Report of the FESAC Subcommittee on Assessment of Workforce Development Needs

Hantao Ji and Ed Thomas

Presentation to Fusion Energy Sciences Advisory Committee
June 16, 2014

Outline

- The charge
- Process to answer the charge
- Key Findings
- Recommendations

Department of Energy
Office of Science
Washington, DC 20585

February 19, 2014

To: **Chairs of the Office of Science Federal Advisory Committees:**
Professor Roscoe C. Giles, ASCAC
Professor John C. Hemminger, BESAC
Professor Gary Stacey, BERAC
Professor Mark Koepke, FESAC
Professor Andrew J. Lankford, HEPAP
Dr. Donald Geesaman, NSAC

From: **Patricia M. Dehmer**
Acting Director, Office of Science

Charge: Assessment of workforce development needs in Office of Science research disciplines

The Office of Science research programs have a long history of training graduate students and postdocs in disciplines important to our mission needs as part of sponsored research activities at universities and DOE national laboratories. In addition, the Office of Workforce Development for Teachers and Scientists supports undergraduate internships, graduate thesis research, and visiting faculty programs at the DOE national laboratories.

We are asking the assistance of each of the Office of Science Federal Advisory Committees to help us identify disciplines in which significantly greater emphasis in workforce training at the graduate student or postdoc levels is necessary to address gaps in current and future Office of Science mission needs. As part of your expert assessment, please consider:

- Disciplines not well represented in academic curricula;
- Disciplines in high demand, nationally and/or internationally, resulting in difficulties in recruitment and retention at U.S. universities and at the DOE national laboratories;
- Disciplines identified in the previous two bullets for which the DOE national laboratories may play a role in providing needed workforce development; and
- Specific recommendations for programs at the graduate student or postdoc levels that can address discipline-specific workforce development needs.

Please submit to me, no later than June 30, 2014, a letter report describing your findings and recommendations. These results will be used to help guide future activities and investments.

If you would like to discuss the charge, please do not hesitate to contact me (patricia.dehmer@science.doe.gov). Thank you very much for your help with this important task.

The Charge Contents

Goals: Assessment of workforce development needs to address gaps in current and future Office of Science research disciplines

Specific Charges to Identify/Provide:

- Disciplines which are not well represented in academic curricula;
- Disciplines in high demand, nationally and/or internationally, resulting in difficulties in recruitment and retention at U.S. universities and at the DOE national laboratories;
- Disciplines identified in the previous two bullets for which the DOE national laboratories may play a role in providing needed workforce development; and
- Specific recommendations for programs at the graduate student or postdoc levels that can address discipline-specific workforce development needs.

Deadline: June 30, 2014

Subcommittee Membership

Jean Paul Allain	University of Illinois at Urbana-Champaign
Lee Berry	Oak Ridge National Laboratory (retired now)
Rich Groebner	General Atomics
Amanda Hubbard	Massachusetts Institute of Technology
Hantao Ji (Chair)	Princeton University and Princeton Plasma Physics Laboratory
Ray Leeper	Los Alamos National Laboratory
Ed Thomas (Vice Chair)	Auburn University

Subcommittee Activity

- Feb 19: charges issued to FESAC
- March 28: subcommittee formed
- April 7: 1^{st} teleconference call: introduction and definition of the work
- April 10: presentation and discussion at full FESAC meeting
- April 17: 2^{nd} teleconference call: agreed on scope of the work, available documents and survey contents etc
- April 25: survey sent to UFA, APS, BPO, PIs of FED-funded projects
- May 7: 3^{rd} teleconference call: preliminary results from survey
- May 15: 4^{th} teleconference call: preliminary analyses for Q1 & Q2
- May 16: 5^{th} teleconference call: discussion of answers to Q1 & Q2
- May 23: 6^{th} teleconference call: preliminary discussions for Q3 & Q4
- June 3^{rd}: 7^{th} teleconference call: in-depth discussions for Q3 & Q4
- June 6^{th}: 8^{th} teleconference call: finalize answers to Q3 & Q4.
- June 11^{th}: Draft report to full FESAC
- June 16^{th}: Presentation and discussion at full FESAC

Processes

1. Gathering community input through a survey on disciplines for Fusion Energy Sciences

2. Analyzing survey data and input to identify disciplines not well represented in curricula; in high demand; and that national labs may help on workforce development

