The Role of US Universities in the Burning Plasma Era

A University Fusion Association (UFA) White paper

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Introduction

The primary focus of the US fusion energy sciences program is becoming the science of burning plasmas. Major advances in this area will occur principally in large-scale experiments, notably ITER, and with the increased emphasis of the program on understanding and achieving stable containment of long-pulse, nuclear-heated plasmas, the expansion of a number of associated research areas will take place. In light of these developments, the program as a whole is re-examining its priorities along with the structure and direction of US fusion research activities. US universities have always played a strong role in advancing the knowledge base of fusion energy, and it is therefore appropriate to reevaluate how the university groups will most effectively participate in this new burning plasma science program. This document highlights the opportunities and challenges facing university researchers in the upcoming decade, and is intended to trigger a discussion among and between the university, national laboratory, industry, and DOE personnel of the US fusion community. The goal of the exercise is to elucidate a clear role for US universities in the Burning Plasma era and to advocate for effective and adequate support of that role.

History and Context

In the early 1990's, federal funding for US plasma physics and fusion research was in decline. In the run-up to this time, a key goal of the US fusion research program was long-term fusion energy development, while reductions in net funding resulted in the program's scope becoming increasingly narrowed to the tokamak confinement concept. By the mid-1990's, the substantial disconnect between the energy development goals of the program and the reduced funding levels had become apparent to Congress and other stakeholders in the fusion energy program. In 1995, the President's Committee of Advisors on Science and Technology (PCAST) recommended a change in research priorities to focus on the plasma science at the core of fusion research and on approaches that could potentially supplement and improve the development path to fusion power. The Department of Energy received similar advice from its Fusion Energy Advisory Committee (FEAC), and in mid-1996 released a plan for a restructured fusion energy sciences research program with the goals of advancing plasma science and developing innovative approaches to fusion science, technology, and plasma confinement while seeking to pursue fusion energy development as a minority partner in the international ITER effort. To deal with the severe cuts in funding, the Tokamak Fusion Test Reactor was shut down, effectively ceding the US' strong role in magnetic fusion energy development to Europe and Japan while maintaining a focused fusion energy science program within the US. Since this restructuring occurred, the scientific progress has been notable. Research on major facilities in the US has provided improved understanding of plasma confinement and behavior under reactor-relevant conditions, and configurations and operating scenarios that could substantially enhance reactor performance have been developed and demonstrated. In addition, US scientists are developing the capability to model and simulate fusion plasmas using first-principles scientific models and are now developing schemes to verify and validate these models using detailed comparisons with experiment with the intent to provide predictive understanding of fusion-grade plasmas from core to edge. Presidential Science Adviser John Marburger summed up the progress when he said in 2002,

> "the ability to predict plasma parameters in realistic simulations, and then test them in detail in actual devices, has changed the character of the entire field substantially. It is fair to say that fusion

research today is proceeding with unprecedented theoretical and experimental confidence."

Moreover a diverse set of small to medium scale experiments to investigate alternate methods of high-temperature plasma confinement and basic plasma physics relevant to fusion research have been influential in sparking creative thinking and new interest in plasma physics, particularly among younger scientists. Broadly speaking, the focus of developing the scientific basis of fusion energy over the last decade has proven to be highly productive, and serves as a guide for the immediate future.

Universities in the US Fusion Program

Much of the activity cited in the previous section has occurred at universities or by collaborations between university-based scientists and engineers and larger-scaled confinement experiments. University faculty, students, and professional research staff participate in the program at all scales ranging from operating a major fusion facility at MIT, hosting NSF and DOE plasma science centers, and collaborating with other major national and world facilities, to working in single-investigator and small-group theoretical and experimental efforts. In doing so, universities play the key role of attracting and educating new talent to engage in the scientific pursuit of fusion energy. By their nature as institutions of diverse intellectual pursuits, universities serve as natural loci for cross-disciplinary exchange of ideas in areas related to fusion plasma physics, e.g., computer science, materials research, fluid dynamics, magnetospheric plasma physics, and astrophysics, to name a few. Similarly, the university is a traditional forum in which the scientific knowledge gained in the fusion research enterprise is communicated to the broader scientific community.

In the 1990s, DOE's Office of Fusion Energy Sciences (OFES) took several important steps that helped determine the scope and scale of current university participation in the US fusion program. OFES established Principal Young Investigator Awards for junior faculty members, and continues to fund a competitive graduate and post-doctoral fellowship program. OFES played a lead role in establishing a joint NSF/DOE program for basic plasma science, and also supports several plasma science centers which link researchers with similar research interests to explore designated topical areas and provide educational workshops and other opportunities for young scientists interested in those areas. Finally, an Innovative Confinement Concepts (ICC) program was launched to explore several different small-scale approaches to high-temperature plasma confinement that might prove suitable as alternate fusion power concepts or for adapting and improving the tokamak approach. Many of the ICC and other relatively small-scale basic and applied plasma experiments are situated at universities where groups containing a large proportion of students carry out the research. In addition, there are a number of university programs focused primarily upon collaborations with the larger tokamak devices.

