Fusion in the Era of Burning Plasmas: Workforce Planning for 2004 to 2014

Final Report of the FESAC Workforce Development Panel

Presentation to Fusion Energy Sciences Advisory Committee

March 29, 2004

FESAC Workforce Development Panel

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Charge to FESAC

CHARGE: “to address the issue of workforce development in the U.S. fusion program".

The key components of this charge are three-fold:

- **Where are we?** Assess the current status of the fusion science, technology, and engineering workforce (e.g., age, skill mix, skill level).
- **Where are we going?** Determine the workforce that will be needed and when it will be needed in order to ensure that the U.S. is an effective partner in ITER and to enable the U.S. to successfully carry out the fusion program.
- **How do we get there?** Provide suggestions for ensuring a qualified, diversified, and sufficiently large workforce and a pipeline to maintain that workforce. The suggestions should be things that are reasonable and within the control of the Office of Science.

Summary of Workforce Panel Findings

- The fusion community, ~1000 personnel, has similar demographics to the larger physics community. But it is has less gender and racial diversity and is slightly older than the physics community.
- Without any changes, by 2014 over 1/3 of the total fusion workforce will be age 65 or older.
- Universities have produced an average of 40 PhD's/year over the past 5 years, but the actual number has fallen steadily from over 60 to below 35 during that period. Roughly 50% of those PhD's leave plasma science entirely.
- Over the next 2 to 3 years, the fusion community is projecting a redirection of personnel into burning plasma related studies, but with no significant change in the total number of personnel.
- However, starting about 4 years from now, the community foresees the need for over 30% growth (300 positions) in the total number of personnel to be able to support ITER and NIF.
- Such projected growth will require hiring rates of over **40 plasma-trained PhD's/year.**
- The Panel strongly suggests that actions be taken now to:
  - Increase available positions at national laboratories and develop a 5 to 10 year hiring plan.
  - Expand training and research opportunities for students and university faculty at large facilities.
  - Stabilize and strengthen university research programs with emphasis on experimental programs.

Panel Process & Progress

July 31, 2003	Workforce Charge presented to FESAC
August – September, 2003	Formed Workforce Panel developed institutional, organizational, and individual survey forms Conference calls - 9/8/2003 & 9/25/2003
Sept. 29 to Oct.5, 2003	Distributed surveys via e-mail
October to November, 2003	Data collection and analysis
October 23, 2003	Released on-line "individual" survey **http://www.auburn.edu/cosam/FESAC_survey**
October 25 - 26, 2003	Panel meeting at APS-DPP meeting (Albuquerque, NM);
November 18, 2003	Report preliminary findings to FESAC
December, 2003	Development of follow-up skills assessment survey Distribution of "skills survey" Begin writing report
January to March, 2004	Final analysis of collected data Writing the final report Conference calls – 1/20/04, 2/3/04, 2/17/04, 2/24/04, 3/2/04, 3/9/04, 3/10/04, 3/16/04, 3/23/04
March 29 - 30, 2004	Report findings to FESAC

Principles and Methods

- Working principles:
  - Ensuring the **continuity of intellectual infrastructure** for the field.
  - Ensuring sufficient professionals are available to maintain a **vigorous domestic program** that is similar in size and scope of the current program and the inclusion of a strong research program in burning plasmas centered on the NIF and ITER devices.
  - Ensuring that the **workforce pipeline** is adequate to maintain a healthy, diverse, and flexible base of highly qualified persons capable of continuing the development fusion energy sciences.

- Methods:
  - Two rounds of surveys were performed:
    - Institutional (survey forms) and individual (online form) survey of demographics
    - Institutional survey of "skills" and projected growth in workforce.
  - Data is normalized against AIP (American Institute of Physics) and NSF (National Science Foundation) databases.