3. Formulating specific recommendations to address workforce development needs

Gathering Community Input

- General call for input/whitepapers from community
- Surveyed the community with a questionnaire
  - Designed for easy answering and quick returning due to the time constraints
  - Numerical scale from 1 to 5 with an option for not-sure or N/A
  - Targeted groups, departments, and institutions, rather than individuals, for effective coverage
  - Distributed through
    - A list of groups/departments/institutions hosting research projects funded by FES
    - American Physical Society (both Division of Plasma Physics and Topical Group of Plasma Astrophysics)
    - Burning Plasma Organization
    - University Fusion Association

Survey Contents (1)

- Established (core) disciplines for FES-funded research
  - Magnetic Fusion Energy (MFE) Sciences
  - High-Energy-Density Laboratory Physics/Inertial Fusion Energy (HEDLP/IFE)
  - Discovery Plasma Sciences (Basic, Low-temperature, Space/Astrophysical Plasmas, etc.)

- Breakdown in approaches
  - Theory/modeling
  - Experimentation
  - Diagnostics

Survey Contents (2)

- Disciplines with emerging opportunities (emerging disciplines)
  - For fusion energy sciences, derived from 15 gap areas identified in the 2007 FESAC Report on Priorities, Gaps, and Opportunities (The Greenwald Report)
  - For HEDLP and Discovery Plasma Sciences, derived from
    - 2007 NRC Report on Plasma Sciences: Advancing Knowledge in the National Interest
    - 2008 FESAC Report on Low Temperature Plasma Sciences
    - 2009 FESAC Report on HEDLP
    - 2010 Community Report on Major Opportunities in Plasma Astrophysics

Survey Contents (3)

- Emerging Disciplines
  - Plasma Material Interaction (PMI) /Divertor
  - Magnets
  - Blankets/Structure
  - Control
  - RF Engineering
  - Tritium Handling
  - System, Safety and Design
  - High Power/Pulse Power Electrical Engineering

Fusion engineering sciences (*integrated subjects from fundamental plasma physics to applied technology*)

  - Multi-phase plasmas (plasmas in solids, liquids, etc)
  - Plasmas in extreme conditions (relativistic, radiation/pair-dominated, strongly magnetized, etc)
  - Micro-plasma and plasma medicine

Discovery plasma sciences

Respondents can suggest new emerging disciplines, as listed in a supplemental slide

Survey Contents (4)

- 3 survey questions directly responding to first 3 charge questions:
  - *How well are disciplines represented in YOUR academic curricula, if your institution is an academic institution?*
  - *Which disciplines are in high demand now or anticipated in the future, in YOUR institution/ department /group?*
  - *Which disciplines may national labs help provide needed workforce development?*

- Additional question on academic institutions: how did the number of faculty and students in your institution/department/group evolve over the past decade? (3 – increased, 2 – about the same, 1 – decreased, 0 – not sure)

Survey Statistics

- Received total 73 completed surveys
  - 54 from university (departments)
  - 9 from national labs
  - 10 from industry
  - Covered most active groups, departments, and institutions

- Majority returned straightforwardly; only a small number of correspondents needed clarifications

- Additional 4 from foreign institutions (Canada, UK, Iran, Japan). Used as references but not in the statistics

Community Input

- On a variety of topics either through direct emails or comments entered into the survey forms
- Emphasized importance of universities in general for workforce development
- Suggested possible solutions: summer school and other successful workforce development programs

Overview of Survey Results

- The three core areas are reasonably represented in academia, but a possible crisis is developing in MFE due to
  - Declining number of faculty,
  - Declining number of universities with viable programs, especially in Physics Departments
  - Declining support for university-based fusion science research
- Emerging disciplines in the discovery sciences represent a vibrant component of plasma science research, and they likely will remain so in the foreseeable future especially in universities.
- Emerging disciplines in fusion engineering sciences represent the largest potential gaps in workforce development.

Eight Key Findings Based on Survey Results and Community Input

- 4 key findings to identify disciplines not well represented in academic curricula (Key Findings 1-4)
- 2 key findings to identify disciplines in high demand (Key Findings 5-6)
- 1 key finding to identify disciplines for which the DoE national labs may play a role in providing needed workforce development (Key Finding 7)
- 1 key finding for specific recommendations for programs at the graduate student or postdoc levels that can address discipline-specific workforce development needs (Key Finding 8)

These Eight Key Findings are bases for the Four Recommendations for programs at the graduate students and post-doc levels

Survey Question: *"How well are disciplines represented in YOUR academic curricula, if your institution is an academic institution?"*

Key Finding1: *Curricula in MFE are reasonably represented in academic departments, but the clear trend toward decreasing size and number of universities in the fusion program is cause for concern and will require deliberate action by FES to stabilize the educational pipeline and reverse this trend.*

Key Finding2: *The universities involved in HEDLP/IFE research are small in number but apparently stable in size.*

