The Role of US Universities in the Burning Plasma Era

A University Fusion Association (UFA) White paper

February 2008

Introduction

The major focus of the US fusion energy sciences program is steadily becoming the science of burning plasmas. New knowledge in this area will emerge principally from the international ITER device, and from large-scale US experiments exploring the pathway to DEMO, the next step toward electric power production from fusion. Theory and modeling are taking up the challenge of simulating the multi-scale behavior of high-gain alpha-heated plasmas. Optimization of the configurations for confining burning plasmas comprise an important strategic element of the US program's approach, and with the increased emphasis of the program on understanding and achieving stable containment of long-pulse, burning plasmas, the expansion of a number of associated research areas such as harsh-environment materials research, fusion nuclear science, and fusion-environment diagnostics should take place concurrently.

US universities have always played a strong role in advancing the knowledge base of fusion energy and plasma physics, and it is appropriate at this time to reevaluate how university researchers and educators can effectively engage in the new burning plasma science program This document highlights some of the opportunities and challenges facing university researchers in the upcoming decade, and is intended to trigger a discussion among university, national laboratory, industry, and Department of Energy (DOE) personnel working within the US fusion community. Its goal is to elucidate effective long-term roles for US universities in the Burning Plasma era.

In addition to burning plasma physics, the research portfolio of the US fusion program also includes the area of fundamental plasma science that underpins most aspects of fusion research as well as providing new understanding and applications of diverse plasma phenomena relevant to geophysics, astrophysics, highly novel plasma confinement schemes, industrial fabrication, lighting techniques, among other areas. Furthermore, the investigation of high energy density laboratory plasmas (HEDLP) in connection with the facilities of DOE's Stockpile Stewardship program is of growing interest to many plasma physicists. University-based researchers contribute to many of these activities, and while this document focuses mainly on the relationship of universities to the emerging burning plasma program, it should be clearly noted that university researchers will continue to be active in the broad variety of areas that encompass plasma physics.

Context of the Emerging Burning Plasma Program

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, and the reductions in 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. Following advice from the President's Committee of Advisors on Science and Technology (PCAST) and its own Fusion Energy Advisory Committee, DOE released a plan in mid-1996 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.

Since this restructuring occurred, US scientific progress in fusion research has been notable. Although the early shutdown of TFTR reduced the US contributions to fusion energy development and the study of alpha particle confinement, continuing research on the other major facilities in the US has provided improved understanding of plasma behavior under reactor-relevant conditions. Configurations and operating scenarios that could substantially enhance reactor performance have also been explored. In addition, US scientists have improved their knowledge of heat transport and other phenomena in fusion plasmas using first-principles scientific models, and are developing programs 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."

Furthermore, 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.

Following a set of community discussions culminating in the Snowmass 2002 meeting, fusion researchers came to the consensus 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 report supported this approach while clearly stating that US collaboration in an international burning plasma experiment must not come at the cost of downgrading domestic fusion science activities that are becoming increasingly integrated with the international burning plasma program. The US Burning Plasma Organization (USBPO), composed of US fusion scientists from universities, national laboratories, and industry, was created to provide a framework for organizing US scientific participation in ITER and activities related to burning plasmas. In response to the evident need for burning plasma research, the US government has recently ratified an agreement to jointly construct ITER with six international partners. The ITER facility will begin operation in the next decade with high-gain burning plasmas to follow. New domestic facilities that will capture the expected benefits of ITER and advance fusion science to the next stage are being contemplated. Furthermore, the US National Ignition Facility for inertial confinement fusion will also begin operation, and is expected to achieve ignition early next decade. It is thus clear that an era of burning plasma research is at hand, providing a new focus for US researchers in both approaches to fusion.

Reviewing the Role of the University in the US Fusion Program

The redefinition of the focus of the US program and a likely transition of major US facilities suggests that it is time to reexamine the role of US universities within the era of burning plasma physics, and determine the optimal roles that they should take going forward. Such a re-examination should include the key fusion science and technology issues emerging from ongoing prioritization taking place with in the research community, 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.

