AUBURN UNIVERSITY

College of Sciences and Mathematics
Department of Physics

National Academies of Science
Board on Physics and Astronomy
Committee for a Strategic Plan for U.S. Burning Plasma Research

30 June 2017

Dear Committee Members,

This document contains a collection of material generated over the course of the past two years by the University Fusion Association (UFA) documenting the status of university-based magnetic confinement fusion research. The collection includes:

I look forward to discussing these university issues with you at your next meeting in Irvine, CA.

Sincerely,

David A. Maurer

David A. Maurer
President University Fusion Association
Associate Professor of Physics
Auburn University

US academic fusion researchers sound alarm

Toni Feder

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US academic fusion researchers sound alarm

Forming new modes of university leadership using off-campus facilities is essential to sustain the field.

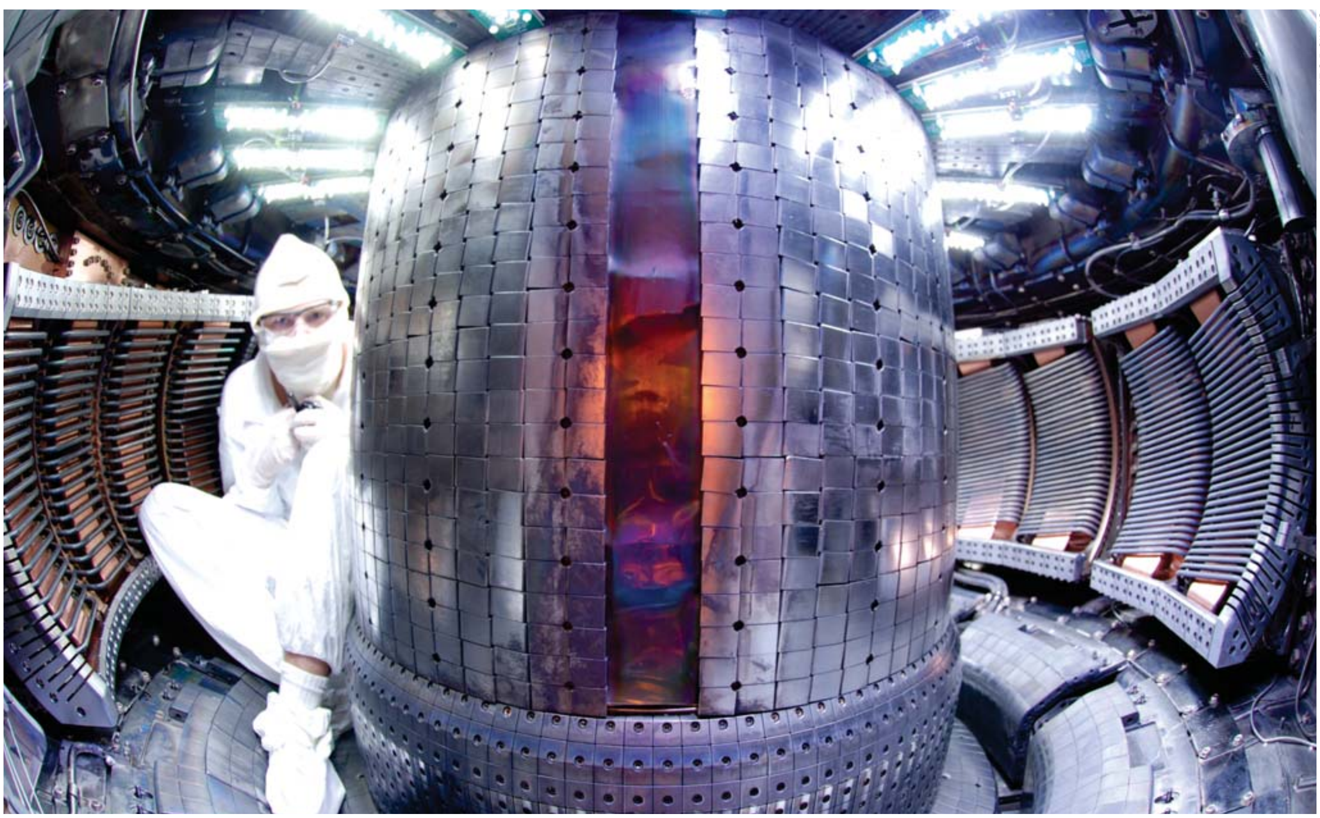
Magnetic confinement fusion research on US university campuses is in crisis, according to a recent white paper by the University Fusion Association (UFA). The report focuses on two worrisome trends: Funding is down, and faculty members are getting older and shrinking in number. The white paper "gets beyond the anecdotal level to become a statement of the challenges facing the community collectively," says UFA vice president John Sarff of the University of Wisconsin—Madison.

The UFA surveyed the 14 institutions that between them get roughly 80% of all funding for university-based fusion and plasma physics provided by the Department of Energy's Office of Fusion Energy Sciences (FES), the field's main funder. At those institutions, the average age of faculty in fusion and plasma research is 56, up from 53 a dozen years ago. Some 30% of current faculty were reported likely to retire in the next five years. Overall, the survey respondents estimated as poor the likelihood of their hiring researchers in the field.

The institutions reported receiving combined experimental fusion funding of $36.8 million in fiscal year 2015, a 17% decrease from FY 2006. Nearly two-thirds of the money went to the two largest campus-based facilities—the Alcator C-Mod tokamak at MIT and the Madison Symmetric Torus at the University of Wisconsin. FY 2015 support for other projects was $12.9 million, a 34% decrease from FY 2006. Over that period, the total FES budget for universities remained roughly flat.

Funding for the Alcator C-Mod was zeroed last year, and as of next year the status of the Madison Symmetric Torus within FES will be revised to take a nonfusion focus, and its funding is expected to go down. For researchers, that leaves the smattering of much smaller on-campus fusion experiments at Auburn University, Columbia University, the Los Angeles and San Diego campuses of the University of California, and the University of Wisconsin—Madison, plus the large national facilities DIII-D at General Atomics and the National Spherical Torus Experiment, which is currently undergoing repairs at the Princeton Plasma Physics Laboratory. (See Politics and Policy on PHYSICS TODAY's website, 29 September 2016.)

The UFA report notes that funding for university researchers to use off-campus facilities has gone up, but not by enough to offset the decrease in funding for on-campus research. Says Dennis Whyte, director of MIT's Plasma Science and Fusion Center, "You need to be able to



CHRIS BOLIN

A GRADUATE STUDENT WORKS ON THE ALCATOR C-MOD TOKAMAK at MIT. The facility lost its funding at the end of last fiscal year. But on its final day of operation, 30 September 2016, it reached an operating pressure of more than 2 atmospheres, setting a new world record for magnetically confined plasma.

attract students, have them work on equipment, prepare equipment. Then they sometimes go to an off-campus facility. The white paper shows how the balance has changed. It's clear that on-campus capabilities have deteriorated." Or, as the white paper puts it, "Without a strong academic foundation our U.S. fusion program will wither in fundamental respects. . . . We are well into such a trend now."

The white paper's main recommendations to FES and the fusion community are as follows:

- Develop new modes of participation for university researchers in off-campus facilities that lead to enhanced leadership roles.
- Develop and sustain predictable funding opportunities.
- Develop a long-term vision and strategy for fusion science.
- Promote the long-term strategy ideas and innovations that are best implemented using on-campus experimental facilities.

DOE is "very sensitive" to the concerns expressed in the white paper, says Edmund Synakowski, the department's associate director of science for FES. "Maintaining a strong fusion research program at US universities is vital. The question is not whether to have such a strong program, but how best to maintain the program's strength." But, he says, "we differ with the UFA on the best strategy to address the two key challenges."

According to Synakowski, the paradigm for fusion research is shifting toward larger collaborations using larger national and international facilities. "A key challenge remaining for the university community," he says, "is how to make this off-site leadership activity visible to university departments and administrations, so that fusion can compete effectively for resources and positions within the university."

Whyte points to US participation in ITER, the international test fusion reactor under construction in France, as evidence of US commitment to support fusion and plasma physics. "ITER obligates us to make sure we have a strong research effort," he says. The white paper, he continues, "signals deep concern, but we feel it should spark a healthy dialog."

Toni Feder PT

University Fusion Association white paper on the status of university-based fusion science research

University Fusion Association

Non-profit Association Established in 1979

Adopted by the Executive Committee of the University Fusion Association on 15 January 2017

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EXECUTIVE SUMMARY

University-based fusion research plays an indispensable role in the U.S. fusion program. Universities are an essential incubator of ground-breaking scientific ideas and discoveries; a source of expertise and ideas for research conducted on major experimental fusion facilities in the U.S. and worldwide; the source of the next generation of fusion and plasma physics researchers; and a primary interface to other Science, Technology, Engineering, and Mathematics (STEM) fields, as well as to the broader academic community and general public.

A critical element in the success of the science and engineering enterprise of the U.S. is the strong federal-university partnership that began during the Second World War.[1] In this partnership, both sides make critical investments in infrastructure and human resources that continue to pave the way for U.S. leadership in basic and applied scientific research. This federal-university partnership is in peril for magnetic confinement fusion research given current faculty demographics and hiring prospects along with recent funding trends discussed in this report. These challenges are occurring at a time of great scientific opportunity and fertility with strong enthusiasm among students and university researchers to tackle the exciting scientific challenges of the field. These realities include:

- Reductions in Fusion Energy Sciences (FES) funding have occurred for many of the university magnetic confinement fusion programs surveyed over the past five years. On-campus experimental research activities have borne the brunt of that reduced funding.