Key Finding3: *A relatively large number of universities have strong curricula in Discovery Plasma Sciences, and they appear to be stable and healthy.*

Key Finding4: *Almost all of the emerging disciplines in fusion engineering sciences are poorly represented in academic curricula.*

Key Finding1*: Curricula in MFE are reasonably represented in academic departments, but the clear trend toward decreasing size and number of universities in the fusion program is cause for concern and will require deliberate action by FES to stabilize the educational pipeline and reverse this trend.*

- 14 universities report offering strong curricula in MFE (rating of 4 or 5 in at least one sub-topic), including 4 universities having multiple departments with integrated research groups
  - 9 Physics and/or Astrophysics Departments
  - 3 Nuclear Engineering
  - 2 Applied/Engineering Physics
  - 2 Mechanical Engineering
  - 1 Electric Engineering
  - 1 Aeronautics and Astronautics

Surprisingly small number of Physics Departments and Engineering Departments

Key Finding1: *Curricula in MFE are reasonably represented in academic departments, but the clear trend toward decreasing size and number of universities in the fusion program is cause for concern and will require deliberate action by FES to stabilize the educational pipeline and reverse this trend.*

- 9 departments reported that their programs have been shrinking in the last decade while 6 are stable and only 2 are growing
  - Some are due to termination of local experiments
  - Several strong departments no longer report strong fusion curricula, while some reported planned discontinuation

- University respondents nearly universally indicate concern about the present and future prospects
  - Declining and highly uncertain funding adversely affects decisions of new faculty hires and student applications

Deliberate efforts by FES required to reverse this trend

Key Finding2: *The universities involved in HEDLP/IFE research are small in number but apparently stable in size*

- Only 8 universities report strong curricula in this area
  - Only 4 Physics Departments
  - 2 Nuclear Engineering
  - 2 Mechanical Engineering
  - 1 Scientific Computing

  - 5 of those also have strong MFE programs, reporting shrinking but not specifying which area(s)
  - 3 focus primarily in this area, all stable or growing

Important to maintain stable support and to seek expansion

Key Finding3: *A relatively large number of universities have strong curricula in Discovery Plasma Sciences, and they appear to be stable and healthy.*

- 19 universities reporting strong curricula in Discovery Plasma Sciences, with several also having strong MFE, less frequently, HEDLP/IFE programs
  - At least 15 Physics/Astrophysics Departments
  - About 2 each in Nuclear Engineering, Computing Science, Electrical or other engineering
  - 3 growing, 2 shrinking, and the others stable
  - Diverse topics, ranging from space/astrophysical plasmas, to low-temperature plasmas, to antimatter
  - Cost-effective in workforce development: ~10% of FES funding to support ~50% of the students and postdocs

Continuing support crucial for connecting to broad scientific areas and for workforce development

Key Finding4: *Almost all of the emerging disciplines in fusion engineering sciences are poorly represented in academic curricula.*

Emerging Area	Average Score	Strong Program (# of institutions scoring 4 or 5)
Plasma material interaction / Divertor	2.33	10
Magnets	1.33	0
Blankets/Structures	1.65	4
Control	1.61	5
RF Engineering	1.74	6
Tritium handling	1.11	0
System, safety and design	1.49	1
High power / pulse power electrical engineering	1.95	6
Multi-phase plasmas (plasmas in solids, liquids, etc.)	1.72	5
Plasmas in extreme conditions (relativistic, radiation/pair-dominated, strongly magnetized, etc.)	2.40	6
Micro-plasma and plasma medicine	1.69	4

Only 25% of the universities have total scores of 20 or more

Survey Question: *"Which disciplines are in high demand now or anticipated in the future, in YOUR institution/ department /group?"*

- A metric, defined as (# of strong demand)/(# of strong curricula), is used to help identify workforce development needs

- Treated each group separately: universities, national labs, and corporations due to different emphases

- High demand in Discovery Sciences in universities matches well their strong curricula in the same areas

Key Finding5: *The demand in workforce in the core disciplines is strong and is well matched by the strong curricula, with an exception of diagnostics for MFE which is least represented in curricula while highly demanded by all three groups: universities, and, most strongly, national labs, corporations*.

Key Finding6: *As a whole, the fusion engineering sciences are in high demand but are poorly represented in the academic curricula*.

Key Finding5: *The demand in workforce in the core disciplines is strong and is well matched by the strong curricula, with an exception of diagnostics for MFE which is least represented in curricula while highly demanded by all three groups: universities, and, most strongly, national labs, corporations*.

