U.S. DEPARTMENT OF ENERGY | Office of Science

On an Emergent FES Vision

Presented by:

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Associate Director
Fusion Energy Sciences
Office of Science, U.S. Department of Energy

March 9, 2010

Welcome… and thank you

- I appreciate the time and energy you spend in making this meeting happen, and your patience in getting to this first meeting of my tenure.

- I recognize the import of the times and the opportunities, and have come to know better many of the challenges we all face.

- There are clear directions in which we need to move. Framing the issues properly so as to create the best, most useful programs is part of our mutual task, and I need your help.

An FES vision is developing that responds to realities and focuses on key opportunities

- Focusing our efforts is part of this vision

- Major elements that inform the judgments made in developing this vision include:

  - Your technical advice

  - Surveying and responding to the landscape: identification of levering opportunities, managing realities of budget constraints

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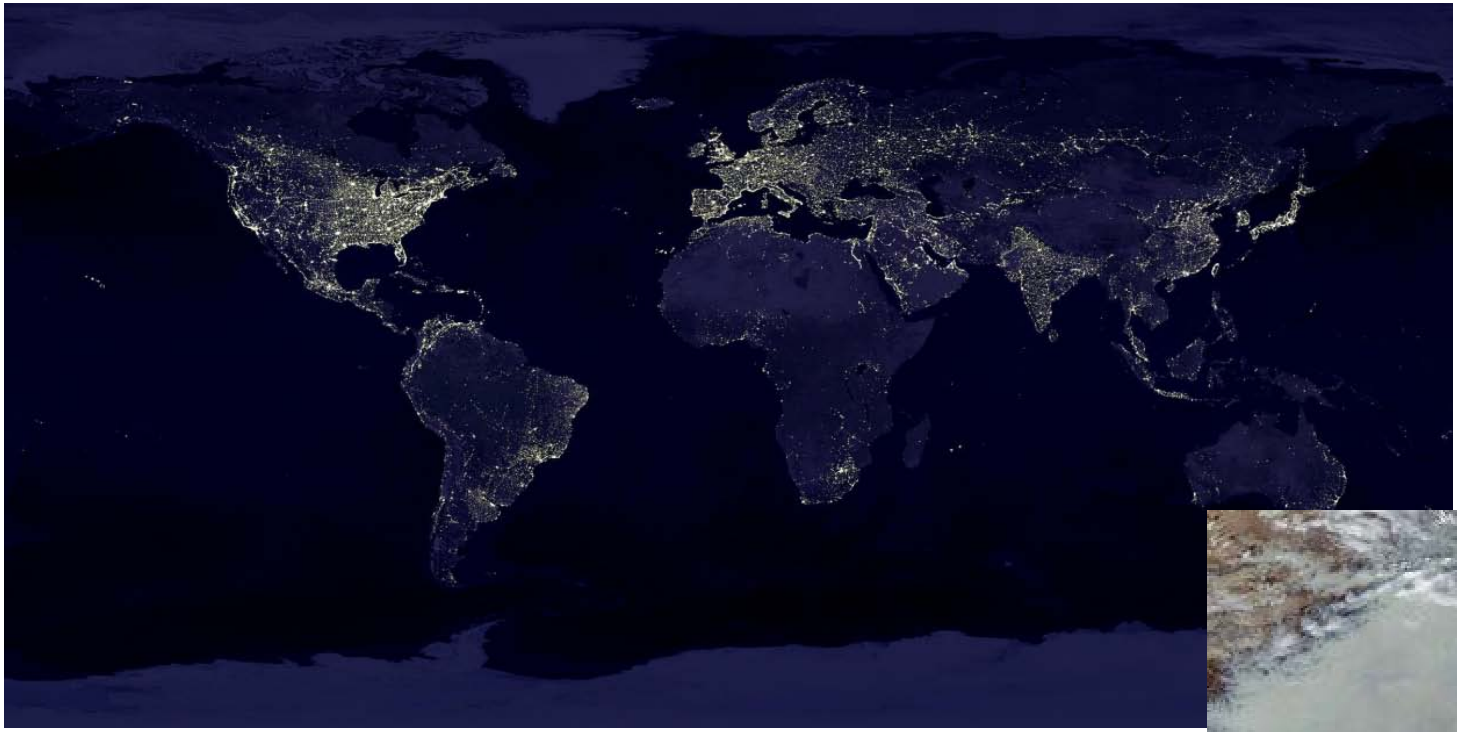
Our ambition is commensurate with the challenges of the times



Pollution plume over Asia

- We are talking about *powering the planet* with a carbon-free energy source

We are also talking about fantastic science

- The discipline that describes the plasma dynamics of a fusion experiment contains a formalism that yields understanding on many great questions of nature, and has yielded significant economic benefit

- The research we need to pursue outside of the plasma physics can also be framed in terms of rich scientific questions that have an impact outside of fusion’s immediate sphere as well

We have an obligation and an opportunity to nurture the broad areas of research that are fusion-related sciences.

Our immediate challenge is about establishing scientific credibility

- Consistent with the mandate of the Office of Science.

- Many elements we need to pursue, but have not pursued yet, are deeply scientific opportunities.

The times call for moving smartly, and bringing forward energy in our lexicon. Establishing scientific credibility is fully consistent with pursuing the energy goal.

… but we need to develop our path forward in a most challenging environment

- Budget deficits are enormous, which implies an all-too-interesting tension between the Administration’s commitment to science vs. managing deficits

  ➔ very tough competition between science and energy with other national interests

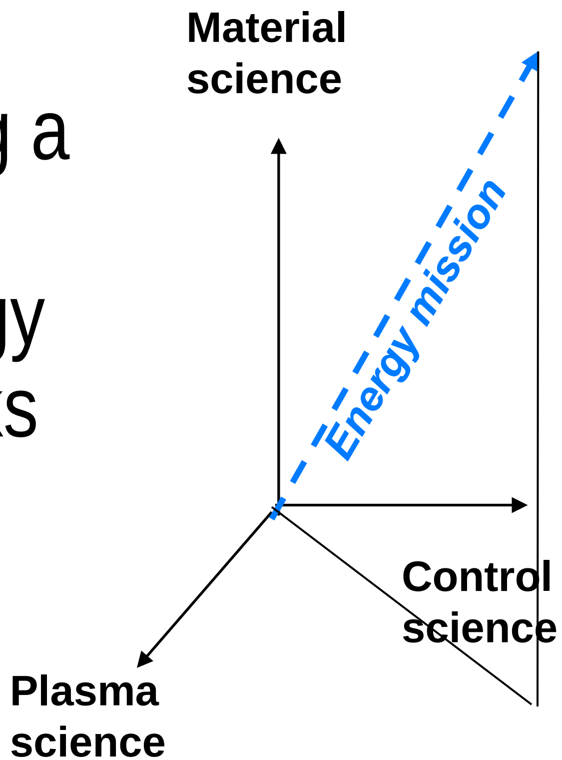
  ➔ very tough competition within the Office of Science

- We need the best technical advice possible to inform our planning and programmatic solicitations

Much of the science we need to develop can be represented in a fairly simple scientific space

There are many “frames of reference” we could choose, but this seems fairly complete

Scientific credibility for fusion ➔ forming a complete enough basis set to enable a description of the requirements for energy development and the accompanying risks



High level goal #1: Plasma dynamics and control

<u>Plasma dynamics and control</u> frames the science questions of both magnetic and inertial fusion energy, industrial applications, and of nature