Where are we?
Where are we going?
How do we get there?
Summary

Where are we? - A "typical" fusion scientist

Area of fusion science:

Magnetic fusion (MFE):	70%
Inertial fusion (IFE/ICF):	30%

Work location:

University faculty:	110
University researcher:	125
National/Corporate lab:	750

PhD Training*:

Plasma Physics	47%
Other Physics	14%
Nuclear Engineering	14%
Electrical Engineering	10%
Other Engineering	11%

*Over 80% of total workforce have PhD's

Gender (Fusion / Physics PhD's):

Male:	94.8% / 92.5%
Female:	5.2% / 7.5%

Race (Fusion / Physics PhD's):

White:	85% / 81.5%
Non-white:	15% / 18.5%

Median Age:

Online survey:	49
Institutional Survey:	50

The "typical" fusion scientist is a 50 year old, white, male PhD physicist at a national laboratory

Where are we? - Age distribution of PhD fusion personnel

Group	% under 40	% over 60	Source
Physics PhD's	27% 29%	18% 16%	NSF AIP
Fusion PhD's	24%	18%	WPS
Physics faculty	16%	32%	NSF
Fusion faculty	17%	36%	WPS
Faculty at major fusion universities*	12%	38%	WPS

*Universities with 5 of more fusion faculty: Columbia, MIT, Maryland, Princeton, Texas, UCLA, UCSD, and Wisconsin

- The data shows that the age distribution of physics faculty is older than the population of all physicists.
- The age distribution of fusion faculty is slightly older than the physics faculty.
- Even more striking is that the age distribution at major fusion institutions more skewed than the the population of all fusion faculty.
- Overall, this data suggests that the fusion community has a similar age distribution as the rest of the physics community.

Where are we? - Fusion, Physics, & Other Fields

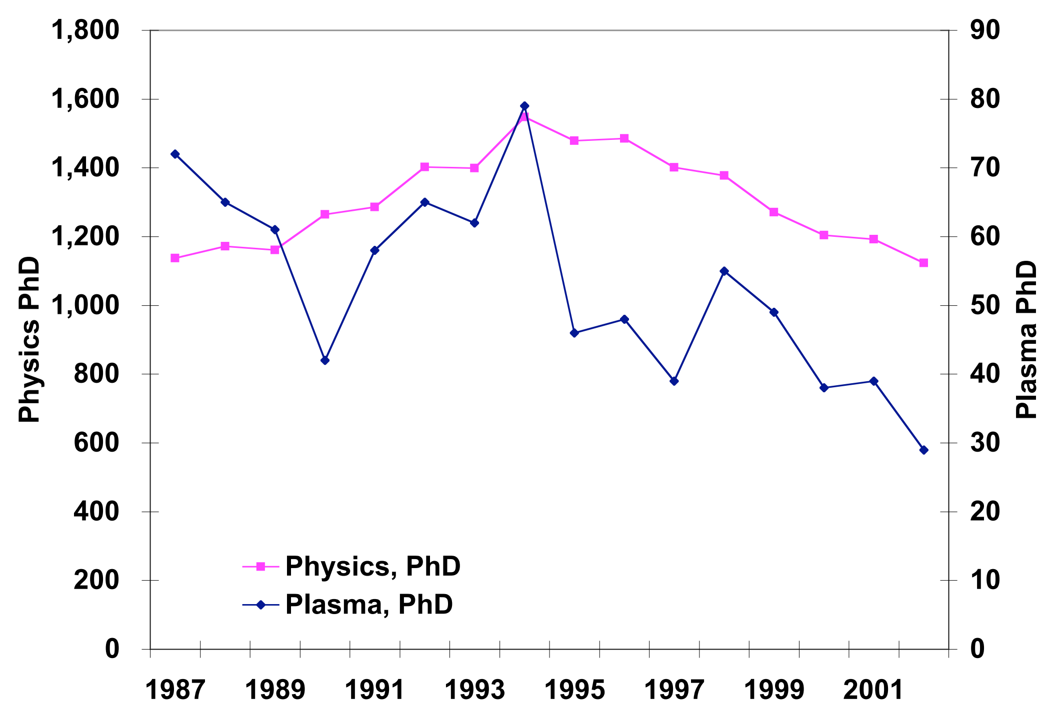
Percentage of PhD's in each age category
(Data from National Science Foundation & Workforce Panel)

