

Research Needs for Magnetic Fusion Energy Sciences

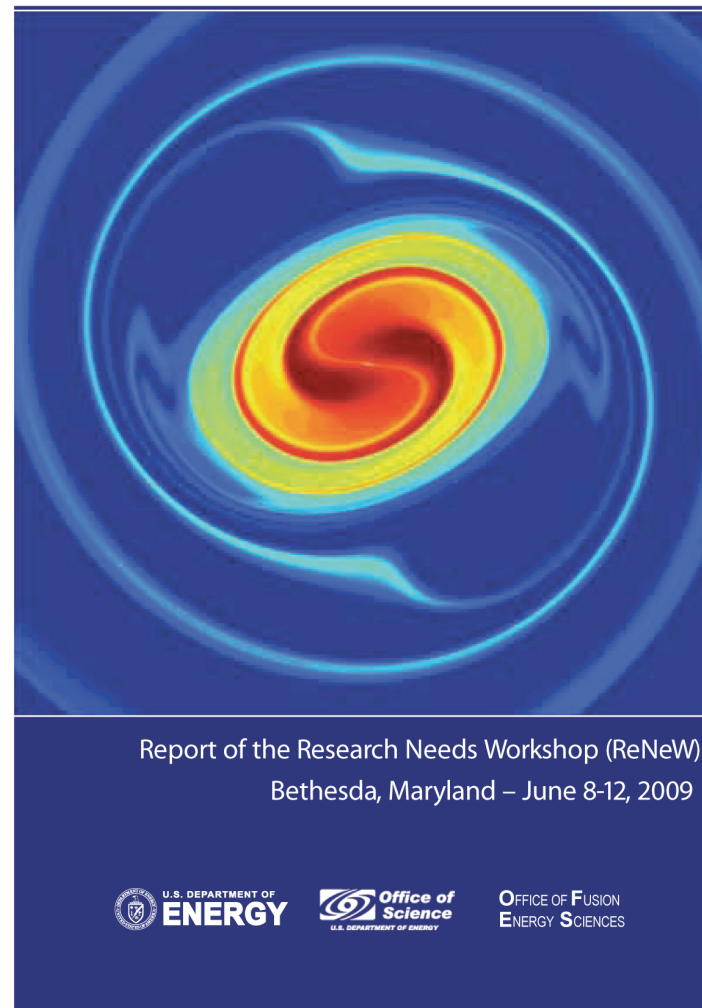
**Research Needs Workshop
June 7-13, 2009**

**David Hill, LLNL
ReNeW Vice Chair**

**Richard Hazeltine, U. Texas
ReNeW Chair**

**Hutch Neilson, PPPL
ReNeW OFES Liaison**

Presented at the APS-DPP meeting
of the University Fusion Association
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<http://burningplasma.org/ReNeW>

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MFE ReNeW in OFES Planning Effort

- **Scientific community (ReNeW):**
 - Identifies key technical issues and opportunities
 - Describes required research activities, and suggests how they can fit together
- **Government (OFES):**
 - Uses the ReNeW reports and builds a plan which includes a task list and timeline that fits the DOE priorities
- **ReNeW process for fusion-fission hybrids and high-energy-density laboratory physics (HEDLP) now under way**