- Fusion: understanding the dynamics and stability of the burning plasma state. Developing a robust control strategy
- Non-fusion applications: understanding the requirements and impact of being able to manipulate the distribution function of low temperature plasmas
- Mysteries of nature: understanding the physics of self-organization comprising phenomena such as plasma jets, dynamos, accretion disks, and supernova

Regarding plasma dynamics and control in fusion…

- *Plasma dynamics and control is our defining research area now, and we arguably are or are among world leaders in terms of detailed measurement of underlying processes, connection to theory, developing an integrated understanding, and demonstration of advanced scenarios in tokamaks. However,*

At present world-wide investment and approach, it will not provide the validated predictive capability we need to take a confident step beyond ITER and it's geometry

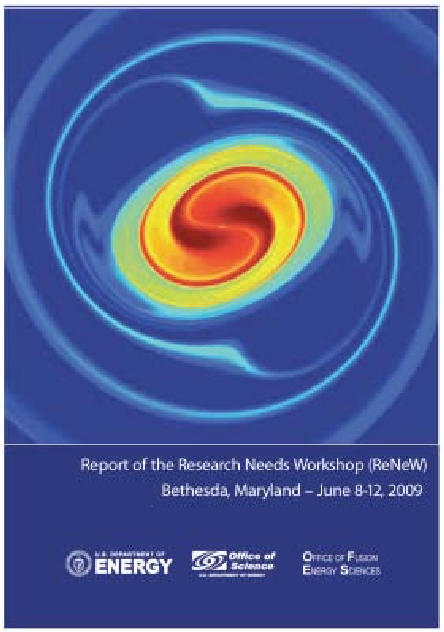
International commitment in plasma control is impressive and worth capturing. In fact, we will need to if we are to remain at the forefront

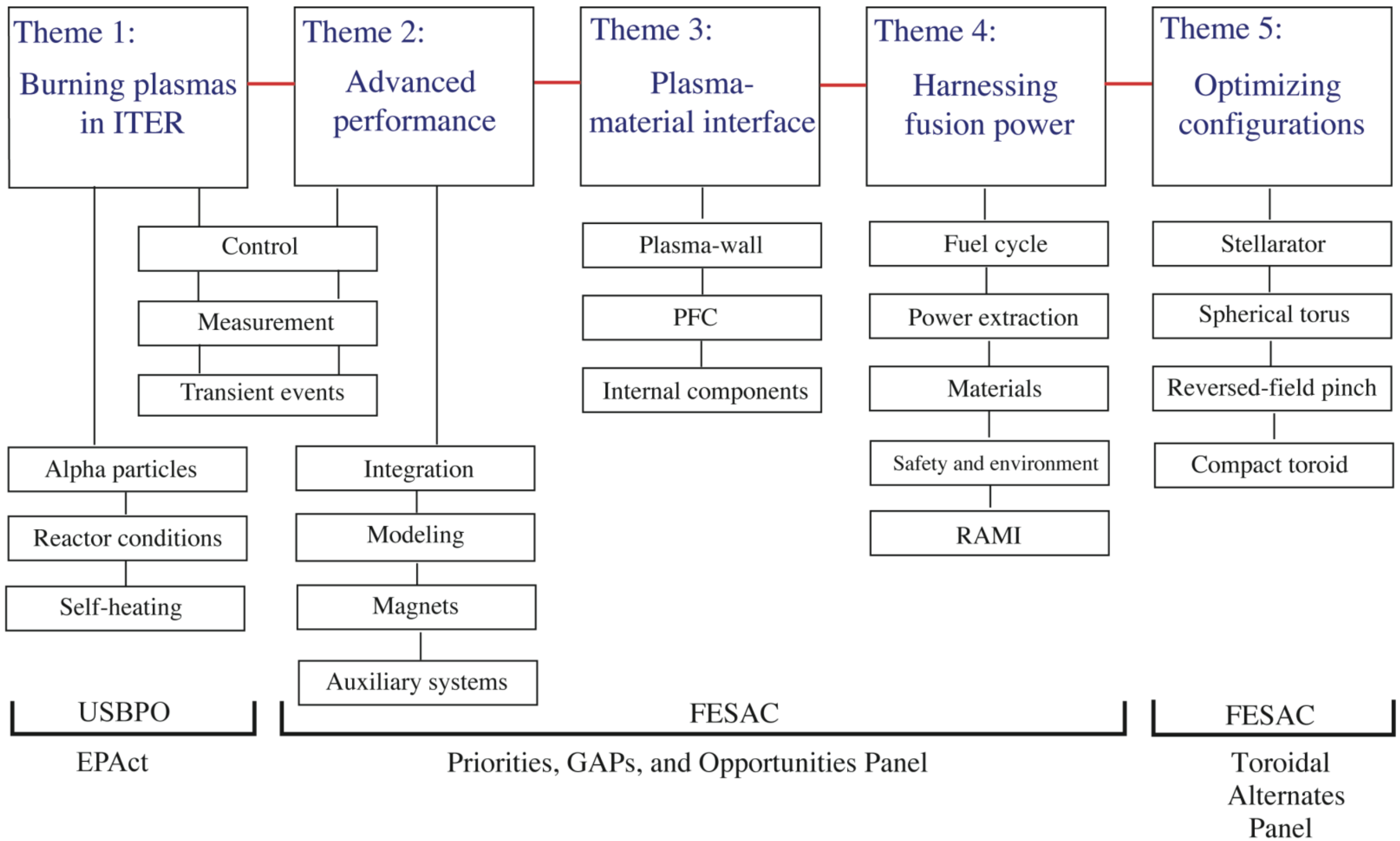
High level goal #2: Materials in a fusion environment

- Plasma/surface interactions: establishing boundary of a fusion plasma. Plasma facing surface survival, renewal: cracking, annealing. Fuel retention. Important for industrial, non-energy applications as well
- Nuclear effects on materials and structures, including the effects of > 100 dpa on structure integrity, helium creation in situ, and time evolving properties
- Harnessing fusion power depends on the nuclear material science above and is extended to tritium breeding and extracting fusion power

This requires the launching of a vigorous materials and nuclear science program that will be part of defining and constructing a fusion nuclear science facility, and will fill gaps en route to a DEMO. Such a program will benefit from and give to other research needs. Synergies will be identified and levered between MFE, IFE, advanced nuclear energy, and defense.