- Small growth in off-campus experimental research activities relative to the decrease in on-campus funding contributes to program contraction in university magnetic confinement research activities. Funding trends reported by the surveyed universities are corroborated by analysis of federal funding data available to the working group. This program contraction, coupled with alarming demographic and faculty hiring prospects, creates a challenging environment for the long-term sustainment of healthy fusion research programs at our universities.

- A key metric for the health of any academic field is prospects for long-term university investment in faculty lines. The surveyed universities report poor prospects for hiring new fusion faculty, despite a 10% decrease in the number of faculty dedicated to fusion research at their institutions over the past five years. This retirement loss rate is approximately double the national average.[2]

- Over the last 12 years, the faculty's average age has risen from 52.7 to 56, and up to 30% of the current faculty at the surveyed institutions are anticipated to retire within the next five years. Extrapolating the reported faculty demography, faculty

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[1] Richard C. Atkinson & William A. Blanpied, "Research Universities: Core of the US science and technology system" *Technology in Society* 30 (2008) 30–48

[2] https://www.aip.org/statistics/faculty

hiring prospects, and the current loss of university-based magnetic confinement fusion research forecasts a bleak future for university participation in fusion science research.

- The absence of a long-term strategy for university-based fusion research, and particularly how university research evolves going forward into the era of burning plasma physics on ITER, contributes to the poor prospects for faculty hires. This absence in conjunction with recent fusion program funding trends, and program uncertainties create a discouraging atmosphere for long-term university investment in fusion science research.

These key findings, distilled from a survey of institutions with historically strong fusion programs, validate and amplify the informal discussion conclusions regarding the crisis felt by the university community on these issues at both the University Round Table and UFA Fusion Forum[3] held in 2015.

Without a strong academic foundation our U.S. fusion program will wither in fundamental respects. From the findings outlined above, we are well into such a trend now. Recovery is possible, but a strong break with current trends must begin immediately. Therefore, the University Fusion Association (UFA) concludes that it is imperative that the Office of Fusion Energy Sciences (FES) begin work with the university and broader fusion community to develop a common understanding of the problems facing U.S. based university fusion energy research and possible remedies.

We make the following specific recommendations that should be supported and acted upon by the Office of Science and the broader fusion science community to help address these issues:

- University engagement on FES user facilities must be strong and viable moving forward into the era of burning plasma physics. New and improved modes of participation in off-campus research based on fusion user facility participation must be developed by the fusion community in partnership with the Office of Science that lead to enhanced university leadership roles; this leadership must be recognizable by the broader scientific community. Models used in other scientific disciplines can inform the best approach for fusion science.

- Over the last several years funding opportunity announcements in some programs within FES have become irregular, with notable exceptions being the NSF/DOE Partnership in Basic Plasma Science and the Early Career Research Program. The absence of predictable annual opportunities to compete for research funding is particularly damaging to university programs given the decision-making structure and the long-time horizon of universities. We recommend the Office of Science develop and sustain more predictable funding opportunities. Stable funding is a hallmark of a strong research field

[3] https://sites.google.com/site/universityfusionassociation/

that drives faculty and student interest, signals growth potential to university administrations, and encourages long-term resource investment.

- The recent FES Ten-Year Perspective and community workshops[4] identify several research thrusts that are critical to the development of fusion energy. While these thrusts are clearly important, the vision and strategy for fusion science is not yet comprehensive. We recommend continued development of a shared long-term vision and strategy for fusion science through a broadly-based initiative led by the Office of Science, the fusion science community, and other stakeholders. Within this long-term strategy, clear paths that encourage and foster university investments in fusion research must be explicitly identified and developed. This can, in part, be accomplished by explicit and strong university leadership in planned National Research Council studies for both fusion and broader plasma science.

- World-leading research programs in fusion physics can be and are being carried out economically in small to medium scale facilities. To maximize innovation and to foster the essential role of academia in fusion science, we recommend that the developed strategy for university fusion research promote new ideas and innovations in fusion science and technology through peer-reviewed initiatives that are best conducted using on-campus experimental facilities.

[4] https://science.energy.gov/fes/community-resources/

Introduction and Background

The University Fusion Association (UFA) has convened a working group to address the health and vitality of university-based magnetic confinement fusion research. This working group is a follow-on activity designed to address issues that were raised during a UFA sponsored Round Table discussion of university program representatives in September 2015, and a well-attended national Fusion Forum in December 2015. At these meetings, widespread community concern was voiced as to current program trends and their impact on the long-term health and sustainment of university based magnetic confinement fusion research. This white paper reports the working group's findings on these matters and is based on (1) the previous results of the Round Table and Forum discussions, (2) a survey of the status and future prospects for university programs in the U.S. with historically major activities in fusion research, and (3) a detailed analysis of federal funding data for university fusion programs. The working group focused on revealing trends and prospects for future research using metrics such as faculty hiring and funding. This analysis is intended to be an important step toward improving the prospects for fusion research, and the working group offers recommendations for next steps that will help achieve a strong basis for fusion research in academia.

The Fusion Energy Sciences (FES) program in the Office of Science, Department of Energy (DOE-SC) is the primary steward of fusion energy science within the federal complex. The larger realm of plasma science, with a diverse and dynamic set of subfields and applications is supported by multiple federal agencies, principally DOE, NSF, and NASA, as well as the private sector. However, research in fusion is unlike most areas of physical science research in that DOE-SC currently provides the vast majority of federal funding for research undertaken by academia in this area. Thus, the trend line that DOE-SC sets has a very direct one-to-one impact on the health and future prospects of research in fusion at our universities and colleges in a way that most other areas in the physical sciences do not experience given their broader agency support. Figure 1 in Appendix B shows a table of all federal funding for research performed at universities and colleges for FY 2011-14 compiled by the National Science Foundation (NSF) National Center for Science and Engineering Statistics.[5] As indicated in this table, NSF is the primary funding source for university-based research in the physical sciences, accounting for 46% of the total funding received by universities and colleges. The next largest federal funding source in the physical sciences is DOE (21%), followed by DOD (15%) and NASA (14%). Presumably most of DOE's funding for universities and colleges is sponsored within DOE-SC.

In contrast to this funding distribution for all physical sciences, DOE-SC provides the vast majority of the total federal funding for fusion research at universities and colleges in the U.S. Total funding in FY 2015 from FES has been estimated by the working group to be between $75M-$85M (see Appendix E) and includes contributions to fusion confinement physics and fusion related materials science, high energy density laboratory plasma (HEDLP) science, as well as basic plasma physics research. In addition to FES support for basic plasma physics, NSF provides $5M-$6M through the NSF-DOE joint

[5] https://www.nsf.gov/statistics/

partnership program. The new ARPA-E program (DOE) for fusion alternatives is a significant development, but by design it will be a short-term funding source that will not significantly encourage long-term university investment in fusion science.

Note that the funding provided by FES for universities and colleges accounts for 20-25% of all DOE funding of physical sciences to academia shown in Appendix B, yet FES's share of total DOE-SC funding is a much smaller fraction and shrinking, even with ITER construction included. This means university funding is a larger percentage of the overall FES budget than it is for the other Offices in the DOE-SC portfolio. Also, note that NSF funding for all university based physical science research is steadily increasing in time, while DOE funding for universities and colleges is steadily decreasing in time. These trends exacerbate the challenge to maintain support for fusion science at universities and colleges in particular given the predominance of FES fusion funding. The lack of other funding agency support for fusion research removes an important buffer for university program evolution in the context of FES program redirection and budget uncertainties.

Given its current dependence on dominant funding from DOE, magnetic confinement fusion science holds a very weak position in the fierce competition for resources on university campuses, including new faculty positions. It is no surprise then that the survey of university programs described below shows poor prospects for hires in fusion faculty at a large majority of universities, despite an increase in the faculty's average age and the anticipation of many faculty retirements in the next five years. The combination of diminishing opportunities for leadership roles in fusion science together with shrinking federal support has eroded and will continue to erode university-based fusion research.

Survey of university fusion programs

The working group undertook a survey of the health and future prospects for magnetic confinement fusion and plasma science university programs funded by FES that have historically had significant activities in fusion research. The university programs included in the survey have been estimated to collectively receive greater than approximately 80% of the current funding provided by FES for university-based research in fusion and plasma science. The survey respondents thus represent an extensive portion of those universities receiving FES funding. The participating university survey responses therefore give a definitive representation of the state of the overall FES funded magnetic confinement fusion and plasma science research community.

The universities surveyed represent most of those institutions that participated in the UFA Round Table held September 25, 2015. Some of the major themes that emerged from those Round Table discussions were that (1) university magnetic confinement fusion energy research programs are contracting, (2) plasma research efforts are shifting to non-fusion areas, (3) few new faculty lines are being created to focus on fusion research, and (4) growth prospects are very limited without a clear indication of stable future research funding. One striking fact that emerged was that no one at the Round Table could identify a single university that has allocated a faculty line to pursue ITER research. Further, it was recognized that the curtailing of on-campus experimental magnetic confinement activities at a number of universities was having a severely negative impact on university research programs and more importantly long-term future university investment in fusion research. These themes were also echoed at the UFA Fusion Forum held in December of 2015 at College Park, Maryland.

The working group survey aimed to further clarify the state of university research programs by better quantifying the major themes raised anecdotally at the Round Table and Fusion Forum discussions. Contacts at each university were asked to assemble information for all fusion and plasma science research activities funded by FES at their respective institutions. The survey inquired as to (1) recent funding history, (2) future funding outlook, (3) metrics for a healthy university fusion program, and (4) faculty and staff demographics within the timeframe of the past five years (2010-2015). A copy of the survey questions is given in Appendix C, along with a list of the fourteen institutions that responded to the survey. Princeton University is not among the surveyed institutions due to the close association of FES funded Princeton University scientists and faculty with PPPL.