	< 35	35-39	40-44	45-49	50-54	55-59	> 60
Physics Total	12.7	14.4	15.9	14.5	11.9	12.3	18.2
Fusion Total	11.6	12.1	11.6	12.4	18.1	16.2	18.1
Electrical Eng.	17.4	21.5	17.1	10.0	8.7	11.7	13.6
Mechanical Eng.	12.2	18.6	18.7	14.9	11.3	11.8	12.5
Biological Sciences	19.4	21.3	16.5	15.3	11.3	8.4	7.9

A more complete picture of the age distribution of the fusion workforce:

- The data shown on the previous page does not present the complete picture.
- For fusion, we must consider the 50-54 and 55-59 age categories in comparison to physics and other fields to determine the actual skewness in the age demographics of the fusion community.
- It is noted that the percentage of fusion scientists over age 50 is larger than that for any of the fields shown.
- By contrast, fusion (and physics), have the smallest percentage of their population below age 40.

Where are we? - Student production is falling



- Student production is an area of great concern.
- The Panel's **5 year average** of 47 PhD's/year is consistent with the NSF data.
- However, the **actual** production rate has fallen from ~60 to ~35 over that period.
- Additionally, the field has had about a 50% "loss-rate" of its new PhD's.

* Plasma science & engineering includes physics and engineering PhD's working on plasma-related projects but excludes any physics or engineering PhD's working exclusively on space physics.

NSF DATA	
5 year total:	210
5 year average:	42
Includes all areas of plasma physics	

FESAC DATA	
5 year total:	235
5 year average:	47
Plasma science and engineering*	

Where are we?
<u>Where are we going?</u>
How do we get there?
Summary

Where are we going?

- The Panel performed a second round of surveys to determine the personnel and skills requirements of the largest laboratories.
- Assume a program that maintains current level of “domestic” activity PLUS participation in burning plasma experiments (NIF & ITER).
- Respondents provided data on their short-term (3 years) and long-term (10 years) workforce requirements.
- Data was gathered using the six “skills” areas defined in FESAC Development Path (Mar., 2003) report.
  - Theory, simulation, and basic plasma science,
  - Configuration optimization,
  - Burning plasmas,
  - Materials science,
  - Engineering science / technology development,
  - Power plant development

Where are we going? - 3 year projections

- In the short term (3 years), the data provided to the Panel suggests that there will not be a significant change in the total number of fusion personnel.
- Among the MFE personnel, there will be a redistribution of personnel from basic plasma science and configuration optimization to burning plasma studies.
- Among the IFE/ICF personnel, there will not be any significant change in the number or distribution of the workforce.

Where are we going? - 10 year projections

Overall change in fusion (MFE AND ICF/IFE†) personnel requirements over the next decade

	Plasma PhD's	Tech/Eng. Staff	Total
Retirements	70	14	**84**
Permanent Staff IFE	20	50	**70**
Permanent Staff MFE	65	35	**100**
Additional post-docs	45	0	**45**
Offsite participants	50	11	**61**
Need	**250**	**110**	**360**

† This IFE/ICF database was much smaller than the MFE database and included primarily OFES-funded personnel.

- This table gives the projected change in fusion personnel in the next decade - also taking retirements into account.
- Recall, that for the next 3 years, there is no significant personnel growth.
- The need for additional staff is projected to support ITER and NIF.
- All of this growth would occur in the out years - years 4 to 10.
- This projection requires a minimum average hiring rate of **42 plasma PhD's/year.**

Where are we?
Where are we going?
<u>How do we get there?</u>
Summary

How do we get there? - Meeting the projected demand

- To meet the projected demand of 42 PhD's/year would require an increase in student production.