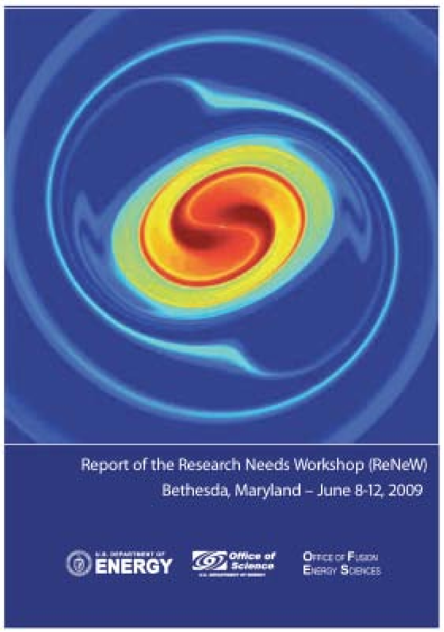
This broad brush view maps well to how you have chosen to represent the program…





Plasma dynamics & control and materials science can be mapped on to the community view of what is important to pursue

<u>U.S. focus and world leadership</u>, but not sufficient for the validated, predictive capability required to fill the gap between ITER and DEMO.
<u>Leadership may be ceded</u> unless we lever international investments



Plasma dynamics and control

- **Theme 1: Burning plasmas in ITER**
  - Control
  - Measurement
  - Transient events
  - Alpha particles
  - Reactor conditions
  - Self-heating
- **Theme 2: Advanced performance**
  - Integration
  - Modeling
  - Magnets
  - Auxiliary systems
- **Theme 3: Plasma-material interface**
  - Plasma-wall
  - PFC
  - Internal components
- **Theme 4: Harnessing fusion power**
  - Fuel cycle
  - Power extraction
  - Materials
  - Safety and environment
  - RAMI
- **Theme 5: Optimizing configurations**
  - Stellarator
  - Spherical torus
  - Reversed-field pinch
  - Compact toroid

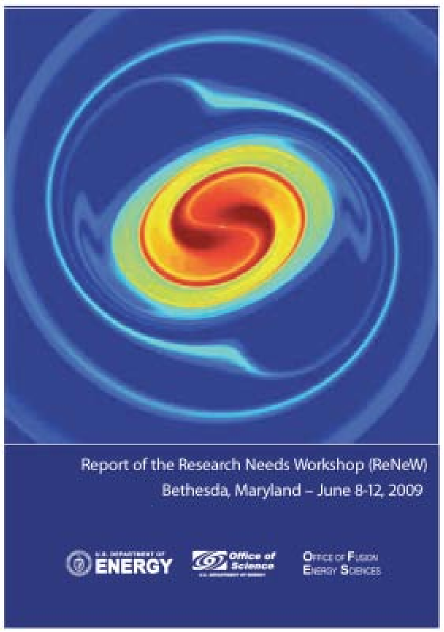
USBPO — EPAct (Theme 1)

FESAC — Priorities, GAPs, and Opportunities Panel (Themes 2–4)

FESAC — Toroidal Alternates Panel (Theme 5)

Plasma dynamics & control and materials science can be mapped on to the community view of what is important to pursue

Urgent international need. U.S. leadership opportunity



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USBPO — EPAct

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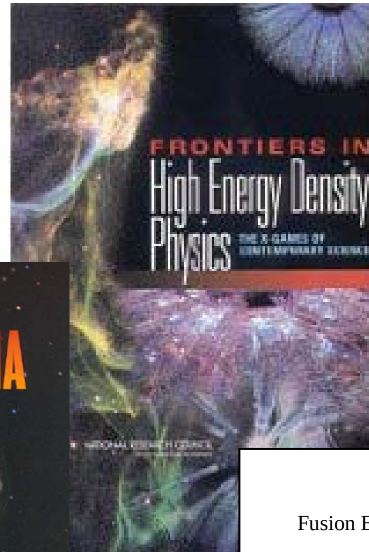
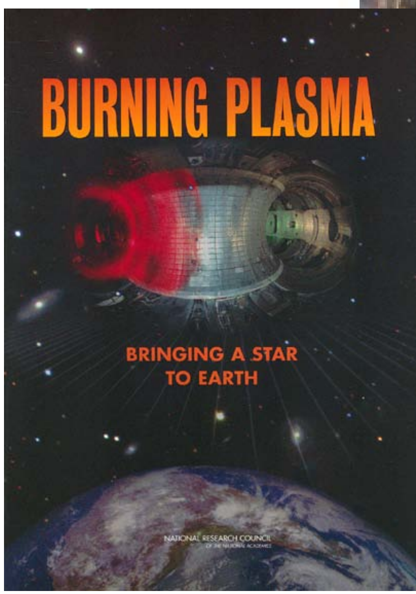
FESAC — Toroidal Alternates Panel

Elements of a path forward are being informed by many high-level panel and community assessments

HEDLP





Urgency of a burning plasma step

Fusion Energy Sciences Advisory Committee

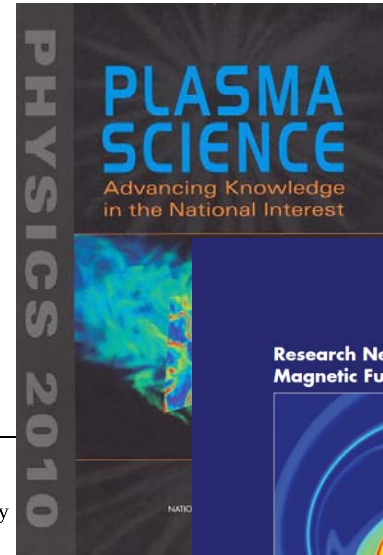
Report on

Priorities, Gaps and Opportunities: Towards a Long-Range Strategic Plan for Magnetic Fusion Energy

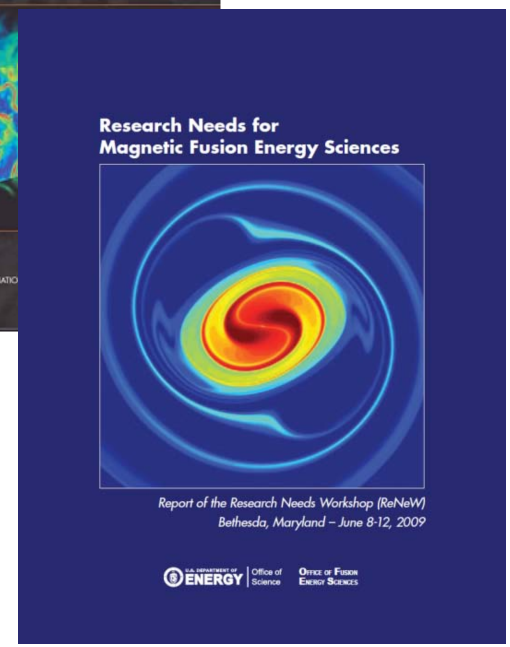
October 2007

U.S. Department of Energy
Office of Science
Office of Fusion Energy Sciences
Germantown, Maryland 20874-1290

FESAC: Priorities, Gaps, and Opportunities



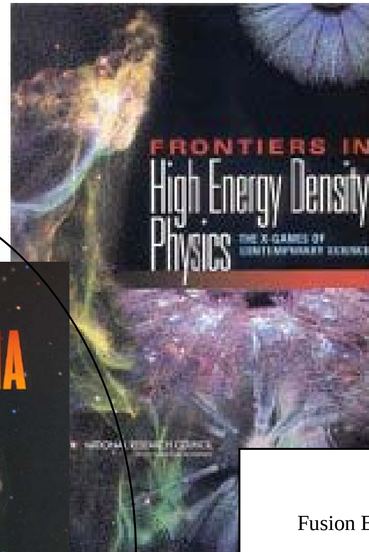
Becoming a steward of the plasma science more generally

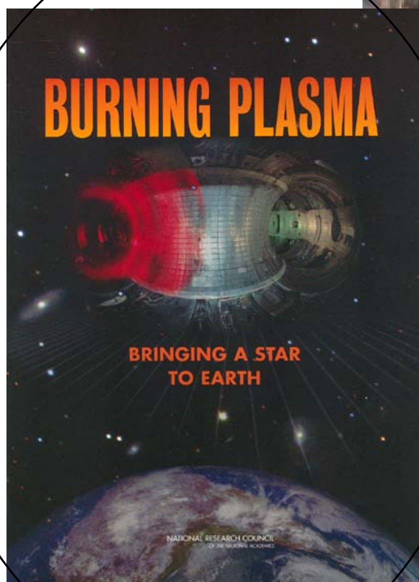


Research Needs for MFE

Elements of a path forward are being informed by many high-level panel and community assessments

