.9B in private funding raised. Since that time, the funding distribution has skewed further as two of those organizations raised additional funding over $2B [19, 35].

Twenty-two of the 23 of the organizations that responded to that survey indicated that electricity generation is one of their target markets. Other possible markets include space propulsion and a wide range of revenue streams supported by the auxiliary technologies. Electricity generation is inherently a capital intensive market. Any fusion energy effort will require the demonstration of an electricity-producing plant (never demonstrated to date) and associated regulatory developments. The extent to which nuclear regulatory clarity is required depends on the particulars of the technical approach, though, in general, the approaches that do not produce a radioactive environment are orders of magnitude more difficult than those that produce neutrons.

The organizations that wish to produce fusion energy are building a series of devices to demonstrate the particulars of their concepts. This process mirrors that of the government-driven research effort of the past, though the industrial firms are not necessarily required to produce academic outputs such as Ph.D. graduates and peer-reviewed research publications. The ties to academia and collaborative development remain strong within the industry. For example, some of the organizations that are focused on designing and constructing facilities are able to create review panels with participation from external researchers who donate their time for the task. Such uncompensated participation is unheard of in other industries, e.g., pharmaceuticals, and this demonstrates the early stage of the transition of fusion energy from a research-dominated effort (driven by cross-institutional collaboration) to a commercialization effort (driven by intellectual property creation and the securing of revenue streams).

The Fusion Industry Association (FIA)[1] is very active in promoting the growth of this industry. The FIA was also the co-lead (with the U.K. Atomic Energy Authority [UKAEA]) of the industry survey [28], and has collected and shared a considerable amount of data that quantifies the resources and goals of its member organizations. The number of patents filed by members of the FIA seems to have begun a rapid increase beginning in 2013. There are 13 different members of the FIA who have filed patents. One possible reason for the increase is that fusion firms may be constructing "patent walls" as a method of increasing the barriers to entry for possible competitors [13]. If so, then this represents a clear commercialization shift that might lead to a reduction in voluntary participation from academia. As an appropriately skilled workforce is built up, however, participation from academia should become less important.

Concerning workforce development, the FIA/UKAEA survey specifically called out the needs for a "diverse and representative workforce." This early acknowledgement of the importance of representation gives the fusion industry an opportunity to prioritize efforts in this area. The goal within the fusion industry is to avoid the development encountered in the information technology industry, where the lack of diversity is detailed in terms of both raw numbers and the negative personal experiences of members of underrepresented groups [30].

3.2 Perspectives on Public-private Partnerships

Members of the U.S. fusion research community, including representation from academia, User Facilities, and industry, produced a long-range plan [40] that has been approved and set as official guidance to the Department of Energy, Fusion Energy Sciences (FES) program. A separate report from the National Academies of Sciences, Engineering, and Medicine (NASEM) [42] focuses on the goal of fusion-produced electricity. Both of these reports provide strong support for the use of public-private partnerships (PPPs) to accelerate the development of fusion-produced electricity. In both reports, the NASA Commercial Orbital Transportation Services (COTS)[2] program is referenced as an example of the type of program that would work in a fusion application.

The concept of the public-private partnership has many different interpretations, and the fusion-relevant issues are discussed here. A simplified description of the fusion

[1] https://www.fusionindustryassociation.org/

[2] https://www.nasa.gov/commercial-orbital-transportation-services-cots

community's request is for PPPs that allow government funding to be used for the development of commercial technologies. This is an entirely reasonable request considering the high capital costs for bringing a yet-unproven technology to the power grid. Since no fusion-based, net-energy, electricity producing device has been demonstrated, and since the achievement of sustainable energy in a human-controlled form (as opposed to the variable nature of wind and solar) is necessary, there is clear public benefit to using government funds to accelerate this development.

In applications around the world, PPPs are commonly employed for projects that produce public infrastructure. In successful PPPs, the skills and expertise (efficiencies) of the private sector are applied to deliver this infrastructure [57]. This differs from simply contracting for-profit firms in that suitable PPP projects involve higher levels of risk for the firm and the PPP structure provides a level of mitigation. PPPs have been applied to electricity generation using renewable sources. In addition to the funding support for infrastructure, governments use tools such as "feed-in tariffs," which provide a period of guaranteed prices, thereby removing a great deal of risk. This is identified as one of the most important ways to provide support for the development of renewable energy [73]. Until fusion energy is demonstrated to produce grid-ready electricity, these types of PPPs are unnecessary.

There is a wealth of experience with PPPs, particularly concerning the ways in which to create a successful one. Critical success factors (CSFs), originally created in the context of information systems [52], are applicable as a general principle to any project or program. Similar to how "critical path" determines the shortest completion time in a project, the critical success factors determine the smallest number of outcomes that lead to a successful attainment of goals. Osei-Kyei and Chan [47] have identified the following five CSFs for public-private partnerships:

1. Appropriate risk allocation and sharing
2. Strong private consortium (difficult for a single organization to execute infrastructure developments)
3. Political support
4. Public/community support
5. Transparent procurement: necessary in both the initial bid/award process and in the execution of the project(s). Regular reporting and data sharing is suggested.

Applied to fusion energy development, these CSFs indicate an opportunity to design effective PPPs. The risks associated with large capital investments may dissuade organizations from pursuing pilot plant projects. A PPP could be a relatively small investment from the government for the sake of improving energy independence and growing a new infrastructure-focused industry. It is unclear just how strong the private consortium of the fusion industry might be at present. In terms of lobbying, the Fusion Industry Association leads a consistent communications program that garners nationwide attention.

Political and public support are certainly increasing for fusion energy development. The level of political support needed may still be well above the present level, however, as the U.S. recently ranked 16th in worldwide infrastructure competitiveness and was experiencing a steady decline as government funding (at all levels) focused more on health care, social security, and defense. The most common reason for a failed PPP (project not starting, with no significant funding delivered) is a lack of political consensus [22]. Federal infrastructure support has recently, just some months ago, made an enormous leap in funding levels due to the Infrastructure Investment and Jobs Act[3]. This development is incredibly timely for the fusion energy industry as many organizations have "shovel-ready" projects.

The final CSF related to transparent procurement is the only metric that is difficult to assess. Existing PPP-types of programs are relatively new, e.g., INFUSE[4], so the reporting mechanisms are evolving rapidly. This will change as new federal support for PPPs is announced.

Data sharing is an area where the fusion industry may benefit from setting standards early in the expansion of PPP programs. Energy production is a security concern for the nation, and for security-based infrastructure, the way that information is managed is important. If the PPP requirement is simply that information must be shared, then that leads to the establishment of information powerhouses or leaders, who may then attempt to maintain a dominant leadership position, thereby reducing the overall effectiveness of the PPP [9]. Once fusion energy becomes established as a producer, there will remain countless opportunities to improve efficiencies and other aspect of performance. Techniques and applications that are developed, in part, through public funds may best serve future national interests by becoming available to other organizations.

Of the negative aspects of PPPs, they may play a role in reducing the level of participation of the public, i.e., reducing the level of engagement in the democratic process. When a for-profit firm has responsibilities for an infrastructure aspect of modern society, that firm does not necessarily have to provide public engagement and

[3]https://www.congress.gov/bill/117th-congress/house-bill/3684/text
[4]https://infuse.ornl.gov/what-is-infuse/

review in the same manner as a government office. This is most concerning for areas like the privatization of prisons [4], though the importance of energy/electricity production demands that a high level of concern be applied for the fusion industry. In the 1990s, the UK privatized much of its energy utility industry. Some years later, analyses show that the ability of public entities to influence UK energy choices and development had weakened [20]. With concern for climate change and support for sustainability growing, there is a good alignment between the government's desire to de-carbonize and industry's desire to profit from sustainable technologies. The fusion energy industry may benefit from identifying methods to facilitate public engagement in facilities built through PPPs.

In lieu of a PPP, or perhaps in addition to such a program, there are various special funding mechanisms that provide equivalent support. In Russia, the concept of a Technology Platform is a type of PPP. In a case study of Technology Platforms (TPs) in Russia [49], nuclear fusion is considered a security priority and the related TP granted "monopoly" status that gives state-owned organizations priority control. Fusion also merits a "high business concentration," which is a setup applied to areas that have narrow goals and specific projects. Government authorities coordinate development projects through special funding instruments to support projects. While a state-controlled fusion energy industry is inconsistent with the economic setup of the U.S., a special recognition for the importance of fusion energy development and a support structure of federal funding would be most welcomed by the industry.

Evidence for the efficiency and the effectiveness of special funding mechanisms in developing new technologies is also found in the defense industry. Other Transaction Authority (OTA) is a special contracting mechanism intended to speed prototyping and delivery, supported through the 2016 National Defense Authorization Act. This provides the U.S. Department of Defense (DOD) with a unique mechanism to engage their preferred partners outside of traditional competitive bidding processes. OTAs have no price ceiling or requirements for small business engagement [34]. In a separate effort, the U.S. House of Representatives Armed Services cyber subcommittee directed the Department of Defense to create and execute a 5-year program of "flexible funding" in order to improve the transition of science and technology programs [31]. This is intended to make it easier for industry, and especially smaller firms, to be able to engage in business with the DOD.

3.3 Survey Feedback from Researchers in the Fusion Industry

Information in this section comes from a series of direct interviews and the responses to a survey (see Appendix A). The survey was designed to gauge respondents' awareness of User Facilities, including the various modes of engagement. While the survey was designed to be taken by multiple researchers at participating organizations, in practice, most organizations appear to have assigned a single individual to respond. As such, the survey results provide low statistical power due to a small sample size, yet still represent some coverage of the few thousand personnel employed by these organizations. Of the 22 survey responses, 18 provided full information and the remaining four provided only details on the labor pool and budget of the organization (one respondent answered all questions except for the number of employees in the organization).