The main findings from the survey are: (1) significant reductions in FES funding have occurred for university magnetic confinement fusion programs over the past five years, (2) on-campus magnetic confinement research activities have borne the brunt of the reduced funding, (3) there is small growth in off-campus experimental research activities relative to decreases in on-campus funding leading to overall program contraction, (4) there has been a 10% decrease in the number of university faculty dedicated to fusion research, and (5) there are poor prospects for hiring new fusion faculty, even though the

On-Campus Funding Level	Institution	Change in On-Campus Funding: Expt., Theory, Comp.	Change in Off-Campus Funding: Experimental
> 5M$	1	−25%	0%
	2	−23%	+4%
	3	−11%	+5%
	4	+4%	0%
< 5M$ > 1M$	5	−73%	no activity
	6	−46%	0%
	7	−40%	0%
	8	−8%	+17%
< 1M$	9	−21%	+35%
	10	0%	no activity
	11	0%	no activity
	12	0%	0%
	13	0%	no activity
	14	+600%	no activity

Table 1. Survey results of recent funding history for on-campus and off-campus research sponsored by FES for the fourteen institutions responding to the survey questionnaire. The institutions are grouped according to funding level ranges in column one. Within each funding range the list is ordered by percent decrease in funding, not by funding level. Twelve of the fourteen institutions report either a decrease or flat funding in FES support (86%) over the past five-year time frame.

faculty's average age has risen to 56 and up to 30% of the current faculty at the surveyed institutions are anticipated to retire within the next five years. A list of comments received from the respondents regarding metrics for a healthy university fusion program are also included in Appendix D. Table 1 summarizes the survey information obtained concerning the history of funding for both on-campus and off-campus magnetic confinement research. The table is organized by the total funding from FES at each institution in three ranges: less than $1M, between $1M and $5M, and greater than $5M. The percentage change for the 2010-2015 five-year period is listed separately for on-campus activities, including experimental research and theory and computation (independent of where the theory/computational research was conducted) and off-campus experimental research. The percentage changes are defined relative to each institution's total funding in 2010, that is, the sum of both on-campus and off-campus research activities. Within each of the three total funding ranges the list is ordered by percent decrease in on-campus funding not by total funding level.

While four institutions report a net increase in FES funding over the past five years, the majority report flat or a net decrease in funding. The funding change reported by institution 14 was of a smaller, of order $100k program, that grew significantly. All of the institutions that experienced decreased funding have > $1M/year programs, which implies a significant overall reduction in FES funding at these universities over the 2010-2015 period. Since the funding is reported in real dollars, the additional impact of inflation tempers the gains and magnifies the losses. The funding reductions are dominated by changes in the experimental rather than theory/computational components of research. Not surprisingly then, survey comments indicate that host university's programs have been substantially weakened over the past five years, particularly where a campus experiment has been shuttered. Such closures have happened recently at Columbia University, MIT, University of Maryland, University of Washington, and on a longer time frame at the University of California, Los Angeles and the University of Texas at Austin. The shutdown of Alcator C-Mod at the end of FY16 (originally slated for 2013) will result in the acceleration of these negative funding trends and further the dramatic shift from on- to off-campus research.

In contrast to on-campus magnetic confinement fusion funding for the institutions surveyed, there are no reported cases for reduced funding of off-campus experimental research, but the reported growth in off-campus funding is much smaller than the reductions in on-campus funding. For off-campus research, three of the programs report increased funding for already existing off-campus research with two indicating that new additional funding had been procured. Of the programs having greater than $1M in total funding, seven of eight have an off-campus component to their research portfolio with three programs experiencing some modest increased funding. Of the programs having less than $1M, only two have an off-campus component to their program, with one of the two receiving new funding.

Given the under-representation of fusion and plasma science research in academia relative to other STEM disciplines, contraction and termination of on-campus experimental programs makes it exceptionally difficult to maintain research infrastructure. The decrease in university experimental research has also occurred without commensurate opportunity for growth in off-campus research activity. There has been no effective discussion between the university community and FES as to how strong university fusion programs can be developed and maintained based on a user-facility model. The transition to increased reliance on user facilities represents a major change in the current and past successful university fusion research and educational paradigm that has existed for decades.

The health of university programs is strongly coupled to faculty representation in academic departments. Unfortunately, the survey reveals there has been a net loss of faculty in the past five years, and in particular the outlook for hiring new faculty with an emphasis on fusion research is poor. Table 2 summarizes faculty demographics at the fourteen institutions participating in the survey. The change in fusion faculty is given in column 3, and the change in plasma science faculty (non-fusion research emphasis) is given in column 4. The table is sorted with respect to the total number of faculty that have been added or lost over the 2010-2015 period. While there has been successful faculty hiring, two institutions account for 67% of all new hires. The other twelve institutions had a combined net loss of 9.5 faculty positions in fusion and plasma science, or a 12% reduction in the total number of faculty over the 2010-2015 period.

New faculty lines with an explicit non-fusion research focus have been added over the past 5 years with an overall gain of 1.5 faculty positions in non-fusion research. There has been an overall loss of 6 positions for faculty who either specialize in fusion research or a major fraction of their research is in fusion physics. Each institution's self-assessment for their prospect of hiring new faculty with an emphasis in fusion research is

Institution	Change in Faculty		Prospect for Hiring Fusion Faculty	Fusion Faculty		Non-Fusion Faculty		Change in On-Campus Funding	Change in Off-Campus Funding
	Fusion	Non-fusion		#	Avg Age	#	Avg Age		
4	+2	+3	very poor	7	53	11	60	+4%	0%
9	+2	+2	very poor	4	46	5	49	–21%	35%
14	+2		poor	3	44	0	–	+600%	no activity
6		+1	very poor	3	54	4	46	–46%	0%
12		+0.5	poor	3	50	0	–	0%	no activity
11			zero	0	–	5	61	0%	0%
10			neutral	2	54	0	–	0%	no activity
13	–1		zero	1	45	0	–	0%	no activity
7	–1		poor	6	59	0	–	–40%	0%
8	–1	–1	neutral	6	70	2	55	–8%	17%
1	–1	–2	+1, possible	4	60	3	60	–25%	0%
3	–2	–1	+1, likely	3	59	3	58	–11%	5%
2	–4	+1	+1, possible	8	55	4	52	–23%	4%
5	–2	–2	very poor	4	62	4	60	–75%	no activity
Total or Average	**–6**	**+1.5**	**poor**	**54**	**56**	**41**	**56**		

Table 2. Survey results for faculty demographics and prospects for hiring new faculty in fusion and plasma science at the 14 institutions listed in Table 1. Institutional ordering is based upon the total change in faculty number from maximum additions to maximum reductions. The change in on-campus and off-campus funding shown in Table 1 is repeated here for reference. The color coding of institution number in column 1 is the same as used in Table 1 to give a measure of overall program size.

shown in column 5. Discrete increments from "likely" to "zero" are used in column 5 to characterize the range of hiring prospects reported by the survey respondents. Of the fourteen institutions surveyed only three report that hiring of fusion faculty is possible or likely. As seen in Table 2, many others say explicitly that fusion will not be a target for hiring. One institution's fusion faculty line is being terminated permanently. A trend for fewer faculty focused on fusion research will therefore continue. We emphasize that changes in faculty numbers are a lagging indicator of the health and vitality of a given field because of the long research lifetimes associated with tenured faculty (~25 to 30 years). Negative demographic trends in number and hiring possibilities for new faculty therefore point to a serious long-term problem in the sustainment of a healthy research program in any area of science.

The alarming trends in faculty hiring prompted the working group to ask for additional demographic age data from the survey respondents, shown in columns 5-8 of Table 2. Eleven of the fourteen institutions explicitly provided demographic data for their faculty, and publically available Ph.D. matriculation dates were used to construct the demographics for the other three institutions. The average age of both fusion and plasma science faculty is now 56. This is a several year increase from the 52.7 average reported in FESAC's 2004 Workforce Study,[6] indicating a further aging of our already senior faculty age demographic relative to other areas of the physical sciences noted in the 2004 Workforce Study. The working group also inquired as to the likelihood of faculty retirements within the next five years. Consistent with their high average age, approximately 31 retirements are expected within the next several years, an unusually large fraction (33%) of the total of the 95 currently active faculty in fusion and plasma science.

The negative assessment of most institutions surveyed for the prospect for hiring fusion faculty, together with the projection that approximately one third of the currently active fusion and plasma science faculty plan to retire in the next several years, signals a looming major loss of faculty and with it fusion research at universities across the country.

Analysis of FES funding trend for university magnetic confinement research

In addition to the survey data collected to provide metrics for the current health and future prospects of university-based magnetic confinement fusion research, federal funding data was analyzed by the working group to quantify current and past trends of fusion-related university research activity. In particular, the working group focused on further quantifying the funding history reported in the survey responses. The data used in the calculation of funding levels presented here were obtained from publically available university funding information on the DOE SC website[7] augmented with funding information taken from the DOE SC Portfolio Analysis and Management System (PAMS) public website. The working group analyzed three distinct data sets, one based

[6] http://science.energy.gov/~/media/fes/fesac/pdf/2004/Workforce_report_mod_2004.pdf

[7] http://science.energy.gov/universities/sc-in-your-state
https://pamspublic.science.energy.gov/WebPAMSExternal/Interface/Awards/AwardSearchExternal.aspx

on funding information from the PAMS system only, a data set based on yearly funding numbers, and a third set that was a combination or hybrid of the PAMS and yearly funding information. A detailed discussion of the funding analysis methodology and analysis results for the three data sets is given in Appendix E. The funding numbers discussed in this section are based on the so-called combined PAMS/yearly hybrid data set.