American universities have always played a strong role in the advancement of plasma science. Much of the progress achieved during the restructured program of the last decade, and in previous ones, has occurred at universities and in collaborations between university-based scientists and engineers at large-scale facilities and laboratories. University faculty, students, and professional research staff currently are active in the program at all levels: operating a major fusion facility at MIT, hosting NSF and DOE plasma science centers, collaborating with national and world facilities, and working in single-investigator and small-group theoretical and experimental efforts with diverse applications. In doing so, universities play the key role of attracting and educating new talent to engage in the scientific pursuit of fusion energy, critical for its future success. Furthermore, universities are 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, nuclear physics and technology, among others. Contributions from many of these areas are essential in the pursuit of fusion energy development. Moreover, the university is a key forum in which the scientific knowledge gained in the fusion research enterprise is communicated to the broader scientific community. In any new US fusion research program, universities should continue to assert a leading role in generating new knowledge and integrating it into the broader scientific, social, and commercial realms if the fusion research enterprise is to remain innovative, healthy, and accepted as a true scientific discipline.

In the light of the changing focus of the program, the question 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, much 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. The burning plasma research effort also encompasses further configuration optimization as part of the next steps toward DEMO; as it is clear that improvements could benefit the current approach. We believe that recent and ongoing community efforts are working to carefully address and prioritize these science issues, and these considerations should assist in shaping new roles for the universities in the program. Given the expected duration of the ITER experiment and the effort to plan for DEMO, this vision will need to credibly extend farther into the future than in previous programmatic plans.

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, It is expected that 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. It is therefore 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. Such university collaborations with large-scale off-site experiments would 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. Models for this type of activity in the existing program might include the Plasma Spectroscopy group at Johns Hopkins University, and the Plasma Science and Technology group at UCLA. Successful fusion theory and simulation groups also require a significant 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 experiment. Such collaborative interactions that fully engage in on-site activity at both institutions will typically require a greater level of support than traditional single-investigator or small-group projects, or university researchers being active only at the host institution. But the intellectual payoffs to both university and host facility or project, and the larger fusion program itself, should be well worth it.

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 highest level of interest of leading US research universities, most likely in collaboration with national laboratories with specialized facilities. 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, and develop and apply new theoretical and computational capabilities.

Fourth, we believe it would be feasible for US universities, or a university-based center or consortium, perhaps in collaboration with a laboratory and/or with industry, to develop,, operate, and administer 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 depending on the particular scientific goals and programmatic mission of the device, it could be advantageous for the US fusion program for experienced university groups to fully participate in such an exercise.

We thus believe that issues of burning plasma physics and technology will attract increasingly more attention in universities if there exist opportunities to pursue them within the US fusion sciences program. Furthermore, a great deal of experimental and theoretical work in more fundamental plasma behavior and novel confinement configurations is highly supportive of the burning plasma program mission, and many of these investigations are suitably pursued on university campuses. 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 numerous 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. While NSF supports some work in plasma science jointly with OFES, DOE's Office of Science should continue to serve as primary steward for basic plasma studies, particularly those with relevance to fusion science. It will be an important but 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. Finally, OFES has embarked on a joint program with the National Nuclear Security Administration (NNSA) to support HEDLP physics by making use of NNSA-run inertial fusion facilities to perform studies of extremely hot, dense plasmas. While it may be an open question at this time as to how broadly university personnel can engage in enterprising science investigations at facilities largely devoted to weapons research, there will nonetheless be opportunities to do so in the immediate future. In all of these cases, it is important that 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

Conclusion

Universities seek to continue their broad-based and innovative contributions to plasma physics as the US burning plasma science program develops and emerges. In doing so, they must carry out their essential mission of engaging young scientists in plasma physics and the increasingly interdisciplinary areas that comprise fusion science in order to carry forward and evolve the long-term vision of producing energy from fusion.

Universities should play key roles in the emerging burning plasma science program, which is currently centered on the ITER project but not limited to that particular device. While the US program will operate some or all of the existing major facilities for a number of years, it 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 such research; other university groups may aspire to collaborate in this activity, but are not currently in a position to do so. The program should assist in identifying relevant opportunities for collaboration on major facilities, projects, and new initiatives emerging from the prioritization process, and facilitate the means by which university groups can more effectively participate and lead in these efforts. 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. Such an enterprise could more fully engage universities in state-of-the-art research at a scale appropriate for the burning plasma physics program.