3.3.1 Organizational Information

The first section of the survey concerns information about the organizations, that is, firmographics. A histogram of the number of employees at the respondent's organization is shown in Figure 3.1. The median reported size is 100 personnel, with 36.4% of the responses coming from organizations with fewer than 10 employees. Seventeen unique values were submitted. The number of smaller teams is consistent with the emergence of many new organizations over the past five years. All but one of the entires qualify as a small business by U.S. standards. This suggests that a fair number of fusion industry participants would benefit from having access to resources provided by government facilities, that is, User Facilities.

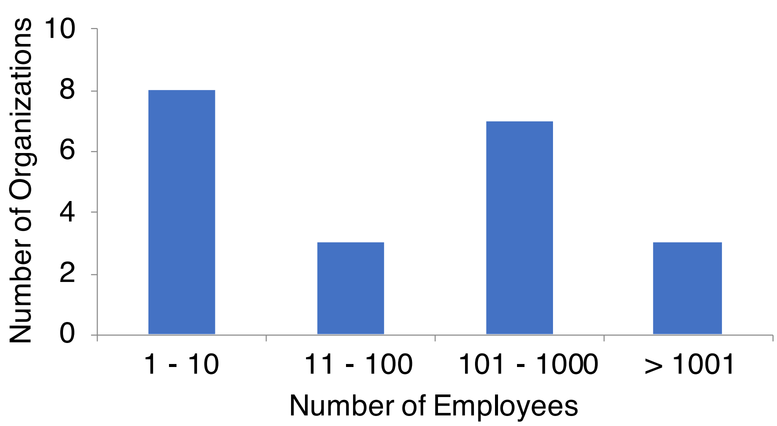

Figure 3.1. Histogram of the number of employees at the organization of the person responding to the survey.

The reported annual operating budgets are shown in Figure 3.2(a). The larger number of organizations with operating budgets over $25M is consistent with the IFA/UKAEA survey that indicated the concentration of private funding in relatively few organizations. Historically high levels of private funding are celebrated in the industry. Remarkably, a number of organizations have minimal capital targets over the next two years, as indicated by Figure 3.2(b). Half of the respondents report seeking less than $5M in new funding over the next two years.

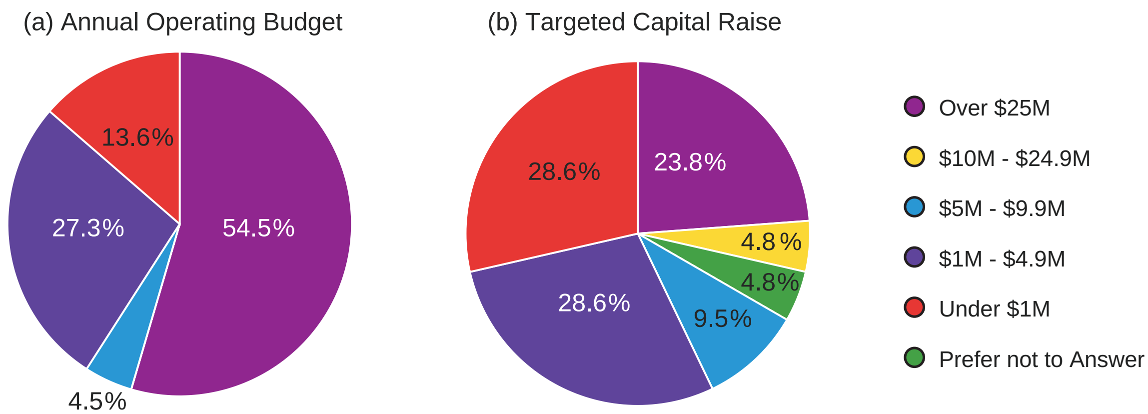

Figure 3.2. Survey respondents' (a) annual operating budget, and (b) targeted capital raise over the next two years.

The next question from the survey concerned the near-term priorities for the organization. Five different business needs were listed, and respondents ranked the importance of each. For an established industry, it should be expected that each of these general areas produce a normal distribution. There is a base level of moderate need for each item, with a few organizations stressing or minimizing the importance of select areas due to the flux of new entrants and departure of other organizations. The distributions are shown in Figure 3.3.

The need related to "Developing Business Operating Processes" most closely resembles a normal distribution in Figure 3.3. This result is sensible considering that all of the organizations that were invited to participate in the survey have established connections with existing User Facilities or professional fusion associations. A skewed distribution on this need is expected if the organization is newly formed (within the past two years), or if the industry is dominated by long-established organizations in a steady technological environment. The need related to "Raising Capital" is well represented at each level of importance. The extremely important designation is the

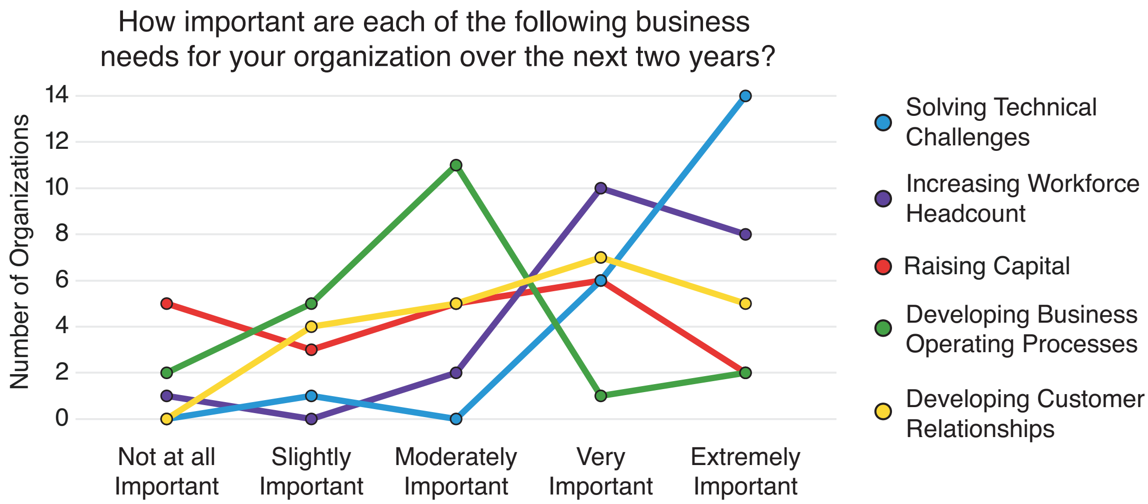

Figure 3.3. Near-term priorities designated according to their importance for respondents to the survey.

least frequent selection for this need. While this may be surprising at first, it makes sense in the context of the top priorities indicated with the other selections.

Three areas that returned a skewing toward higher importance are "Solving Technical Challenges," "Increasing Workforce Headcount," and "Developing Customer Relationships." Solving technical challenges is reported as the overall most important area, featuring a mean value response of "extremely important." Both customer relationship development and workforce increases feature mean values of "very important." These results provide context for the reduced importance on raising capital. Solving technical challenges, for example, validating a material's properties to confirm applicability in a fusion device, requires project execution that may limit the extent to which parallel developments may be entertained. Furthermore, each solved challenge provides guidance toward the selection of an approach for the larger goal. Raising capital itself requires resources, yet fusion industry organizations may need more technical answers before they can set targets for their capital needs (and they may need technical successes in order to have compelling arguments for venture capital investors). With the fusion industry needing to solve technical challenges above all other business concerns, there is a definite role for U.S. Department of Energy (DOE) User Facilities to provide access to the capabilities that are required to develop solutions.

A second business need that is skewed strongly toward high importance is "Increasing Workforce Headcount." Nuclear fusion energy includes an incredible range of physics and engineering areas, e.g., high-purity vacuum, high-intensity magnetic fields, particle and photon radiation, plasma physics, and real-time system control. With a few dozen for-profit organizations attempting to develop electricity-producing facilities, there simply are not enough people with experience in even a few of the relevant subject matters. Talented personnel with science and technology backgrounds can certainly adapt to the fusion environment, but that comes with a learning curve delay that increases the burn-rate for these companies. Furthermore, a large number of qualified engineering and scientific staff are employed at the research facilities that may serve as partners for the industry. Actions taken by the DOE to improve workforce development specifically in fusion-related fields are necessary to serve the industry (this need has been detailed in the community long-range plan [40]).

The final background question asked respondents to describe the ways in they engage partners and collaborators to address business needs. Responses confirm that the industry is a tight-knit community. Of the 16 responses to this question, 15 indicated that direct, one-on-one discussions are part of, or the primary method, for interacting with potential partners. Only three responses indicated that social media and public-facing web presence were part of their collaboration strategy. Multiple responses indicated that research personnel within the organization had good relationships with either other for-profit organizations or existing government-funded research institutions, e.g., “we have deep connections to the fusion community.”

In summary, the survey responses largely come from organizations with near-term focus on solving technical challenges and adding to their headcount. Outside assistance on technical issues comes from professional networks (consistent with the volunteerism described in Section 3.1), and those networks are also the primary mechanism by which new personnel are identified and recruited.

3.3.2 Industry Awareness of User Facilities

The next section of the survey examines the level of awareness respondents have for User Facilities. Respondents were asked to describe their level of awareness before and after viewing the User Facilities homepage[5]. These questions were provided in serial order, so respondents provided their current level of awareness before being directed to the website. The survey system confirms that respondents went to the website and spent some amount of time looking through it. Once complete (and with no prompt or request to spend any particular amount of time reading the website), respondents were asked to once again quantify their level of awareness.

Reviewing the change in awareness for each respondent provides a more complicated interpretation of the results[6]. Out of all the responses to this question,

[5] https://science.osti.gov/User-Facilities

[6] Ideally, a paired-samples t-test would be performed to quantify the change in awareness level. This is not possible, however, given the low statistical power associated with this sample size.

38.9% reported no change in their level of awareness after viewing the website. Another 27.8% reported a one-unit increase, e.g., moving from “Slightly Familiar” to “Moderately Familiar,” and 11.1% reported a two-unit increase. Interestingly, the remaining 22.2% respondents reported a decreased awareness after viewing the website (e.g., moving from “Very Familiar” to “Moderately Familiar”). One possible interpretation of the decreased awareness is that respondents believed they had a certain level of familiarity through their knowledge of the two fusion-focused User Facilities, but then learned about the other 26 User Facilities through the website. The net effect would then be for the respondent to acknowledge that their wider awareness of the User Facility program is more limited than they originally considered.