Given that the survey responses discussed in the previous section have stated that the main decreases in university research over the last five year period have occurred in the experimental component of their magnetic fusion programs, the working group concentrated its effort on quantifying the funding level change in university based experimental research. As a measure of those funding trends, Table 3 contains a summary of the funding level and changes in it for on-campus experimental magnetic confinement research over the 2006 to 2015 time frame. The change in funding level has been estimated for the years 2006 and 2015. On-campus experimental funding numbers for the FY2006 are given in column two, while those for the FY2015 are given in column three, with the percent change between the two years given in column four.

Over the past decade the experimental portion of the university magnetic confinement program as shown in Table 3 decreased overall by 17%, from $44.6M to $36.8M in 2015. Given the sizes of the Alcator C-Mod and Madison Symmetric Torus (MST) programs (which represent a ~$23M baseline) with respect to the rest of the experimental grant portfolio, their funding has been subtracted out of the total funding level in rows two and three to give a better measure of the size and change in funding for the rest of the experimental program. As shown in Table 3, the change in program size with C-Mod funding subtracted out indicates a decrease of 27%, from $25.3M to $18.4M over the time frame between 2006 and 2015. If both the C-Mod and MST funding are removed from the overall total to give a measure of funding trends in the smaller scale experimental magnetic confinement fusion program we find a net 34% decrease from $19.5M to $12.9M over the previous decade.

On-Campus Funding: Experimental	Year 2006 (M$)	Year 2015 (M$)	Change in On-Campus Funding: Experimental
Total	44.6	36.8	−17%
w/o C-Mod	25.3	18.4	−27%
w/o C-Mod & MST	19.5	12.9	−34%

Table 3. Funding levels for university experimental fusion research activities that are predominantly based on-campus. Funding amounts are given for the 2006 and 2015 fiscal years as a measure of the change in funding over the last decade. The funding levels and trends given in this table support and substantiate the information presented in the survey section on funding. Estimated 2017 funding including the closure of C-Mod leads to a 54% decrease in program size relative to 2006.

We note that these negative funding trends will undergo a substantial step-change decrease in 2017 with the closure of C-Mod. To gain a measure of the effect of C-Mod shutdown on overall university based experimental magnetic confinement research funding, we estimate the projected FY2017 total funding as equal to current FY2015 spending taking into account the expected decrease due to the closure. This projected 2017 total leads to a 54% decrease in program size relative to funding levels in 2006. The key points summarized in the survey section as to university fusion research program contraction and reduction are supported by the analysis presented here.

Key findings and recommendations

- Reductions in Fusion Energy Sciences (FES) funding have occurred for many of the university magnetic confinement fusion programs surveyed over the past five years. On-campus experimental research activities have borne the brunt of that reduced funding.

- Small growth in off-campus experimental research activities relative to the decrease in on-campus funding contributes to program contraction in university magnetic confinement research activities. Funding trends reported by the surveyed universities are corroborated by analysis of federal funding data available to the working group. This program contraction, coupled with alarming demographic and faculty hiring prospects, creates a challenging environment for the long-term sustainment of healthy fusion research programs at our universities.

- A key metric for the health of any academic field is prospects for long-term university investment in faculty lines. The surveyed universities report poor prospects for hiring new fusion faculty, despite a 10% decrease in the number of faculty dedicated to fusion research at their institutions over the past five years. This retirement loss rate is approximately double the national average.[8]

- Over the last 12 years, the faculty's average age has risen from 52.7 to 56, and up to 30% of the current faculty at the surveyed institutions are anticipated to retire within the next five years. Extrapolating the reported faculty demography, faculty hiring prospects, and the current loss of university-based magnetic confinement fusion research forecasts a bleak future for university participation in fusion science research.
- The absence of a long-term strategy for university-based fusion research, and particularly how university research evolves going forward into the era of burning plasma physics on ITER, contributes to the poor prospects for faculty hires. This absence in conjunction with recent fusion program funding trends, and program uncertainties create a discouraging atmosphere for long-term university investment in fusion science research.

These key findings, distilled from a survey of institutions with historically strong fusion programs, validate and amplify the informal discussion conclusions regarding the crisis

[8] https://www.aip.org/statistics/faculty

felt by the university community on these issues at both the University Round Table and UFA Fusion Forum[9] held in 2015.

Without a strong academic foundation our U.S. fusion program will wither in fundamental respects. From the findings outlined above, we are well into such a trend now. Recovery is possible, but a strong break with current trends must begin immediately. Therefore, the University Fusion Association (UFA) concludes that it is imperative that the Office of Fusion Energy Sciences (FES) begin work with the university and broader fusion community to develop a common understanding of the problems facing U.S. based university fusion energy research and possible remedies.

We make the following specific recommendations that should be supported and acted upon by the Office of Science and the broader fusion science community to help address these issues:

- University engagement on FES user facilities must be strong and viable moving forward into the era of burning plasma physics. New and improved modes of participation in off-campus research based on fusion user facility participation must be developed by the fusion community in partnership with the Office of Science that lead to enhanced university leadership roles; this leadership must be recognizable by the broader scientific community. Models used in other scientific disciplines can inform the best approach for fusion science.

- Over the last several years funding opportunity announcements in some programs within FES have become irregular, with notable exceptions being the NSF/DOE Partnership in Basic Plasma Science and the Early Career Research Program. The absence of predictable annual opportunities to compete for research funding is particularly damaging to university programs given the decision-making structure and the long time horizon of universities. We recommend the Office of Science develop and sustain more predictable funding opportunities. Stable funding is a hallmark of a strong research field that drives faculty and student interest, signals growth potential to university administrations, and encourages long-term resource investment.

- The recent FES Ten-Year Perspective and community workshops[10] identify several research thrusts that are critical to the development of fusion energy. While these thrusts are clearly important, the vision and strategy for fusion science is not yet comprehensive. We recommend continued development of a shared long-term vision and strategy for fusion science through a broadly-based initiative led by the Office of Science, the fusion science community, and other stakeholders. Within this long-term strategy, clear paths that encourage and foster university investments in fusion research must be explicitly identified and developed. This can, in part, be accomplished by

[9] https://sites.google.com/site/universityfusionassociation/

[10] https://science.energy.gov/fes/community-resources/

explicit and strong university leadership in planned National Research Council studies for both fusion and broader plasma science.

- World-leading research programs in fusion physics can be and are being carried out economically in small to medium scale facilities. In order to maximize innovation and to foster the essential role of academia in fusion science, we recommend that the developed strategy for university fusion research promote new ideas and innovations in fusion science and technology through peer-reviewed initiatives that are best conducted using on-campus experimental facilities.

Appendix A

Working group charge and membership

In response to the crisis in university fusion research, as described during the December 2015 UFA Forum, the Working Group is charged with:

(1) providing a clear articulation of the crisis that is supported by evidence and

(2) identifying actionable remedies that address the crisis and can be presented to DOE FES to enlist their participation.

The Working Group is charged with providing a final report to the UFA ExComm by April 30, 2016.

Working Group Membership:

Martin Greenwald	Massachusetts Institute of Technology
Mark Haynes	Concordia Power
Christopher Holland	University of California, San Diego
David Maurer	Auburn University (Chair)
Stewart Prager	Princeton University
John Sarff	University of Wisconsin, Madison
Uri Shumlak	University of Washington

Appendix B

Federal funding summary for basic science research at universities and colleges

TABLE 2. Federal obligations for basic research performed at universities and colleges, by selected agency and broad field of science and engineering: FYs 2011–14

(Dollars in millions)

Agency	Total	Computer sciences and mathematics	Engineering	Environmental sciences	Life sciences	Physical sciences	Psychology	Social sciences	Other sciences nec
All agencies surveyed									
2011	15,720	1,237	1,455	896	8,972	1,652	646	245	617
2012	15,674	1,162	1,511	930	8,917	1,754	688	255	457
2013 (preliminary)	15,528	1,143	1,498	922	8,987	1,620	690	262	406
2014 (projected)	16,279	1,265	1,610	1,016	9,099	1,776	707	279	527
Department of Health and Human Services									
2011	9,439	67	387	117	7,832	89	606	55	284
2012	9,181	42	374	99	7,808	75	636	46	101
2013 (preliminary)	9,247	43	376	98	7,867	76	641	46	101
2014 (projected)	9,296	43	378	99	7,909	76	644	46	101
National Science Foundation									
2011	3,797	936	582	539	619	729	27	135	231
2012	3,759	838	599	530	620	742	31	160	239
2013 (preliminary)	3,822	852	609	539	631	755	31	163	243
2014 (projected)	4,128	920	658	582	681	815	34	176	263
Department of Defense									
2011	1,084	181	383	87	121	261	12	27	11
2012	1,188	234	383	91	160	260	19	21	20
2013 (preliminary)	1,027	218	358	94	133	172	17	19	16
2014 (projected)	1,228	256	401	105	137	262	28	23	16
Department of Energy									
2011	725	44	26	50	111	438	0	0	56
2012	699	35	28	37	109	440	0	0	51
2013 (preliminary)	535	18	23	24	85	386	0	0	0
2014 (projected)	678	33	31	44	107	365	0	0	98
National Aeronautics and Space Administration									
2011	314	3	58	89	14	124	1	*	25
2012	578	6	107	164	26	228	1	*	47
2013 (preliminary)	557	6	103	158	25	219	1	*	45
2014 (projected)	623	6	115	177	28	245	1	*	50
Other agencies									
2011	360	7	18	13	273	11	*	27	10
2012	269	7	22	10	194	9	0	27	0
2013 (preliminary)	340	8	29	9	247	13	0	34	0
2014 (projected)	326	7	27	9	237	13	0	33	0

* = value less than $500,000 in obligations.

nec = not elsewhere classified.

