# Perspectives on fusion energy research: on our science, leverage, and credibility

**E.J. Synakowski**

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UFA Meeting
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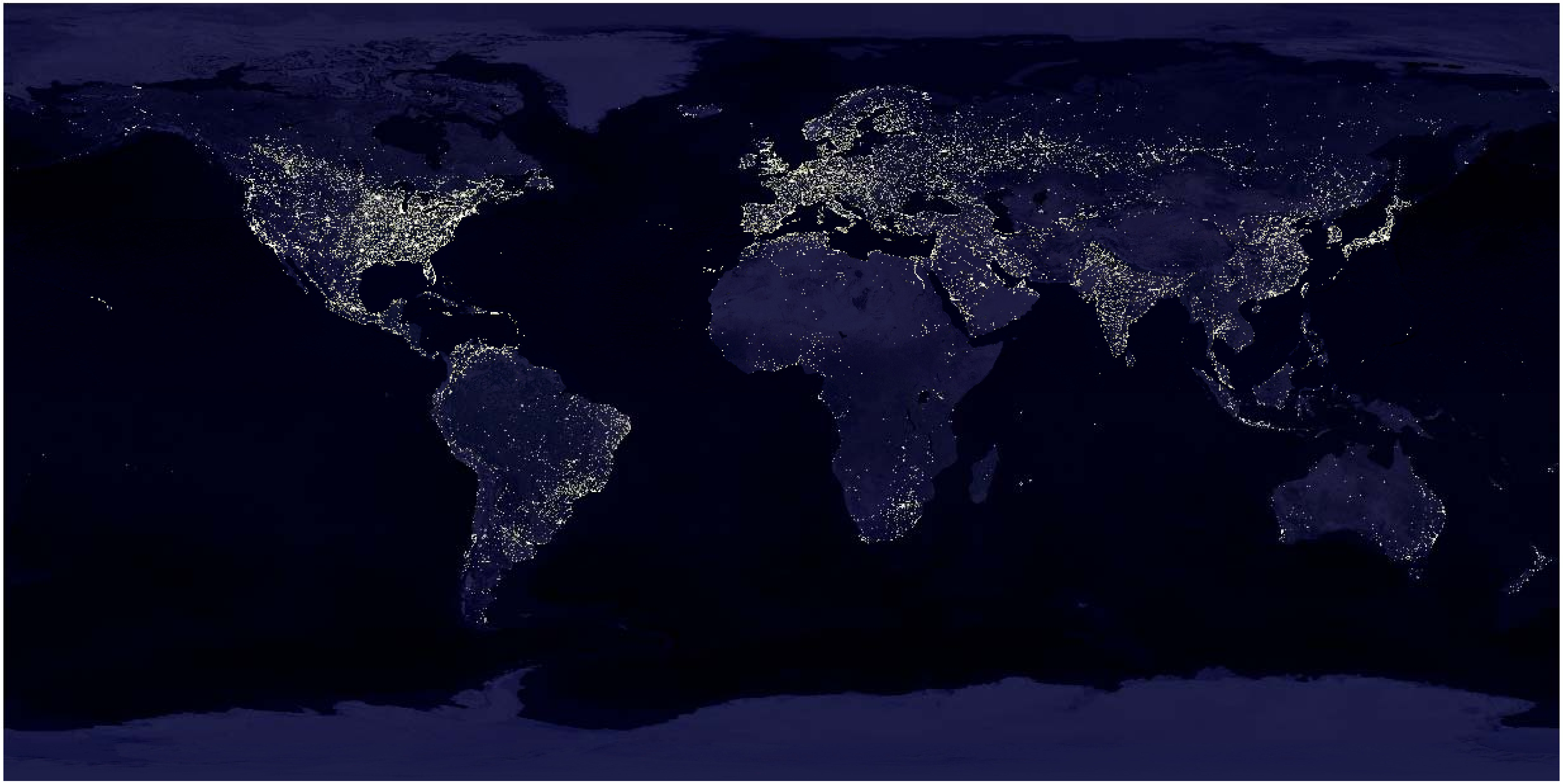
# The ambition for fusion research has to be no less than powering the planet



# In this talk…

- For those who don't know me: a bit about myself and some experiences I've had that inform my views regarding the character of our science and the power of scientific partnership

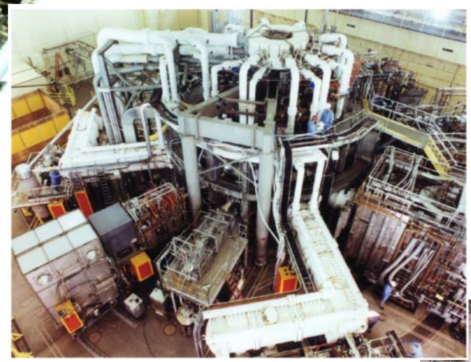
- Comments on an emerging vision: towards fusion's credibility and the role of partnerships