- If the recent 50% loss rate is assumed, this demand would require a production of no less than 80 new plasma PhD's/year.

- Even with a lower loss rate, the Panel believes some level of overproduction is necessary to ensure that the most qualified persons become professional fusion educators and research scientists.

- The key challenge is the **5 to 7 year** time lag in generating new PhD's coupled with an **additional 2 to 4 year** delay before that new PhD becomes a productive scientist or faculty member.

- Thus, it is necessary to adjust both ends of the workforce pipeline **NOW**:
  - ⇒ Students need to be attracted to fusion science now in order to meet the projected demands.
  - ⇒ However, students will generally enter fields that are perceived as growing and that have good prospects for employment - therefore a strategy to ensure the creation new fusion jobs is vital.
  - ⇒ Attracting new students and creating new jobs are strongly coupled.

How do we get there? - Short Term Suggestions

Short term suggestions are designed to attract existing members of the plasma science community (especially faculty and their students) into fusion energy research and development and to prepare for the greater PhD production rate needed 4 to 5 years from now.

The Panel believes the OFES should engage in the following activities:

1. Perform an expanded, comprehensive assessment of the fusion workforce at the national laboratories with the goal of developing a five to ten year hiring plan.
2. Optimize operations of existing large experiments to foster student-training opportunities with both affiliated and external academic institutions.
3. Implement of periodic reviews of existing graduate and postdoctoral fellowship programs as well as the junior faculty program to ensure that they are competitive and meet current needs.
4. Develop programs in coordination with professional societies that enhance the visibility of fusion researchers.
5. Create of a jointly-funded professorship similar to the recently developed NIF professorship.

How do we get there? - Long Term Suggestions

Long term suggestions are proposed as means of enhancing the possibility that students that are first-year undergraduates in 2004 become fusion scientists and engineers in 2014.

The Panel believes the OFES should engage in the following activities:

1. Implementation of outreach programs at all educational levels with the goal to attract a diverse group of students into pursuing a career in fusion science and engineering.
2. Expand support of new, fusion-relevant, university-class experimental, theory, and computational research programs, with a particular emphasis on experimental programs.

The Panel notes that all of these suggestions are dependent upon maintaining the current number of fusion job positions while creating the new positions suggested by this report as needed to support ITER and NIF.

