TOPIC ISSUE PAPER

The Department of Energy's Basic-Applied Research and Development Integration Efforts

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1. EXECUTIVE SUMMARY

Throughout its over 30 year history, the Department of Energy's research and development (R&D) efforts have led to tremendous advancements in scientific discovery and innovation, and the development and deployment of new technologies that have made significant contributions to energy security, economic development, national security, and the quality of life in U.S. Like other large R&D organizations, the Department of Energy (DOE) faces two broadly recognized gaps: the translation of new concepts arising out of basic research to the conceptual stage through targeted R&D, and the translation of near-mature technologies from working prototypes to commercial deployment. This topic issue paper focuses on the Department's ongoing and recent efforts to bridge the former—the gaps in communication and R&D activities between the DOE basic and applied programs. The Department's efforts on technology transfer and commercial deployment is the subject of a separate topic issue paper.

Since its inception, the Department has engaged in efforts to coordinate its basic and applied R&D programs. The primary focus of these efforts is to improve communication and collaboration between federal program managers and within the S&T communities, and increase opportunities for collaborative research efforts focused on gaps at the interface of scientific research and technology development to ultimately accelerate DOE mission goals. The Department has a responsibility to coordinate its basic and applied research programs in headquarters to enable effective basic-applied R&D integration by the science and technology (S&T) communities (national laboratories, universities, and private companies) that support the DOE mission.

Current R&D Coordination Processes

The Department has coordinated its basic research efforts of the Office of Science with the Department's applied technology offices through several processes and mechanisms. These processes have identified a number of S&T opportunities that, if pursued, have the potential to overcome barriers to meeting the Department's goals for energy and national security, and environmental stewardship. Taken in sum, these coordination activities are widespread and have contributed greatly to DOE's capabilities and impact on mission goals. Processes include:

Scientific and technical workshops—The workshops include broad participation from the S&T communities and have been successful mechanisms for identifying and prioritizing research opportunities directed at overcoming scientific barriers to technologies. Twenty-four Office of Science-led workshops held over the past six years and their relevance to DOE's applied technology programs are highlighted in this paper. The results of the workshops typically lead to new program initiatives, joint basic-applied program planning meetings, and co-funded R&D opportunities.

Structured targeted research efforts—These program manager-level driven coordination activities between the basic and applied programs account for the majority of current R&D integration efforts. Programs facilitate the bridging of basic and applied research through joint program planning, joint solicitations and/or coordinated merit review of proposals, coordinated program reviews, and joint grantee/contractors meetings. Research areas coordinated under these types of activities include, but are not limited to: biofuels derived from biomass; solar energy utilization; hydrogen production, storage, and use; building technologies, including solid-state lighting; advanced nuclear energy systems and advanced fuel cycle technologies; vehicle technologies; and improving efficiencies in industrial processes.

DOE-wide Portfolio Assessments—Under the leadership of an R&D Council of DOE senior leadership, two S&T portfolio assessments were conducted in 2006 and 2007 to inform the annual budget process. The portfolio assessments led by a Laboratory Working Group, charged with the goal of identifying opportunities for S&T research integration and improving R&D management strategies, evaluated the potential of technology options over three time frames. The LWG identified a number of S&T options across a spectrum from discovery to application, recognizing that achieving desired mission impact requires an S&T portfolio that spans discovery and innovation.

The Energy Policy Act of 2005 (EPAct 2005) established the position of the Under Secretary for Science. The Under Secretary for Science serves as the principal scientific advisor within Department, advising the Secretary on scientific matters relating to all programmatic elements within the Department and the National Nuclear Security Administration (NNSA). The Under Secretary for Science has a primary responsibility for advising the Secretary with respect to long-term planning, coordination, and development of a strategic framework for Department research and development activities spanning the basic and applied programs.

As a requirement under EPAct 2005, the Under Secretary for Science led nine program reviews in 2006 that identified over 21 areas for coordination between the basic and applied programs that present opportunities for increasing mission success. Six of these coordinated research areas were selected to initiate in FY 2009. These include: Advanced Mathematics for Optimization of Complex Systems, Control Theory, and Risk Assessment; Electrical Energy Storage; Carbon Dioxide Capture and Storage; Characterization of Radioactive Waste; Predicting High Level Waste System Performance over Extreme Time Horizons; and High Energy Density Laboratory Plasmas. Three additional crosscutting areas are in the planning stage to initiate in FY 2010: Materials under Extreme Environments, Catalysis, and Applied Mathematics for Cyber Security.

Additional Mechanisms to Facilitate Communication and Research Integration—The Department's basic and applied programs facilitate communication and integration within the S&T communities through processes discussed above, but also through the joint support of research and leading-edge research tools at the DOE national laboratories; through the Department's SBIR/STTR and EPSCoR Programs; and through funding mechanisms such as the Funding Opportunity Announcement that enable the formation of partnerships between basic and applied researchers from multiple institutions.

Lessons Learned and Challenges to R&D Coordination

Bridging the gaps between basic and applied R&D is not a challenge unique to DOE. Virtually all areas of technology share the challenge of transforming basic research discoveries into technology development and, similarly, effectively tapping basic research to help overcome technological barriers. It is also a universal challenge, not unique to R&D in the U.S. The experience of the Department's basic and applied programs in executing the R&D coordination processes, as well as their experience in managing R&D portfolios over many years and budget cycles, has led to the identification of several key lessons learned as well as identification of challenges that the Department still faces regarding planning for and implementing R&D integration efforts.

Lessons Learned

- R&D coordination activities are but one of many factors that contribute to the quality of the Department's research programs and the ability of those research programs to impact mission goals. Preserving the distinct mission focus of individual programs while exploring areas of connectivity and mutual benefit is an important goal in basic-applied coordination and collaboration efforts.
- The different interests, missions, stakeholders, and external pressures of each DOE program presents challenges to sustained cooperation. Reinforcement by senior DOE management of the importance this effort encourages enhanced coordination for advancing DOE's mission.
- Many opportunities for R&D integration have been identified in recent processes such as the technical workshops and program reviews. Finite budgets require that the basic and applied programs prioritize.
- R&D coordination efforts to identify new opportunities greatly benefit from technical input by a broad spectrum of the S&T communities at universities, national laboratories, and the private sector.
- Program managers' integral involvement in portfolio reviews and R&D coordination planning processes increases likelihood of successful implementation.
- Reducing "impedance mismatches," both in technical expertise and in research portfolios between the basic and applied programs, will help ensure that the primary organizations have the capabilities to function as effective partners so that collaboration can happen in meaningful ways.

Challenges

- Pressures by stakeholders for short-term outcomes present multiple challenges to collaborative R&D efforts by the basic and applied programs, and can impact the integrated research efforts that those programs fund.
- Likewise, pressure by stakeholders on the basic research programs to support more obvious mission-relevant "use-inspired" research has the potential to erode funding for longer-term grand challenge and discovery research that may have much broader impacts on technology solutions of the future.
- None of the Department's current basic-applied R&D coordination planning processes or mechanisms is coupled to the annual budget process or allows for a regular, ongoing dialogue at all management levels.
- Most of the current R&D coordination processes do not enable the DOE program managers and senior management and its S&T communities to learn about the successful efforts of other large R&D organizations in the public and private sector (IBM, Google, GE, etc).
- New efforts within the Department to implement integrated and collaborative R&D efforts require regular communication to stakeholders, particularly Congress and the OMB, to gain their support. Directions from Congress and abrupt changes in funding can challenge the integrity of research portfolios and strain working relationships between DOE programs.

- The Department does not currently have a process or appropriate set of analytical tools or methodologies for measuring progress in its R&D coordination efforts.