# A few touchstones: experiencing the power and beauty of our science and the value of partnerships and leverage

***Graduate work**: experience the scientific aesthetic of fusion research*

*TEXT tokamak*

***Career in Research**: Power of detailed experiment/theory coupling. Crossing institutional boundaries to collaborate*



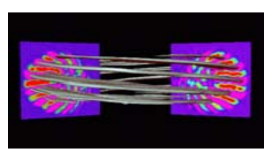
*TFTR*

*Alcator C-Mod*

*NSTX*

*DIII-D*

*Joint experiments*



*TTF*

***Moving to Program Leadership (PPPL, LLNL)***

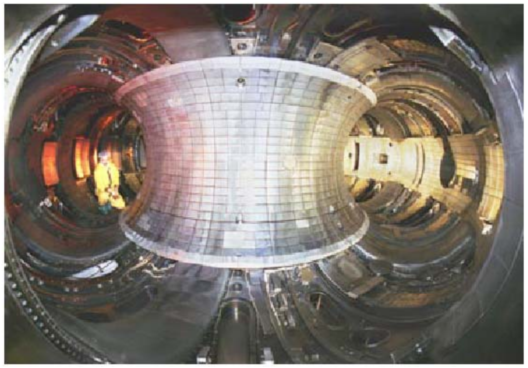
*The necessity and challenge of forging a coherent, directed program*

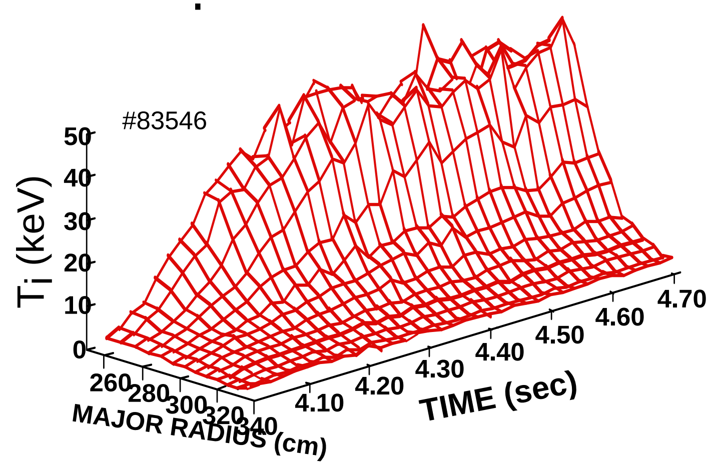
*Witnessed and experienced effective, as well as untapped, partnerships*

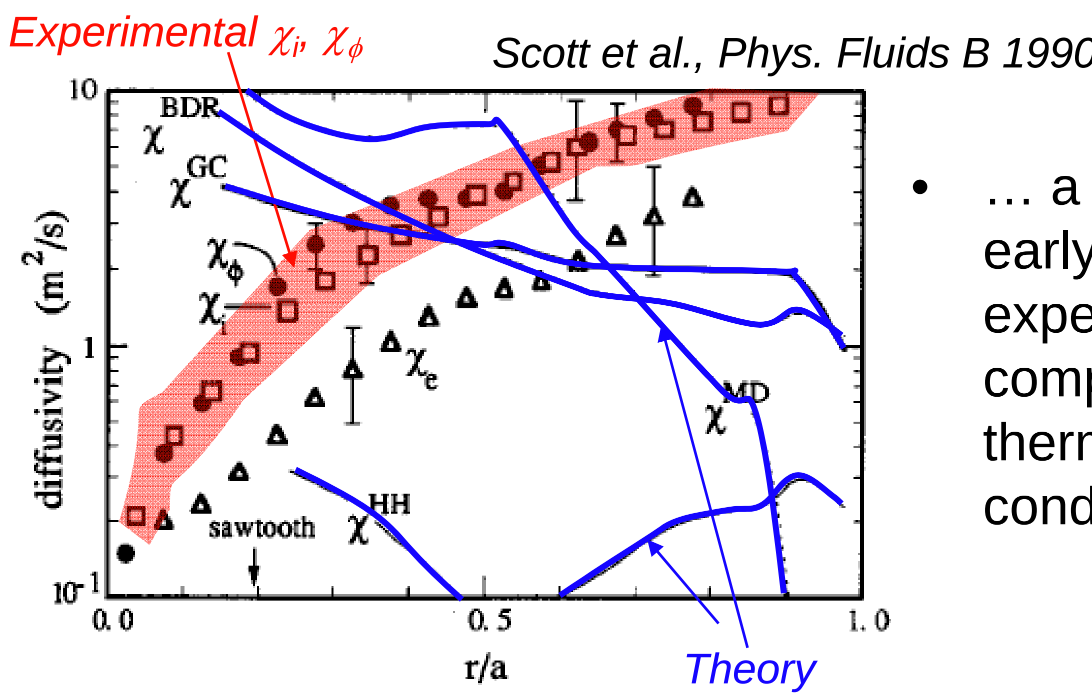
***Now**: **OFES and Washington:** What are the opportunities for **leverage**, how is our science **valued**, what is the relation between our **science and our energy ambitions**?*