NOTES: Because of rounding, detail may not add to total. Seven agencies are required to report data for this section of the survey: the Departments of Agriculture (USDA), Defense, Energy, Health and Human Services, and Homeland Security (DHS); the National Aeronautics and Space Administration; and the National Science Foundation. Basic research obligations of these seven agencies represented over 99% of total federal basic research obligations to universities and colleges in FYs 2011–14. Other agencies includes USDA and DHS.

Figure 1. Analysis of federal funding for basic research in the sciences. Taken from NSF publication 14-318 "Info Brief: Federal Funding for Basic Research at Universities and Colleges Essentially Unchanged in FY 2012" by the NSF National Center for Science and Engineering Statistics.

Appendix C

UFA university survey

Dear Colleagues,

Recall that this past September you participated in a round table discussion on the current state of health of university programs in fusion and plasma science. As one of the follow-on activities the UFA has appointed a working group to articulate the situation in a form that can be conveyed persuasively to DOE and other stakeholders. I am writing to seek just a bit more information from you, in part to help us reconcile two apparent facts. First, from the round table we know that the outlook for nearly every university represented is either bleak or highly uncertain, with reports of program contraction, few new faculty lines, weak university administration commitment to fusion, and limited growth prospects. However, data from the PAMS system would indicate that annual FES funding for universities nationwide has been roughly constant over the past five or more years at about $90M. To engage DOE and others in a remedy, we must reconcile how it is that university programs are in crisis while this overall PAMS generated funding number has not declined significantly. To answer this question, we are requesting that you answer five questions below for your university. None of the university-specific information you provide will be disseminated. We will only convey aggregate information.

We would be most appreciative if you could respond, by email to me, by March 21. Please let me know if you have any questions or concerns. And we thank you in advance for your response.

Funding history

Over the past five years, how has total funding from FES varied for your university? How has funding from other agencies varied, e.g., NSF, NASA? If it is important that funding for individual programs within your university varied differently than the total, please provide that information as well.

Funding outlook

Please describe the outlook for FES funding at your university for the next five years and the next ten years – the expectation and the confidence in the expectation. How does this compare with the outlook for funding by other agencies, e.g., NSF, NASA?

Metrics for a healthy university fusion program

Please describe the attributes of the FES-funded program at your university during a period when you considered your local program to be healthy and thriving.

Faculty and staff demographics

Please list the number of faculty and staff in fusion and plasma science that have been hired during the last five years. Also list the number that have retired or otherwise left your institution during the same period. Please describe the prospects in your department or institution for hiring new faculty and staff in fusion and plasma science. What are the primary barriers for new hires? Are there specific programmatic changes that could be helpful to increase prospects in hiring?

Synthesis of the above

If the overall FES funding at your university has indeed not decreased significantly, we would welcome your comments on why that metric does not describe the health of your programs.

Additional comments

We welcome any further information that would be useful.

Sincerely,

Uri Shumlak

UFA President

Participating institutions

Auburn University

Columbia University

Lehigh University

Massachusetts Institute of Technology

New York University

University of California, Berkeley

University of California, Irvine

University of California, Los Angeles

University of California, San Diego

University of Illinois at Urbana-Champaign

University of Maryland

University of Texas at Austin

University of Washington

University of Wisconsin, Madison

Appendix D

Survey response comments on metrics for a healthy university fusion program

The UFA survey asked the respondents to describe the requirements for a healthy fusion program at their university. The collection of respondents' comments are:

- There should be a well-described vision for the overall program and at universities in particular
- A perspective of a healthy, vibrant science program is necessary for recruiting
- There should be on-going open dialogue and effective communication between university researchers and FES
- Technical leadership recognized nationally, internationally AND by the university is essential for university programs
- Historically, research activities on shared user-facilities are strongly guided by the host programmatic management, which makes leadership-class research very difficult at universities; this decreases the institution's interest in fusion science
- FES deference to a few major facility programs for determining scientific directions and resource allocations in the overall national program strongly suggests no respect or recognition of scientific and technical expertise in the university community
- The best route for leadership is on-campus research
- There should be strong integration of on-campus and off-campus personnel and activities
- There should be a diversity of ideas and projects; new ideas should be rewarded
- Stable funding with cost-of-living increases is essential
- There should be support for non-faculty career researchers
- There should be recognition of university personnel as valuable sources of independent expertise
- There is great concern about the funneling of DOE graduate student support toward national laboratories, e.g., the NUF program and DOE-SC wide postdoc fellowships
- Apparent absence of cultivating university research by FES
- ITER is a barrier to hiring university faculty in fusion science

Appendix E

Analysis of trends in FES university fusion funding

In addition to the survey data collected to quantify recent university program evolution for fusion research, the working group also collected several forms of federal funding data that were then analyzed to quantify current and past trends of fusion related university research activity.

The data used in the calculation of funding levels presented here were obtained from publically available university funding information on the DOE SC website[11] augmented with funding information taken from the DOE SC Portfolio Analysis and Management System (PAMS) public website. The working group analyzed three distinct funding data sets based on this information. The first data set was based on funding information from the PAMS system only, a second data set was generated based on yearly funding numbers, and a third set was a combination or hybrid of yearly data and a subset of PAMS funding information.

Funding data was downloaded from the Portfolio Analysis and Management System (PAMS) public website in February of 2016. This PAMS data was filtered to extract funding information for all universities[12] that received funding from FES (Org. Codes SC-24.1 and SC-24.2). The start and end dates are used to isolate projects that were active during a given calendar year. A project is active if it starts before or during that year and ends during or after that year. A significant deficiency of the PAMS public website data is that it provides funding amounts integrated over the duration of the project and hence no historical profiles of the annual funding levels are available. Therefore, only annual funding levels averaged over the duration of the project can be computed by dividing the amount awarded to date by the duration of the project. We note that the lack of historical profiles will remove actual gradients in the funding time series and suppress important details of yearly funding trends. The second data set was downloaded in May of 2016, and is composed of actual yearly funding figures available on the DOE SC website. This yearly data set is composed of the actual funding disbursed for a given grant in a particular year. Hence, the yearly data allow the working group to track actual funding trends that are suppressed in the averaged PAMS data set. The yearly funding data set therefore gives a more accurate picture of past and current funding levels for the university research community. The effects of forward funding were accounted for in both the 2015 PAMS and yearly data. Finally, a hybrid data set composed of the total set of yearly funding data along with a subset of PAMS data was developed to account for grants that were not listed in the yearly data, but were listed in the PAMS

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[11] http://science.energy.gov/universities/sc-in-your-state
https://pamspublic.science.energy.gov/WebPAMSExternal/Interface/Awards/AwardSearchExternal.aspx

[12] Public/State Controlled Institution of Higher Education, Private Institution of Higher Education, and Historically Black Colleges and Universities (HBCUs)

data and would suggest that they are currently active. This hybrid data set therefore makes the assumption that PAMS is correct that a given grant is active even if it is not listed in the published yearly data made public by DOE SC due the Freedom of Information Act (FOIA). The working group filtered all three data sets to generate funding trend information on the total university program as well a breakdown of the overall program into specific research areas. A summary of overall funding changes over the last decade with a breakdown of that funding into major components of the program is given in Table 1.

Funding Data Set	FES Funding Category	Year 2006 (M$)	Year 2015 (M$)	Change in Funding
PAMS	Total	80	91.3	+14%
	MCF	70.6	73.3	+4%
	ICF/HEDLP	4.4	7.9	+80%
	Basic plasma	4.9	9.8	+100%
Yearly	Total	81.2	74.2	–9%
	MCF	71	64.4	–9%
	ICF/HEDLP	5.3	2.0	–62%
	Basic plasma	4.8	7.4	+54%
Hybrid PAMS/Yearly	Total	81.2	86.6	+7%
	MCF	71	68.5	–4%
	ICF/HEDLP	5.3	7.6	+43
	Basic plasma	4.8	10.0	+108%

Table 1. Funding levels for all university research activities sponsored by FES. Overall funding levels are given for three main components to the university program. These three areas are research directed at magnetic confinement (MCF), inertial confinement and high energy density plasmas (ICF/HEDLP) and basic plasma physics. Funding amounts are given for the 2006 and 2015 fiscal years as a measure of the change in funding over the last decade.

The major components of the program summarized in Table 1 for the three data sets are the total funding calculated for each, as well as estimates of the amount of funding in the research areas of magnetic confinement, inertial confinement and high energy density plasma physics, and basic plasma physics. Each of the three research areas have both experimental as well as theory/computational components.

Table 2 investigates changes in funding over the last decade in the area of magnetic confinement, and also includes fusion technology and materials research components.

Funding Data Set	MCF Funding Category	Year 2006 (M$)	Year 2015 (M$)	Change in Funding
PAMS	MCF Total	70.6	73.3	+4%
	Theory/Computation	20.6	20.5	0%
	Expt. On-campus	42.2	40.2	–5%
	Expt. Off-campus	5.8	12.0	+107%
Yearly	MCF Total	71.0	64.4	–9%
	Theory/Computation	21.4	19.0	–11%
	Expt. On-campus	44.6	35.1	–21.3%
	Expt. Off-campus	5.6	11.0	+96%
Hybrid PAMS/Yearly	MCF Total	71.0	68.5	–4%
	Theory/Computation	21.4	20.0	–7%
	Expt. On-campus	44.6	36.8	–17%
	Expt. Off-campus	5.6	12.0	+114%

Table 2. Overall funding levels for university magnetic confinement fusion (MCF) research in theory/computation and experimental activities. The experimental research has also been sorted into on- and off-campus research components. Funding amounts are again given for the 2006 and 2015 fiscal years as a measure of the change in funding over the last decade.