HEDLP





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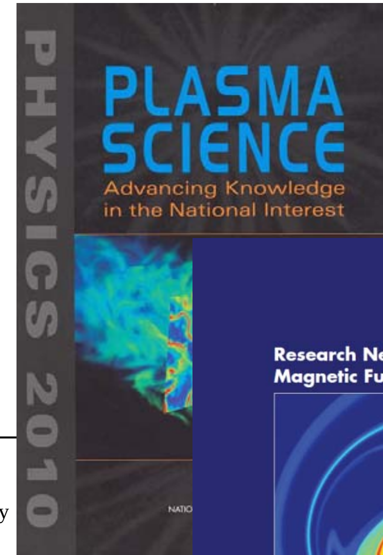

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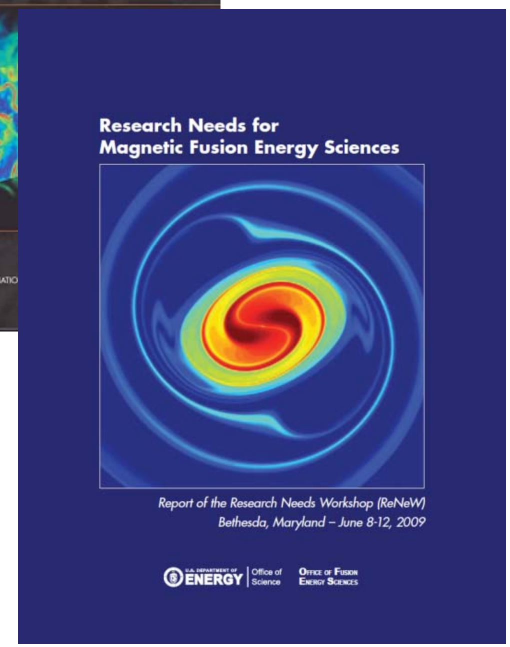


Research Needs for MFE

On ITER

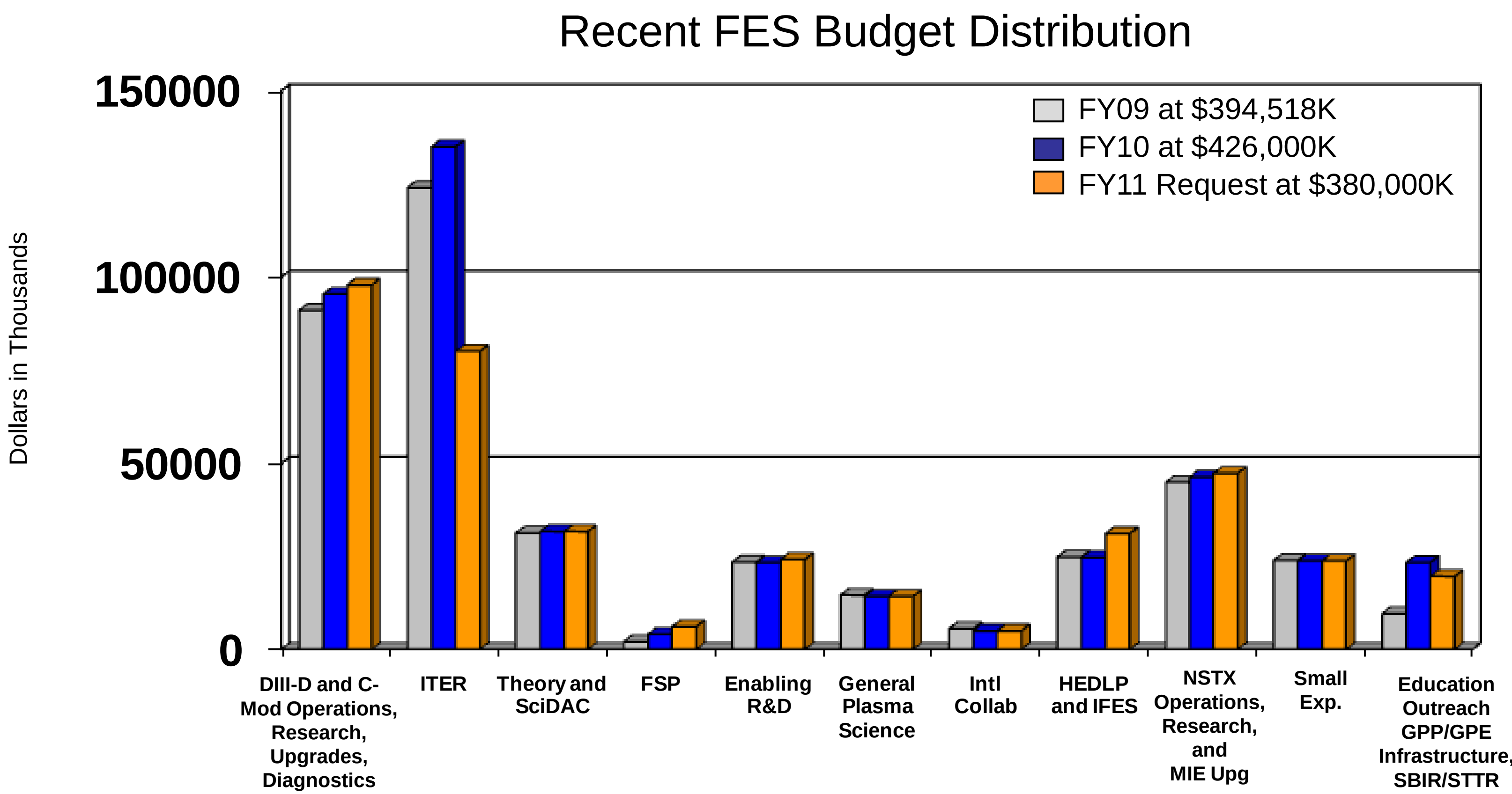
ITER represents an extraordinary commitment of funding and effort

- The U.S. Contribution to ITER project represents an enterprise that will cost more than anything the Office of Science has ever undertaken.

- It represents our choice for pursuing the science of burning plasmas and burning plasma control.

- We have been diligent at ensuring that the ITER project meets U.S. project management standards and expectations.

Managing the reality of budget constraints



U.S. ITER will have to peak at more than triple the funding beyond the $80M FY’11 request in the near future

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ITER activities and status includes…

- A directed effort this spring to develop an agreed-upon schedule and baseline by the June ITER Council meeting. A sampling:
  - ITER Heads of Delegation (HoD) +1 meeting in late February
  - Management Advisory Committee (MAC) meeting right now to assess ITER Organization's (IO) proposed integrated schedule
  - IO activity to develop baseline, using this schedule
  - Additional HoD+1 or Council meeting in April, as well as MAC meeting in early May
  - European Union (EU) request to it's Council of Ministers

- In parallel with the international front efforts, we will be continuing to review our own activities at ORNL, and keeping Congress, OMB, OSTP, and the other high levels of the Administration apprised of developments.