# A personal view of the evolution of a slice of our science…

*TFTR ('82 - '97)*





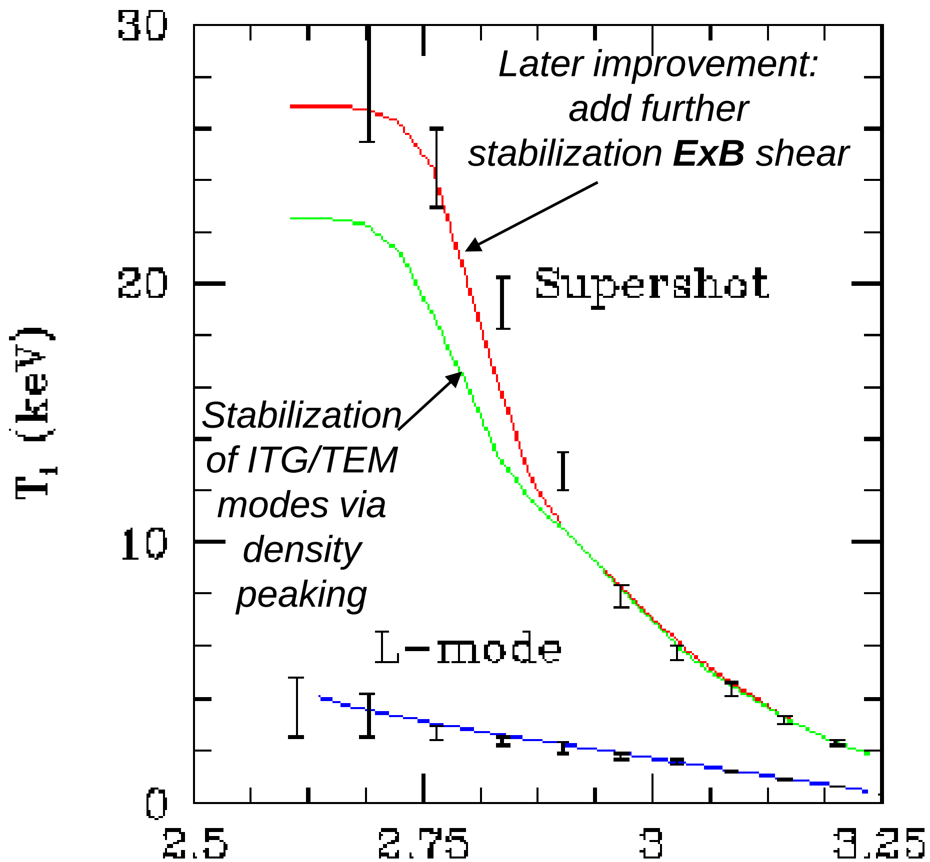




- … a taste of the early theory-experiment comparisons in thermal conduction

# … and realizing that business can no longer be "as usual" between experiment and theory

## *A big shift: turbulence theory-based ion transport model challenges experiment(alist)*

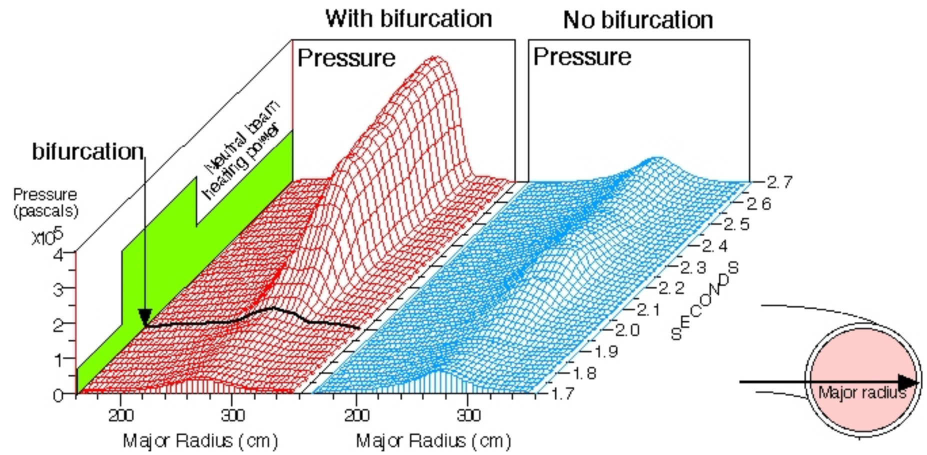
- **IFS-PPPL model** gets $T_i(r)$ in very different confinement regimes about right
  - Linear gyrokinetics identify critical gradients.
  - Nonlinear gyrofluids map out parametric shape of $\chi_i$.
- **I hear for first time from theorists**: "We think your $T_i$ data are incorrect in some cases - can you reanalyze these shots?"
  - Theorists are *right*: the analysis was *wrong*
- **Indicated we cannot responsibly ignore what simulation has to say about turbulent systems**