Where are we?
Where are we going?
How do we get there?
<u>Summary</u>

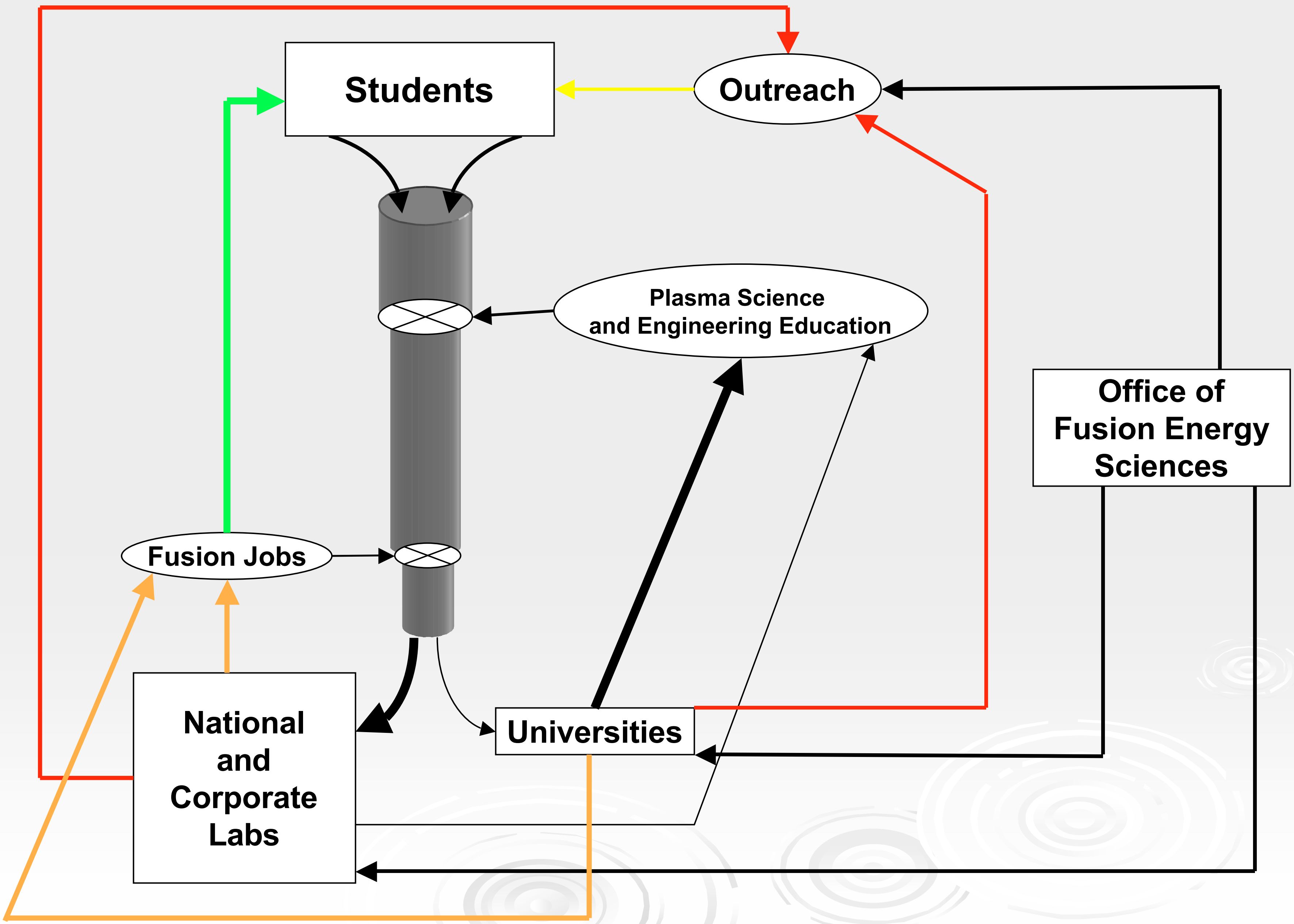
Panel Concerns

- As noted in the 2001 NRC assessment of the OFES:
  "…the broader scientific community holds a generally negative view of fusion science. This isolation, combined with the generally negative perception of the field, … endangers the future of plasma science."
- The Panel reaffirms this assessment and emphasizes the detrimental impact this has on attracting students to fusion science.
- The Panel is also concerned that only one-half (10 out of the 20 hires since 1991) of recent fusion faculty hires have occurred at institutions that have traditionally had large personnel or infrastructure investments in fusion energy.

Summary

- The Panel has responded to the three components of the charge.
- Over the next decade (2004 to 2014), the fusion community will undergo a SIGNIFICANT loss of its most experienced and highly trained personnel - this is inevitable.
- The fusion community has projected over 30% growth in the number of personnel starting approximately 4 years from the present to be able to support ITER and NIF.
- To meet this demand, new students will need to be attracted to the fusion program immediately.
- However, this growth MUST be coupled to plans for creating the new positions that are required to maintain a domestic program that includes a strong burning plasma component.