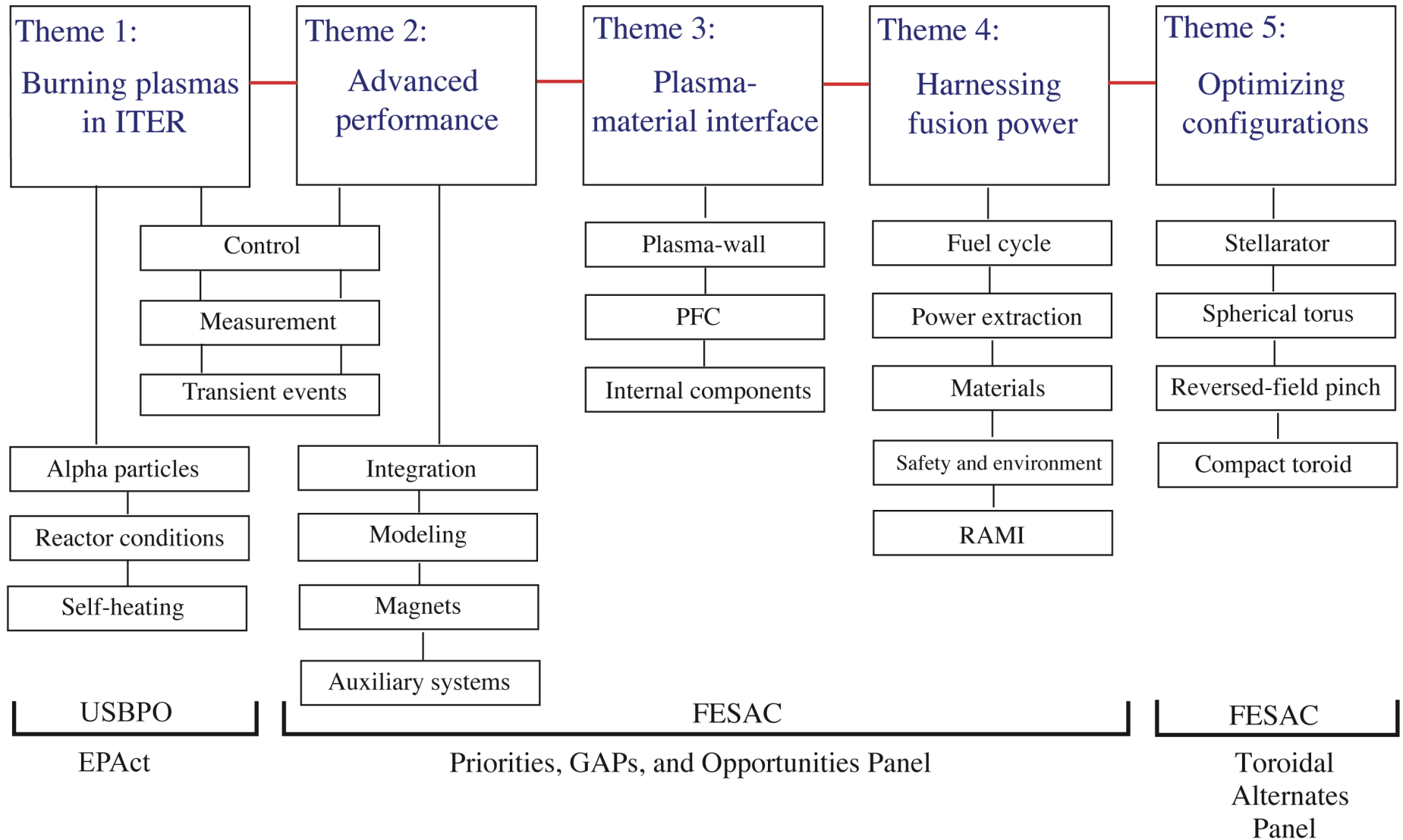
MFE ReNeW **Product** and Process

- **ReNeW participants identified research needs to address key scientific issues for magnetic energy**
 - A research portfolio, rather than a program plan: no timelines, decision points, milestones, etc
- **Thrust: an organized, multi-faceted attack on a coherent set of questions that are essential to the goals of magnetic fusion research**
 - The OFES will incorporate Thrust elements as it constructs its strategic plan

MFE ReNeW Product and **Process**

- **Started with FESAC and USBPO EAct reports**
- **~200 fusion scientists and engineers, mostly but not exclusively from US**
- **~9 months of preparation activity: meetings, teleconferences, calculations, debates...**
- **Five Theme Workshops @ UCLA(2), PPPL, and GA(2).**
- **Culmination: week-long Workshop in June, 2009, to finalize scientific content of a 420-page report to DOE**