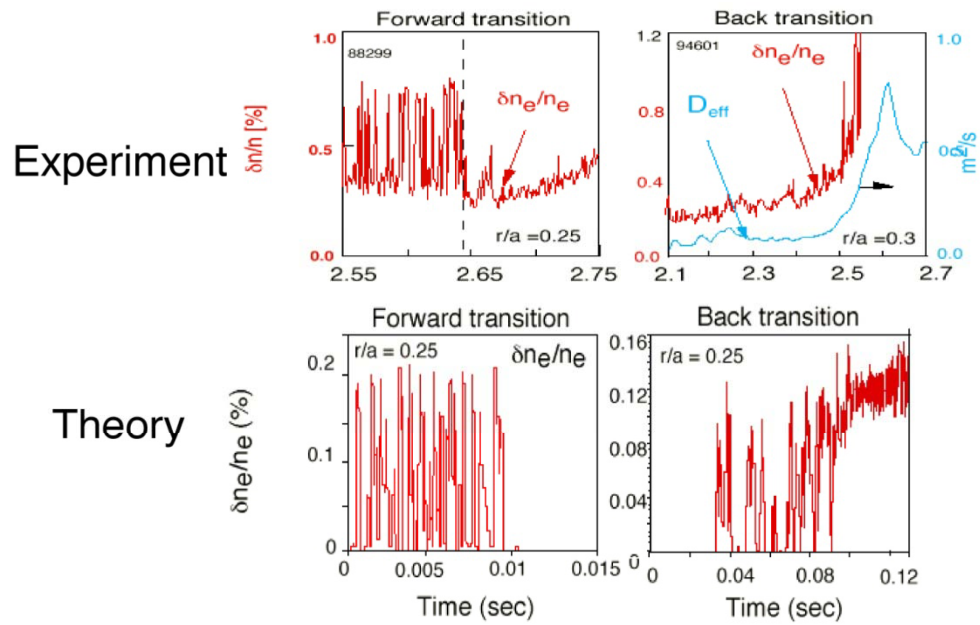

*Kotschenreuther, Dorland, Hammett, Phys. Plasmas 2 (1995)*

# Transport barrier studies: exciting dynamics in the plasma drive important dynamics in the community

- An exciting period scientifically and with respect to the community. The theoretical minimum in core transport can be realized
  - Scientific cross-connects: core and edge physics. ExB shear, a bifurcating core joins the bifurcating edge, the language of phase transitions enters the lexicon…
  - **Institutional cross talk/stimulation/competition was vibrant** – far more so than I had experienced up to that point




*Density turbulence & confinement*



## Experience with transport barrier dynamics gives lessons in physics and in group and community dynamics that may be of value

- The cross-institution cross-talk was vibrant, exciting, and productive
- I believe the cause was a combination of powerful physics and *having shared interests. The power of this combination was reinforced for me through experiencing cross-lab collaborations*
- The emergence of these shared interests fundamentally changed the way we interacted from between laboratories and universities, and for the better

# Perspective: we need to break out of scientific and political isolation

- *Scientifically: Our challenges are too deep, and the stakes are too high, to not use resources outside of our immediate sphere that could help advance the fusion cause.*

- *Politically: No one will help you fight for research dollars and defend you if they don't have a shared interest in your program*

- *Isolation is a risky attribute that FES is living with, both scientifically and politically, but smart leverage through partnerships can change this*

## On advancing the fusion energy sciences…

## We need to *focus and lever* our efforts in the U.S. to make fusion energy a credible option

- The leading challenge: establish scientific credibility
- You have identified gaps in the world program that are enormous and can be filled in enabling the U.S. to assert world leadership and establish credibility
- You have identified research needed to fill those gaps

# Fusion Energy Sciences (FES) Mission

Mission

- The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to develop the scientific foundations needed to develop a fusion energy source. This is accomplished by the study of the plasma state and its interactions with its surroundings. An essential element of the FES program is the invention of advanced measurement techniques to ascertain the properties of plasma and its surroundings at a level required to test, challenge, and advance theoretical models. This validation forms the foundation of computational tools used to understand and predict the behavior of natural and man-made plasmas systems, including burning plasmas for fusion energy.