The Fusion Workforce Pipeline



Supplemental documents for the FESAC workforce presentation

Where are we? - Gender and diversity details

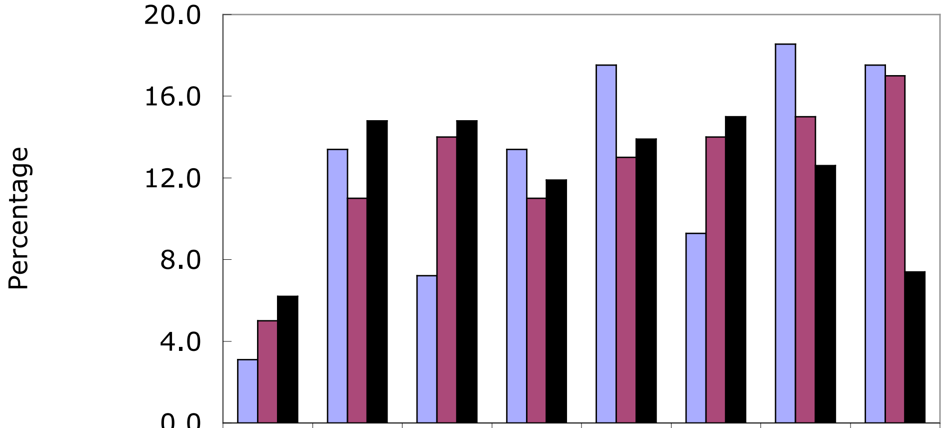
Gender	Males # (%)	Females # (%)
National / Corporate Labs*	362 (94.3%)	22 (5.7%)
University faculty (tenure-track)*	106 (97.3%)	3 (2.7%)
University research staff*	114 (94.2%)	7 (5.8%)
Fusion total	582 (94.8%)	32 (5.2%)
Physics and Astronomy**	92.5%	7.5%

Diversity	White # (%)	Non-White # (%)
National / Corporate Labs*	325 (84%)	61 (16%)
University faculty (tenure-track)*	75 (86%)	12 (14%)
University research staff*	104 (86%)	17 (14%)
Fusion total	504 (85%)	90 (15%)
Physics and Astronomy**	81.5%	18.5%

* WPS
** NSF

RESULT: Fusion has less gender and racial diversity than the overall physics community

Where are we? - Age distribution of fusion faculty

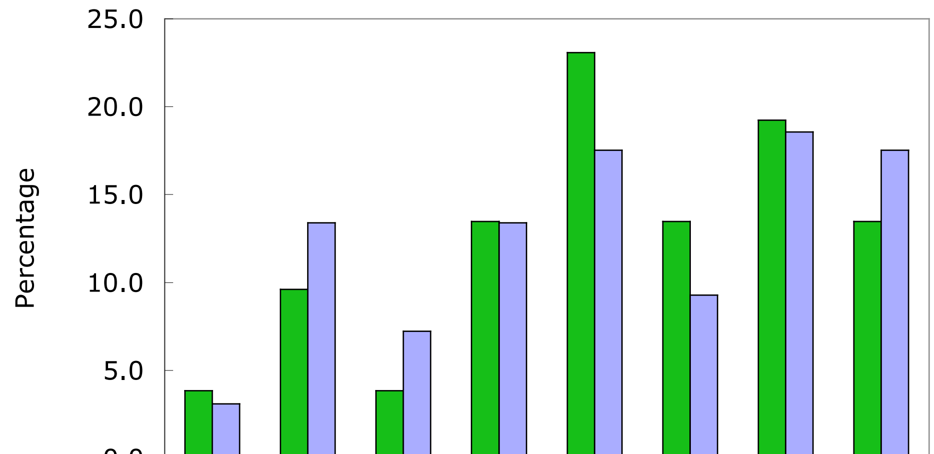


	< 35	35-39	40-44	45-49	50-54	55-59	60-64	> 65
Fusion Fac.	3.1	13.4	7.2	13.4	17.5	9.3	18.6	17.5
Phys. Fac.	5.0	11.0	14.0	11.0	13.0	14.0	15.0	17.0
Physics	6.2	14.8	14.8	11.9	13.9	15.0	12.6	7.4

Age

BELOW: Age distribution of fusion faculty at universities with 5 or more fusion faculty compared to all fusion faculty. The "major" institutions have slightly older faculty than the overall fusion faculty population.