These challenges are primarily attributed to communication within DOE and among the S&T communities; to budget related issues and pressures on current program priorities contributed to by stakeholders, including those with oversight responsibilities such as OMB and Congress; and the absence of a sustained R&D coordination planning process that engages all management levels. While some of these challenges are quite formidable, none should be considered insurmountable.

Strengthening Our Efforts to Meet DOE and National Needs

Today, the U.S. faces significant challenges in energy and national security, and environmental stewardship. Global energy demand is said to double by the end of this century; some say it will triple. How do we meet growing energy demands and do so without significantly impacting the environment? This challenge comes at time when modern science has made significant advances in our understanding and control of matter, energy, and information at the molecular level, and positions scientists and engineers to apply this knowledge and new capabilities across a wide spectrum of critical technologies. A new wave of the Nation's scientists and engineers at universities and national laboratories have mobilized over the past several years to create research programs and research centers focused on tackling the energy challenges. Now more than ever, the Department is positioned to capitalize on over 30 years of scientific advancement and technology innovation to aggressively address the energy needs of the country through a years-to-decades-to-centuries strategy.

The Department also has the responsibility to address the nearly 5,000 contaminated nuclear and industrial facilities requiring decontamination and decommissioning and 10,000 areas needing remediation across the DOE complex, the legacy of activities during the Cold War. Likewise, the Department and the National Nuclear Security Administration (NNSA) face the need to transform the Nation's nuclear weapons stockpile and supporting infrastructure to be more responsive to the threats of the 21st Century. Improving basic-applied R&D program coordination within the Department and research integration within the S&T communities is integral to the Department efforts to improve the effectiveness of its R&D portfolio in meeting U.S. energy challenges, and environmental stewardship and national security responsibilities.

Previous efforts by the Department have identified many new opportunities, helped establish good working relationships between program managers, and identified several management needs. As the Department develops new strategies to meet the challenges we now face, more deliberate, sustained, and appropriately resourced planning processes for basic-applied R&D coordination and structured communication efforts with stakeholders will significantly contribute to the Department's future success. Several such processes have been suggested.

Alternative and Complementary Processes for R&D Coordination

Improve communication within DOE and learn from past experiences through a DOE-wide workshop or retreat

- A DOE-wide program manager workshop or retreat with senior management would provide a forum for obtaining broad Department input on improving coordination between the basic and applied programs. A structured forum for senior management to exchange views and suggestions for improvement with program managers would be a valuable first step in establishing new or more effective processes department-wide. A workshop could also serve as a forum to:
  - Learn from the practices, successes, and failures of other large S&T organizations; and
  - Evaluate how current program management authorities and funding mechanisms can be better utilized to facilitate integration.

Serve as a catalyst for communication between the basic and applied S&T communities

- An annual DOE R&D conference that brings the DOE basic and applied S&T communities together, along with DOE program managers, would serve to improve communication across the research communities that support the DOE mission. Such an annual forum would enable a more focused exchange on progress and promising new directions and capabilities between DOE-supported researchers and other scientists and engineers engaged in DOE relevant research, and enable the DOE program managers to be an integral part of this exchange.

Established structured processes for sustained coordination planning

- Standing committees led by program managers from both the basic and applied programs focused on communicating and coordinating crosscutting research areas is one example of a process that could build on current efforts. The Energy Materials Coordinating Committee (EMaCC) provides a model for such committees. Additional committees could be established for other crosscutting areas of research.

- Alternatively, a National Science and Technology Council (OSTP)–like structure currently used by the White House Office of Science and Technology Policy for coordinating interagency R&D activities may be a model to consider for a long-term, corporate-wide process for evaluating R&D coordination opportunities and research gaps within the DOE portfolio and identifying priorities for implementation. Such a structure of subcommittees led by technical program managers from the DOE basic and applied programs would provide a more sustained, deliberate, and resourced approach to R&D coordination than the previous, more ad hoc portfolio review and assessment processes of recent years.

  The subcommittees would provide an appropriate scientific and technical basis for analyses and development of opportunities and priorities in particular research areas. The deliverables could serve to inform the annual budget process. Such an institutionalized processes and documented outcomes would transparently demonstrate to DOE stakeholders, including OMB and Congress, the programmatic R&D coordination efforts and senior management's involvement. As such coordination processes mature and R&D integration efforts are reviewed, it may become more feasible to develop criteria for quantitative measures for determining the impact of basic-applied R&D integration efforts on program goals, DOE mission goals, and national goals.

Align coordination efforts with the annual budget process

- Establishing an integrated budget element in the annual Congressional Budget Request for basic-applied R&D coordination would serve as a driver for internal DOE planning processes and help

communicate the Department's interests to stakeholders such as the S&T communities, OMB, and Congress**.** The Department's effort to do this on a small scale in for the FY 2009 budget request was well received by parts of Congress.

Future R&D portfolio assessments and other efforts by the Department to identify and address research gaps and opportunities for better basic-applied R&D coordination and collaborations will benefit from being done within the context of consistent frameworks from year to year. Frameworks, whether they be for energy, environmental legacy waste management, or stockpile stewardship, that are independent of policy factors, market drivers, and particular societal interests will enable processes that are science and innovation driven and the promote consistency needed to effectively manage research portfolios over time frames needed to see impacts.

As with other large R&D organizations, DOE faces the challenge of translating new concepts that arise out of basic research to the conceptual stage through targeted R&D. The Department and its S&T communities recognize that advances in basic sciences create entirely new technology possibilities. Likewise, technology efforts identify key issues requiring improved scientific understanding or new approaches. Central to bridging R&D gaps between the basic and applied research communities is leadership by the Department's senior management and program managers in improving communication and coordination between DOE programs in headquarters, and, through these coordination efforts, provide opportunities for the basic and applied scientists and engineers in the field to collaborate and build integrated R&D efforts that target DOE mission needs.