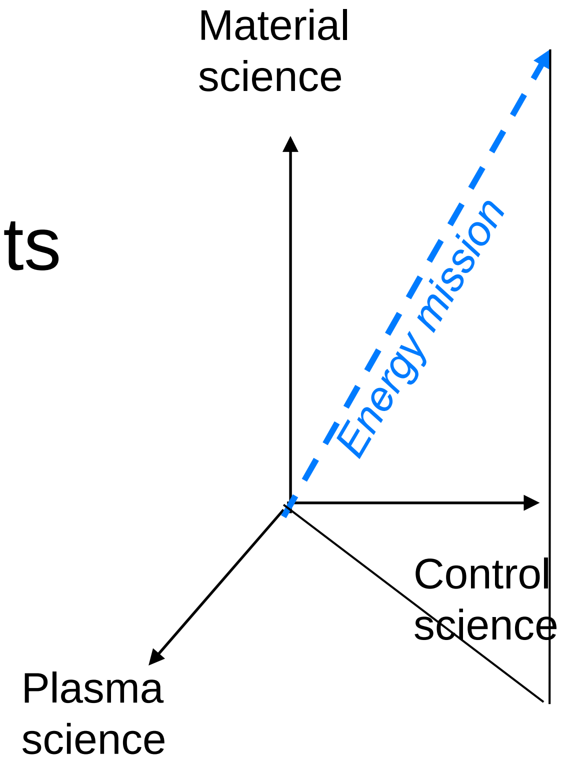
Program Priorities

- Advance the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source;
- Pursue scientific opportunities and grand challenges in high energy density plasma science to explore the feasibility of the inertial confinement approach as a fusion energy source, to better understand our universe, and to enhance national security and economic competitiveness;
- Support the development of the scientific understanding required to design and deploy the materials needed to support a burning plasma environment; and
- Increase the fundamental understanding of plasma science beyond burning plasmas to include low temperature plasma science and engineering, to enhance economic competeviveness, and to create opportunities for a broader range of science-based applications

# The science of fusion is rich and deep, and we can cast our research needs in the language of fusion science

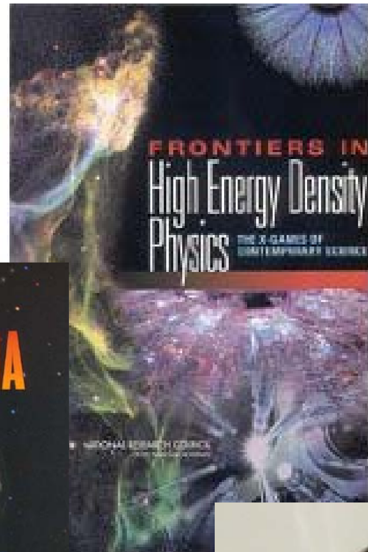
Energy or science? Nearly moot right now: what we need to do to establish credibility towards an energy goal is deeply scientific in character.

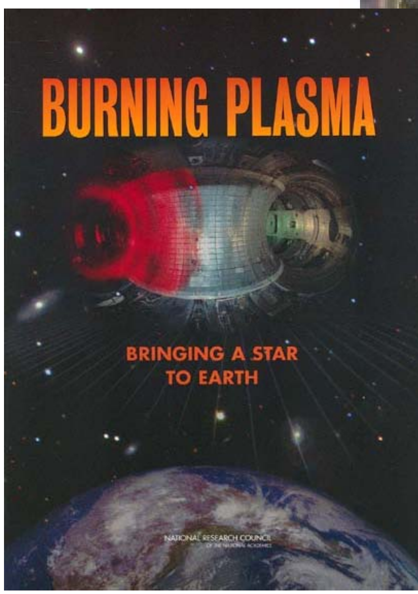
The energy and basic science pursuits elevate each other