Emergence of a US Burning Plasma Program

Following a set of community discussions culminating in the Snowmass 2002 meeting, fusion researchers generally agreed that assessing the scientific feasibility of fusion through the experimental investigation of a self-heated burning fusion plasma was the highest priority of the future program. Participation in the international ITER project was seen to be the most effective choice for US scientists to engage in burning plasma research. The 2004 National Research Council Burning Plasma Assessment Committee (BPAC) report supported this approach while clearly stating that US collaboration in an international burning plasma experiment must not come at the cost of downgrading an essential domestic fusion science program. Accordingly, the US government has recently affirmed its commitment to the ITER project by providing significant additional funds to support US participation in ITER construction while maintaining support for relevant domestic research activities. The ITER facility will begin operation in the next decade with high-gain burning plasma performance expected early in the following one. The US National Ignition Facility will also begin operation, and will attempt ignition experiments early next decade. Thus it is clear that a new era of burning plasma research is at hand, providing a focus for US researchers in both approaches to fusion.

With the physics of burning plasmas projected to assume predominant importance in the US fusion program over the next decades, there is a recognized need to review the mission and long-term goals of the program managed by OFES. In the 2005 Energy Policy Act that provided for US participation in ITER, Congress directed the OFES to provide a plan for US participation in ITER and a description of the relationship of ITER to the domestic elements of the US fusion program. The US Burning Plasma Organization (USBPO), composed of US fusion scientists from universities, national laboratories, and industry was also formed in the past few years, and now serves to provide a framework for US scientific participation in ITER and activities related to burning plasmas. Most recently, a sub-panel of the Fusion Energy Sciences Advisory Committee (FESAC) has largely completed its response to a major charge from DOE Under Secretary for Science Ray Orbach to prioritize the broad range of scientific and technical issues to be addressed in studies to prepare for DEMO, the next major device envisioned to follow ITER. While a complete summary of the panel's present conclusions is out of place in this white paper, it is worth noting that the panel places high priority on a number of issues, e.g, research on materials, plasma-facing components, and plasma-wall interaction among others related to the high heat-flux, tightly-coupled fusion nuclear environment, implying that the needs of the US fusion science program are indeed broadening to fully include the interface of plasma physics with materials science, nuclear science, and other disciplines. The report also advances suggestions for initiatives to be pursued in new facilities that would provide significant new capabilities in fusion energy science and technology to extend or replace those in our aging existing devices. In short, OFES and the fusion research community are in the midst of reformulating their shared vision for the US fusion program to highlight the scientific role of ITER in opening the era of experimental burning plasma studies. Given the expected duration of the ITER experiment and the effort to plan for DEMO, this detailed vision will need to credibly extend farther into the future than in previous research plans. The issues of burning plasma physics and technology will attract increasingly more attention throughout the program. Nonetheless, the pursuit of more diverse aspects of plasma science remain important to society, not only for the benefit of the fusion program, but also for industrial applications, connections to other branches of science, and for continued intellectual development of the field. The recent National Academy Plasma 2010 decadal survey (Plasma Science: Advancing Knowledge in the National Interest) highlights a number of productive areas worthy of continued or increased support in plasma physics in addition to the broad range of magnetic and inertial fusion studies. These include low temperature plasmas, basic and applied investigations of plasma turbulence, dusty plasmas, and magnetic reconnection, to name a few that are particularly conducive to university-scale investigations. The responsibility for supporting basic plasma physics has typically been split between NSF and OFES. It is expected that DOE's Office of Science will continue to serve as primary steward for basic plasma studies, particularly those with relevance to fusion science, and it will be a necessary challenge to find appropriate levels of support for these important areas without constricting opportunities in the new thrusts of the burning plasma science program.

Rethinking the University Role in the US Fusion Program

The redefinition of the US Program focus and a likely transition of major US facilities suggests that it is time to reexamine the role of US Universities within the emerging era of burning plasma physics, and determine the optimum role that they should take going forward. Such a re-examination should include the key fusion science and technology issues, and also take into account the needs of faculty-led academic research groups to have high impact, visible, and compelling research programs that are of interest to their home institutions and to the broader academic research community. In the face of these considerations, the question then emerges:

What roles should American universities play in a US fusion energy sciences program that contains a strong emphasis on burning plasma physics with the major experimental facility located abroad and in which there may be new opportunities for research on existing or new domestic facilities?

There are several considerations to keep in mind as a response to this question is formulated. First, all of the work carried out in the fusion energy sciences program – including that done by the universities - must increasingly address the key fusion energy science issues that arise in a burning plasma science program, and it is essential that the program continue to clearly identify the urgent and most important scientific issues that bear on the development of fusion energy. The advent of US participation in ITER motivates new burning plasma physics research and associated fundamental materials and fusion nuclear science research within the universities. ITER also motivates comprehensive work in first-principles and full-scale fusion simulation; universities, particularly computer science and engineering researchers, should thus become stronger contributors over the next decade. We believe that recent and ongoing FESAC, USBPO, and community efforts are working to carefully address and prioritize these science issues, and these considerations should assist in shaping the formation of a new role for the universities in the program.