2. INTRODUCTION

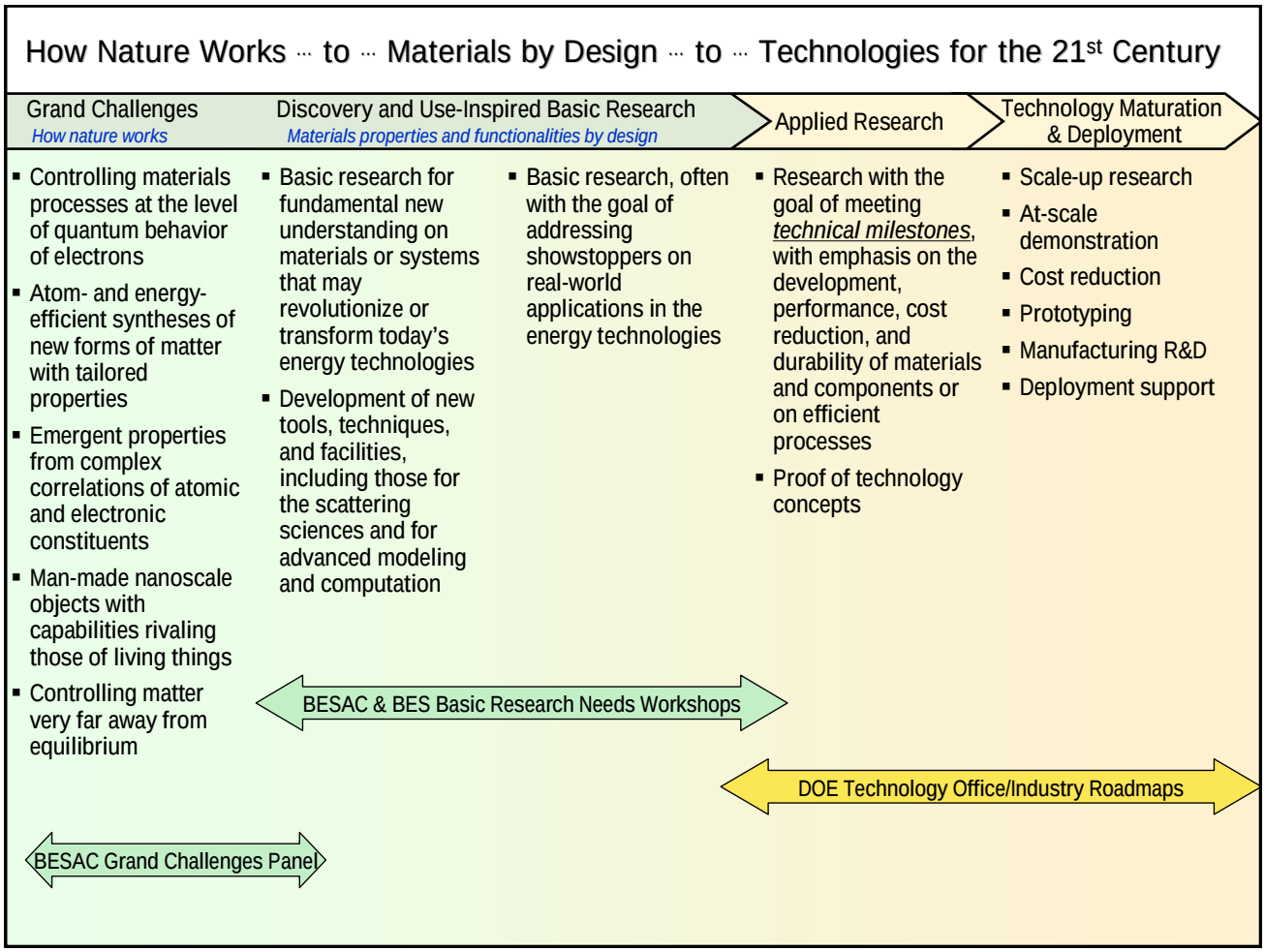
The Department of Energy (DOE) emphasizes that sustained momentum and progress towards achieving its mission and national goals requires a high level of commitment and joint exploration of underlying issues, incentives, and successful management mechanisms by both the basic and applied programs. Currently the Department of Energy's research and development (R&D) coordination activities among the Office of Science and the DOE applied technology programs seek to accelerate the seamless transfer of next generation solutions among basic discovery science, applied research, and technology development stages. This collaboration within DOE between the science and technology programs allows for the concentrated focus of each program's strengths in solving our Nation's energy security, national security, and environmental management challenges. The primary focus of the Department's R&D coordination activities is to improve communication between federal program managers and within the science and technology (S&T) communities and, increase opportunities for collaborative research efforts focused on gaps at the interface of scientific research and technology development to ultimately accelerate DOE mission goals.

The Office of Science pursues high-risk, game-changing knowledge that has the potential to create transformational technologies that will impact the Department and national goals. Basic research supported by the Office of Science also seeks solutions to the longer-term scientific issues that bring about paradigm shifts in our understanding of how nature works and challenges multiple technology platforms (such as materials in extreme environments, basic biological processes in plants and microbes that form the basis of renewable biomass, control of energy, charge transduction in solar energy conversion, and climate change research that underpins national and international energy).

DOE's technology programs rely on and incorporate basic and applied research into their efforts to improve the performance and reliability of existing technology platforms towards specific near-to-mid-term goals and enable the acceleration of commercialization of those technologies. The applied technology programs also develop productive partnerships with industry to leverage the technical expertise of the private sector and to help ensure technologies develop into commercial applications and find their way to the marketplace. Partnerships with the private sector also help strengthen the technical competencies of the DOE complex. The Department's efforts on technology transfer and commercial deployment is the subject of a separate Topic Issue Paper.

The collaborative efforts between basic and applied research can be described in the context of a continuum of research, development, development and deployment. Figure 1 is one way to illustrate this continuum; however, progress in basic and applied research is not a linear process. A single basic research discovery can have many applications, impact multiple technologies, enable the bridging of a technological barrier or lead to a significant leap in technology performance or efficiency. Likewise, the technological obstacles faced in applied research can inform where further fundamental knowledge is needed from basic research.

Figure 1. An illustration of the continuum between basic research, applied research, and technology development and demonstration.



The Department's basic and applied programs are committed to establishing and maintaining studied, thoughtful, and deliberate research portfolios. Program's long-term, mid-term, and short-term research priorities are informed by several processes that incorporate expert opinion from the science and technology communities to ensure quality and balance. These processes include: program reviews and studies by Federal Advisory Committees, open technical workshops, regular program reviews by external review panels, and commissioned studies by the National Academy of Sciences. The Department's R&D coordination activities and corresponding research integration efforts are one of many factors that contribute to the quality of the Department's research programs and the ability of those research portfolios to impact mission goals and address national priorities.

This topic issue paper presents several processes and mechanisms that the Department of Energy has used in recent years to facilitate coordination between its basic and applied science programs. For some areas of science and technology (S&T), these processes and mechanisms of coordination have been ongoing. In other areas, the targeted, enhanced coordination efforts have been more recent. Through these processes, several elements have been identified as being essential for the successful and sustained coordination between the basic and applied programs. Included in this paper are key

challenges that need to be addressed to improve coordination efforts. The paper also highlights potential alternative and complementary mechanisms that would serve to build on recent efforts with the goal of establishing sustained, deliberate, and resourced processes for identifying opportunities, and prioritizing and implementing future R&D integration efforts

3. R&D COORDINATION PROCESSES AND IDENTIFIED OPPORTUNITIES

The Department of Energy coordinates its basic research efforts in the Office of Science with the Department's applied technology offices through a number of processes and mechanisms. These include:

- Scientific and technical workshops;
- Structured targeted research efforts driven by program manager-level coordination between the basic and applied R&D programs;
- Joint program planning and/or program reviews;
- Jointly funding solicitations or jointly coordinated solicitations;
- Shared grantee/contractors meetings or conferences to bring the research communities together;
- Portfolio assessment efforts by structured oversight groups (R&D Council); and
- Coordination working group efforts guided by senior management (S&T Council).

Coordination between the basic and applied programs is also enhanced through joint programs, jointly-funded scientific facilities, the program management activities of the DOE Small Business Innovation Research (SBIR) and Small Business Technology Research Programs (STTR), and the Experimental Program to Stimulate Competitive Research (EPSCoR). DOE program managers have established formal technical coordinating committees (e.g. The Energy Materials Coordinating Committee – EMaCC) that meet on a regular basis to discuss R&D programs that have wide applications for basic and applied programs. Additionally, co-funding research activities and facilities at the DOE laboratories and using funding mechanisms that encourage broad partnerships are also means by which DOE facilitates greater communication and research integration within the S&T communities. Taken in sum, these coordination activities are widespread and have contributed greatly to DOE's capabilities and impact on mission goals.

Technical Workshops

Department-sponsored scientific and technical workshops involve broad participation of the scientific and technology communities and have been successful mechanisms for identifying research opportunities for both the basic and applied research programs and typically form the technical basis for the determination of new research areas that could benefit from better coordinated efforts and enhanced funding. The "Basic Research Needs" workshop series, led by the Office of Science's Office of Basic Energy Sciences (BES), begin with the "Basic Research Needs to Assure a Secure Energy Future" workshop in October 2002. This workshop led to 10 follow-on workshops, each focused on a particular energy technology or technology enabling area. The workshop participants include subject matter experts from academia, government, the national laboratories and industry.