MFE ReNeW Organized by Panels, Within Themes

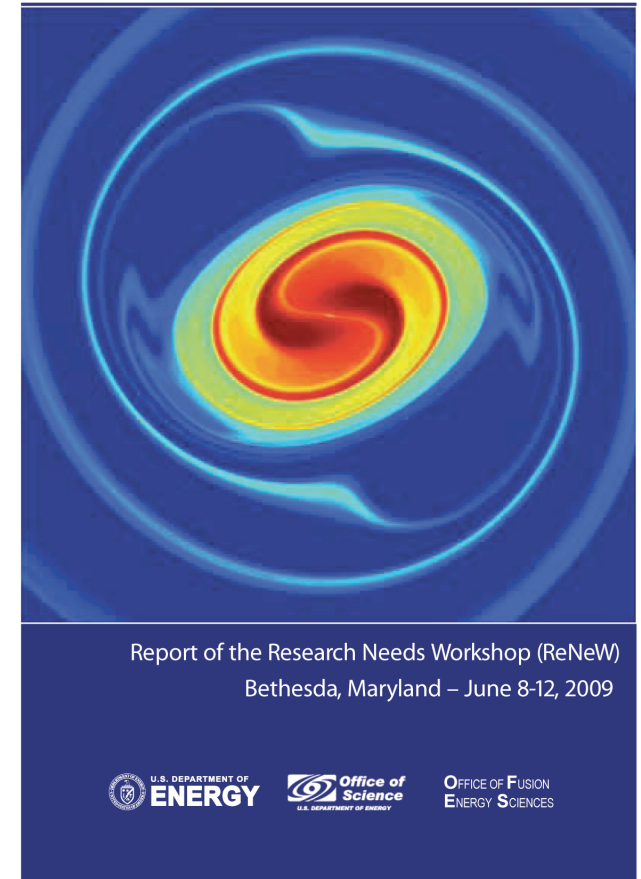


Workshops

- **Theme Workshops, held in the early Spring of 2009, identified research requirements**
 - Built on FESAC and EPACT reports
 - Strong community participation, vigorous debate
 - Public comment, including “white papers”
- **Theme workshops produced more than 50 research thrusts**
 - Consolidated into 18 thrusts for further consideration
- **June Workshop used research requirements to evaluate and finalize 18 thrusts, each grounded in a compelling program need**
 - ~220 hardworking attendees
 - General consensus on 18 thrusts, including logical and temporal connections between them

Structure Of the Report

- **A single comprehensive document consisting of two parts**
- **Part I: 5 chapters, one for each theme**
 - Progress to date
 - Issues and gaps
 - Research needs and goals
 - Relationship to Research Thrusts
- **Part II: 18 short chapters, one for each thrust**
 - Single-page summary opens each thrust
 - Issues to be addressed
 - Actions
 - Scale of effort



18 Thrusts Address Research Needs for One or More Themes: Not Strictly One-to-One

		Primary focus	Contributes significantly	Contributes marginally	Themes for Magnetic Fusion Energy Science				
					1	2	3	4	5
					Burning Plasmas in ITER	Steady State High Performance	Plasma-Material Interface	Harnessing Fusion Power	Optimizing Magnetic Configuration
Research Thrusts to Resolve MFES Issues	1	Measurement techniques to understand and control burning plasmas							
	2	Control transient events in burning plasmas							
	3	Understand the role of alpha particles in burning plasmas							
	4	Qualify operational scenarios and the supporting physics basis for ITER							
	5	Expand the Limits For Controlling and Sustaining Fusion Plasmas							
	6	Develop predictive models for fusion plasmas supported by theory and challenged with experimental measurement							
	7	Exploit high-temperature superconductors and other magnet innovations to advance fusion research							
	8	Understand the highly integrated dynamics of dominantly self-heated and self-sustained burning plasmas							
	9	Unfold the physics of the boundary layer plasma							
	10	Decode and advance the science and technology of plasma-surface interactions							
	11	Improve power handling through engineering innovation							
	12	Demonstrate an integrated solution for plasma-material interfaces compatible with an optimized core plasma							
	13	Establish the science and technology for fusion power extraction and tritium sustainability							
	14	Develop the material science and technology needed to harness fusion power							
	15	Create integrated designs and models for attractive fusion power systems							
	16	Develop the spherical torus to advance fusion nuclear science							
	17	Optimize steady-state, disruption-free toroidal confinement using 3D magnetic shaping, emphasizing quasi-symmetry principles							
	18	Achieve high performance toroidal confinement using minimal externally applied magnetic field							

Thrust Activities: Theme 1 – Burning Plasmas in ITER

- **Diagnostic development for high performance fusion plasmas (nuclear environment, limited maintenance, data for robust control)**
- **Facility improvements to existing tokamak experiments (additional heating/CD power; increased current, field, and pulse length; improved control capability; selected ITER prototyping work)**
 - Push studies closer to fusion conditions where possible (e.g., $T_e = T_i$)
- **Diagnostic improvements and increased run time in existing experiments; participation in experiments with next generation tokamaks expected to come on line before ITER**
- **Improved physics models and simulation tools**

Where possible, develop and validate key aspects of physics and technology needed to meet or exceed performance goals for ITER. Build knowledge base to realize benefits of success in ITER for optimizing future fusion devices.