The overall total funding in this area of research sponsored by FES is also categorized into research directed towards theory/computational activities and predominantly experimental research. The experimental research has been further filtered as to whether it is primarily based on- or off-campus. Inspection of the off-campus funding data indicates that the average duration of active grants is 10 years, with approximately 40% of the off-campus grants having a duration less than 5 years. Percent change in the various areas is given in the last column of the table.

Finally given the institutional responses discussed in the white paper, the working group further analyzed funding trends in the three data sets for experimental fusion research that is carried out primarily at the universities surveyed. The evolution of this on-campus research activity is presented in Table 3 below for the three data sets. The FES funding information discussed in the main narrative of the white paper was taken from the so-called hybrid data set. This hybrid data set gives intermediate levels of funding decrease relative to the PAMS and yearly only data sets as can be seen in Table 3. We also note that all three data sets indicate program reduction in this area of the FES fusion portfolio.

Funding Data Set	On-campus Funding: Experimental	Year 2006 (M$)	Year 2015 (M$)	Change in Funding
PAMS	Total	42.2	40.2	−5%
	w/o C-Mod	25.9	23.1	−11%
	w/o C-Mod & MST	19.7	16.8	−14%
Yearly	Total	44.6	35.1	−21.3%
	w/o C-Mod	25.3	16.7	−34%
	w/o C-Mod & MST	19.5	11.2	−42%
Hybrid PAMS/Yearly	Total	44.6	36.8	−17%
	w/o C-Mod	25.3	18.4	−27%
	w/o C-Mod & MST	19.5	12.9	−34%

Table 3. Funding levels for university experimental fusion research activities that are predominantly based on-campus for the three funding data sets analyzed. Funding amounts are given for the 2006 and 2015 fiscal years as a measure of the change in funding over the last decade. The funding levels and trends used in the white paper discussion of FES funding (Table 3, page 11) are the hybrid data set listed again as the last entry in the above table.

Summary document of the University Fusion Association Fusion Forum held at University of Maryland, College Park

Summary of

A Forum on the Future of Fusion Energy and Plasma Science Research in the U.S.

Sponsored by the University Fusion Association (UFA)

A two-day forum on the Future of Fusion Energy and Plasma Science Research in the U.S. was held Dec. 14-15, 2015 on the University of Maryland-College Park campus. A remarkable degree of agreement was reached on the issues and approaches discussed for a strong and vibrant fusion and plasma science research community in the U.S – including the need for prompt action to address challenges to our University programs and many of the elements needed for a broadly-based and systematic approach to strategic research planning for fusion energy and plasma science. The Forum identified several follow-on activities that could help resolve critical issues for the success of fusion and plasma research in the U.S.

Background and workshop goals

The fusion and plasma science community has in recent years conducted comprehensive studies of research opportunities and needs for a broad spectrum of science and technology issues related to plasmas and fusion, but while these studies are generally well received, the outside world, including important policy makers, still does not perceive a consistent, cohesive vision coming from our community. As a consequence, the support for plasma and fusion science is constantly in jeopardy, despite the community's enthusiastic view of the vitality and importance of our science both now and in the future. The forum provided an opportunity for a broad segment of the research community to discuss key challenges and strategies needed to strengthen the position of fusion research and plasma science in the U.S. The need for this forum recognized that no recent or currently planned process would address the questions of the type that were discussed at the forum.

The forum was organized on two broad topics: (1) opportunities and requirements for nurturing the growth of fusion and plasma science in the academic environment and (2) means for developing a strategic plan for fusion and plasma science. Forty-eight scientists attended from the major segments of the research community: large laboratories, universities, privately funded research enterprises, and observers from federal funding agencies. The agenda (Appendix 1) included a plenary session on Monday morning that featured three invited speakers who helped set the stage for discussion, followed by breakout sessions on Monday afternoon and Tuesday morning, and closed with a plenary session on Tuesday afternoon with summaries from the breakout groups and discussion of follow-on activities. The forum website[1] includes links to the presentations in the plenary sessions. The plenary sessions were also streamed, with approximately 12 remote participants in total. While many of the questions posed in the breakout discussion are relevant both to fusion energy development and basic plasma science, scientists with active interest in magnetic fusion research dominated the attendance.

[1] https://sites.google.com/site/universityfusionassociation/forum

Opening plenary session

Prof. Gerald Navratil (Columbia U) was invited to help set the stage for discussion of the opportunities and requirements for nurturing the growth of fusion and plasma science research in the academic environment. Prof. Navratil has a long history in fusion plasma research having both local experiments at Columbia and collaborative research on major fusion facilities. He also served as Dean of Columbia's School of Engineering from 2007-2009. He reviewed the history of the federal-university partnership that is the basis for today's university research environment. Among the recommendations of the Bush report "Science–the Endless Frontier" in 1945 was that universities should be the principal sites to conduct basic research and the exclusive sites for graduate and post-graduate education. Typically, universities invest their own resources to recruit top researchers in any given sub-field, paying close attention to the anticipated support that will be available. In most DoE funded research areas, university researchers utilize national and international user facilities for much of their research. The national laboratories do not provide the majority of research personnel and scientific leadership for these facilities. The fusion program is distinctly different from other fields of research, given the adoption of a project-driven research model akin to that of NASA or the weapons program. This results in a relatively small number of university faculty and creates a disadvantage for fusion research in the intensely competitive academic environment. Prof. Navratil then summarized a stepwise erosion of fusion research at major research universities that has occurred since the major restructuring of the fusion program in 1990. He nevertheless emphasized that the situation is not hopeless, recommending a two-time-scale approach to first immediately "stop the bleeding" and then "start the healing" via 5-year strategic objectives.

Dr. Martin Greenwald (MIT) was invited to help set the stage for discussion of means for developing a strategic plan for fusion and plasma science. Dr. Greenwald is Deputy Director of MIT's Plasma Science and Fusion Center and has a long history in fusion research. He has provided important program leadership through his involvement in many research-planning exercises and served as chair of FESAC from 2008-13. Dr. Greenwald reviewed the history of research-planning exercises for the fusion energy sciences program but noted that strategic planning for the program is not seen as satisfactory. He outlined the general components of a strategic planning process and those parts the fusion and plasma science community does well, e.g., conveying scientific excitement and describing research needs. He also noted areas that tend not be done well, for example, assigning priorities and managing risk. He commented on how the community's recent strategic planning efforts have failed due to lack of a systematic approach and too great an emphasis on resource allocation, which is fundamentally an executive function. He advocated a systematic process that is transparent, involves active participation of all stakeholders, and avoids well-know cognitive biases. Citing examples from high energy and nuclear physics, their strategic planning processes have broad community participation and require 1.5 years or more to develop. He noted the importance of international research and ITER but emphasized the role of a strong domestic program with unique research facilities. Successful planning efforts provide many benefits: strong and bold advocacy, a framework for decision making, a roadmap to advance our vision, and a vehicle for reaching and documenting community consensus.

Dr. Michael Knotek, the former Deputy Under Secretary for Science and Energy, DoE , was invited to give his perspectives on the state of the U.S. fusion energy sciences program. One of his main points of emphasis was the need for effective governance, citing examples from other communities and his own experience in leading scientific program change. In his view, there is a lack of effective governance in the fusion energy sciences program, and this compounds the challenges associated with ITER in particular. He offered a frank assessment of the status and nature of the ITER project, but he emphasized that the fusion community must accept liability for its direction and the need to provide leadership for its success. At the same time, he emphasized that the program must effectively articulate its research aims in addition to ITER, including dimensions other than fusion energy, e.g., plasma science and technology. An effective governance process is essential to deal with this complexity and allow the program to react and evolve. When asked for specific examples of effective governance, he outlined several general characteristics: an accepted decision making process vis-à-vis scientific goals and priorities, broad community involvement, agreement on purpose and deliverables, truthfulness with respect to the state of the science, and cooperation between the community and DoE via FESAC, given the legal ramifications associated with the Federal Advisory Committee Act (FACA). In reference to larger experiments, Knotek noted that "facilities do not set scientific priorities". Instead, community governance processes should set scientific priorities. He offered his opinion that major budget relief for the fusion energy sciences program is not likely in the near future and that the community needs to take advantage of available opportunities, stressing predictive modeling utilizing the DOE strengths in high performance computing, and the fleet of national and international facilities (ITER included) as examples.

Breakout sessions

The forum Steering Committee divided the attendance into three groups, each with 16 members (Appendix 2). These groups were charged to discuss the two broad topics with the guidelines shown in Appendix 1 and report their discussions in the closing plenary session. The distribution of membership in the three groups was balanced for representation by institution type (large lab, university, privately funded enterprise, and federal agency), and attendees from the same institution were assigned to different groups. Each group had a designated discussion leader and a scribe who were charged to moderate and summarize the discussion. For the breakout session on Monday, each group was charged to spend equal time on topics related to the two broad questions. This ensured that all attendees were allowed the opportunity to engage in and hear their colleagues' thoughts on all topics. In the Tuesday morning breakout, attendees were given the opportunity to make short presentations within their breakout group. Hence, the discussion on Tuesday was guided by these presentations and previous discussions during the breakout sessions on Monday.