The workshop reports describe the scientific and technical challenges and identify high priority research areas that, if pursued, have significant potential to provide needed knowledge to overcome scientific barriers to particular energy technologies. The workshop reports are a product of the scientific community and help communicate to Office of Science and DOE stakeholders (Office of Management and Budget, Congress, the scientific community, Federal Advisory Committees, the DOE technology programs) where the research needs exist and the reports help inform the Office of Science research portfolio investment decisions. The BES workshops established a successful model for productive technical workshops carried out by other Office of Science programs. The workshops often involve participation, or co-sponsoring and co-planning by the DOE's technology programs. Table I lists 24 of the recent Office of Science technical workshops and identifies the DOE technology programs relevant to the focus of each workshop. In many cases the focus of the workshop is relevant to multiple DOE technology programs.

For the each of the Basic Research Needs workshops, four-column charts were created that describe the opportunities and needs for basic research (discovery, and "use-inspired" research) and applied research and development (technology maturation and deployment) in the particular technology area. Those charts are provided in Appendix B. The results of the workshops can serve as a means for basic and applied programs to determine were research gaps exist in their current portfolios and areas that could benefit from enhanced coordination. The results of the workshops typically lead to a range of activities including jointly held program planning meetings (e.g. hydrogen), co-funded R&D opportunities (e.g. biomass and biofuels), and technology roadmaps (e.g carbon sequestration).

Table I. Office of Science Technical Workshops and Relevance to DOE Technology Programs

Office of Science Workshop	**DOE Technology Programs**						
	EERE	**FE**	**NE**	**OE**	**RW**	**EM**	**NNSA**
Basic Research Needs to Assure a Secure Energy Future (BES, October 2002)	X	X	X	X			
Basic Research Needs for the **Hydrogen Economy** (BES, May 2003)	X	X	X				
Basic Research Needs for **Solar Energy Utilization** (BES, April 2005)	X						
Basic Research Needs for **Superconductivity** (BES, May 2006)	X			X			X
Basic Research Needs for **Solid-state Lighting** (BES, May 2006)	X						X
Basic Research Needs for **Advanced Nuclear Energy Systems** (BES, July 2006)			X				X
Basic Research Needs for the **Clean and Efficient Combustion** of 21st Century Transportation Fuels (BES, October 2006)	X	X					
Basic Research Needs for **Geosciences** (ASCR, BER, BES, February 2007)	X	X			X	X	
Basic Research Needs for **Electrical Energy Storage** (BES, April 2007)	X		X	X			

Office of Science Workshop	DOE Technology Programs						
	EERE	**FE**	**NE**	**OE**	**RW**	**EM**	**NNSA**
Basic Research Needs for **Materials Under Extreme Environments** (BES, FES, EERE, NNSA, June 2007)	X	X	X		X	X	X
Basic Research Needs: **Catalysis** for Energy (BES, August 2007)	X	X	X				
Nanoscience Research for Energy Needs (BES, March 2004)	X		X	X		X	X
Advanced Computational Materials Science: Application to **Fusion and Generation IV Fission Reactors** (ASCR, BES, FES, March 2004)			X				
The Path to Sustainable Nuclear Energy: Basic and Applied Research Opportunities for **Advanced Fuel Cycles** (BES, NP, September 2005)			X			X	
Workshop on Simulation and Modeling for **Advanced Nuclear Energy Systems** (ASCR, August 2006)			X				
Nuclear Physics and Related Computational Science R&D for **Advanced Fuel Cycles** Workshop (ASCR, NP, August 2006)			X			X	X
Biomass to Biofuels: Breaking the Biological Barriers to Cellulosic Ethanol [and other **biofuels**] Workshop (BER**,** EERE, December 2005)	X						
Mathematical Research Challenges in **Optimization of Complex Systems** Workshop (ASCR, December 2006)		X	X	X	X		X
Computational **Subsurface Sciences** Workshop (ASCR, EM, FE, RW January 2007)		X			X	X	
Computational Research Needs in **Alternative and Renewable Energy** (ASCR, EERE, September 2007)	X						
Cyber Security Research Needs for Open Science (ASCR, July 2007)				X			X
Workshop on Research Needs for **Wind Energy** Characterization (EERE, BER, January 2008)	X						
Workshop on the Nations Need for **Isotopes**: Present and Future (NP, NE, August 2008)			X				X
Opportunities for **High Energy Density Laboratory Plasma Science** (FES, NNSA, May 2007)							X

Structured Targeted Research Efforts

The majority of the coordination activities between the Office of Science basic research programs and the DOE applied technology programs have been carried out at the program manager to program manager level with support by the programs' senior management. The coordination is usually driven by the Department's energy technology-based initiatives (e.g. the Hydrogen Fuel Initiative and Solar America Initiative) and scientific opportunities identified in technical workshops. In general, program managers (informed by technical workshops, current science and technology, external

reviews, etc.) will define proposed areas of research to be supported by the respective programs, coordinate on the merit-based review of proposals, and, when appropriate, hold joint program solicitations for proposals. The Office of Science programs and DOE technology programs also facilitate the bridging of the basic and applied research by holding joint grantee and contractor meetings to promote communication between researchers and technology developers and stimulate the sharing of ideas and collaboration. The R&D coordination carried out under this model includes activities in biofuels derived from biomass; solar energy utilization; hydrogen production, storage, and use; building technologies, including solid-state lighting; advanced nuclear energy systems and advanced fuel cycle technologies; vehicle technologies; and improving efficiencies in industrial processes. These research areas are described in greater detail below.

DOE-wide Portfolio Reviews

The Department established an R&D Council in 2005 to perform a DOE-wide Energy, Science, and Environment Portfolio Assessment to inform the annual budget formulation process. The R&D Council reported to the Under Secretary for Energy and Under Secretary for Science and was comprised of deputy assistant secretary-level representatives from the science and technology DOE program offices. In late 2006, the R&D Council evolved to the Science and Technology (S&T) Council and consisted of the Under Secretary for Science, the Under Secretary for Energy, and the Administrator of National Nuclear Security Administration. The S&T Council and their associate under secretaries or deputies meet regularly to discuss issues of importance across the organization, including R&D coordination.

2006 R&D Council – Laboratory Working Group S&T Portfolio Assessment

In fall 2005, the DOE launched a review under its R&D Council to assess the energy S&T portfolio's potential impacts on the Nation's energy goals and identify the primary scientific and technical challenges that must be met by the DOE programs to achieve the Department's energy objectives. The initial analytical effort was largely undertaken by the Laboratory Working Group (LWG), a collection of deputy directors in both science and technology from each of the major DOE national laboratories, and was complemented by the Integration Working Group made up of Federal analysts.

The LWG was charged to identify opportunities for integration and extension of DOE's S&T base and provided recommendations to the R&D Council and the S&T Under Secretaries. The results of the review were delivered at a senior level briefing to the Under Secretaries to inform the FY 2008 budget process. The review consisted of a balanced look at major technology research needs (representing challenges for the scientific community), areas where science might create fundamentally new options and technologies, and areas of technology investment that could help accelerate the development and market acceptance of commercially viable, improved energy options.

Specifically, the portfolio assessment by the LWG focused on several key questions:

1. What outcomes can each of the major program elements accomplish at what point in time?
2. What impact against national goals can be realized through these outcomes?
3. What are the primary technical and scientific challenges to realizing these accomplishments?
    a. What are the key areas of science that enable these goals?

   b. Are there emerging scientific discoveries that create opportunities for new approaches to innovation in energy systems?
   c. Are there crosscutting technologies that can enhance the outcomes?
4. What are the critical deployment barriers that impact realization of these benefits?
5. Given these challenges:
   a. Are there gaps in the DOE R&D portfolio?
   b. What are the opportunities to increase and/or accelerate impacts?
   c. Are there emerging scientific or technological discoveries that could enhance, accelerate or revise current development paths?