A lack of awareness of the non-fusion User Facilities has a negative impact on industry engagement. As detailed in Chapter 2, the User Facility program provides capabilities in areas of utility to fusion industry, for example, high-performance computing, and these are provided through the Facilities outside of the fusion program. The User Facilities website has a challenge in that the program includes disparate research areas, making it more difficult to convey relevant capabilities to prospective Users.

Following the review of the User Facility website, survey respondents were asked to assess the likelihood that any User Facility resources may be able to improve their business activities. This question is asked in an optimistic tone, that is, without any consideration of technical issues or other barriers to this use. Figure 3.4 summarizes the responses. Half of the responses indicated that it was likely that User Facility resources could be applied to improve their own business activities. A total of 22% find it unlikely that User Facilities are able to assist with those business needs. In general terms, fusion industry organizations have enough awareness of User Facilities to be able to determine the extent to which engagement can improve their business development.

3.3.3 Industry Engagement with User Facilities

Survey respondents were provided multiple opportunities to describe existing engagement with User Facilities and areas of potential future engagement. Figure 3.5(a) shows the reported level of engagement with any User Facility. Of the 18 responses, 83% indicated some level of engagement. Those with any engagement were then asked about the two User Facilities of the Fusion Energy Sciences (FES) program. Figure 3.5(b) shows the results from this specific question. A moderate level of engagement, or greater, is reported by 67% of respondents. Overall, the respondents

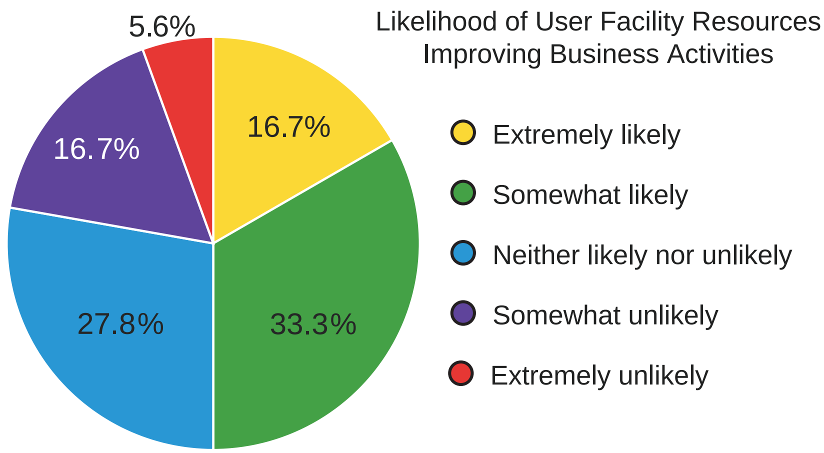

Figure 3.4. Reported likelihood of User Facility resources improving respondents' business activities.

demonstrate a moderate level of knowledge for the capabilities, resources, and functional processes of the User Facilities.

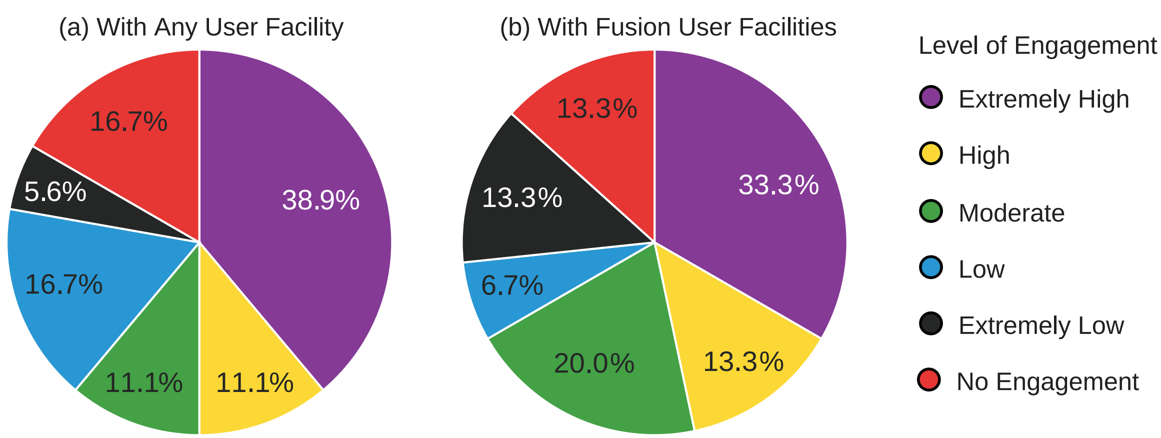

Figure 3.5. Present level of engagement reported with (a) any User Facility, and (b) User Facilities under the Fusion Energy Sciences program.

The seven respondents who indicated a low level of engagement or less (see Figure 3.5[a]) were then asked to identify the extent to which select barriers contributed to that situation. Perhaps obvious, "Internal issues within my organization," was not identified as a significant contributor to low levels of User Facility engagement. The strongest contributions are identified as high cost and a lack of relevant resources and capabilities. The lack of relevant resources is a sensible reason; there is no need for an organization to approach User Facilities if the overlap in technical capability is nonexistent.

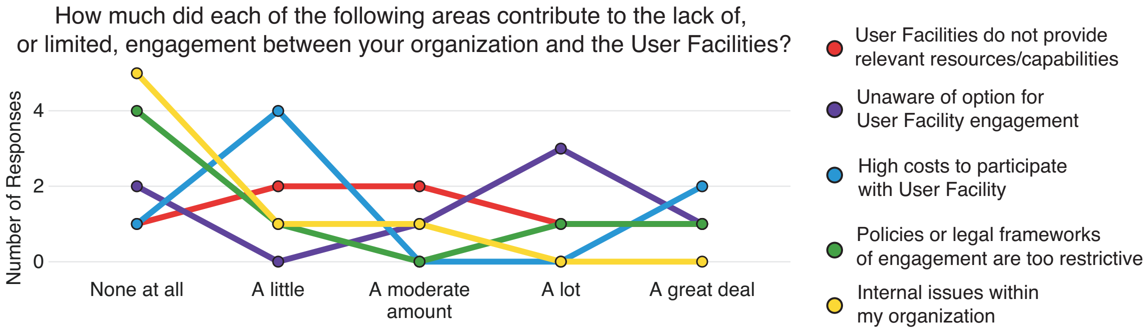

Figure 3.6. Issues contributing to low levels of engagement with User Facilities.

The concern over the cost of participation is interesting for multiple reasons. As discussed in Chapter 2, non-proprietary projects conducted at User Facilities are provided free-of-charge to users. For that type of use, the organization would only need to pay for the additional costs of travel (if necessary) and any special efforts or equipment required. The cost of their own personnel is already required, regardless of whether they are performing independent company work or User Facility projects. In a non-proprietary use case, the organization should only save on costs compared to addressing the same technical problem internally. If the work is proprietary, then the potential for large expenses due to the required cost recovery of the User Facility could well be an issue. The focus group here is involved in fusion energy research, however, and no proprietary work is known for the fusion-related User Facilities (see Section 2.6.6 for a discussion of the potential exception). It is unclear how these organizations are determining that high cost is a barrier to this involvement.

An open-ended question asked which capital investments could potentially be avoided by using resources from a User Facility. This is a meaningful question given the demonstrated relationships between respondents and the User Facilities. Table 3.1 provides a high-level breakdown of the responses, indicating that nine of 14 responses indicate some level of capital investment that could be replaced with User Facility engagement.

Table 3.1. Classification of the Scale of Capital Investment that Could be Saved through Engagement with User Facilities.

Level of Capital Investment	Number of Indications
Major and Minor Items	7
Minor Items Only	2
No Items, or Unsure	5

In the detailed responses related to capital investments that might be transferred to User Facilities, multiple technical areas of need are discussed. A histogram of words used in these responses is shown in the word cloud of Figure 3.7. While five of the responses declared that their technical approach cannot benefit from User Facility engagement (hence the inclusion of the word "none" in the cloud while other basic words were filtered out), the others provided a consistent statement on needs. Respondents indicated that some of their staff could be stationed at a User Facility, thereby reducing their need for office space and other real property. Technical areas of fusion development that are best served by User Facilities were called out as those involving neutron radiation and associated equipment to either produce relevant (high) levels of neutrons or to investigate their effects on materials. Multiple references were also made to the development of plasma diagnostics. In those cases, the diagnostics would either be provided to the industrial organization (directly, or in terms of technology transfer), or a relevant parameter space would be provided by the User Facility and the industrial organization would develop their diagnostic technology with it.

Figure 3.7. Word cloud indicating the frequency of terms in the response to which capital investments can be reduced or avoided by engaging with User Facilities.

For the sake of comparing with the possible areas of use described above, the survey asked respondents to describe their work within the FES User Facilities (question only presented to those who indicated some level of present engagement). Three respondents indicated that they wished to increase their level of interaction with these Facilities, while two called out the unavailability of the NSTX-U facility (see Figure 2.12) as a contributor to their limited interaction. In this open text response, the inputs mostly discussed challenges or barriers to participation more than the literal tasks or work performed. A general participation statement was similar to, "We regularly participate in physics experiments" was common.

Of the statements indicating challenges that limit present participation, they indicated one of two broad themes. The first theme related to the difficulty of establishing a connection with the existing tight-knit community, for example, "It's challenging to establish and grow a partnership with the well-established Facility organizations, particularly as a small business that isn't near-by." The other theme consists of messaging that the supporting government office creates barriers to participation, for example, "We would like to be more deeply involved with both DIII-D and NSTX-U but have encountered deliberate barriers with FES in both cases." The fusion research community, including its industrial organizations, benefits from close relationships among its members, but this also appears to make it more difficult for new entrants to establish connections necessary to advance their technical needs.