While consensus was not an explicit goal for the forum, the reports from the three breakout groups were remarkably similar. This is a significant outcome of the forum's discussion. Below are bulleted statements that capture key conclusions from the breakout discussions:

- A healthy plasma and fusion science program must have strong university programs that involve experiments, theory, and computation
- Unlike some fields, world-class research programs in fusion and plasma physics can be carried out in small to medium-scale experimental facilities located at universities
- Student training (workforce development) is a strong benefit but not the primary motivation for university research, which is instead frontier science and innovation

- University faculty need local, on-campus research efforts, but this does not always have to be centered on a local facility
- A combination of local and off-site activities is powerful and stimulates useful synergies
- Multilateral collaborations between university-located research and large labs should be pursued
- Scientific leadership opportunities in frontier-class research are essential for the viability and growth of fusion and plasma science faculty hires
- University programs are relatively fragile due to the long time constant for developing and maintaining faculty slots, lab space, and infrastructure
- Our national fusion facilities already involve university researchers but a better model and process is needed to support faculty leadership for off-site-focused research programs
- Models for user facilities used by other communities could be viable but work best if they are in place at the start of large programs, not implemented midstream; we need a better understanding of how other communities deal with this issue
- Funded "missions" or "campaigns" on important science topics that are linked to multiple facilities, theory and computation is one possible approach
- Validation and material science offer possible growth areas, given DoE emphasis on high performance computing and leveraging with BES
- Stewardship of all of plasma and fusion science by a single federal agency is challenging and may be limiting the scope of our research program; we should nurture growth in multiple agencies and learn how this is done in other communities
- The fusion program needs a community-engaged strategic planning process that includes ITER plus a vision for other compelling program components
- Partnership with DoE is key to developing strategic planning and should be mediated through FESAC
- Strategic planning should not be "one off" but rather continual, as done for P5 and HEPAP, for example, allowing the program to adapt to evolving needs in fusion and plasma science
- Strategic planning should engage younger researchers to help develop future leadership
- U.S. contributions to ITER should not be a barrier to progress
- The development of predictive capability is essential to ITER's success
- The U.S. should prepare for modes of participation in ITER research; we should be a leader in developing this common need for the world fusion effort

Suggested follow-on activities

1. Complete a report on the UFA Round Table, documenting the situation in university research and conveying the boundary conditions for the academic environment. This might include additional data, e.g., faculty demographics
2. Immediately establish a working group to develop an approach to addressing the crisis in university fusion research
3. Initiate a dialog with the NRC panel on coordinating UFA and other group-led planning and/or forums that link research strategies to the broad practice of plasma science
4. Initiate a dialog with DoE on strategic planning that is adaptive to changing circumstances
5. Develop a community-wide, systematic approach to strategic planning with a scientific roadmap for fusion and plasma science, i.e., a Snowmass-like process; this could be part of the NRC Decadal Study process

6. Collect information and best practices on strategic planning in various fields of science
7. Collect information on modes of university participation on user facilities in various fields of science

Forum organization

Steering Committee:
- Brett Chapman (UW-Madison)
- Martin Greenwald (MIT)
- Michael Mauel (Columbia U)
- Dave Maurer (Auburn U)
- John Sarff (UW-Madison), Chair
- Uri Shumlak (U Washington)

Breakout Discussion Leaders:
- Troy Carter (UCLA), Group 1
- François Waelbroeck (U Texas), Group 2
- Anne White (MIT), Group 3

Local Organizers (U Maryland):
- William Dorland
- Adil Hassam
- Matthew Landreman

Appendix 1

A Forum on the Future of Fusion Energy and Plasma Science Research in the U.S.
December 14-15, 2015

Sponsored by the University Fusion Association (UFA)
Hosted by the University of Maryland-College Park

Agenda

Monday, Dec 14

Plenary Session (Chair, Uri Shumlak)

8:30 AM Welcome and Introduction, John Sarff, University of Wisconsin-Madison
9:00 AM Overview 1, Gerald Navratil, Columbia University
"Nurturing Research in the Academic Environment: Federal-University Partnership"
10:00 AM Coffee Break
10:15 AM Overview 2, Martin Greenwald, M.I.T.
"Community Planning For Fusion Energy and Plasma Science: The Good, the Bad, and the Ugly"
11:00 AM Overview 3, Michael Knotek, Former Deputy Under Secretary for Science and Energy, US DoE

12:00 – 1:30 PM Lunch

Parallel Breakout Session #1 (see group membership assignments)

1:30 – 3:30 PM (2 Hours)
3:30 – 3:45 PM Coffee Break
3:45 – 6:00 PM (2 1/4 Hours)

Tuesday, Dec. 15

Parallel Breakout Session #2

8:30 – 10:00 AM (1 1/2 Hours)
Opportunity for contributed presentations (2-3 slides, 5 minutes)
10:00 – 10:15 AM Coffee Break
10:15 – 12:00 PM (1 3/4 Hours)

12:00 – 1:30 PM Lunch

Plenary Session (Chair, John Sarff)

1:30 PM Reports from breakout groups
3:00 PM Discussion and organization of follow-on activities

4:00 PM Forum ends

Appendix 1 (continued)

Guidelines for Breakout Group Discussions

Each breakout group will engage the two broad topics and several subtopics listed below:

1. Opportunities and requirements for nurturing the growth of fusion and plasma science research in the academic environment
   A. Role of experiments located on campus
   B. Model(s) for university leadership on shared user facilities for fusion and plasma science
   C. Growing the stewardship of plasma science in the federal complex

2. Means for developing a strategic plan for fusion and plasma science
   A. Developing and nurturing a strategic plan
   B. Impact of delayed ITER

Each group has a Discussion Leader and a Scribe. The Discussion Leaders will manage the Monday afternoon breakout sessions such that equal time is devoted to the two broad topics. Thus, all participants will have an opportunity to share their points of view and engage their colleagues' points of view on both topics.

On Tuesday morning, participants will be able to make short presentations within their breakout groups (2-3 slides, 5 minute). We strongly encourage participants to align their presentations with the discussions that occur Monday afternoon. Hence, the discussions Tuesday morning will be guided by the ideas that evolve within each breakout group separately.

The Discussion Leaders and Scribes will prepare short summaries of their breakout discussions to be presented in the plenary session Tuesday afternoon.

Anticipated outcome: The ultimate goal of the effort being initiated by this forum is the development of a comprehensive vision and plan that strengthens the future of fusion energy and plasma science research with broad support by the community, policy makers, and funding agencies. While complete answers to key questions are beyond the scope of a two-day meeting, the forum will promote discussion on the challenges and future research that is not likely to occur in current and anticipated planning activities. Specifically for this meeting we aim to identify:

a) Areas and issues with broad agreement
b) Issues for which there is a significant divergence in viewpoints
c) Issues where follow-on effort can provide the additional information needed to continue the discussion
d) Ideas for further deliberation, aiming toward consensus on open issues

Appendix 1 (continued)

Questions to Guide Discussion

To help stimulate and focus the dialog, a number of questions related to the topics above are recommended as starting points for discussions. These sets of questions are listed below. Other questions may be raised, but each group should manage the time available such that all of the topics listed above are covered in the Monday sessions.

1. Opportunities and requirements for nurturing the growth of fusion and plasma science research in the academic environment

   A. Role of experiments located on campus
      i. ***Can experimental plasma physics and fusion sustain their presence at universities without local experiments? i.e. can it generate and maintain faculty positions and significant student engagement?***
      ii. ***What are the unique advantages of university-based experiments and what has their role been historically?***
      iii. ***What are the advantages of facilities at the national labs?***
      iv. ***What is the appropriate scale(s) for each venue?***
      v. ***What about computational plasma physics? Do similar arguments apply?***

   B. Model(s) for university leadership on shared user facilities for fusion and plasma science
      i. ***What models for university participation and university leadership in large scientific endeavors are there? (e.g., large telescopes and observatories, space probes, light/particle sources, accelerators …)***
      ii. ***What governance models are used?***
      iii. ***How does (or should) research on plasma physics and fusion map onto these models? What is similar and different?***
      iv. ***Are there models within the Office of Science complex relevant to fusion?***
      v. ***Will this be feasible for U.S. participation on ITER?***
      vi. ***Who should we talk to find out more?***

   C. Growing the stewardship of plasma science in the federal complex
      i. ***What is working or not working about the current model?***
      ii. ***How can we establish a broader base for plasma science within the U.S. government? Which Agencies are appropriate?***
      iii. ***How would this come about?***

2. Means for developing a strategic plan for fusion and plasma science
   A. Developing and nurturing a strategic plan
      i. ***What are the essential elements of a strategic plan for a science program?***
      ii. ***Are there special features or issues particular to plasma and fusion science?***
         – ***Can we employ an "industry-standard" logical and stepwise process for developing such plans?***
         – ***What processes have other science communities used for their plans?***

- ***What has worked or been difficult?***

iii. ***What are the strengths and weaknesses of the FESAC plan?***

B. Impact of delayed ITER

i. ***ITER has been the centerpiece of our future planning for more than 20 years***

ii. ***Given the current schedule and uncertainties, how do we maintain the overall health of the program?***

iii. ***What types of new activities should we be pursuing?***

iv. ***In addition to efforts already planned, what can the U.S. community do to hasten ITER's progress?***

v. ***How should we plan for ITER operations?***

vi. ***What should be our contingency plan in case U.S. participation in ITER is terminated?***

Appendix 2

Attendees and Breakout Groups

Group 1	Group 2	Group 3
Troy Carter (UCLA), Discussion Leader	François Waelbroeck (U Texas), Discussion Leader	Anne White (MIT), Discussion Leader
Brett Chapman (U Wisconsin), Scribe	David Maurer (Auburn U), Scribe	Martin Greenwald (MIT), Scribe
Dylan Brennan (Princeton U)	John Canik (ORNL)	Sarah Castro (U Washington)
Michael Brown (Swarthmore)	Julie Groeninger (Princeton U)	Michael Delage (General Fusion)
Richard Buttery (General Atomics)	Richard Hawryluk (PPPL)	David Ennis (Auburn U)
Sean Finnegan (DoE)	David Hill (General Atomics)	Charles Greenfield (General Atomics)
Chris Hansen (U Washington)	Chris Holland (UCSD)	Mark Haynes (Concordia Power)
Adil Hassam (U Maryland)	George McKee (U Wisconsin)	Matthew Landreman (U Maryland)
Thomas Jarboe (U Washington)	Bob Mumgaard (MIT)	Jeffrey Levesque (Columbia U)
Catherine Johnson (U Wisconsin)	Gerald Navratil (Columbia U)	Richard Majeski (PPPL)
Mike Knotek (retired)	Hutch Neilson (PPPL)	Joshua Reusch (U Wisconsin)
Michel Laberge (General Fusion)	Nirmol Podder (DoE)	Ned Sauthoff (ORNL)
Earl Marmar (MIT)	David Ruzic (U Illinois-UC)	Uri Shumlak (U Washington)
Michael Mauel (Columbia U)	John Sarff (U Wisconsin)	Ryan Umstattd (ARPA-E)
Jon Menard (PPPL)	Fred Skiff (U Iowa)	James Van Dam (DoE)
Stewart Prager (PPPL)	Derek Sutherland (U Washington)	Michael Zarnstroff (PPPL)