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

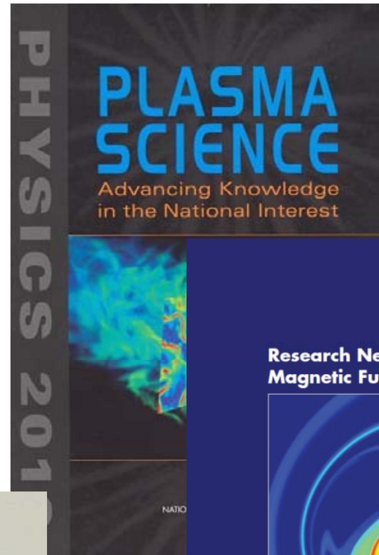
HEDLP



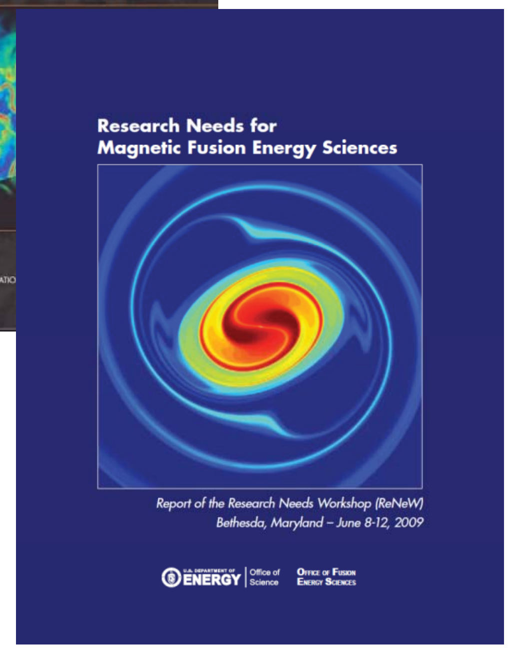




Urgency of a burning plasma step

FESAC: Priorities, Gaps, and Opportunities




Becoming a steward of the plasma science more generally




Research Needs for MFE

# Establishing credibility is our challenge

- There are at least three major scientific needs for establishing credibility for fusion energy:

  (1) We must generate, study, optimize, and learn to predict the properties of the burning plasma state

  (2) We must develop the scientific basis for robust control strategies for the burning plasma state: in MFE, this includes developing the scientific understanding to enable long plasma pulses.

  (3) We must develop the understanding of the material/plasma interface, and the fusion nuclear science needed to endure the fusion environment and to harness fusion power

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# From my Congressional testimony, 10/29/09

**Oral Statement of Dr. Edmund Synakowski**
**Associate Director for Fusion Energy Sciences**
**Office of Science**
**U.S. Department of Energy Before the**
**Subcommittee on Energy and Environment**
**Committee on Science and Technology**
**U.S. House of Representatives**
**October 29, 2009**

"…Strategic planning is underway aimed at filling gaps in the world program so as to assert U.S. leadership where it best advances fusion as a whole while maximizing U.S. scientific return. For magnetic fusion, the scientific challenges can be broadly stated as follows.

– (1) Understanding and optimizing the burning plasma state. Experiments, theory, and simulation have significantly advanced our understanding of what to expect from a burning plasma, and will continue to do so. But ITER provides the only platform planned to directly test and expand our understanding of this complex physics.
– (2) Understanding the requirements for extending the burning plasma state to long times – days, weeks, and longer. Many aspects of this are pursued in the U.S., and the second ten years of ITER's operation will put our understanding to crucial tests. However, overseas fusion programs are set to assert leadership in part through new billion dollar class research facilities in Europe, Japan, South Korea, and China. We are exploring growing our collaborations to increase their impact and the knowledge returned. And finally,
– (3) Advancing the materials science for enduring the harsh fusion plasma environment, for extracting energy, and for generating fusion fuel *in situ*. We will be exploring what is required to develop a materials and fusion nuclear science program, one that addresses the necessary fundamental scientific issues while weaving the results and advances into our best concepts of future fusion systems."

# Establishing credibility is our challenge

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# Establishing credibility is our challenge

- There are at least three major scientific needs for establishing credibility for fusion energy:

  **(1)** We must generate, study, optimize, and learn to predict the properties of the burning plasma state

➔Our participation in ITER, ensuring its success through present-day research, and developing a validated predictive capability for going beyond it has to be our highest priority

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# But we need to get the most out of our facilities and increase understanding to cross some pretty substantial divides

Do we really have an in-our-bones understanding of the challenge to develop a knowledge of plasma and material science deep enough to create a validated predictive capability that will enable us to reach out of our present comfort zone?

- For example, DEMO demands Q > 20, while ITER aims for Q = 10. Plus, DEMO needs 2-3 times the power density. What is required in our understanding to take that step from ITER to a DEMO?

# Filling gaps is, in large part, about risk mitigation

- There is concern that the steps required to optimize the reactor vision will be unattractive to an investor, despite the success of any fusion demonstration

➔ places an enormous demand on taking a qualitative step forward – or two – in validated simulation.

Leverage:

- can we lever experience and computational resources of the ASC community?

- are we doing the best experiments and measurements to enable us burrow down on some of the critical basic physics questions for validation?

# Establishing credibility is our challenge (continued)

- There are at least three major scientific needs for establishing credibility for fusion energy:

  **(2)** We must develop the scientific basis for robust control strategies for the burning plasma state: in MFE, this includes developing the scientific understanding to enable long plasma pulses

# Establishing credibility is our challenge: steady-state

- There are at least three major scientific needs for establishing credibility for fusion energy:

  **(2)** We must develop the scientific basis for robust control strategies for the burning plasma state: in MFE, this includes developing the scientific understanding to enable long plasma pulses.

  ➔ We need to understand far better than we do what our opportunities are in international collaboration, given the investments made overseas in long-pulse tokamaks and stellarators

# For steady-state research, our programmatic challenges are many

- What do the most effective collaborative efforts look like? Can we learn from the other sciences?

- What do the overseas programs need from us?