3.3.4 Indications of Future Needs from the Fusion Industry

The final section of the survey provided opportunities for respondents to indicate areas of future importance. Figure 3.8 illustrates the perceived attractiveness of select programs that User Facilities may offer in the future. Assigning numerical values (i.e., 1 for "definitely not" through 5 for "definitely yes") to these responses allows for determination of the mean values. Any mean value above 3.0 indicates that the responses skew toward a desirable resource or capability.

The greatest interest is indicated for computational resources (mean of 3.7), including access to high-performance computing. Mentions of the importance of computational resources appear throughout the responses. The capital costs for building a local supercomputer, and then the required maintenance and auxiliary support, put them beyond nearly all companies (not only those in the fusion energy industry). While commercial access to powerful cloud computing machines exists, for example, Microsoft Azure[7] or Amazon Web Services[8], the capabilities of national supercomputing centers remain far more powerful (additionally, research-grade computations can often be optimized for the architecture of national supercomputers, which further increases the efficiency gains compared to commercial options). The desire of the fusion industry to increase access to high-performance computing from User Facilities confirms that commercial options remain either too expensive or insufficiently powerful to serve their immediate needs.

[7]https://azure.microsoft.com/en-us/
[8]https://aws.amazon.com/

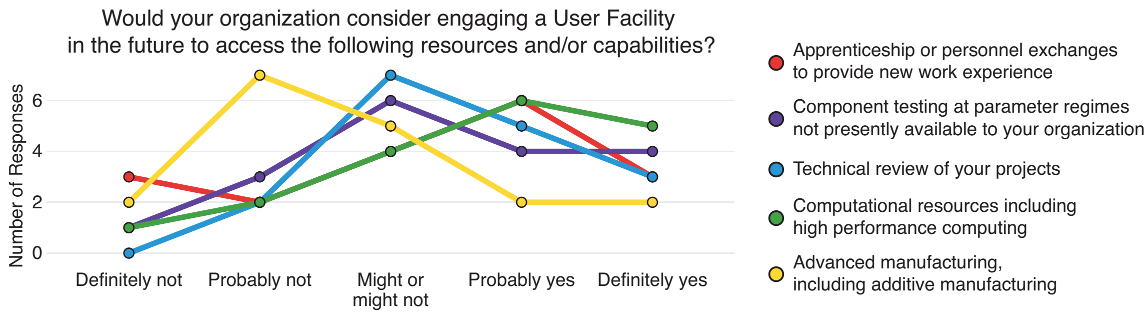

Figure 3.8. Likelihood that a respondent's organization would participate in User Facility research program given the offered resources and capabilities.

Component testing (mean of 3.4) and contributions to technical reviews (mean of 3.5) were identified as desirable. Component testing through User Facilities allows for more development to be conducted in parallel, which speeds project completion. For example, an organization designing and constructing a fusion energy device can commission diagnostics and other auxiliary systems at existing fusion devices (in the U.S., the two fusion devices that come closest to the parameter regime of an energy producing reactor are the User Facilities). Without that option, otherwise simple technical issues with these subsystems will not be discovered until the primary facility itself is complete. Technical reviews with personnel from User Facilities will not necessary speed development, but the additional perspectives do potentially reduce risk in design and operation.

The availability of apprenticeships or other work experience programs is also identified as desirable (mean value of 3.2). This result is consistent with the previously discussed priority afforded to increasing workforce headcount (see Figure 3.3). Breaking this down according to the annual operating budget of the organizations, there is a slight skewing toward higher affirmation for those with \$25M or larger annual budgets (56% in that category responding with a "probably" or "definitely" yes).

An informative result is that advanced manufacturing, including additive manufacturing, is the least desirable capability reported and the only one indicated as unlikely to be helpful (mean value of 2.7, below the 3.0 threshold to indicate usefulness) to these industry members. While the goal of building complete facilities is common amongst these organizations, none of them are actually attempting (at this time) to mass produce components. It is still somewhat surprising that this does not rank higher, especially since advanced techniques might be expected to lower risk (fail rates) in unique components.

The final open-ended survey question asked respondents to describe a potential new Department of Energy User Facility that would provide resources and capabilities of value to helping their organization execute its business model. Responses were varied, with little overlap in the descriptions. Ten responses were collected, and the suggestions are summarized in the following list.

- Unification of computational resources, for example, providing code access and distribution alongside a more user-friendly mechanism by which to acquire supercomputing time (this entry combines two responses)
- Nuclear science and engineering facility: reactor-relevant neutron environment (this entry combines two responses)
- Focus on processing low-level radioactive waste
- Advance inertial fusion energy
- Alternative fusion concepts with small size and weight: applicable to maritime and shipping vehicles
- Magnetic fusion device offering increased run time and more access than existing User Facilities: focused on enabling rapid prototyping of component subsystems such as diagnostics

The six descriptions above represent at least five different possible User Facilities. As might be expected, each respondent potentially suggested a future User Facility that would arrive on a timescale consistent with their organization's future needs (this is how the question was intended to be answered). This indicates that, even with an industry facing the same set of technical, logistical, and resource challenges, there remains an appreciable range of approaches that lead to a similarly wide range of support needs. The common thread amongst the proposed User Facilities is that they are all potentially billion-dollar class facilities that represent a single step in the progress toward fusion-produced electricity. The level of investment required for this industry remains quite large, which provides for a continued major role of at least the federal government, if not the Department of Energy and its User Facilities specifically.

3.4 Additional Feedback from the Fusion Industry

A series of formal interviews were conducted with employees representing organizations from the fusion industry. The base questions provided to the interviewees in advance are listed in Appendix B. In this Section, the suggestions and observations that provide unique input additional to those conclusions from the survey are presented. All those interviewed encouraged adjustments or major changes in the way that the U.S. Department of Energy approaches fusion energy development. Some differences in opinion arise when the specific actions necessary are discussed. Even in cases of differing opinions, however, all mentions of funding levels noted that billion-dollar levels are necessary (that would include new User Facilities, not just funding directly to for-profit organizations).

All interviewees were asked to describe the present role of the government in developing fusion energy. There was a consensus that the government role is to enable necessary technologies, for example, through the Small Business Innovation Research (SBIR) grant program discussed in Section 2.4. Due to its size and complexity, the U.S. government is viewed as a reactive and cautious partner (as opposed to being proactive). The sentiment is that industry must provide the impetus for fast-action and decisiveness, and that selective support from federal funding agencies reduces the associated risks.

A wealth of suggestions for ways in which government approaches and support might change to better serve the fusion energy industry were provided. Those suggestions that are not reflected in the survey are listed below. They fall into two broad categories: adjustments to how funding is provided to industry, and changes to how User Facility resources are made available to industry.

- Providing Funding to Industry
  - Grants should expand their scope to allow for the performance of services. For theory and modeling grants, they should allow for the infrastructure and user support services that would increase usage of the codes outside of the researchers' home institution.
  - Grants should take a holistic approach to fusion energy development. For example, fusion diagnostic development grants allow only for the design, construction, and commissioning of a new diagnostic system. Performing research under that grant is not allowed, as the system presently considers research grants separate from technology development.
  - Reduce the administrative overhead required to service a grant or other award. Reporting requirements are disproportionately challenging for small businesses in which researchers and managers are the same people. Most grants are 2-3 year awards, which is a short cycle requiring annual labor dedicated to further grant applications and reporting.
  - Dual-use for grant projects should be supported. At present, a fusion grant is limited only to the non-defense application of fusion energy. Many of the technologies required for fusion energy development have applications in completely different fields. To require a separate funding stream to explore those other uses is inefficient.
- Accessibility of User Facility Resources

- Simplifying access to theory and modeling support, e.g., making it easier for personnel at User Facilities to provide direct support to industrial organizations (note: this is one option enabled by the INFUSE program).
- Simplify the ability of industry personnel to have access to User Facility data. Interviewees report that Fusion Energy Sciences (FES) User Facilities do not have a standardized access process for potential users not funded by FES.
- Provide options for small businesses to engage in operational areas of User Facilities. This might include an open bidding process to provide such services, e.g., operation of a particular diagnostic or data analysis system, or specific encouragement of User Facilities to outsource to industry were efficiencies may be expected (note: User Facilities are allowed to subcontract as they wish, though there is no direct encouragement to do so for the purposes suggested by the interviewees).
- Apply the User Facility designation to more university-scale facilities. While smaller facilities produce a more limited research parameter space compared to larger facilities, there are many areas of technical need where sufficient parameters are available. A User Facility designation then requires the facility to be open to outside researchers, and additional funding directed toward user support should be provided.

CHAPTER 4
PROPOSED MARKETING EFFORTS TO IMPROVE INDUSTRY USAGE OF USER FACILITIES AND TO ACCELERATE FUSION ENERGY COMMERCIALIZATION

This Chapter summarizes proposed efforts that should be expected to accelerate the development of fusion energy. In this case, the efforts detailed are meant for consideration by the U.S. Department of Energy (DOE), not the fusion industry. The context is that the DOE has a considerable set of resources and capabilities that are underutilized by the burgeoning fusion energy industry. The biggest issue limiting industry use of DOE and DOE Fusion Energy Sciences resources is the lack of communication between the two groups. Perhaps this is to be expected due to the relatively young age of the fusion energy industry. Even so, a series of new activities and corrections will greatly improve this situation.

4.1 Relevant Marketing Experience of the Higher Education and Museum Industries

As an introduction to the specific marketing approaches indicated for the fusion energy User Facilities, examples of relevant issues and approaches within the higher education and museum industries are presented. These industries have considerable overlap with federally-funded research institutions, while providing a suitable literature base for exploration.

4.1.1 Higher Education Institutions

Just as fusion energy now faces, institutions of higher education faced a challenge to commercialize their research outputs many years ago. The Bayh-Dole act, discussed in Section 1.2, spurred this challenge. Universities found themselves in possession of a large research talent pool, but generally lacking relationships with commercialization-focused entities. These educational organizations needed to increase their level of interaction with industry while simultaneously defending their access to the relevant talent pool.