In their analysis, the LWG viewed energy S&T as a pipeline of evolving innovations supporting the DOE mission that included the discovery research, targeted research and development, and technology maturation and deployment, similar to the "continuum" presented in Figure 1. The portfolio review also evaluated the potential of technology options over three time frames: 2006 through 2010, 2006 through 2015, and 2025 and beyond.

Several high-level observations were made at the conclusion of the review:

- There is value in the diversity of the Department's S&T portfolio because the probability of having a significant impact on energy goals increases due to the multiple S&T pathways the Department is pursing.
- There is no dominant science and technology solution because the energy and environmental challenges before us are so large we will need to attack them on many fronts.
- The diversity of the portfolio also means that the Department's progress toward mission goals are not held hostage to any one driver (market, policy, science, or technology)

The portfolio analysis identified S&T options across a spectrum from discovery to application, recognizing that achieving the desired outcomes requires an S&T portfolio spanning discovery and innovation. These options included:

- Discovery research advancing the frontier of science to create new paradigms and enable disruptive energy technologies by advancing the frontier of knowledge;
- Targeted research and development bridging technology gaps where incomplete understanding blocks technological progress and focused efforts could substantially accelerate portfolio objectives;
- Technology maturation and deployment to bring cost/performance to competitive levels and refine system design and integration parameters; and
- Crosscutting research and development that would enable several technology options.

The crosscutting S&T analysis asked four fundamental questions focused on identifying gaps at the intersection of science and technology:

- What are the technology gaps where scientific breakthroughs are required to enable valuable new approaches?
- Are there advances in scientific knowledge and tools that could enable revolutionary new approaches?
- Are there areas of science and technology discovery that, if addressed, could accelerate several portfolio elements?
- What approaches offer the best likelihood of success in closing these gaps?

The LWG noted that several areas of discovery research offer potential foundations for disruptive innovation and deserved increased attention in portfolio planning. Table II lists the priority opportunities concluded in the review. Significant opportunities were identified in four areas of integrated basic-applied research. Two areas were identified as crosscutting that required greater communication and collaboration on S&T across the basic and applied programs. The LWG also identified 10 areas of S&T opportunities for enhanced investment that could accelerate outcomes towards national goals.

Table II. Opportunities for enhanced efforts identified by the LWG in the 2006 R&D Portfolio Review

Integrated Basic-Applied Research	• Hydrogen storage • Advanced nuclear fuel cycle • Synthetic and systems biology • Chemical transformation catalysis and control
Better S&T Communication	• Advanced materials • Advanced computing
S&T Opportunities for Investment	• Electricity storage • Carbon capture and storage • Unconventional fossil • Bioenergy • Adaptive grid controls • Power electronics • Superconductivity • Solar energy utilization • Buildings systems • Complex systems assessment

The LWG also suggested several R&D management approaches to increase impact:

- Establish clear, actionable goals at all levels (national energy goals, DOE mission goals, Program goals, etc.) to guide portfolio decision making.
- Base portfolio decisions on a common, consistent corporate view of the energy system.
- Establish a culture and employ management practices that encourage communication, coordination, and innovation across DOE programs.
- Apply appropriate management strategies for technologies at different stages of maturity to avoid non-productive competition between programs.
- Implement mechanisms to "bridge" the two barriers that inhibit technology progress—translating basic science to application and translating technologies to practice.

2006 Under Secretary for Science Portfolio Reviews

The position of the Under Secretary for Science was created in Energy Policy Act of 2005 (EPAct 2005) with responsibilities that include advising the Secretary of Energy on long-term planning and coordination of R&D across the Department. EPAct 2005, Section 994(b) required the Secretary of Energy to "develop a coordination plan to improve coordination and collaboration in research, development, demonstration, and commercial application activities across the Department organization boundaries." In 2006, the Under Secretary for Science conducted a series of DOE Program Office reviews with the Department's basic science and applied technology programs to identify areas of research where enhanced coordination between the basic and applied programs could accelerate progress toward program and mission goals. The open review meetings with the broad participation of program managers from the Office of Science programs and the applied technology programs also brought to light well established communication and coordination efforts between programs that were not known to senior management.

As a result of the Program Reviews more than 200 discrete opportunities for mutual collaboration were brought to the table through the briefing materials or discussions in the Reviews. Of that set, 21 areas were identified as having the best opportunity to increase mission success or were previously unidentified opportunities for mutual collaboration. These areas were in addition to the structure research areas the Department has been coordinating for several years. The *DOE Strategic Research Portfolio Analysis and Coordination Plan* submitted to Congress in July, 2006, outlined 21 of the research areas and elements of a plan for improved coordination. Table III lists 22[1] of the research areas organized into four mission related categories: highly crosscutting, energy, national security, and environmental management, as well as the corresponding basic and applied programs. A more detailed description of these research opportunities are provided in Appendix C.

Table III. Opportunities for basic-applied coordination identified in the 2006 Program Reviews led by the Under Secretary for Science

CATEGORY	AREA OF OPPORTUNITY	OFFICE OF SCIENCE PROGRAM	DOE TECHNOLOGY PROGRAM
Highly Crosscutting	Radiation-Resistant Materials	BES, ASCR, HEP, NP, FES	NNSA, NE, EM, RW
	Energy Storage	BES, ASCR, HEP, NP, FES	OE, EERE, NNSA
	Advanced Mathematics for Optimization of Complex Systems, Control Theory, and Risk Assessment	ASCR	OE, FE, NE, RW, EERE, NNSA
	Building Synergies with Work-for-Others, LDRD, and DOE University-Sponsored Research	Department-wide	Department-wide

[1] Twenty-one areas were included in the report that went to Congress. An additional area, High Energy Density Physics (HEDP) was identified in the Portfolio Reviews but was not included in the report. An interagency report on HEDP highlighted the need for improved stewardship in collaboration between the Office of Science and NNSA in high energy density laboratory plasmas. This area was considered a high priority in the coordination efforts in FY 2009, which included the creation of a joint program.

CATEGORY	AREA OF OPPORTUNITY	OFFICE OF SCIENCE PROGRAM	DOE TECHNOLOGY PROGRAM
Energy	Superconductivity	BES, HEP, NP	OE, EERE
	Power Electronics/Switching	BES, ASCR, HEP	OE, EERE
	Grid Control	ASCR	OE, EERE
	Wind Power	ASCR, BER	EERE
	Catalysis for Energy Efficiency and Renewable Energy	BES, BER	EERE
	Nuclear Fuel Materials and Design	BES, ASCR, NP	NE, NNSA
	Catalysis for Hydrogen Production from Nuclear Energy	BES	EERE, NE
	Risk Assessments for Geological Carbon Sequestration	BES, ASCR, BER	FE
	Gasification and Combustion Modeling and Computational Systems Dynamics	BES, ASCR	FE
	Advanced Sensors and Controls for Gasification and Combustion Systems	BES, ASCR, HEP, NP	FE
	High Performance Materials for Advanced Fossil Energy Processes	BES	FE
National Security	Innovative Materials for Safeguards and Security	BES	SSA, NNSA
	Nuclear Test Detection	BES, ASCR, HEP, NP	NNSA, NE
	Remote Sensing and Analysis of Radioactive Materials and Nuclear Weapons	BES, ASCR, HEP, NP	NNSA
	High Energy Density Physics – HED Laboratory Plasmas	FES	NNSA
Environmental Management	Chemistry and Separations for Radioactive Waste	BES, ASCR, BER, NP	EM, NE, RW
	Modeling, Simulation, and Scaling Issues for Environmental Management	BER	EM
	Predicting High Level Waste System Performance over Extreme Time Horizons	ASCR, BES	EM, RW