ABOVE: Age distribution of fusion faculty compared to physics faculty and all physics PhD's. The fusion faculty is somewhat older than the population of physics faculty.



	< 35	35-39	40-44	45-49	50-54	55-59	60-64	> 65
Major	3.8	9.6	3.8	13.5	23.1	13.5	19.2	13.5
Fusion	3.1	13.4	7.2	13.4	17.5	9.3	18.6	17.5

Age

Where are we? - Recent fusion faculty hires

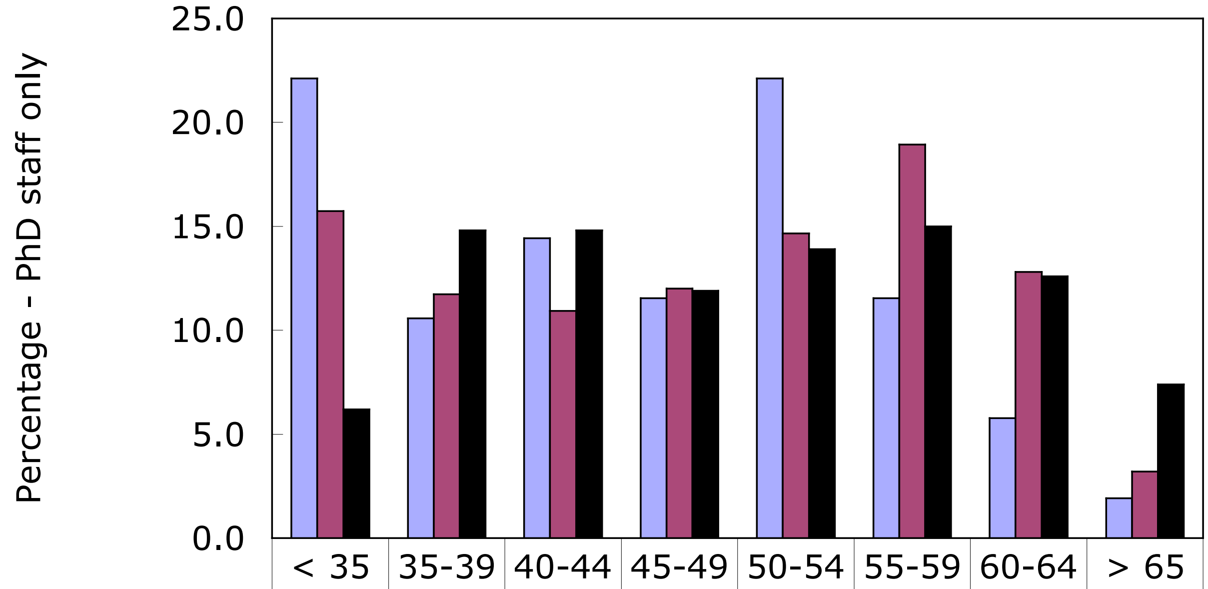
- Generally, the universities that have hired the most recent fusion PhD's are those that have not previously had large infrastructure or personnel investments in fusion science.
- Furthermore, the major institutions have reported an average replacement rate of 0.5 to 0.8/institution over the next 5 years - suggesting that there may not be a complete replacement of retiring fusion faculty.
- Given the aging of the fusion faculty at all institutions, and especially at the major institutions, and the potential that retiring faculty may not be replaced, these younger faculty members at smaller institutions represent a valuable, but often overlooked resource for the fusion community.