A study by Carayannis, Cherepovitsyn, and Ilinova focused on the approach to establishing industry connections taken by the University of Maryland, College Park (UMCP) [12]. The university established two separate offices to maximize the ability of their associated intellectual property to be commercialized. The Office of Technology Commercialization (OTC)[1] facilitates intellectual property licensing to businesses. The Maryland Technology Enterprise Institute (MTech)[2] connects state businesses with the university to identify resources of interest to business. The broader goal of increasing technology licensing and commercialization of university-led research has been largely met. From 2014 through 2019, the number of technologies licensed from UMCP grew 143% and the number of patents issues grew 19%[3]. The effectiveness of this effort stems from the university providing the relevant staffing expertise in these areas that are well-removed from the actual research lines. Equivalent resources are not uniformly available across DOE User Facilities, though they may be at higher levels within the institutions that have management oversight of the Facilities.

Another popular approach to serve these needs involves establishing (or adjusting) the institution's brand. Projects to develop "brand identities" grew exponentially from 2006 to 2013 as universities sought to secure the notion that they were good places for students to matriculate, and for businesses to develop new product or service lines. During this time, institutions of higher education found themselves in an increasingly competitive environment for students and government research grants. In some states, governors attacked "lazy" professors, and having an effective brand provided some shielding against public acceptance of such a characterization [26].

Educational institutions also use their customer base (students) as part of reinforcing their brand. Internationalizing higher education is a common goal because it increases their access to talented students and potentially extends their reach globally after the students graduate. Universities need to measure the perceived service quality of their international student population in order to proactively address that demographic, and the relevant analyses are unique compared to domestic students [55]. The base concept of using analytics to determine customer satisfaction is largely not applied within the DOE User Facilities, and certainly not used within those of the fusion energy case study.

Universities are also engaging in market-like behaviors to compete for resources other than the students. These resources include benefactors, industrial partners, and various government subsidies/support. As a classic manifestation of New Public

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[1] OTC has since morphed into UM Ventures, https://www.umventures.org/
[2] http://www.mtech.umd.edu/index.html
[3] https://www.umventures.org/about-us/reports

Management, universities are tensioned to highlight financially responsible behaviors such as increased international student participation at full tuition payment, with their originally intended purposes of educating the local populace (which may be heavily dependent on donations and government funds) [64]. DOE User Facilities face a similar challenge, namely, they must provide access to unique (often first-of-a-kind) capabilities that can be resource-intensive, while also demonstrating fiscal responsibility and efficiency as expected for programs that use public funds.

4.1.2 Museums

The marketing experience of the museum industry also provides indications of issues that are important for DOE User Facilities. Museums perform both educational and research activities and are frequently non-profit organizations. They also depend on expenditures from their patrons, similar to an educational institution collecting tuition and fees from students. One unique aspect of museums, compared to universities, is that museums feature a short-lived transactional element. Patrons can visit a museum, which consists of some few-hour on-site interaction during which there is increased possibility for the museum to extract revenue from the visitor. This provides museums with the ability to engage on a transactional level, for which modern promotional techniques (such as mobile applications suggesting gift shop purchases relevant to the specific exhibit a visitor is experiencing [24]) are expected to be effective.

The perception that museums collect and disseminate knowledge sets a patron/customer expectation that all aspects of their interaction will be state-of-the-art quality. Lukáč, et al., [41] analyzed museum communications with a goal of determining the analyses that are most relevant to determine whether the communications are efficiently bringing in visitors. The museum visitor demographic expects a high-quality in communications received, further indicating the importance for organizations to employ professional communications and marketing staff. It was separately found that professional marketing efforts correlated with increased museum attendance.

Social marketing is a specific approach that is useful to the museum industry and seems highly applicable to the DOE User Facility focus here. The term social marketing refers to activities that seek to change customer behavior (this can be a different approach from marketing that seeks to change customer perception). Gonsales [32] proposes a museum social marketing strategy that extends across funding organizations, management and leadership, and patrons. For patrons, the goal is to increase their frequency of museum visits (known as the downstream channel), Managers are targeted to increase their willingness to invest resources in marketing strategies (midstream channel). Finally, for decision makers, including legislators, the targeted change is to stop budget cuts (upstream channel). An application of this framework, including all three channels, is relevant to the fusion energy User Facilities and is provided in Section 4.3.

A final connection of relevance between museum and potential User Facility marketing is detailed in the work of Tsai and Lin [62], who provided a highly analytical approach to determining museum patron needs and the best ways to satisfy them. That work is concerned with performance analysis and performance management. It provides a classification of museums that includes the "science museum," which is very closely related to the concept of a research facility. For a science museum, the greatest risk term is related to competition from non-museums, while competitive advantage is most strongly influenced by ticket sales, visitor revenue collected through activities, and the creation of innovative experiences. Given that ticket sales are not part of DOE User Facilities, the importance of visitor revenue generated during participation (effectively, the same as cost recovery for proprietary use) and the focus on innovative experiences play a role in the execution of a valuable marketing strategy.

4.2 Brand vs. Market Orientation

Gromark and Melin [33] provide a comprehensive assessment of brand orientation compared to market orientation, and then argue that organizations in the public sector are better served by adopting a brand orientation. The crux of this argument is that organizations in the public sector typically exist to serve some need, but often a need that, while valuable to the masses, is not necessarily something for which individuals would specifically contribute funds (hence, the collection of these funds through taxes). A brand identity can convey to the stakeholders, which includes the served or benefitted public, that the organization is competent, sincere, and operating in the best interests of society. By comparison, if brand was not important, then the public and the legislature may be more willing to privatize this particular function under the influence of a perception that private sector approaches improve cost-effectiveness (though it may come at the price of reduced equity as discussed in Section 1.3).

Market orientation involves learning and understanding the current and future needs of the customers, and then sharing this information across the organization. That sharing aspect is important because the organization needs to design business processes that meet these needs. This is a shareholder primacy approach, so the customers' needs are important, ultimately, in order to maximize profits and return for shareholders.

Brand orientation is exemplified when an organization expresses strategic intent through the formation of a vision, mission, and core values. The vision concerns the status that the organization strives to attain. The mission concerns the outputs that the organization wishes to deliver. The core values represent the high-level priorities that are followed in the execution of the mission en route to achieving the vision. Customers have a lessened importance because stakeholders are considered most relevant to the brand. In the private sector, profit is one of multiple goals, as required to be consistent with a vision that typically involves being the best at some product or service category. In practice, non-profit organizations learn and understand stakeholder needs.

Continuing with the argument for the efficacy of a brand orientation in the public sector, Gromark and Melin [33] categorize public sector organizations according to their "perceived benefit" and "degree of competition." DOE User Facilities provide collective benefits and have a low degree of competition, which categorizes them as *Society-keeper Institutions*. By definition, User Facilities cannot compete with capabilities available across industry [21], so they naturally operate in areas where they hold a monopoly or near-monopoly in those offered capabilities. A society-keeper institution specifically generates benefits to the whole of society. This is easily understood for society-keeper institutions such as the court system, but perhaps less obvious for a national research institution. The benefits of public funding for basic and applied research were presented in Chapter 1. Much like a public education system, a public advanced research system improves both the functional and economic aspects of society.

In addition to the benefit of maintaining strong public support, a brand orientation can help a public institution maintain its "competence supply." This relates to the organization's ability to recruit personnel with appropriate expertise. For publicly-funded research institutions, the ability to recruit and retain researchers and related technical staff is critical. Considering that the same skills are compensated at higher levels in the private sector, DOE User Facilities partially rely on their reputation (brand) to convince technical laborers to join their ranks. Maintaining a brand that conveys the quality of the research environment (e.g., engaging with unique and first-in-kind technologies) and the priority on workforce development (e.g., professional development opportunities, including access to mentorship, beyond those typically available in industry) serves the competence supply need.

The fusion energy User Facilities of the case study do not have brands expressed through vision statements, mission statements, and core values. Across all User Facilities, some of the managing institutions (e.g., national laboratories) do have complete and publicly-shared brand identities. Considering the categorization of these organizations as described above, a set of basic guidelines for the creation of a User

Facility brand identity are provided in Table 4.1. These considerations are then applied in the generation of a proposed brand identity for one of the fusion energy Facilities seeking to increase industry participation, the DIII-D National Fusion Facility.

Table 4.1. Considerations in the Generation of a User Facility Brand

Brand Component	Guidelines
Vision	- Foundation of Excellence: support or demonstration? - Competitive Nature: be the best, or be a partner?
Mission	- Products: tangible or intangible goods? - Service: director or guide?
Core Values	Themes: sustainability, societal advance, and people

The vision statement, describing the desired status the Facility wishes to achieve or maintain, is influenced by whether the organization is demonstrating the technologies of the future or supporting others in doing so. For DIII-D, the DOE funding stream supports the demonstration of technologies as proof-of-principle, but not through the required stages for commercialization. This suggests that the DIII-D role is supportive, mixed with some responsibility to identify the areas in which a new technology could be transformational. Whether or not the Facility aspires to being the preeminent location for this work depends on whether their role is as a supporting partner or the global leader. In fusion energy, the scale of the challenge is undoubtedly large enough that no single organization has demonstrated an ability or resource-level capable of solving all remaining challenges. The best DIII-D brand should therefore embrace the role of a supportive partner that provides collaborators with access to the resources and capabilities that are not easily produced for themselves.

A mission statement is heavily influenced by the outputs of the organization. These might be tangible goods (mobile phones, automobiles, etc.) or intangible goods such as services. Tangibility is itself a spectrum in which the actual purchase may be of an item that is not purely physical or entirely a service. The primary products of DIII-D are knowledge and information. Graduate students perform Ph.D. work to develop research skills that may be applied in fields entirely unrelated to fusion energy. The design of plasma scenarios and control algorithms for future fusion pilot plants are informed by the results of DIII-D experiments. In this way, DIII-D provides a service to the community that seeks to overcome gaps in knowledge that prevent designing and building a power plant immediately. As with the vision statement, the mission statement needs to acknowledge DIII-D's role as a partner with many other organizations. Even when taking the initiative to establish new techniques, the service provided by DIII-D is that of guide more than a director, because the ultimate execution of the project remains dependent on the technical performance of partner institutions.