Summary of G7 & UFA University Round Table Discussion on Fusion Energy and Plasma Science Research

Summary of G7 & UFA University Round Table Discussion on Fusion Energy and Plasma Science Research, 25 September 2015

Motivated by a perceived decline in university fusion energy and plasma science research programs, the G7 and UFA organized a round table discussion of university leaders of the field to discuss and evaluate the health of university programs. A selection of faculty members from U.S. universities were invited to give short presentations that summarized fusion and plasma science research at their institutions. The trend in fusion research is particularly alarming: few participants report the possibility for growth and most report a declining trend in faculty lines. Faculty lines constitute long-term commitments from universities, and because the number of faculty is a lagging indicator on the field's health, the reduction in faculty lines portends a bleak future for this field.

Background and Motivation

Many fusion researchers have perceived a precipitous decline in university fusion energy and plasma science research over the last several years. It has been observed that fewer institutions are involved in the research and many on-campus experiments have been shuttered. A sampling of universities to assess the situation is consistent with this observation. See Fig. 1. The sample size is relatively small and suggests that the picture could be incomplete. A complete dataset is difficult to obtain through self-reporting by universities.

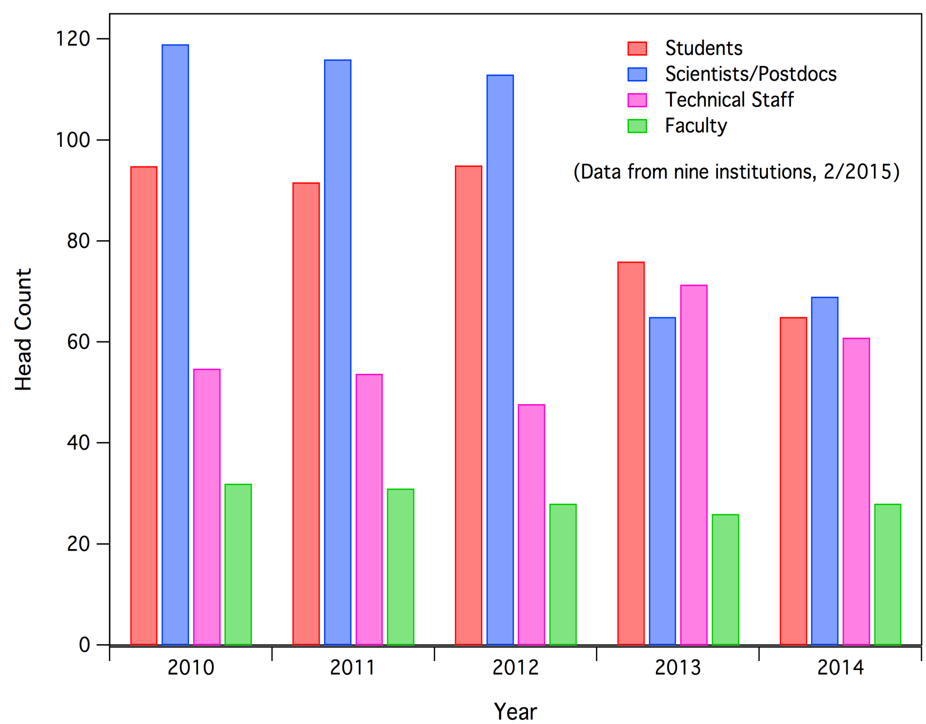

Fig. 1 – Number of people involved in FES-funded fusion energy and plasma science research at nine institutions over a five-year period.

Statistical evidence alone does not adequately convey the reality on university campuses. To further assess the health of university research programs in fusion energy and plasma science, the G7 and UFA assembled an online round table discussion with university leaders of our field. The purpose of the discussion was to evaluate the health of university programs through local observations, personal opinions, and anecdotes. Fifteen round table attendees representing twelve institutions with historically strong research efforts in fusion energy science participated in a discussion that lasted over three hours.

Round Table Structure

Institutions and representatives attending the round table discussion:

Auburn (Maurer)	Texas (Waelbroeck)	Washington (Jarboe)
Columbia (Mauel)	UC-Berkeley (Wurtele)	Wisconsin (Sarff)
Maryland (Dorland)	UC-Davis (Hwang)	G7/UFA (Fonck)
MIT (Greenwald)	UC-Irvine (Heidbrink)	G7/UFA (Shumlak)
Princeton (Bhattacharjee)	UCLA (Carter)	G7/UFA (Whyte)

Each participant was asked to prepare a 5-10 minute presentation that addressed: (1) the present and predicted future status of their research funding and personnel for fusion energy and plasma science, (2) the response of their institution's administration to the changing funding and educational landscape, and (3) actions that could help move their fusion and plasma research forward. The complete text of the invitation is included as an appendix. The discussion took place with the understanding that statements would not be attributed to individuals or specific institutions.

The round table discussion was conducted using a web-based videoconferencing service. Each participant delivered his presentation, which was followed by brief clarifying remarks and discussion. After the twelve representatives had given a presentation for their institution, a general discussion ensued. The presentations and discussion were a free exchange of information and perspectives during which several recurring themes emerged.

Summary of Round Table Discussion

Here the recurring themes from the presentations and discussion are summarized.

<u>All but one institution stated that their university fusion energy research programs are contracting, and plasma efforts are shifting to non-fusion areas.</u> Few new faculty lines are being created to focus on fusion research, and growth prospects are limited without a clear indication of stable research funding. No one could identify a single university that has allocated a faculty line to pursue ITER research. The NSF-DOE partnership program has been successful, but shifting FES resources into the partnership program weakens fusion research since NSF explicitly precludes research focused on fusion. Furthermore, the NSF-DOE partnership program has a low success rate for proposals and low funding levels, which hinders the promotion and tenure of junior faculty.

Many on-campus experimental projects have been terminated, which was broadly recognized as having a severely negative impact to university research programs. The closures of even small projects have tempered enthusiasm nation-wide. Student interest in plasma science remains strong, but closing on-campus projects reduces exposure to fusion energy research. Experimental plasma research typically requires lab space that is larger than most university research projects, and competition for lab space is intense on most university campuses. When on-campus experiments are closed, the lab space is difficult to retain and once lost is next to impossible to reclaim. An on-campus research component is necessary for a viable plasma research program. Universities extract no benefit from an "off-campus only" research model and are interested in supporting projects with an on-campus presence, such as a local experiment.

University faculty do not currently set the scientific research directions at the national fusion facilities, which is unlike other fields of science. Our field needs a model that promotes university leadership at these facilities. Effective partnership requires shared authority. Off-campus research has value to university administrations only if their faculty are the recognized leaders.

Plasma physics needs an eager steward. Since funding support for plasma physics outside of DOE/FES is small, FES is the most appropriate steward. Under the dedicated stewardship of DOE/FES, plasma physics can thrive and contribute in major ways to the DOE mission of addressing America's energy needs. Effective directorship of the program would include support for fundamental plasma physics, multi-PI projects in basic plasma science, and investigations of alternative approaches to fusion energy.

Appendix – Round Table Invitation, 24 August 2015

The G7 and UFA are assembling a roundtable discussion of university leaders of fusion energy and plasma science research, and we invite you to participate. The purpose is to evaluate the health of university programs through your local observations, personal opinions, and anecdotes; such evidence conveys the reality of our predicament more convincingly than statistical evidence alone. Your input is critical to provide an accurate assessment, which will be communicated to government decision and policy makers.

The roundtable meeting will have approximately ten participants and be conducted online. To stimulate discussion and identify commonalities, participants will give 5-10 minute (2-3 slides) presentations that address the following areas for their institutions:

1. ***Research Status***. What is the present and predicted future status of your research funding and personnel for fusion energy and plasma science? How have funding opportunities evolved in the last 5 -10 years? Have the sources of funding shifted from FES to other agencies, e.g. NSF, NNSA, AFOSR, NASA, ARPA-E? Are these funding sources predictable? Have research programs been reduced or terminated? And have new starts compensated for these reductions? Is there an observable difference between how FES and other Office of Science Directorates (e.g. HEP and NP) nurture their university programs?
2. ***Institutional Response***. How has your institution responded to the changing funding and educational landscape? Specifically, has your academic department hired new tenure-track faculty in fusion energy and plasma science, or have future plans to hire in this area? Have the new hires had difficulty building funded research programs and making connections to the national and international fusion research effort? Are the new hires being tenured and promoted? How is our research field viewed by your upper administration? Is it identified as a strategic growth area? Has your institution committed long-term lab space and other resources?
3. ***Future Progress***. To help move your fusion and plasma research forward, what are the most important actions that might be taken by FES? by Congress? by the community?

Material from our discussion will be kept confidential and only qualitative information or redacted anecdotes will be communicated externally.

Your contributions are essential to the success of this effort. Please respond to indicate your willingness to participate and complete the online poll with your availability.

Sincerely,

Uri Shumlak and Dennis Whyte