2007 S&T Council – Laboratory Working Group Focused Portfolio Review

In early 2007, the S&T Council charged focus groups of the Laboratory Working Group to perform a more detailed review of two areas of the energy portfolio highlighted in the 2006 S&T Portfolio Assessment, transportation and the electricity grid system. The focus groups were asked to assess near, mid- and long-term options for accelerating progress in these two key areas, address the impact of those options against the Department's goals, and address actions required for innovations to find their way into the marketplace. Detailed presentations were given to the S&T Council and senior

program management. They highlighted six overarching conclusions regarding DOE's energy S&T portfolio resulting from the assessment:

1. Vehicle efficient technologies offer a near-term, economic route to energy import reduction and play a critical role in all fuel diversification pathways and CO_2 emission reductions.
2. Realizing the full potential of biofuels requires fundamental scientific advances, broadening options, and addressing sustainability and infrastructure issues.
3. Hydrogen represents a long-term energy option, requiring fundamental use-inspired science and technology breakthroughs.
4. Achieving a 2X increase in electrical energy storage density can transform the prospects for hybrid and electric vehicles.
5. There is an important role for DOE in leadership of power systems science and technology innovation [for the electricity grid].
6. Emerging technologies can increase the power system capacity to more effectively meet the projected 30% demand growth by 2020.

S&T Council Portfolio Working Group Development of Enhanced Efforts for FY 2009

In 2007, a Portfolio Working Group consisting of technical staff of the applied technology programs and basic science programs in the Office of Science was tasked by the S&T Council to indentify a subset of the 21 research areas in the *DOE Strategic Research Portfolio Analysis and Coordination Plan* for enhanced program coordination and coordinated funding investments in FY 2009 budget request. Six of the 21 areas were highlighted in the FY 2009 DOE budget request with targeted funding requested from both the Office of Science programs and the relevant applied technology programs. Those six areas were: Advanced Mathematics for Optimization of Complex Systems, Control Theory, and Risk Assessment; Electrical Energy Storage; Carbon Dioxide Capture and Storage; Characterization of Radioactive Waste; Predicting High Level Waste System Performance over Extreme Time Horizons; and High Energy Density Laboratory Plasmas. In early 2008, the S&T Council agreed that three new areas should be considered for the FY 2010 budget request for enhanced coordination that are of great interest to both the basic and applied programs and are likely to have cross-cutting impacts on programs' mission goals. These areas are: Materials Under Extreme Environments, Catalysis, and Applied Mathematics for Cyber Security.

The Office of Science has sponsored one or more scientific workshops corresponding to these nine areas in collaboration with related applied technology offices, which identified high priority research areas. The results of the workshops form the technical basis for the coordinated efforts being proposed. A description of these nine research areas and the budget request in FY 2009 are provided below.

SBIR, STTR, and EPSCoR Programs

DOE's Small Business Innovation Research (SBIR) and Small Business Technology Transfer Programs (STTR) are managed by the Office of Science, for the Department, in collaboration with all of the applied technology programs that contribute funds – the Offices of Fossil Energy, Energy Efficiency and Renewable Energy, Nuclear Energy, Environmental Management, Defense Nuclear Nonproliferation, and Electricity Delivery and Energy Reliability. The Office of Science coordinates with technology program offices to assemble the specific mission-relevant research for the annual

solicitation, to identify peer reviewers and conduct the review of proposals, and collaborate in aspects of management of the SBIR/STTR projects selected.

The SBIR/STTR programs were created to simulate technological innovation and use small businesses to meet Federal R&D needs. One of the Department's goals for the programs is to increase private sector commercialization of technology developed through DOE SBIR-supported R&D. Because of the technology development focus of the projects often a program manager from the relevant technology program will become the topical manager to oversee the projects sponsored by the Office of Science. This is particularly the case for BES supported projects. For example, BES projects related to Materials for Advanced Nuclear Energy Systems are overseen by a program manager in NE. Projects related to Solid-State Lighting are overseen by a program manager in EERE; and BES projects in the area of Advanced Coal Research are overseen by a program manager in FE. The SBIR/STTR programs also provide a mechanism for the research community to bridge basic and applied research for the development of new technologies.

The DOE Experimental Program to Stimulate Competitive Research (EPSCoR) is a federal-state partnership program designed to support DOE's overarching mission of advancing the national, economic, and energy security of the United States, by promoting scientific and technological innovation in designated EPSCoR states and territories. The mission of DOE EPSCoR is to support basic research activities spanning the broad range of science and technology programs within DOE, and to increase the number of scientists and engineers in energy-related areas. Several EPSCoR projects make significant contributions to the applied program mission needs. For example, a jointly funded Office of Science and Office of Fossil Energy project is focused on contributing to the study of carbon mitigation through geological storage where both deep and shallow subsurface research is needed to understand the environmental responses associated with large scale injection of CO_2. The project is a collaboration between three Montana University system campuses and five DOE national laboratories and is focused on determining the influence of CO_2-related injections of fluids on pore structure, material properties, and microbial activity in rock cores from potential geological carbon sequestration sites, and determining the effects of potential CO_2 leakage on shallow subsurface ecosystems using field experiments.

Additional Mechanisms Facilitating R&D Integration Within the S&T Communities

Knowledge transfer – fundamental to bridging the research gaps between the basic and applied programs – is best accomplished by people. A new wave of the Nation's scientists and engineers at universities and national laboratories have mobilized over the past several years to create research programs and research centers focused on tackling our energy challenges. Researchers in the basic sciences are becoming increasingly engaged in these efforts and bringing the basic and applied research communities together in different forums is essential for promoting the communication and sharing of research results that ultimately lead to bridging science and technology gaps.

The Department's basic and applied programs facilitate this communication and integration through processes identified above (joint contractor meetings, etc.), but this is also achieved through the support of research and leading-edge research tools at the DOE national laboratories. The DOE national laboratories are good examples of how basic and applied research communities come together under one roof to tackle difficult research problems and bridge science and technology gaps to ultimately impact Department mission needs. Strong leadership and talented researchers at the

DOE laboratories have led to productive research programs that effectively span the basic-applied research continuum. These research programs are enabled by Department's major scientific user facilities—light sources, neutron sources, Nanoscale Science Research Centers, electron micro-characterization facilities, and supercomputers—located at the laboratories.

The co-funding of research activities and facilities also helps the laboratories bring the basic and applied research and technology communities together. There are many examples where the co-siting and co-funding of basic and applied researchers have led to effective knowledge transfer and significant technological progress. Examples of such successes include multi-junction solar cell research at the National Renewable Energy Laboratory that set the world record in photovoltaic efficiency; development of intermetallic alloys at Oak Ridge National Laboratory that achieved savings of millions of dollars at U.S. steel plants; and ultrananocrystalline diamond research at Argonne National Laboratory that enabled world-wide commercialization of abrasion-resistant coatings. The Combustion Research Facility (CRF) at Sandia Livermore was originally implemented 28 years ago as an Office of Science user facility and, as with all Office of Science user facilities, has served both basic and applied researchers in the area of combustion science by providing unique experimental and computational resources. Over the years, the CRF has evolved into a laboratory with a significant internal portfolio of basic research, supported by the Office of Science, and applied research, supported by DOE technology programs. At the same time, the CRF has maintained a leading presence in the combustion science community as a center for collaborative research that has included strong connections with U.S. automotive and engine manufacturing industries. Another example of co-funded research facilities is the Advanced Photon Source (APS) at Argonne National Laboratory. The Office of Science built the APS and now supports its operations while the NNSA and BES jointly support the High-Pressure Collaborative Access Team (HP-CAT) beamline, one of several beamlines at the APS, for x-ray diffraction studies of fundamental properties of materials under high-pressure, high-temperature conditions.