Finally, it is proposed that the core values of any DOE User Facility need to strike on the themes of sustainability, societal advance, and people due to their society-keeper status. These are the types of core values that argue for the acceptability of a monopoly in any given area (including the court system). In the case of DIII-D, sustainability and societal advance overlap as relevant for an energy development program. Global energy needs are a well-known issue for governments and support agencies. Quality-of-life measures are known to directly correlate with energy consumption [48], further connecting the need to develop sustainable energy sources with the need to scale them rapidly. The final theme of people is likely to involve the workforce development aspect of any User Facility, and this is the case for DIII-D.

This leads to the following example brand identity for the DIII-D National Fusion Facility,

Vision: To be the research partner of choice for organizations that seek to advance fusion energy and related technologies.

Mission Statement: Our mission is to develop the solutions that inform the design and performance advance of fusion energy power plants. We achieve this by identifying new capabilities necessary to solve outstanding challenges, and then facilitating the cooperation of fusion researchers from academia, government, and industry.

Core Values: The DIII-D program supports growth in its people and in its lines of research. Our core values are,
Sustainability: we support actions that account for the needs of future generations,
Teamwork: we acknowledge that the challenges facing modern society require the combined efforts of skilled teams to address, and
Progress: we support our teammates as they engage personal and professional development opportunities that improve their ability to contribute to the team.

4.3 Social Marketing Approach

The approach of Gonsales [32] involved creating a social marketing plan intended to increase the frequency of museum visits. This plan includes treatment of the classic four-P's of marketing [38]: product, price, place, and promotion. An outlined plan for the User Facilities of the Fusion Energy Sciences (FES) program within DOE is presented. This includes outlines for the target audiences of the downstream (customer/user), midstream (User Facility management and leadership), and upstream (government decision makers) approaches.

4.3.1 Downstream Approach: Targeting the Fusion Industry

Table 4.2 outlines the social marketing strategy for the downstream approach that focuses on members of the fusion energy industry. This target audience presently has a low level of engagement with the FES User Facilities (detailed throughout Chapter 3). Ideally, this audience would proactively approach the Facilities to determine the viability of cooperative efforts that would serve the business' needs while advancing fusion energy development. There is presently a legal barrier in the setup of the User Facilities that prevents most modes of industrial participation, but those barriers are expected to be removed soon (for the DIII-D program, at least, see Section 2.6.5). Should that outcome be realized, then it remains for the User Facilities to actually capture these potential industry participants.

Once industry participation is an option, then User Facilities must face the competition. Both universities and other publicly-funded research institutions (e.g., national laboratories) are strong candidates for assisting the fusion industry with its development needs. There are two services (still referred to as products in Table 4.2) that the User Facilities can provide to industry: workforce development and cost-effectiveness. These both represent opportunities for the User Facilities to develop a positive perception from industry. The fusion energy industry is unique (and will remain so over the near-term period of the next few years) in that many of their proposed, recently-built, and under-construction devices represent the first of their kind. The integrated technologies and environmental requirements of fusion energy (see Section 2.6.4) are uncommon in the present workforce. The two fusion-focused User Facilities provide access to much of the control and operation experience that the new devices require. Offering on-site and remote training experience for industry personnel satisfies the workforce development goals of the government program, and it provides a much needed resource for the industry.

In a way, the workforce development service is itself a cost-effective option for industry. If the participating personnel are truly working with the User Facilities to gain experience, then their participation can be performed under a non-proprietary agreement for which their host organization would only be responsible for its own costs (i.e., the User Facility resources are provided free-of-charge to the industry participants). The primary cost-effectiveness service offered by the User Facilities,

Table 4.2. Social Marketing Outline for Fusion Energy User Facilities: Downstream Approach

Target Audience	Researchers and decision-makers within fusion energy industry
Present Undesirable Behavior	Low level of engagement with User Facilities
Target Behavior	- Approaches User Facility with ideas for engagement - Provides feedback to inform future User Facility project selection
Main Barriers	Participation not allowed under present User Facility setup
Competition	Universities, publicly-funded research institutions outside of the User Facility system, other industry organizations
Product: the social proposition (benefit to the audience)	Workforce development: industry personnel able to work with User Facility subject matter experts in non-competitive environment. Cost-effectiveness: reduce required capital investments.
Price: costs of involvement (monetary and non-monetary costs to audience)	Cost-recovery: paying for User Facility resources consumed. Travel and Remote Connection: costs associated with participation at external User Facility Time: progressing through the learning curve in order to be productive at the User Facility
Place: accessibility (location where target behavior occurs)	On-site: physically present at the User Facility. Remote: present in the digital spaces of the User Facility.
Promotion: social communication (consider hyper-connected world)	Web Site: clear indication of resources and capabilities available, and the participation and engagement processes Social Media: highlighting current success stories

however, is the access to equipment that would otherwise be capital intensive for the industry organizations to produce. In addition to the devices themselves, the auxiliary systems (e.g., high-current power supplies) easily represent multimillion dollar investments. Both the DIII-D and NSTX-U facilities offer such power systems and can make them available for technology development outside of the actual fusion experiments that the tokamaks perform. The industry partner should consider whether such work could be performed under the non-proprietary agreement to further extend the cost-effectiveness of the effort. This should be a powerful mechanism for the User Facilities to increase industry participation.

Having highlighted the potential for cost-effective engagement, there are still costs charged to the industrial participants. Any User Facility work that the industrial participant wishes to keep proprietary would require cost recovery paid to the User Facility. Given the unique resources involved, including the highly educated technical staff, these costs might be expected to be on par with that of industry itself. Other costs relate to the travel and remote connection requirements that allow the industry team to perform their interaction with the User Facility. Options for remote participation appear poised to greatly reduce the need for on-site presence. The global COVID pandemic that began affecting the entire collection of User Facilities in 2019 led to the rapid development of remote participation options on a scale far greater than any previously considered project [66]. The DIII-D program highlighted their efforts to increase remote participation[4].

Under a scenario where cost-recovery is avoided through the use of a non-proprietary agreement, and the industry partner minimizes travel for their participation, then the non-monetary cost of time could be the most significant cost. This time consumption includes however long it takes for the industry personnel to progress through the learning curve of the User Facility. These new users need to learn how to access the data and other resources of the User Facility, which are largely provided through custom (home-grown) systems. Conceivably, should a User Facility allocate resources to improve the user experience (see upstream approach to follow), then this cost could be reduced. Taken together, the User Facilities are in a strong position to develop a price position that is attractive to the fusion energy industry.

The place where this target occurs is a combination of on-site and remote. The User Facilities need to ensure that industry participants have positive experiences during any visits. This includes both the industry management and decision-makers,

[4]https://www.ga.com/diii-d-researchers-leverage-videogaming-app-for-remote-operation-during-covid-19

but importantly, also includes the staff members who will be performing the actual work of engagement with the Facilities. While observing impressive and efficient operations within the User Facilities does not guarantee the industry participants will recommend further engagement, observing unimpressive and inefficient operations greatly reduces the likelihood of continuing efforts.

In a combination of place and promotion, the digital space provides considerable opportunity for the User Facilities to encourage the target behavior. The target audience should develop a positive perception of the User Facilities based on their web presence. With the relevant resources and capabilities being uncommon, it is highly likely that any web search performed by industry will return few results. The User Facility websites should ensure that their offerings (not necessarily cost-recovery pricing) are listed on publicly available websites. This is far from the present state, for example, as both websites focus on the achievements of the programs in terms of publications and conference participation, instead of showing what they provide to other teams who wish to advance fusion energy. The lack of information relevant to prospective industry users on the present websites may be an indication that the programs have marginalized the needs of this newer segment of the research community (as described in Section 1.3).

The web presence of the User Facilities provides many opportunities for rapidly deployed improvements that serve this social marketing campaign. The NSTX-U website provides a link to "NSTX and NSTX-U Engineering," but the resulting page is a list of separate documents and pages from the NSTX device. That page features a tag indicating it was built with Adobe Pagemill 3.0, a webpage editing software that was discontinued 22 years ago[5]. A prospective industry user may not find the relevant technical information they seek, and they certainly will not be impressed by the delivery. The DIII-D website provides a link to "DIII-D Capabilities & Tools," which returns a 40-page document download last updated in 2019, and focused on the capabilities and tools "for Plasma Science Research." The sections described various capabilities and engineering setup of the tokamak, but none of the non-tokamak resources that may also be of interest to the fusion energy industry. Visitors seeking more information are asked to contact the responsible individuals listed for each system, but, as a fixed document, there were several out of date contacts provided (retirees and departures).

Finally, the social media aspect of their web presence also provides room for rapid improvement. NSTX-U is represented in social media through the accounts of its

[5]https://web.archive.org/web/20050307094733/http://www.adobe.com/support/salesdocs/1000592.html

host laboratory. The Princeton Plasma Physics Laboratory (PPPL) Twitter account[6] frequently shares content focused on NSTX-U. A dedicated social media presence would provide more opportunity to engage prospective users as it can focus on those types of relevant content (PPPL, as a U.S. National Laboratory, performs research on a wide variety of non-fusion areas). The DIII-D program has dedicated social media accounts, but a low production quantity (e.g., their Twitter account[7]). As these User Facilities perform activities with industry users, they should focus on highlighting the successful projects, including the participating organizations, in order to promote these opportunities to the target audience.

4.3.2 Midstream Approach: Targeting Management and Leadership at the Fusion User Facilities

As with the museum example that informs this outline [32], the midstream approach targets the management and leadership of the User Facilities. Table 4.3 provides the summary. The audience is defined to include leadership because the discussions with the fusion industry uncovered that they often engage directly with research staff at relevant conferences and events. Senior personnel at the User Facilities in both the fusion research and engineering/technology areas wield influence over the topical direction of the programs. This target audience demonstrates a low awareness of the value of marketing considerations in reaching a user base, as evident in the low level of industry participation and the close-knit community that erects a high-barrier to new entrants. Increasing industry participation will require both management directives and support from key staff. A successful social marketing effort will produce a target behavior in which this audience assigns resources that improve the collection of user feedback and awareness of stakeholder needs.