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Elements of a path forward are being informed by many high-level panel and community assessments

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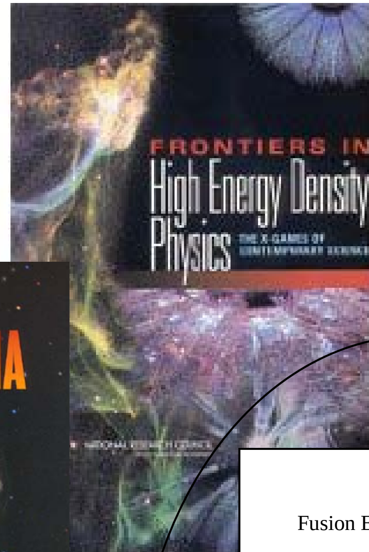

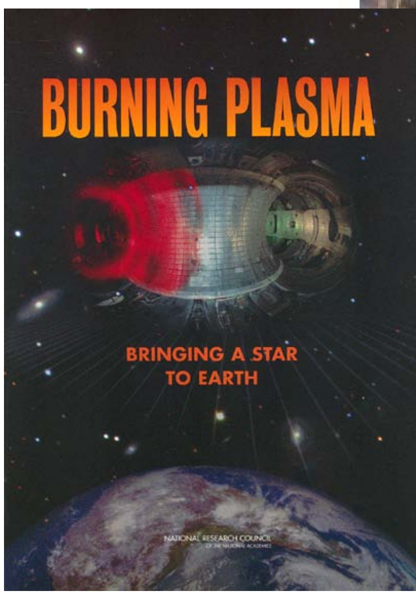

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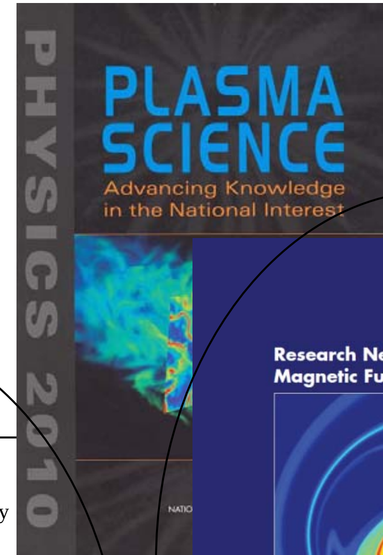

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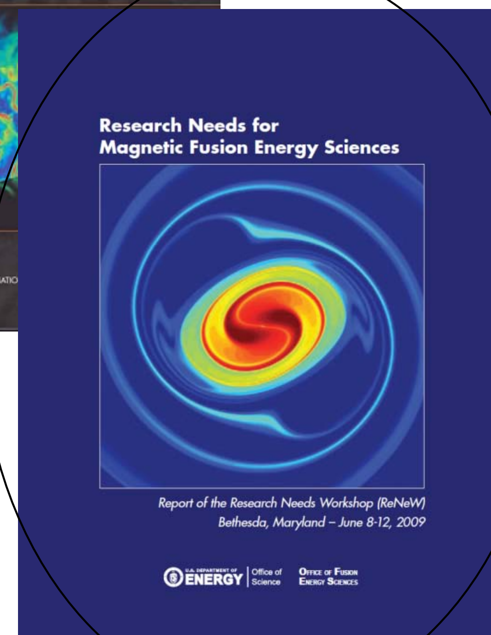


Research Needs for MFE

Risks and Opportunities Were Delineated in "FESAC Report on Priorities, Gaps and Opportunities: Towards a Long-Range Strategic Plan for MFE, Oct 2007"

	Areas Where the U.S. has Leadership	Areas Where the U.S. is Strongly Competitive	Areas Where the U.S. is in Danger of Losing Standing	Opportunity to Sustain Leadership through Strategic Planning	Opportunity to Gain Leadership through significant investment
Measurement	X		X	X	
Theory and Predictive Modeling	X			X	
Control	X		X	X	
Plasma-Wall Interactions		X	X	X	
Integrated, Sustained, High Performance Plasmas		X	X		
Safety and Environment		X	X		
Materials			X		X
Antennae and Launchers			X		
Magnets			X		
Plasma Facing Components			X		X

Research beyond the last closed flux surface

On the scope of this area…

- In discussions with Office of Science leadership, I have defined a major leading challenge as being quite broad, but I think you may agree with my intent: *building on Greenwald and the MFE ReNeW, a leading challenge for fusion, and an opportunity for the U.S., pertains to understanding and controlling*

  - the processes beyond the last closed flux surface, including the open field line plasma physics, the plasma/material science governing the plasma-surface interactions, and how these processes couple to define the close flux surface boundary, and

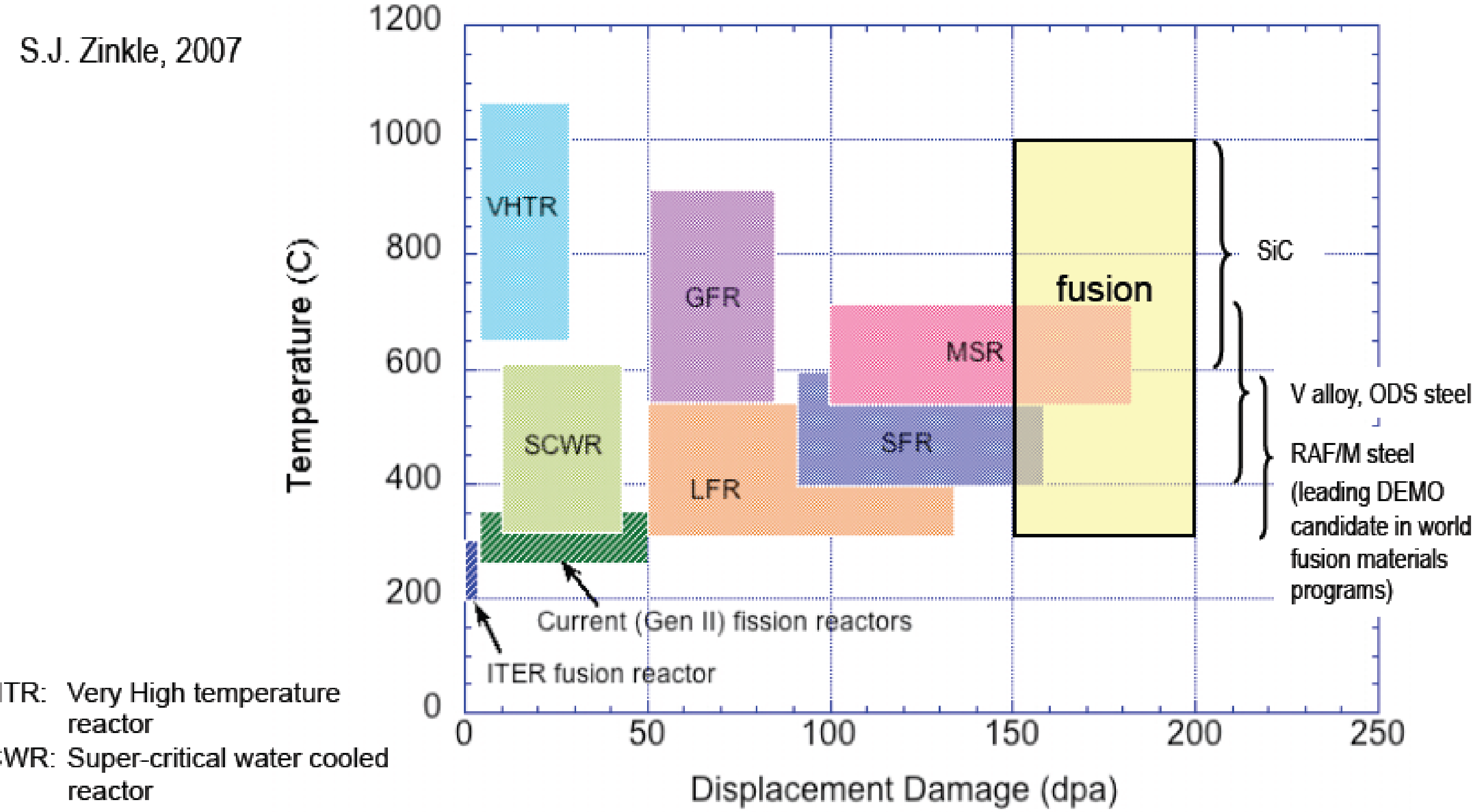
  - the nuclear science related to structural evolution, integrity, and harnessing fusion power