The Department also enables collaborations between the basic and applied research communities at laboratories and universities by funding mechanisms and initiatives that encourage these partnerships. For example, in 2006 the Office of Science used a Funding Opportunity Announcement (FOA) for the creation of three new Bioenergy Research Centers to openly compete the Centers among academia, the national laboratories, and industry. The FOA enabled the Nation's best scientific and technical talent to come together to form partnerships for the development proposals for a Center. The three DOE Bioenergy Research Centers selected are focusing on a broad range of discovery and use-inspired basic research targeted towards developing biofuels from plants, however all three have established formal partnerships with technology programs in their home institutions (some funded by EERE) and with industry to facilitate the translation of new discoveries and concepts to technology applications. The Office of Science's BES program has also issued a similar solicitation for Energy Frontier Research Centers to be awarded in FY 2009 (pending appropriations) that will tackle fundamental research in energy technology areas indentified in the ten "Basic Research Needs" workshops. BES anticipates that once the Centers are identified and awarded, productive partnerships will form with research groups funding by DOE's applied technology programs and industry.

There are also examples where the Department has sought other outside partners to bring the basic and applied research communities together to accomplish its program and mission goals. One example of this is in the area of Environmental Management. EM's Office of Engineering and

Technology (OET), the US Nuclear Regulatory Commission, U.S. National Institutes for Science and Technology, the Savannah River National Laboratory, and the Consortium for Risk Evaluation with Stakeholder Participation have initiated a partnership to conduct a multi-year project that spans from the basic research needed to support predictions of the service life of cement used in nuclear applications to the deployment of computer models for depicting the performance of cementitious barriers for many thousand of years. The "Partnership for the Development of Next Generation Simulation Tools for Evaluating Cementitious Barriers and Materials Used in Nuclear Applications" was initiated in 2007 to develop a modular, integrated set of simulation tools to predict evolution of cementitious barriers used in nuclear applications over time. These tools will be used to evaluate and predict the behavior of cementitious barriers and structural concrete components of nuclear facilities and their interaction with the immediately adjacent environment. OET anticipates that this research collaboration will address fundamental questions related to enhancing the credibility of performance assessments over long to very long time horizons.

4. CURRENT BASIC-APPLIED R&D COORDINATION AREAS

For the purpose of this paper, the Department's areas of R&D integration are described in two categories:

1) Structured research efforts that have been long-standing areas for basic-applied research coordination; and
2) Newly initiated areas of coordination, informed by DOE-wide portfolio reviews and technical workshops of recent years, specifically fiscal years 2009 and 2010.

Structured Research Efforts

The research areas of opportunity for collaboration highlighted in each the structured research efforts described in this section represent ongoing research areas as well as proposed areas for expanded collaboration. This represents some of the Department's major coordinated activities, but is by no means a comprehensive list.

Biomass (including cellulosic ethanol and other biofuels) – Designed to reduce U.S. dependence on foreign oil, breakthroughs in biological sciences (including genomic science) and applied research have resulted in significant new opportunities and potential efficiencies that bring this goal within reach. However, significant technical barriers remain to realizing the enormous commercial potential of cellulosic ethanol and other biofuels, and collaboration between the basic research and applied research communities is critical to positioning this technology to move forward. Promising research areas have been identified through two technical workshops.
Programs: SC/BER, SC/BES and EERE.
Midterm technology focus areas for collaboration include: *feedstock use and optimization, cell wall deconstruction, and fermentation and recovery*.
Long-term areas of opportunity for collaboration: *feedstock genomics, plant metabolism and photosynthesis; cell wall structure, physiology, and deconstruction; enzyme development and biocatalysis; fermentation organism development for cellulosics and hemicellulosics; single reactor saccharification, hydrolysis, and fermentation; catalytic and thermochemical processing of plant materials; sustainability of new approaches to biofuel production.*

Buildings (including solid state lighting) – Residential and commercial buildings, together, are the largest users of energy in the U.S. There exist considerable opportunities to continue to increase the energy efficiency of buildings through collaborative R&D. Past successes between the basic and applied research programs are numerous, with significant accomplishments in such areas as LEDs, OLEDs, structural materials, smart materials and windows, and sensors and controls, to name a few. One of the Basic Research Needs workshops was dedicated to solid-state lighting. Strong collaboration has been enabled throught the SBIR/STTR programs.
Programs: SC/BES and EERE
Areas of opportunity for collaboration include: *advances in solid state lighting (materials science for GaN or other materials);research into advanced cooling technologies such as thermotunneling, thermoelectric materials, thermocaloric materials, and thermomagnetic materials; and dynamic and highly insulating windows (e.g., electrochromic materials).*

Solar – The cost of solar energy production has been steadily decreasing for several decades, owing in large part to the technological advances brought about by EERE and SC and their collaboration. With developments in thin film technologies and advances in nanoscale science and new "designer" materials, the possibilities for even greater efficiency improvements seem very likely, as do the prospects for solar to assume a significant and expanding role in the U.S. energy future. The Department's Solar America Initiative goal is to make solar energy competitive in the national energy mix. Integration of research activities will provide a critical opportunity to link the science-intensive research capabilities with the applied solar research activities within the Department. Past successes included joint workshops and cooperation leading to the development of a world record 39% efficient concentrator cell.
Programs: SC/BES and EERE
Areas of opportunity for collaboration include*: properties of thin film materials, including the physics of CIS (copper indium diselenide) nanostructure domains; first-principle calculations of compound semi-conductor band-structure and other properties; physics of crystalline/nanocrystalline heterojunctions; interface physics of small organic molecules (organic heterojunctions); novel bandgap-engineered materials, e.g., quantum-dot materials allowing enhanced impact ionization; thermal storage materials for Concentrating Solar Thermal Power Systems; and power electronics*.

Vehicle Technologies (including Freedom Car) – The transportation sector accounts for fully 28 quads of U.S. energy consumption (excluding on-site transportation use in the industrial sector) and current forecasts are for continued rapid expansion through 2025. This sector is 96% dependent on oil and, as such, represents a significant area of opportunity to reduce dependency on foreign oil. There are significant opportunities to increase efficiencies and switch to alternative energy supplies that will only be realized through continued research and, more specifically, cooperation between the basic and applied research communities. Past successes have been realized through collaborative research at the Combustion Research Facility at the Sandia Livermore National Laboratory (SNL/CA) and at the Advanced Materials Lab at the Oak Ridge National Laboratory (ORNL). Past collaboration enabled advances in such areas as battery technology, composites, materials for extreme conditions, and welding and joining.
Programs: SC/BES and EERE
Areas of opportunity for collaboration include: *combustion modeling; sensors for high temperature environments; heat resistant materials; energy storage (nanomaterials and chemistries for next*

generation high energy batteries); computational modeling of materials for energy conversion and energy storage, including batteries and super-capacitors; nanostructured high efficiency thermoelectrics; and chemistry of fuels from emerging feedstocks (e.g., biomass).