For this target audience, the main barrier is their expertise. The target audience is almost entirely populated by nuclear engineers and plasma physicists with advanced degrees. Even some positions that manage the operational aspects of the User Facilities are held by former research staff who have been promoted accordingly. This audience has mostly described their understanding of marketing as promotional (i.e., advertising). With so much of their experience based in research, the leadership of these User Facilities naturally prioritizes the output of research products such as refereed journal publications and invited talks at specialist conferences. Those outputs, therefore, compete against marketing-type activities that would consume resources from

[6] https://twitter.com/ppplab
[7] https://twitter.com/d3dfusion

Table 4.3. Social Marketing Outline for Fusion Energy User Facilities: Midstream Approach

Target Audience	Management and leadership at the User Facilities
Present Undesirable Behavior	Low awareness of, or low priority assigned to, marketing approach to facility oversight
Target Behavior	Dedication of resources to professional approach for marketing issues: user feedback engagement and stakeholder awareness
Main Barriers	Audience background is overwhelmingly in the physical sciences where management and marketing experience is nonexistent
Competition	Facility upgrades and new capabilities are primary target for resource allocation
Product: the social proposition (benefit to the audience)	Marketing approach will grow level of industry participation, which can be communicated to funding agency and Congress as examples of value of the User Facility, thereby leading to continued or increased support
Price: costs of involvement (monetary and non-monetary costs to audience)	Labor costs for new class of staff, or service expenses to be contracted out to third-parties. Service costs associated with training and coursework for existing management personnel.
Place: accessibility (location where target behavior occurs)	Leadership meetings, review panels and teams charged with informing resourcing decisions
Promotion: social communication (consider hyper-connected world)	Topical conferences, industry events

the same source. Maintaining the ability to generate high-impact research products (in the fusion energy field, at least) requires a constant expansion and rearrangement of the devices' parameter ranges. That parameter range accessibility is achieved through projects that upgrade various aspects of the device. Every dollar spent to communicate with prospective users is reducing the number and/or extent of those upgrades.

The product (benefit to this target audience) must be related to an increasing in the pool of resources available. The marketing approach is designed to grow the level of industry participation, which is then communicated to the DOE and Congress as examples of the continuing and future value of the User Facility, thereby leading to continuing or increased support. This benefit claim would fail if the DOE and Congress demonstrated a lack of concern for the further development of the fusion industry (they are the target audience of the upstream approach in Section 4.3.3).

The price, or costs, to the target audience are minimal. These include either the dedicated personnel or third-parties contracted to execute the marketing plan, or the relevant coursework and training to develop some level of proficiency in-house. On-the-job training in marketing areas is common in non-profits, as discussed in Section 1.3, and taking that path could be more cost-effective than hiring new permanent staff or contractors.

The place where this target behavior occurs is wherever the relevant decisions about the industrial user base are made. This includes leadership meetings, but also review panels and teams that are assigned a charge to assess proposed projects. If some staff are dedicated to the cause of bringing in more users from industry, then they would be presenting the case for the importance of supporting that class of project. In a successful social marketing campaign, these meetings would produce decisions that confirmed and solidified the allocation of resources dedicated to communicating with the fusion energy industry and educating them about the value of performing some aspects of their work with the User Facility.

Promotion for the midstream approach is focused on topical conferences and industry events. Having the target audience attend industry events is probably among the most cost-effective way to improve their understanding of industry needs and the future value of maintaining contact with, and marketing directed toward, this part of the user base. This type of promotion is best conducted directly, as the target audience is small and there is no obvious method for using web-based information displays to reach them in a convincing manner.

4.3.3 Upstream Approach: Targeting DOE Program Management and Congress

The upstream approach, summarized in Table 4.4, for the social marketing campaign targets the DOE Program Management for the fusion energy program, and the U.S. Congress. The program management sets the research targets and operational milestones for its User Facilities, along with submitting the initial funding level requests through the annual President's Budget Proposal. Congress sets the actual funding levels after receiving this initial request from the Executive Branch. At present, this audience demonstrates a low level of resourcing for the fusion energy industry, both in terms of total funding provided and in the resources provided to the User Facilities to support industry needs. Assuming that the fusion energy industry is capable of performing its own lobbying effort to increase its direct funding, this social marketing outline focuses on changing the behavior of the target audience such that new, additional resources are allocated to User Facilities for the express purpose of implementing a "customer service" approach that improves their ability to serve industry (existing users would benefit, as well).

There are two main barriers that prevent the desired behavior. One of these is a series of technical limitations that dictate the ways in which federal funding can be used to support industry. Specific examples of the limits in how federal grants can be applied were listed in the feedback collected through fusion energy industry interviews detailed in Section 3.4. A less technical barrier is the well-developed focus on academic research at the User Facilities. The DOE Office of Science, as its name implies, is dedicated to fundamental energy research. While one obvious suggestion is to migrate the fusion energy industry support to other government offices, this would result in a significant inefficiency as the resources and capabilities needed lie almost entirely within the Office of Science User Facilities (including the high performance computing programs).

As implied previously, the fusion energy industry lobbying program leads the way in terms of convincing Congress to fund their member organizations directly. This is competition for the effort to increase funding allocations to the User Facilities because both needs typically come from the same source. The proposed strategy to overcome this competition is to demonstrate a more effective and equitable use of funding resources is achieved through investment in the User Facilities (this is one of the products to highlight in this approach). The argument is that the User Facilities are, by definition, open access laboratories that can provide any single resource to multiple organizations across the fusion energy industry.

Table 4.4. Social Marketing Outline for Fusion Energy User Facilities: Upstream Approach

Target Audience	DOE Program Management and U.S. Congress
Present Undesirable Behavior	Low resource support for engaging industry
Target Behavior	Allocate new, additional resources provided to User Facilities to allow for "customer service" approach that improves ability to serve industry
Main Barriers	Technical funding restrictions that do not allow research funds to be used for such purposes. Focus on involvement of academia in User Facility work.
Competition	Industry lobbying for resources to be provided directly to industry through grants, subsidies, and equivalent
Product: the social proposition (benefit to the audience)	More effective and equitable support of technology development as User Facility capabilities are available to a wider user base compared to alternatives. Successful efforts lead to recognition of high-quality job performance (DOE) or contribute to re-election (Congress).
Price: costs of involvement (monetary and non-monetary costs to audience)	Funds allocated for this purpose. Potential for negative assessment by competing interests (low risk in area of fusion energy development).
Place: accessibility (location where target behavior occurs)	Fusion Energy Sciences Advisory Committee (FESAC), appropriations committees, and in proposals submitted to Funding Opportunity Announcements (FOAs)
Promotion: social communication (consider hyper-connected world)	Lobbying efforts, political action committees (PACs), constituent support venues, and fusion energy industry associations

The other product in this approach is the job performance benefit to the target audience. If increased funding support to User Facilities causes them to support more high-paying jobs while also improving the delivery of resources to the growing fusion energy industry (thereby further increasing the number of high-paying jobs), then the DOE Program Managers and members of Congress should be able to reap the reputation benefits of supporting successful programs. This might be an easier benefit to be realized by the DOE Program Managers as their responsibilities are limited to the fusion energy realm. Members of Congress are subject to review of the price for this effort, namely that increased funds for fusion energy development may be perceived (rightly or wrongly) as having come from other, completely unrelated, government programs. This may be a low risk in the area of fusion energy development as it is not commonly considered to be a federal program that competes with more sensitive and strongly supported programs such as national defense.

The places where this targeted behavior would occur includes the Fusion Energy Sciences Advisory Committee (FESAC), Congressional appropriation committees, and in the Funding Opportunity Announcements (FOAs) released by DOE. FESAC is the official advisory committee for the Fusion Energy Sciences program, but its charges (topics to consider) are defined by FES. A successful social marketing effort would increase the industry-relevance of the charges assigned to FESAC for review, analysis, and comment. In appropriation committee meetings and hearings, the target behavior should manifest as vocal support for providing these increased funding levels. In FOAs, the language of requirements would evolve to allow User Facilities to be proactive in soliciting participation from industry users.

Promotion must be performed through venues that reach this target audience, which is a challenge. The DOE Program Managers are a select group unlikely to be effectively reached through public web presence or media. Fusion energy industry associations and their relevant panels and meetings provide an opportunity to engage the DOE Program Managers in a way that demonstrates effective cooperation between the industry members and the User Facilities. Many lobbying options exist for reaching Congress, though it is an indirect method for the User Facilities because it would be performed by their managing organizations (General Atomics and Princeton University) and, therefore, subject to dilution by the other non-fusion organizational needs serviced. Promotion through constituents is possible, but it seems unlikely that the concerns of fusion energy User Facilities will ever gain the traction required to be a consistent concern of an appreciable segment of the voting population (fusion-adjacent concerns such as sustainable energy production may provide some connection).

4.4 Adjustments for the Fusion Energy Sciences Program

As the subject of the focused case study, the suggestions and findings related to the fusion energy development effort are more detailed than those above. The nature of the fusion energy research community is that of a well-connected and tightly-integrated unit. This is to be expected for a field that has spent the past many decades mostly centralized within an international, but always government-led, academic research environment. As the fusion energy industry grows out of this environment, it is important that information dissemination be improved.

Industry voices need to be amplified in order to improve community awareness of their unique needs and the limitations in their ability to make use of User Facilities. While various reports and investigative groups have included members from industry, this has not been sufficient to provide accurate and meaningful input for Fusion Energy Sciences (FES) program decisions. As detailed in Section 2.6.4, feedback related to fusion spinoffs, that is, commercial projects, is overly optimistic due to the singular input from researchers who have little connection to the organizations attempting to commercialize them. A dedicated industry panel, meaning, a panel without membership from the national laboratory or User Facility, should be established to provide input on issues related specifically to commercialization. Such a panel would be able to identify industry-specific needs as they emerge, and if this were a part of the Fusion Energy Sciences Advisory Committee (FESAC), then they would have a direct line of communication with FES.