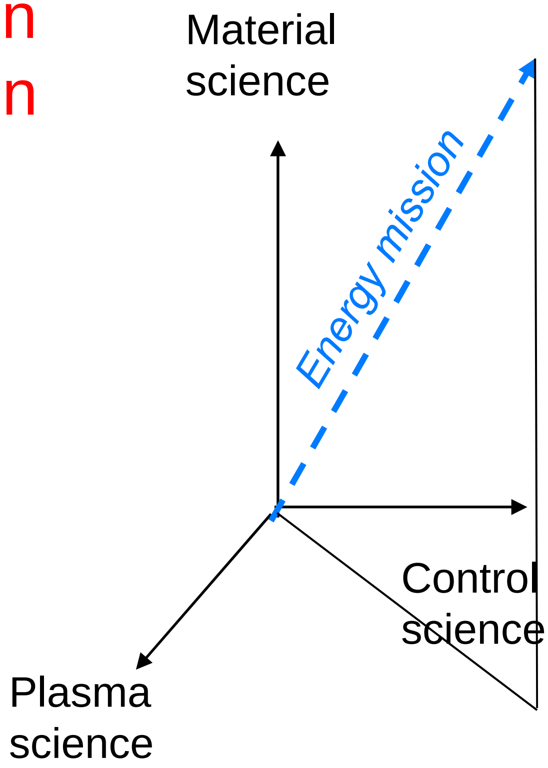
- Again, what are the requirements for a truly deep understanding that will enable us to reduce risk in next-steps? For example,
  - the wave physics at DEMO conditions
  - we see benefits of 3-D fields in tokamaks ($10^{-3}$) and stellarators (10's of %). Will our predictive capability enable us to bridge the gap and find an optimal configuration, given the few data points we will ever obtain in this operating space?

# Establishing credibility is our challenge: materials

- There are at least three major scientific needs for establishing credibility for fusion energy:

**(3)** We must develop the understanding of the material/plasma interface, and the fusion nuclear science needed to endure the fusion environment and to harness fusion power

*At present, fusion materials and nuclear science is our smallest projection on our needed basis set, but it may be where the most opportunity for leverage resides*



# 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"

# There are opportunities for leverage in the materials arena

- Critical to explore leverage because
  - Resources are tight
  - Others have expertise we need
  - We have intellectual capital others need

  *End result: advance the science, and gain much-needed support*

- Other disciplines have research needs in materials as well: advanced fission (NE), NNSA, for example. Within Office of Science, there is BES, NP. Perhaps NSF. ASCR and NNSA leverage and partnership for computing (materials by design)

- IFE needs are strongly related to MFE needs.

- I've been given the green light by leadership to explore a broad, cross-office assault on "Materials for Energy" in harsh environments

# On IFE and HEDLP: we need to be prepared

- Fusion is hard, and the stakes are high. We can work with NNSA and lever the nation's investments in ICF to develop this option with very different technical risks.