Thrust Activities: Theme 2 – Creating Predictable, High Performance Steady-State Plasmas

- **Develop plasma control methods including appropriate sensors, actuators, and algorithms. Near-term focus on existing devices.**
- **Increased effort to validate (test against experiment) a spectrum of computer models to be used by fusion community. Hire analysts.**
- **Develop and utilize high temperature superconducting magnets. Laboratory development, test stands, installation in future experiments.**
- **Pursue long pulse, high gain plasma operation on new and existing non-DT facilities**
- **Examine options for enhancing ITER SS operation or building a high gain D-T facility in the US to complement ITER. Implement decision.**

Develop sufficient knowledge base to construct, with high confidence, a device that permits the creation of sustained plasma that meet simultaneously, all the conditions required for practical production of fusion energy: high fusion power density and steady-state operation.

Thrust Activities: Theme 3 – Taming the Plasma Material Interface

- **New diagnostics for comprehensive boundary layer measurements, measurements of PFC materials and RF-launcher interactions.**
- **Improve and test models for the boundary layer plasma and plasma-surface interactions. Develop more comprehensive models.**
- **Develop new materials and technologies to improve steady-state and transient power handling of PFC materials and assemblies.**
- **Upgraded and new test stands capable of extending PSI parameters closer to fusion reactor conditions; high heat flux test stands (components).**
- **Test alternate divertor configurations and PFC solutions in experiments.**
- **Integrated testing in a new facility featuring high heat flux, long pulse, hot walls, low activation, relevant core plasma.**

Develop a credible approach to reliably handling heat and particle loads consistent with the performance requirements of the fusion power core plasma for next generation fusion devices such as DEMO.

Thrust Activities: Theme 4 – Harnessing Fusion Power

- Perform multiple-effects studies (experimental and theoretical) to understand impact of operating conditions and component complexity.
- Improve existing materials and develop new fusion-capable materials; use new and existing test facilities for materials development.
- Detailed, integrated, advanced design studies for DEMO and FNSF options.
- Test stands and fusion-relevant neutron sources
- ITER Test Blanket Module Program
- Long pulse D-T Fusion Nuclear Science Facility or Component Test Facility

*Develop solutions to the science and technology challenges associated with designing and operating a fusion reactor; more urgently, resolving these issues to prepare the foundation for design and construction of DEMO.
(emphasis on fusion nuclear environment)*

Thrust Activities: Theme 5 – Optimizing the Magnetic Configuration

Great science from research on alternate configurations; primary motivation remains attractive fusion energy.

- **Spherical Torus/Tokamak**: application to a CTF. Startup/ramp-up CD, magnet technology, confinement, power loading. Upgrades to NSTX for higher field, current, NBI and RF power, liquid-metal divertor. Extend performance in new device.
- **Quasi-symmetric stellarators**: disruption-free, steady-state, high density operation. Two QS stellarator experiments @ low collisionality with high plasma pressure. Investigate simpler QS configurations. Design 3D divertors.
- **Low external field configurations** (RFP, FRC, spheromak): Improve diagnostics to understand stability and confinement. Use new and upgraded facilities to form basis for PE experiment (RFP) or PoP experiment (FRC, spheromak).

Additional Comments

- **Growing awareness that ITER era is bringing us to the point where technology issues will limit fusion development. Plasma physics is only part of the solution.**
 - Nuclear Science (fuel cycle, materials development)
 - Reliable operation
 - Power and particle control
- **Greater emphasis on “coordinated” predictive modeling and validation**
- **A range of significant new facilities have been proposed: lab facilities, test stands, specific-use tokamaks, general performance extension tokamaks, alternate concepts.**
- **As requested, ReNeW report provides a set of building blocks for OFES strategic planning requiring significantly increased resources in all areas (a lot more in some areas). It’s an inclusive set for a complete, scientific solution to fusion energy.**