Other suggestions are indicated from the industry feedback collected in this study. Increased access to existing User Facilities should be a high priority, and FES indicates this is the case for the DIII-D National Fusion Facility (see Section 2.6.3). The need for access to computational resources is frequently identified, but that's also a fairly common request across all fields of research. Unique to fusion energy development, however, is the demand for workforce development. The fusion energy industry seeks to grow their headcount, and developing fusion-specific skills in otherwise capable personnel can itself be a capital-intensive effort. Funding mechanisms for workforce development should be developed, which may include shifting non-FES programs into fusion-specific focuses, or allocating FES funds directly to the support of development programs. FES User Facilities provide the experience that industry needs, yet the mechanisms to bring industry personnel into the Facilities for training purposes is lacking.

In terms of awards and grants, the FES role in supporting industry would be improved by providing more logistical support. Industry participants engaged in technology development, e.g., modeling codes and diagnostic systems, are limited in their use of grant funds. The line between fusion academic and commercialization-relevant research is blurring. An award structure that provides opportunity for the holder to simultaneously engage other researchers and potential customers would speed commercialization. Consideration for dual-use applications and enabling cross-support from awards, e.g., from Department of Energy and Department of Defense awards, would similarly allow researchers to more efficiently plan and execute their projects.

In summary, the fusion energy industry is advancing their collective goal of demonstrating a sustainable energy production source for humanity. Emerging from a long-established fundamental research enterprise, this industry needs to convey the importance of adjustments in the government approach to supporting fusion energy science and technology development.

4.5 Improved Communication of General User Facility Capabilities

The representation of User Facilities on the web should be improved to better convey capabilities and resources to prospective users. While there is a "Getting Started," webpage[8] that is intended to direct potential users to each User Facility, it is out of date. During a test, there were 28 User Facilities linked on that page. Of those links, 11 (39%) were broken, that is, they led to "page not found" errors[9]. With such a large number of broken links, it is possible that the User Facility coordination with the Office of Science communications team is lacking.

In addition to improving the consistency and accuracy of web links, the User Facility website may benefit from providing classifications according to potential user needs. The present organizational structure groups the User Facilities according to their sponsoring program. While this provides some separation according to research area, potential users frequently have needs that require capabilities extending across research areas. As uncovered through the fusion energy case study, high-performance computing and materials research are in great demand from the industry. Those capabilities are not exclusive to the User Facilities of the Fusion Energy Sciences

[8] https://science.osti.gov/User-Facilities/User-Resources/Getting-Started

[9] This information was forwarded to DOE prior to the completion of this thesis, and some of those links have since been repaired.

program, however, and a more holistic approach to its Facilities is likely to generate more users for the Department of Energy.

Increasing consistency in the reporting across User Facilities would also be beneficial. As multiple findings in Chapter 2 illustrate, the user reports generated by User Facilities are of limited utility and prone to errors. The user reports detail the organizations that find the User Facilities to be useful, therefore, this is incredibly useful information for industry at-large. New entrants into an industry should be able to easily identify the User Facility participation of established players, as that may indicate a common cost-saving measure. Standardizing the identification of institutions in the reports is likely the most effective change. This could be achieved by using any particular third-party database to ensure that institutions are consistently identified across User Facilities.

The set of proposed marketing projects and basic corrections are intended to increase the participation of for-profit organizations (industry) in the Office of Science User Facility program. In the case study of the fusion energy field, there are many potential benefits from increased engagement. Ultimately, growing industries through federal support benefits society more broadly, as discussed in Section 1.1. Perhaps growing the fusion energy industry will also accelerate the arrival of that sustainable, carbon-free, energy source.

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APPENDIX A

Survey of Firms Operating in Fusion Industry

Survey of Firms Operating in Fusion Industry

This appendix provides the survey questions and instructions that were provided to researchers employed by organizations that identify as being part of the fusion industry. Instructions shown here represent those embedded in the survey. Additional interactions with potential respondents occurred through email correspondence, and through meetings of the Fusion Industry Association (the author of this thesis did not attend those meetings).

The survey was constructed using the Experience Management Platform (XM) from Qualtrics[1]. When possible, the XM-suggested ranking texts were used as the available responses.

A.1 Introduction

This survey is being conducted as part of a Masters Thesis within the Fowler School of Business at San Diego State University. The survey is anonymous, with no identifying information relating to individuals collected. In addition, while you will be asked for select characteristics of your organization, you will not be asked for its name.

As part of this survey, you will be asked to review a website from the U.S. Department of Energy. The amount of time you devote to reviewing that site is at your discretion.

Thank you for your help in completing this study!

The first part of this survey contains questions concerning background information about your organization.

A.2 Questions

1. Approximately how many employees are in your organization:
   accepts open text input
2. Which range best describes the annual operating budget for your organization:
   - $1M - $4.9M
   - $5M - $9.9M
   - $10M - $24.9M
   - Over $25M

[1] https://www.qualtrics.com/

- Prefer not to Answer

This next section concerns the resources that you expect to need in the near future.

3. How important are each of the following business needs for your organization over the next two years?

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Raising Capital					
Increasing Workforce Headcount					
Solving Technical Challenges					
Developing Business Operating Processes					
Developing Customer Relationships					

4. How much additional capital do you target raising in the next two years?
   - Under $1M
   - $1M - $4.9M
   - $5M - $9.9M
   - $10M - $24.9M

- Over \$25M
- Prefer not to Answer

5. How do you engage partners and collaborators to address your business needs?
accepts open text input

The next section concerns your awareness of User Facilities that are supported under the U.S. Department of Energy, Office of Science.

6. What is your current level of awareness concerning User Facility resources and capabilities that are available to your organization?
   - Not familiar at all
   - Slightly familiar
   - Moderately familiar
   - Very familiar
   - Extremely familiar

If the previous question indicates any level of familiarity, i.e., the respondent selected any option other than "Not familiar at all," then Question 7 is shown to them.

7. Given your current level of awareness of User Facilities, which of your capital investments could potentially be avoided by using resources and capabilities from a User Facility? .
accepts open text input

Before beginning the next section, please review the following U.S. Department of Energy website that provides basic information about User Facilities and the resources they provide to interested users. The link below will open a new browser window. After reviewing that website, please return to this browser window to continue the survey.
https://science.osti.gov/User-Facilities

The survey records the time spent by the respondent at the User Facility overview website. The respondent is unaware of the timer and it has no bearing on the questions they later receive. Technically, this timer records the time spent on the *link provided, and cannot (of course) account for any distractions or other work that the respondent may engage in once away from the survey.*

8. The following U.S. Department of Energy website provides basic information about User Facilities and the resources they provide to interested users (this link opens in a new window), https://science.osti.gov/User-Facilities
   After looking at information from this site, how would you describe your current awareness of User Facility resources?
   - Not familiar at all
   - Slightly familiar
   - Moderately familiar
   - Very familiar
   - Extremely familiar
9. What is the present level of engagement between your organization and any of these U.S. Department of Energy, Office of Science User Facilities?
   - No Engagement
   - Extremely Low Level of Engagement
   - Low Level of Engagement
   - Moderate Level of Engagement
   - High Level of Engagement
   - Extremely High Level of Engagement

If the response to the previous question indicates any level of engagement, i.e., the respondent selected any choice other than "No Engagement," then Question 10 is shown to them.

10. The DOE Fusion Energy Sciences office operates two User Facilities, the DIII-D National Fusion Facility (DIII-D) and the National Spherical Torus Experiment – Upgrade (NSTX-U) Facility. What is the present level of engagement between your organization and these User Facilities?
    - No Engagement
    - Extremely Low Level of Engagement

- Low Level of Engagement
- Moderate Level of Engagement
- High Level of Engagement
- Extremely High Level of Engagement

If the response to the previous question indicates any level of engagement with FES User Facilities, i.e., the respondent selected any choice other than "No Engagement," then Question 11 is shown to them.

11. Please describe the engagement between your organization and either the DIII-D or NSTX-U User Facilities:
accepts open text input

If the response to Question 9 indicates "No Engagement," "Extremely Low Level of Engagement," or "Low Level of Engagement," then Question 12 is shown to them.

12. How much did each of the following areas contribute to the lack of, or limited, engagement between your organization and the User Facilities?

	None at all	A little	A moderate amount	A lot	A great deal
User Facilities do not provide relevant resources/capabilities					
Unaware of option for User Facility engagement					
Policies or legal frameworks of engagement are too restrictive					
Internal issues within my organization					
Other (describe below)					

The final section of this survey concerns the emerging needs of your organization.

13. Based on your awareness of User Facility resources after reviewing the DOE website, how likely is it that accessing those resources may be able to improve your business activities?

    - Extremely unlikely
    - Somewhat unlikely
    - Neither likely nor unlikely
    - Somewhat likely
    - Extremely likely

14. Would your organization consider engaging a User Facility in the future to access the following resources and/or capabilities?

	Definitely not	Probably not	Might or might not	Probably yes	Definitely yes
Apprenticeship or personnel exchanges to provide new work experience					
Component testing at parameter regimes not presently available to your organization					
Computational resources including high performance computing					
Advanced manufacturing, including additive manufacturing					
Other (please describe)					

15. Please describe a potential new DOE User Facility that would provide resources and capabilities of value to helping your organization execute its business model: *accepts open text input*

We thank you for your time spent taking this survey.
Your response has been recorded.

APPENDIX B

Base Interview Questions

Base Interview Questions

The following set of questions were provided to interviewees prior to the discussion. Subjects were informed that these comprise the base questions, and that the discussion topics would adjust based on their responses.

1. How would you describe your role and responsibilities in this firm?
2. How would you describe the current role of governments, generally, in developing fusion energy?
3. How might this role change to speed your development efforts and the success of the technologies within your firm?
4. How would you classify your level of awareness about the U.S. DOE User Facilities and the resources and capabilities they provide to interested parties?
5. What could User Facilities provide to your firm that would speed your development and improve your chances of success?
6. How might the DIII-D and NSTX-U User Facilities help your firm in its work?