Core Sciences	Q1 Strong Curricula (# of institutions scoring 4 or 5)	Q2 Strong Demand (# of univ scoring 4 or 5)	Q2 Strong Demand (# of lab/corp scoring 4 or 5)	Univ Demand/ Curricula (Q2_univ / Q1)	Lab_corp Demand/ Curricula (Q2_lab_corp / Q1)
Theory/modeling MFE	15	11	8	0.73	0.53
Theory/modeling HEDLP/IFE	9	8	4	0.89	0.44
Theory/modeling Discovery	17	19	3	1.1	0.18
Experiment MFE	15	11	6	0.73	0.40
Experiment HEDLP/IFE	10	10	4	1.0	0.40
Experiment Discovery	15	17	2	1.1	0.13
Diagnostics MFE	8	9	7	1.1	0.88
Diagnostics HEDLP/IFE	9	7	4	0.78	0.44
Diagnostics Discovery	10	16	2	1.6	0.20

Key Finding6: *As a whole, the fusion engineering sciences are in high demand but are poorly represented in the academic curricula. It is difficult to single out specific disciplines.*

Emerging Disciplines	Q1 Strong Curricula (# of institutions scoring 4 or 5)	Q2 Strong Demand (# of univ scoring 4 or 5)	Q2 Strong Demand (# of lab/corp scoring 4 or 5)	Univ Demand/ Curricula (Q2_univ / Q1)	Lab_corp Demand/ Curricula (Q2_lab_corp / Q1)
Plasma material interaction / Divertor	10	10	8	1.0	0.8
Magnets	0	4	3	inf	inf
Blankets/Structures	4	5	5	1.3	1.3
Control	5	4	5	0.8	1.0
RF Engineering	6	6	6	1.0	1.0
Tritium handling	0	2	0	inf	0
System, safety and design	1	3	6	3.0	6
High power / pulse power electrical engineering	6	6	9	1.0	1.5
Multi-phase plasmas (plasmas in solids, liquids, etc.)	5	6	1	1.2	0.20
Plasmas in extreme conditions (relativistic, radiation/pair-dominated, strongly magnetized, etc.)	6	12	2	2.0	0.33
Micro-plasma and plasma medicine	4	6	2	1.5	0.5

Survey Questions: *"Which disciplines may national labs help provide needed workforce development?"*

- **Key Finding7**: There are general recognitions that national labs can play a role in workforce development for the emerging disciplines, especially in fusion engineering sciences.
  - "Multi-phase plasma, micro-plasma/plasma medicine" are exceptions

One key finding for specific programs at the graduate student or postdoc levels that can address discipline-specific workforce development needs

- **Key Finding8**: It is critical to support faculty who deliver curricula of sufficient depth and breadth and provide research training needed for the workforce development.

Importance of programs such as joint lab-university faculty appointments, support of faculty research in gap disciplines

Two specific recommendations on curriculum development and classroom education for programs at graduate student and postdoc levels

- **Recommendation 1**: *Enhanced periodic summer schools for graduate students and postdocs on fusion engineering sciences*.
  - Successful examples from other fields
  - Jointly with relevant fields, e.g. with material sciences, superconductor technology, nuclear sciences etc.
  - Lectures by experts from all sectors and countries
  - Online resources

- **Recommendation 2:** *Establish a consortium between national labs and academic institutions to enhance graduate student training and advanced curriculum development for plasma diagnostics and fusion engineering sciences.*
  - Share best practices in teaching and research
  - Smaller programs benefit from larger institutions
  - National labs can play important roles

Two specific recommendations on the workforce development needs in research training for programs at graduate student and postdoc levels

- **Recommendation 3:** *Establish a renewed program to encourage graduate students and postdoc to pursue fusion engineering sciences.*
  - *Significant funding challenges in the past decade*
  - *Students have been discouraged to pursue in this area*
  - *The survey results show a particular strong need for a renewed effort*
  - *A targeted graduate and postdoc research award program in areas of fusion engineering sciences should help address this discipline gap.*

Two specific recommendations on the workforce development needs in research training for programs at graduate student and postdoc levels

- **Recommendation 4a:** *Increased participation of academic institutions in large FES projects – particularly in the areas of advanced diagnostic and materials development.*
  - "Ownership" of diagnostics by universities at large devices
  - Scientific leadership by universities at large devices
  - Training also at closely coupled local experiments or test devices
  - Help reverse the trend of shrinking fusion research at universities

- **Recommendation 4b:** *Establish a focused program at national labs to support student and postdoctoral researchers in targeted emerging engineering science areas including advanced diagnostics and nuclear materials.*
  - Partnership between labs and universities as in Recommendation #2
  - Rotation/practicum programs to increase mobility of student/postdoc between universities and national labs

Final Comments

- The perceived future demand in workforce may be altered by the outcome from the ongoing FESAC strategic planning (SP) subcommittee and later from FES, therefore the mix and priorities of disciplines considered here could be modified.