University	Year of PhD
UC Los Angeles*	2001
Columbia*	2000
UC Irvine*	1999
U. New Mexico	1999
Utah State*	1999
Auburn	1996
UW-Madison*	1995
Maryland	1993
New Mexico Tech*	1993
Auburn	1992
Hampton	1992
Montana*	1992
Nevada-Reno*	1992
Southeast Louisiana	1992
U. Washington	1992
UW-Madison	1992
UW-Madison	1992
West Virginia*	1992
Florida A & M	1991
UC San Diego*	1991

* DOE Junior Faculty award winners (OFES website)

Where are we? - Laboratory workforce

- Summary of the fusion laboratory workforce at both university and national / corporate laboratories.
- This population has similar demographics to the physics community.
- The "non-PhD's" are typically engineers and other technically trained persons. About 15% of the lab workforce are in this category.



	< 35	35-39	40-44	45-49	50-54	55-59	60-64	> 65
Univ. Res.	22.1	10.6	14.4	11.5	22.1	11.5	5.8	1.9
Nat'l Lab	15.7	11.7	10.9	12.0	14.7	18.9	12.8	3.2
Physics	6.2	14.8	14.8	11.9	13.9	15.0	12.6	7.4

Age Categories

Group	% < 40	% > 60	Source
Physics PhD's	27%	16%	NSF
University Labs	33%	8%	WPS
National Labs - PhD's	27%	16%	WPS
National Labs - non-PhD's	25%	7%	WPS

	Mean Age	Median Age
National labs - PhD's	54	50
University labs - PhD's	45	46
National lab - non-PhD's	45	48

Where are we going? - MFE Short term needs (3 years)

- Summary of short-term (3 year) workforce needs.
- Data presented from the among the largest laboratory employers in the fusion community.
- Numbers represent total persons, including outside participants and post-doctoral researchers.
- Data suggests that in the short term, as burning plasma relevant studies become more important, there will be a reorganization of personnel without significant growth in overall totals.

Research area	Current number of persons	Projected number of persons	Change
Theory, Simulation, Basic Plasma Science	103	101	-2
Configuration optimization	418	306	-112
Burning Plasmas	159	274	115
Materials Science	0	0	0
Engineering Science / Technology Development	30	31	1
Power Plant Development	1	1	0
TOTALS:	**711**	**713**	**2**

Major institutions included in this data (MIT, PPPL, LLNL, GA, LANL) represent 70% of current workforce

Where are we going? - MFE Long term needs (10 years)

- Summary of long-term (10 year) workforce needs.
- An overall increase in MFE staff of just under 200 persons is projected.
- There is a continued redistribution of research effort with significant emphasis on burning plasma related issues.
- A significant growth in engineering science and technology (by over a factor of 2) is projected.

Research area	**Current number of persons**	**Projected number of persons**	**Change**
Theory, Simulation, Basic Plasma Science	103	127	24
Configuration optimization	418	336	-82
Burning Plasmas	159	358	199
Materials Science	0	1	1
Engineering Science / Technology Development	30	74	44
Power Plant Development	1	1	0
TOTALS:	**711**	**897**	**186**

Major institutions included in this data (MIT, PPPL, LLNL, GA, LANL) represent 70% of current MFE workforce

Where are we going? - ICF/IFE Long term needs (10 years)

- Summary of long-term (10 year) workforce needs.
- Data presented from the among the largest laboratory employers in the fusion community.
- Numbers represent total persons, including outside participants and post-doctoral researchers.
- Data suggests that in the short term, as burning plasma relevant studies become more important, there will be a reorganization of personnel without significant growth in overall totals.

Research area	Number of persons	Projected number of persons	Change
Theory, Simulation, Basic Plasma Science	47	69	22
Configuration optimization	0	0	0
Burning Plasmas	0	4	4
Materials Science	9	17	8
Engineering Science / Technology Development	49	97	48
Power Plant Development	0	1	1
TOTALS:	**105**	**188**	**83**

Major institutions included in this data (MIT, PPPL, GA, LANL, LLNL) represents ~30% of current IFE/ICF workforce