  - the coupling of these non-nuclear and nuclear elements

- The materials science per se represents the most urgent need, but the open field line science/divertor issues are quite urgent

- Overall, this represents a major, leading challenge for the field, an opportunity for U.S. leadership, and a significant responsibility

The demands on materials for fusion overlap and extend beyond those of Gen IV fission



VHTR: Very High temperature reactor
SCWR: Super-critical water cooled reactor
GFR: Gas cooled fast reactor
LFR: Lead cooled fast reactor
SFR: Sodium cooled fast reactor
MSR: Molten salt cooled reactor

A common theme for fusion and advanced fission is the need to develop high-temperature, radiation resistant materials.

Potential for high-leverage collaboration with Nuclear Energy (NE) and Basic Energy Sciences (BES). Also NNSA interest. How to work between offices is a challenge; identifying technical synergies may be part of a FESAC charge, or a joint charge with another advisory committee

Elements of what we need to do in materials research in the coming decade

- Growth Areas and Needs

  - Expand R&D efforts on all aspects of plasma facing, structural, and blanket materials

  - Upgrade/build testing capabilities to address both single and multiple effects.

  - Enhance modeling and simulation capabilities in parallel with both activities above.

  - Increase both domestic and international collaborative activities on ITER Test Blanket Modules.

Materials for nuclear energy: Seek to develop joint initiatives on materials with BES, NE, and NNSA.

The materials challenge is enormous, both non-nuclear and nuclear, and the program needs to be carefully thought out

We need to construct a sensible program: deeply scientific as well as directed

➔What does a sensible program look like that advances materials science efficiently and effectively, towards a facility to investigate volume neutron effects on structures and materials and for harnessing fusion power?

Fundamental materials science **Computation, facilities, improved diagnostics**	⟺	**Fusion Nuclear Science Facility concept: What is it's mission? What are it's characteristics?**

"A tightening spiral of research and concept definition"

Towards a fusion nuclear science facility (FNSF)

Objective: Develop experimental data base for all fusion reactor internals and, in parallel with ITER, provide the basis for DEMO.

- Our programs must be smartly directed to inform critical decisions:
  - Determine the FNSF Geometry.
  - Determine the materials the FNSF will be made from and should test
- International Collaborations with Asian tokamaks will support physics data base for non-nuclear plasma-wall science and operational scenarios.

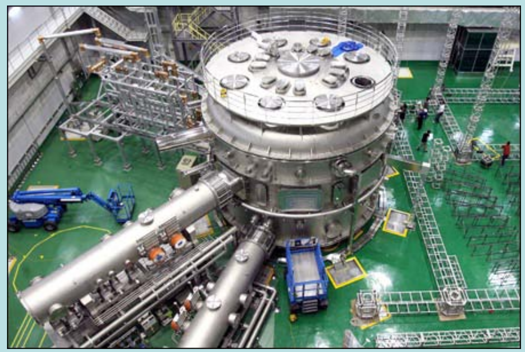
FESAC's technical input will be critical in our constructing programs to help make these informed judgments. In the near term, this especially includes your technical advice regarding the construction of a prerequisite materials science program (nuclear and non-nuclear). It also includes clarifying the relationship between the knowledge base we must have in hand to build an FSNF and the risk associated with an incomplete knowledge base.

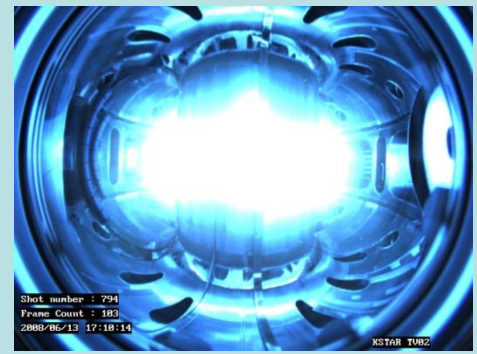
On high performance steady-state tokamak research

There have been large investments in the steady-state tokamak arena

The DIII-D control system has been implemented on both devices by a national team. . .

K-STAR
Daejon, S. Korea
Goal: 300 s pulse
2 MA





EAST
Hefei, China
Goal: 1000 s
1 MA

Mid-decade vision: we should be well established in international research in steady-state tokamak physics

- Grow international research teams
  - Opportunities in core plasma control science as well as materials science
  - Some experiments seek all manner of expertise, especially boundary/divertor physics and, in the near term, plasma control

- Consider remote control rooms. University data node for diagnostics, perhaps

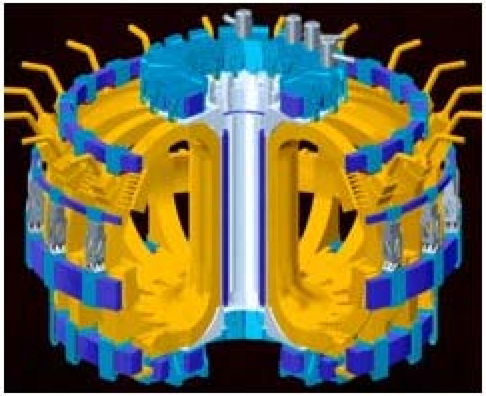
- FES needs to increase management staff with expertise in tokamak steady-state research, and an interest and ability to engage international programs

- Near-term: FES working with community to develop understanding of international research opportunities.

A FESAC charge in international research opportunities in key physics areas would be appropriate and timely

Engineering vs. physics complexity: 3-D effects

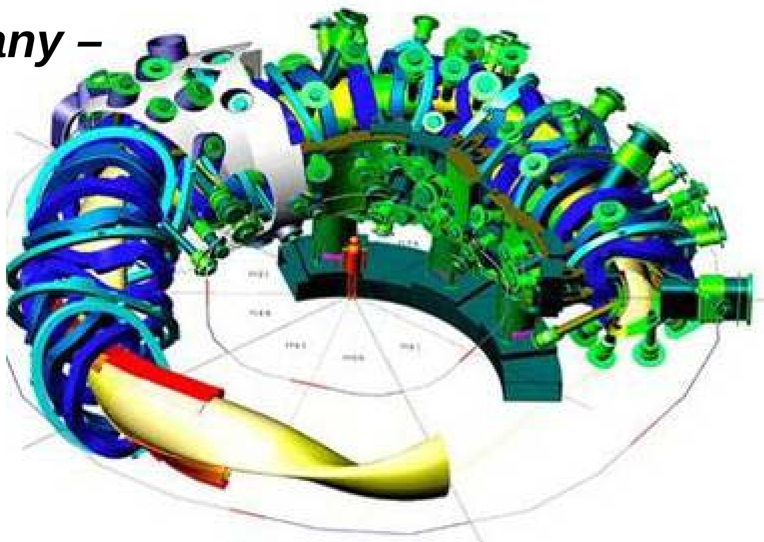
While stellarators are complex, they may address some Achilles' heels of tokamaks