Second, many – but not all – of the experimental issues can best be addressed in large facilities that are beyond the capabilities of most university groups; indeed, it is expected that at most there will only be a few such facilities within the US in the foreseeable future. Upcoming large-scale computational initiatives such as the Fusion Simulation Project are also clearly multi-institutional in nature, and require interdisciplinary integration. Thus it is reasonable to expect that many university researchers in both theory and experiment will increasingly participate in collaborative work on large fusion projects, including ITER, and it is crucial that opportunities exist for university faculty, research staff, and students to do so in collaborations both fruitful to the host fusion projects and to the academic institutions contributing to them. In this context, it is important to recognize that effective, long-term university collaborations on larger devices operate best as a two-way interaction. Successful university collaborations with large-scale off-site experiments typically require on-campus research staff including post-doctoral scholars, graduate students, technical staff and faculty with access to on-campus instrumentation and data analysis facilities collaborating directly with university-based professional researchers who are sited at the large-scale facility and/or travel from the university. In this manner, the knowledge and experience gained in the collaborations benefit both the experimental program goals and the intellectual environment of the home academic institution. Furthermore, improving and expanding the linkages between university researchers and larger facilities could positively impact the workforce problem identified by an earlier FESAC panel. This could be done by engaging a greater number of younger, early-career scientists on comprehensive, integrated facilities during the run-up to ITER, and beyond. Successful fusion theory and simulation groups also require a minimum level of collaborative effort to maintain excellence. This framework for healthy collaboration will become increasingly important when the focus of burning plasma modeling, experimentation, and analysis becomes the ITER facility. That said, a great deal of experimental and theoretical work in more fundamental plasma behavior and configuration improvement is highly supportive of the burning plasma program mission, and many of these investigations may be suitably pursued on university campuses. In such cases, it is important that within the framework of the relevant fusion energy science questions, the role of this work be accounted for in ongoing strategic planning within OFES, and appropriate avenues of support made available through a competitive peer-reviewed process.

Third, given the priorities in the 20+ year period envisioned for burning plasma science research, it is clear that there is an increasing need for a stable, broad-based, interdisciplinary fusion energy science and technology research program. Fusion nuclear science promises to be among the intriguingly rich emerging research areas of relevance to burning plasma science that should attract the interest of leading US research universities. It is important to recognize that fusion research competes within this intellectual environment with other actively-supported research areas. Thus to attract and maintain the intellectual commitment of universities to these key programs, healthy support must be provided over a sufficiently long period of time to build the next generation of academic fusion researchers and allow them to impact not only fusion energy science but also the broader affiliated science and engineering communities. The experience of US academic fusion research suggests that this requires investment on a decadal time scale which allows for the university group to either build, diagnose, and operate the necessary first-rate experimental facilities, collaborate with a remote large-scale facility, or develop and apply new theoretical and computational capabilities.

Lastly, we believe it would be feasible for US universities, or a university-based center or consortium, working perhaps in collaboration with a laboratory and/or with industry, to propose and develop plans for specific future US fusion facilities in preparation for DEMO. Capable expertise and strong interest exists with US universities to explore the possibility of developing and operating a modern innovative facility, and it could be advantageous for the US fusion program for experienced university groups to fully participate in such an exercise.

Conclusion

The University Fusion Association continues to support DOE's decision to fully participate in ITER in collaboration with international partners as an essential step to demonstrate the scientific feasibility of fusion. Universities seek to continue their broad-based and innovative contributions to plasma physics as the US burning plasma science program develops and emerges. Furthermore, they must carry out their essential mission of introducing young scientists to plasma physics and the interdisciplinary areas that comprise fusion science to carry forward and evolve the long-term vision of the new program.

Clearly universities should play key roles in the emerging burning plasma science program, which is centered on the ITER project. In addition, the US program will operate some or all of the existing major facilities for a number of years. it also expects to replace some of these facilities with one or more advanced experiments. The results from these new facilities will supplement what we expect to learn from ITER and NIF, and should allow the US to prepare for a DEMO fusion device. Many university research groups have demonstrated the skills to participate in the exploration and development of such options; other university groups may aspire to collaborate in this activity, but are not currently in a position to do so. The program should identify relevant opportunities for collaboration and then actively seek out opportunities to increase the number and scope of university groups that are collaborating on the existing and/or proposed major devices, and on computational initiatives. This also includes the pursuit of smaller-scale experiments and theoretical investigations that are relevant to burning plasma science, and are of suitable scale for a university campus. The determination of which approach is best must be determined by the research focus and, ultimately, by the individuals proposing the work. It is also conceivable that, operating through an appropriate center, a university-based consortium could develop, manage, and operate a new facility jointly with industry and/or national labs.