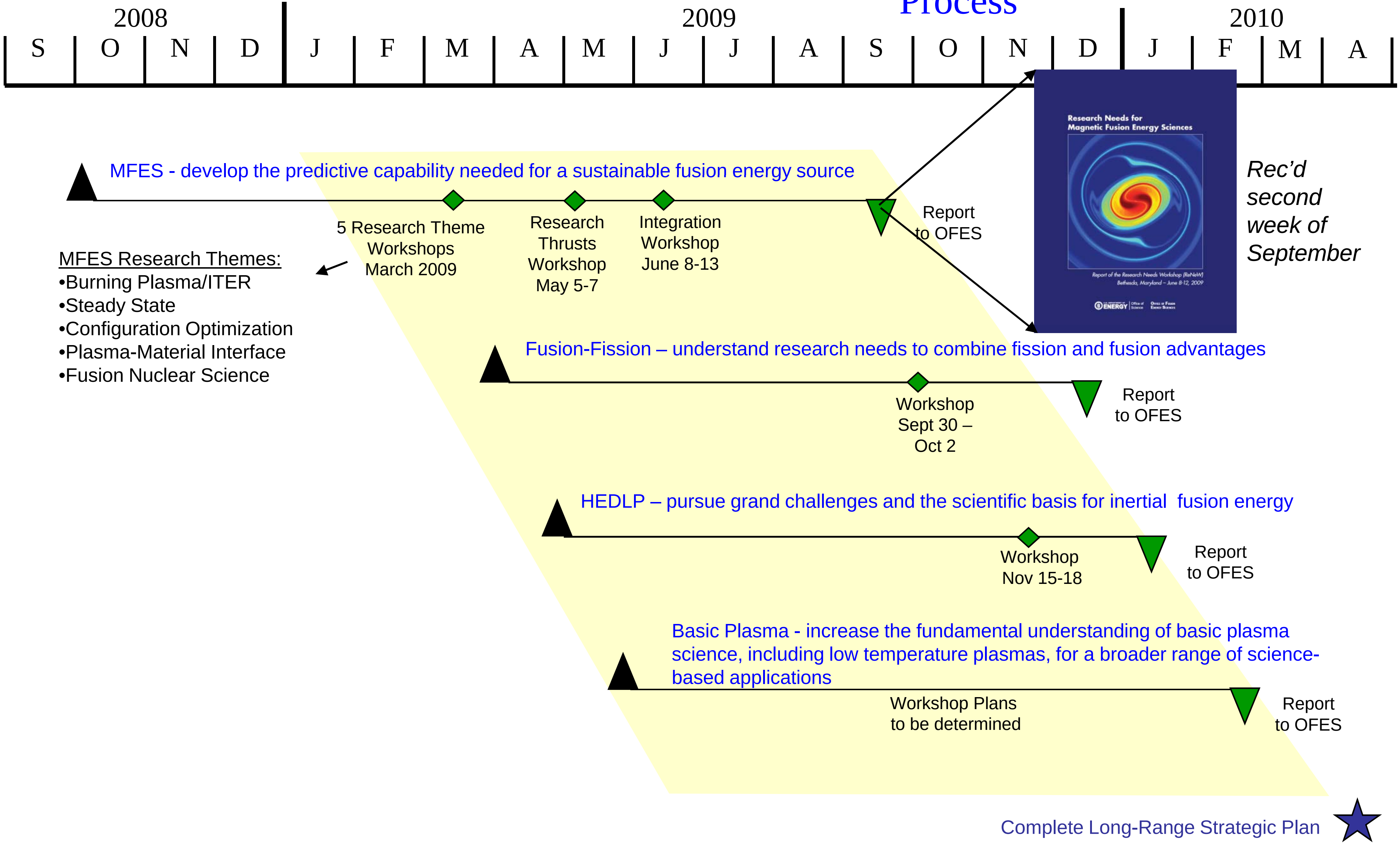
- The science of HEDLP is rich; lab astro, for example, can answer many fundamental questions
  - Missing x-ray emission from black hole accretion disks
  - Scale of the universe: Radiative transfer of "standard candles"
  - Earth's magnetic field generation: melt point of iron
  - More…

- Science of IFE-related science is deep
  - e.g. Multiscale physics of advanced ignition scenarios

# MFE and IFE have many common needs regarding materials science

- NIF success is going to bring even further attention to the area of materials science and fusion nuclear science
- This provides a further reason to look for levering opportunities

# Fusion Energy Sciences Program
# Research Needs Workshops and Strategic Planning Process



# On process(1) – we have received your input for MFE via ReNeW

- Received in our office early September
- I was part of the process up to half-way through – I know the amount of work that went into it was tremendous
- Now OFES's challenge is crafting a plan based on this input and awareness of the opportunities and limits.

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# On process (2): clearing the path; aligning leadership and other forces

- Question to me recently from one with an interesting experimental idea, understandably eager to move forward: "How can we get on this train?"

- Answer: I need to work to align the leadership above myself. We all need for me to ***establish the rights of way for the railroad, especially since what is emerging includes elements that have not been supported in the past. It also includes possible alliances that will be invaluable, but will require leadership's endorsements in order to mature.*** ReNeW and the Priorities and Gaps reports have informed my briefings and discussions with
    - the Office of Science leadership
    - the Department of Energy leadership
    - OMB

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# On process (3): clarifying approaches and needs to lay the groundwork for initiatives

- As this alignment approaches a reasonable point, we will ask some of you into the Office in Germantown to clarify ReNeW initiative suggestions and to discuss with and reflect off of you an emerging vision, given opportunities and limits that we see. For example,
  - how to fulfill a ReNeW need when the leading opportunities are international rather than domestic.
  - the materials science program challenge outlined above: basic questions of the relation between the evolution between test stand experiments, theory, and any needed future major experimental concept

  Follow-up workshops (smaller working discussions) are possible.

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# Were I a student…

… I would be very excited about becoming engaged in experiment or theory that is directly linked to our burning plasma aspirations

➔ *continue to promote university-lab links, appropriate scale facilities with this focus. Look for co-investment with university leadership*

… if my research provided a link to answering fundamental questions about the universe, or had the prospect of practical application that would improve people's lives, I would stay up late at night making that succeed

➔ *general plasma science, HEDLP are obvious areas where we can help students succeed and make leading contributions. Need to promote relevant links to the country's leading facilities and to nature's most compelling questions*

# If my tenure in this Office is successful…

- Fusion will move to the front page: the path to credibility will be clear
- We will be speaking with a clear, coherent voice, and touting a vision that is sharp, focused, relevant, and scientifically rich
- The plasma and energy-related sciences will naturally broaden and deepen, as their relevance and power is increasingly demonstrated