ITER

LHD (Japan; operating)

W7-X (Germany – 2016)



There is an optimization between very small and very large deviations from a tokamak

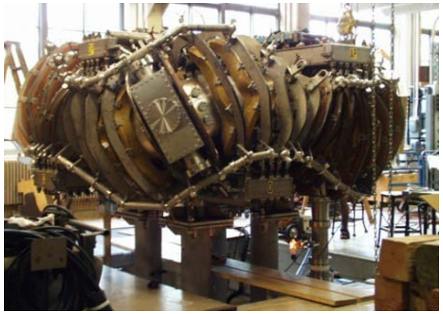
- ELM coils: perturb B about 10^{-3} ➔ ELMs can (may) be controlled. No influence in disruptions

- Stellarator: perturb B ~ 0.1 - 1 : disruptions *may robustly disappear*.

  In the limit of a "pure" stellarator, need for auxiliary current drive systems can be eliminated

Stellarators are complex and expensive

HSX (Wisconsin)



➔Need to participate in stellarator research globally

➔University-scale can address targeted physics challenges

➔3-D theory research; ensure that FSP can capture this physics

Simulation has to be sophisticated enough to predict between pure tokamaks and full blown stellarators to find an optimum. We need to account for both physics and engineering complexity.

Mid-decade vision: 3D Physics research

- Growth in theory of 3-D equilbria stability and transport research
- Increase emphasis on DIII-D and NSTX in 3-D fields near term: seek common understanding of seemingly contradictory results
- Solicit theory/simulation proposals that have the potential for bridging the gap between small and large topological variations from a tokamak, aiming for inclusion in FSP
- Deploy diagnostics overseas

Identifying the key physics elements and research needs of a coordinated program nationally and internationally in 3-D physics would be a useful topic for FESAC to address.

High Energy Density Laboratory Plasmas (HEDLP) and Inertial Fusion Energy Sciences (IFES)

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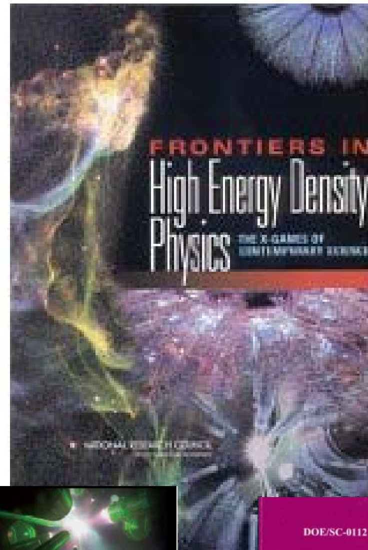
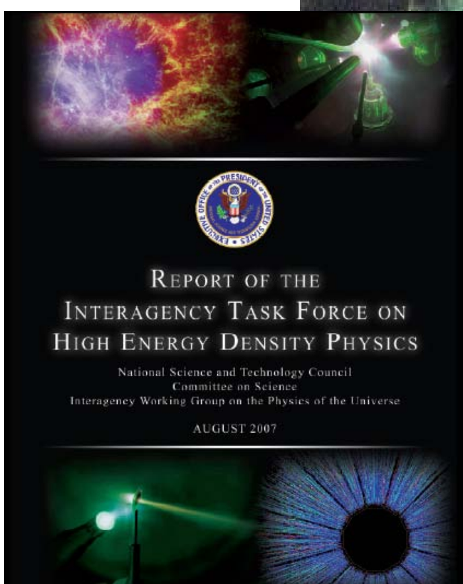
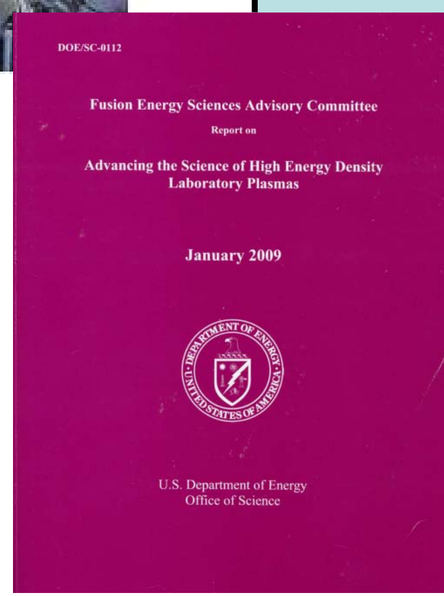
Elements of a path forward in HEDLP and IFE science are being informed by many high-level panel and community assessments



Research Needs for HEDLP Sciences Workshop Held on November 2009

Report coming soon!



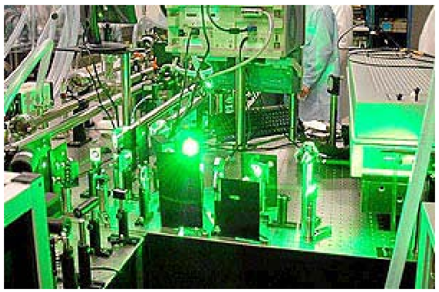


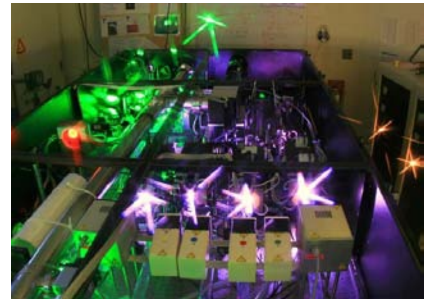
National Academies Study on IFE

To be Undertaken

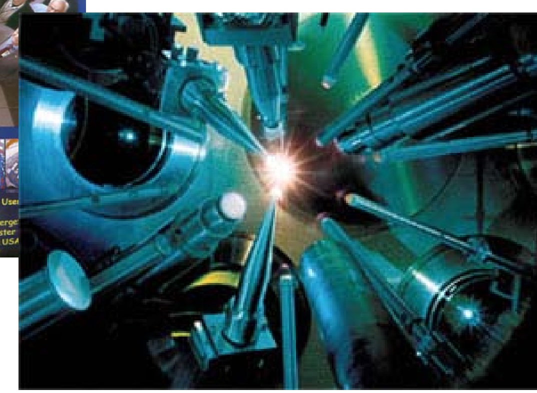
Range of facilities on the NNSA side is impressive: scientific leverage opportunity

e.g. Petawatt lasers at Texas, LLNL, Michigan, Rochester…





Omega-EP (Rochester) has a well-run Users Group



HEDLP/IFES outlook, 5 years

- **National Ignition Facility (NIF) will have ignited.** FES will have a leadership role in developing IFES and astrophysical science experiments on NIF and on HEDLP facilities nationwide, in partnership with NNSA.