- Input to the SP subcommittee based on our findings:
  - *Importance of a complete educational pipeline from pre-college to employment opportunities, beyond graduate students and postdocs.*
  - *Importance of strong coupling between academia, national labs, and industry, covering diversity of professional opportunities crucial for the health of our field.*
  - *Importance of establishing and supporting faculty in the emerging disciplines for stability and future growth in achieving missions by FES over a long period of the time*

- A healthy and strong FES program requires its each component to be healthy and strong; emphasis in one cannot be at the expense of the others

Summary

- The subcommittee has responded to the four charge questions in assessing workforce development needs for FES in the coming decade, based on the community survey and input.

- The three core areas for FES are reasonably represented in academia, but a possible crisis is developing in MFE due to declining number of faculty, departments and institutions, requiring deliberate efforts by FES.

- Discovery plasma sciences represent a vibrant component of plasma science research connecting to broad scientific areas, and also an attractive venue for workforce development for FES to maintain and strengthen.

- Emerging disciplines in fusion engineering sciences represent the largest potential gaps in workforce development, requiring immediate and special attention.

- Specific programs at graduate and postdoc levels are recommended to meet the workforce development needs, involving both universities and national labs.

- Input provided to the FESAC SP subcommittee and FES based on our findings.

Other Emerging Disciplines Suggested Through the Survey

Fusion Plasma Sciences

- Fusion Engineering/Nuclear Science/Technologies (3)
- Integrated thermofluid/thermomechanical modeling
- Heat Removal
- Neutronics and nuclear analysis
- Energy and Environmental Studies
- Privately funded fusion concepts
- IFE target physics

Discovery Plasma Sciences

- Astrophysical and space plasma (2)
- Atmospheric plasmas (2)
- Antimatter Plasmas / Anti-hydrogen
- Saturn ring plasmas
- Noctilucent cloud plasmas
- Dusty plasmas in astrophysics
- Magnetic reconnection (experimental)
- Dusty Plasmas
- Intense beam physics and beam-plasma interactions
- Hydrodynamics (the collisional, unmagnetized limit)
- Plasmonics
- Plasma nanosynthesis
- Plasma Metamaterials/photonics
- Plasma Accelerators
- Plasma propulsion
- Proton therapy

Your name:		The name(s) of the insitution, department, or group that you are representing:	
If your instituion is an academic institution, how did the number of faculty and students in your institution/department/group evolve over the past dacade? (3 - increased, 2 - about the same, 1 - decreased, 0 - not sure)			

Disciplines	How well are disciplines represented in YOUR academic curricula, if your institution is an academic institution? (1-5)	Which disciplines are in high demand now or anticipated in the future, in YOUR institution/ department /group? (1-5)	Which disciplines may national labs help provide needed workforce development? (1-5)	Additional comments, concerns, and recommendations
	(5 - strongly represented) (1 - poorly represented) (0 - not sure or N/A)	(5 - high demand) (1 - low demand) (0 - not sure or N/A)	(5 - labs contribute greatly) (1 - labs do not contribute) (0 - not sure or N/A)	
Established Disciplines **Theory/modeling**				
MFE Sciences				
ICF/HEDP Sciences				
Discovery Plasma Sciences (Basic, Low-Temperature, Space/Astrophysical Plasmas)				
Experimentation				
MFE Sciences				
ICF/HEDP Sciences				
Discovery Plasma Sciences (Basic, Low-Temperature, Space/Astrophysical Plasmas)				
Diagnostics				
MFE Sciences				
ICF/HEDP Sciences				
Discovery Plasma Sciences (Basic, Low-Temperature, Space/Astrophysical Plasmas)				
Disciplines with Emerging Opportunities				
Plasma material interaction / Divertor				
Magnets				
Blankets/Structures				
Control				
RF Engineering				
Tritium handling				
System, safety and design				
High power / pulse power electrical engineering				
Multi-phase plasmas (plasmas in solids, liquids, etc.)				
Plasmas in extreme conditions (relativistic, radiation/pair-dominated, strongly magnetized, etc.)				
Micro-plasma and plasma medicine				
Other Disciplines with Emerging Opportunities				
Discipline 1				
Discipline 2				
Discipline 3				
Discipline 4				
Discipline 5				
Discipline 6				

(specify disciplines above)