- FES, through its development of coordinated marches using the wide range of HEDLP facilities available, will be resolving fundamental questions of nature and pursuing science essential to assessing the viability of IFE. This range of scales can be levered in a scientifically sensible way

- For IFES, key questions to be pursued by FES include the multiscale physics challenges of advanced ignition concepts and the science of different drivers on the target

- Matter in Extreme Conditions Instrument (MECI) project at SLAC will be producing unique research on matter in extreme conditions relevant to fusion, planetary and astrophysical science, equations of state…

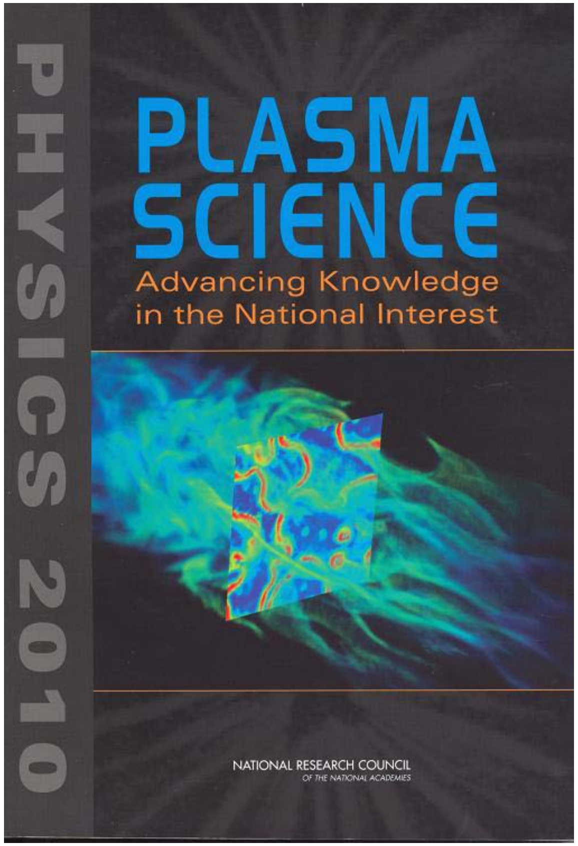
- National Drift Compression Experiment-II (NDCX-II) at LBNL will be assessing the issues surrounding the viability of heavy ion fusion.

The NAS study and NIF ignition campaign results will have a large impact on the specifics of what we ask FESAC.

Deepening credibility of plasma science as a discipline demands nurturing the field broadly

Principal Recommendation: To fully realize the opportunities in plasma research, a unified approach is required. Therefore, the Department of Energy's Office of Science should reorient its research programs to incorporate magnetic and inertial fusion energy sciences; basic plasma science; non-mission-driven, high-energy-density plasma science; and low-temperature plasma science and engineering.

The new stewardship role for the Office of Science would extend well beyond the present mission and purview of the Office of Fusion Energy Sciences (OFES). It would include a broader portfolio of plasma science as well as the research OFES currently supports. Two of the thrusts in this portfolio would be new: (1) a non-mission-driven, high-energy-density plasma science program and (2) a low-temperature plasma science and engineering program. The stewardship framework would not replace or duplicate the plasma science programs in other agencies; based research. These changes would be more evolutionary than revolutionary, starting modestly and growing with the expanding science opportunities. '



FES can be the home for plasma science broadly. It makes scientific and political sense.

On validated predictive capability

The FSP is critical to our predictive science effort, but it is only part of it

- Fusion Simulation Program will only be as good as the physics models that go into it

- Our reliance on validated prediction to fill gaps will demand a kind of confidence we don’t yet appreciate

- Plan: grow our emphasis on validation of physics models that are incorporated in the FSP

By mid-decade, in validated predictive capability…

- FSP is underway. Partnership with ASCR forged. Overall structure of the code identified and development is ongoing. Code is beginning to be used to reveal new science.
- Potential leverage/collaborative opportunities with NNSA clarified and perhaps engaged
- SciDAC portfolio includes materials science relevant to divertors and first walls. Some of SciDAC elements have graduated into the FSP.
- Identified opportunities in stand-alone validation platforms and begin to launch them.

The importance of the sensible use of massively parallel computing and the role theory and experimental validation play is very high. FESAC and ASCAC technical advice will be sought as needed, and both will be kept apprised of the progress of this program.

Fusion needs to take on new classes of challenges, and to do so requires leverage

Key elements of the vision: Plasma dynamics and control

- ITER success is critical: successful project execution, diagnostic development, training of students and young researchers towards an ITER research team.
- Seek to develop global scientific partnerships in steady-state tokamak and 3D B science.
- Validated predictive capability: support work to take our confidence to a much higher level to enable extrapolation that can improve the tokamak with reasonable risk. Lever NNSA experience, learn/lever experience from other offices (BER and climate, for example)
- HEDLP and IFE science: grow to capture NIF success. For IFES, emphasize multiscale physics questions. Lever NNSA investments. Bring Recovery Act investments to scientific maturation. Coordinate HEDLP facilities to address great questions of nature.
- Low temperature plasma science and engineering: discovery is driven by a coordinated community.

Fusion needs to take on new classes of challenges, and to do so requires leverage

Key elements of the materials science vision

- Develop prerequisite programs in materials science, nuclear and non-nuclear, that inform the assessment of reasonable risks in FNSF design, construction and operation.
- Clarify the optimal geometry for an FNSF, informed by a much better understanding of the operating environment, which translates to a better understanding of risk tolerance
- Leverage cross-office opportunities: links with NE, BES, NNSA.

From the FESAC Report on Priorities, Gaps and Opportunities: Towards a Long-Range Strategic Plan for MFE, Oct 2007

	Areas Where the U.S. has Leadership	Areas Where the U.S. is Strongly Competitive	Areas Where the U.S. is in Danger of Losing Standing	Opportunity to Sustain Leadership through Strategic Planning	Opportunity to Gain Leadership through significant investment
Measurement	X		X	X	
Theory and Predictive Modeling	X			X	
Control	X		X	X	
Plasma-Wall Interactions		X	X	X	
Integrated, Sustained, High Performance Plasmas		X	X		
Safety and Environment		X	X		
Materials			X		X
Antennae and Launchers			X		
Magnets			X		
Plasma Facing Components			X		X

Significant Increased Emphasis (purple) **Strengthened International Collaborations** (green) **Maintain Existing Programs** (yellow)

I would like to have a discussion about some big questions

- For the second half of this time period, I would like to talk about a few urgent questions.

For materials science:

- what it means to move with a science program where we will not gather all the data we would like, but where we have to make decisions to move forward and define a major nuclear facility in any case. How can FESAC advise us on metrics, the balance between experiment and computing, and how to assess risk of any particular technical approach?

- what kind of exercises FESAC might carry out that provide FES with information <u>without the edges smoothed out</u> – we need more than consensus recommendations where tough questions are avoided. At FES, we need to know what risks we are taking when we choose a certain path.

Regarding predictive capability….

Even with full success in the global fusion program, there will be knowledge gaps in stepping to a DEMO. A key element for fusion's development is risk mitigation. Validated predictive capability will play a key role in mitigating risks, in part since experimental demonstrations of prototype systems will not be as numerous as we would like. In short, *we have to take a qualitative step forward in our reliance on and confidence in validated predictive capability.*

Classes of questions for FESAC include:

- What kinds of new experiments or measurements might be developed that can answer critical questions that will increase confidence in prediction of future configuration performance and control requirements?

- What can we learn from other fields that rely more heavily than does fusion on such validated simulation capability?

- How do we assess the uncertainties in future simulations? What can we learn from other communities that have embraced this question?

Thank you