Hydrogen – America currently imports almost 60 percent of the oil it consumes; that is expected to grow to 70 percent by 2025. Over two-thirds of the 20 million barrels of oil Americans use each day is used for transportation. Hydrogen has the highest energy content per unit of weight of any known fuel and can be produced using abundant domestic energy resources including fossil, nuclear, and renewable. Continued research is needed to reduce the cost and improve the performance of hydrogen production, storage, delivery, and use (fuel cell) technologies to enable their commercial viability and realize the Department's goal of achieving mass commercial introduction of hydrogen fuel cell vehicles into the market by 2020 and the long-term goal of significant replacement of conventional technologies in our Nation's vehicle inventory by 2040. DOE's basic and applied research communities have integrated the planning and implementation of hydrogen and fuel cell activities through joint workshops and annual program reviews, and through the development of the Hydrogen Posture Plan.
Programs: SC/BES, SC/BER and EERE, FE, NE
Areas for opportunity for collaboration include*: hydrogen storage materials, including metal hydrides, chemicals, carbon-based, and new materials; fuel cell materials, including membranes, non-precious metal catalysts; nanomaterials for ultra-high power density fuel cells; and hydrogen production drawing on thermochemical, electrochemical, biochemical, photolytic, microbial, and other processes*.

Industry Processes – U.S. industry consumes over 30 quads of energy each year, more than a third of all energy used in the United States. The DOE conducts research and works with industry to reduce the energy intensity of manufacturing processes. Significant ancillary benefits are realized with reduced use of toxic feedstocks, reduced emissions and by-products, reduced production costs, and increased industrial competitiveness. Most industrial facilities harbor significant opportunities for energy savings and continued research is needed. Cooperative research between the basic and applied programs are expected to pay large dividends as we enter a new era of materials science, biology, and computational sciences that have the ability to transform industrial processes as we now know them. Cooperation in the past has yielded many successes, including joint development of nickel aluminides; palladium-nickel alloys for hydrogen sensing; lost-foam casting; and numerous developments from SBIR/STTR joint work.
Programs: SC/BER, SC/ASCR, SC/BES and EERE
Areas of opportunity for collaboration include: *reaction and separation technologies, including those for high temperatures and catalysis; computational fluid dynamics, especially for multiphase flows; nanostructured materials; manufacturing technologies for the scale-up of production of nanoscale materials and their ultimate application in energy technologies; alloy chemistry and processing; non-destructive evaluation of properties; combustion science with reduced emissions; sensors for high temperature and/or corrosive application; inferential sensing and control at the micro-scale level of manufacturing processes; and biocatalysis and bioprocessing in specific low temperature conversion processes.*

Advanced Fuel Cycle –The mission of the Department's Advanced Fuel Cycle Initiative (AFCI), is to develop technologies that will meet the need for economic and sustained nuclear energy production while satisfying requirements for a controlled nuclear materials management system. The

primary near-term goal of the AFCI program is to develop and demonstrate advanced fuel cycle technologies for treatment of commercial light water reactor used fuel, to develop an integrated spent fuel recycling plan, and support initiation of processing and fabrication demonstrations . In the longer term, AFCI's development supports a system involving used fuel partitioning and recycling of actinides and other long-lived radioactive components in fast reactors for destruction through transmutation. Collaboration between the basic and applied programs continues to evolve and strengthen, with key areas and recent successes centered on relevant materials research. Over four workshops in the last 4 years have focus on identifying challenges and research needs.
Programs: SC/BES, SC/ASCR, SC/NP and NE
Areas of opportunity for collaboration include: *research to reduce uncertainties in certain actinide cross sections that are needed to precisely analyze the closed transmutation fuel cycle; advanced monitoring technologies for near real-time chemical and isotopic analyses of flowing streams in separations facilities; advanced analysis tools for more rapid design and analysis of transmuting fast reactors; and the development of advanced, powerful simulation and modeling tools to accurately predict reactor and fuel performance behavior in order to improve understanding of physical behaviors and reduce the need for lengthy irradiation campaigns in test reactors.*

Generation IV Nuclear Energy Systems – Nuclear energy holds the potential to significantly help meet our nation's growing need for safe, reliable, and environmentally responsible energy supply. The goal of the Generation IV Nuclear Energy Systems Initiative is to address the fundamental research and development issues necessary to establish the viability of next-generation nuclear energy system concepts. Successfully addressing the fundamental research and development issues of Generation IV system concepts that excel in safety, sustainability, cost-effectiveness and proliferation-resistance will allow these advanced systems to be considered for future commercial development and deployment by the private sector.
Programs: SC/BES, SC/ASCR and NE
Areas for opportunity for collaboration include: *application of massively parallel supercomputing technologies in the analysis of reactor fuels and materials performance issues in order to substitute computation and simulation for lengthy experimentation. Additionally ,radiation resistant materials the development of instrumentation and controls that may have common applications in both fusion and fission systems are another examples of where basic research can benefit applied technologies.*

FY 2009 Initiated R&D Coordination Areas

The following six areas highlighted in the FY 2009 budget request for enhanced coordination were identified in the 2006 Program Reviews and the corresponding report, *DOE Strategic Research Portfolio Analysis and Coordination Plan.* A detailed description of the proposed research contributions to these efforts by each program can be found in the FY 2009 Congressional Budget Request narrative. The funding summary requested for these six areas, provided in a table in Appendix D, also identifies funding in previous years related to the proposed activity (Appendix D). Over $166M in FY 2009 budget request across the basic and applied programs is dedicated to these coordinated research areas.

Advanced Mathematics for Optimization of Complex Systems, Control Theory, and Risk Assessment: A recommendation from the December 2006 ASCR-led workshop focused on this subject indicated that additional research emphasis in advanced mathematics could benefit the optimization of fossil fuel power generation; the nuclear fuel lifecycle; and power grid control. Such

research could increase the likelihood for success in DOE strategic initiatives including FutureGen and the modernization of the power grid.
Programs: SC/ASCR with EERE and NE

Electrical Energy Storage: The report from the 2007 workshop on electrical energy storage (EES) noted that revolutionary breakthroughs in EES have been singled out as perhaps the most crucial need for this nation's secure energy future. The report concluded that the breakthroughs required for tomorrow's energy storage needs will be realized with fundamental research to understand the underlying processes involved in EES. The knowledge gained will in turn enable the development of novel EES concepts that incorporate revolutionary new materials and chemical processes. Such research will accelerate advances in developing novel battery concepts for hybrid and electric cars and will also help facilitate successful utilization and integration of renewable, intermittent power sources such as solar, wind, and wave energy into the utility sector, making these energy sources base-load competitive.
Programs: SC/BES with EERE and OE

Carbon Dioxide Capture and Storage: The storage portion of this R&D coordination focus area was a subject of a BES workshop on Basic Research Needs for Geosciences in February 2007, which addressed the research challenges posed by carbon dioxide storage in deep porous geological formations. The workshop report noted that the chemical and geological processes involved in the storage of carbon dioxide are highly complex and its prediction would need an interdisciplinary approach that strongly couples experiments with theory, modeling, and computation bridging multiple length and time scales.
Programs: SC/BES, SC/BER with FE

Characterization of Radioactive Waste: This R&D coordination focus area was the subject of six SC workshops, including three BES workshops. The workshop reports noted that the materials and chemical processes involved in radioactive waste storage are highly complex and their characterization would need an interdisciplinary approach that strongly couples experiments with theory, modeling, and computation bridging multiple length and time scales. The knowledge gained from this fundamental research will lead to breakthroughs in radioactive waste characterization necessary for permanent solutions to nuclear waste disposal, making nuclear power a major component in primary energy usage and lessening our dependence on oil.
Programs: SC/BES, SC/BER, SC/NP with NE and EM

Predicting High Level Waste System Performance over Extreme Time Horizons: This R&D coordination focus area was a subject of a BES workshop on Basic Research Needs for Geosciences in February 2007, which focuses on research challenges posed by geological repositories for high level waste. The workshop report identified major research priorities in the areas of computational thermodynamics of complex fluids and solids, nanoparticulate and colloid physics and chemistry, biogeochemistry in extreme and perturbed environments, highly reactive subsurface materials and environments, and simulation of complex multi-scale systems for ultra-long times. The knowledge gained will in turn enable finding the permanent solutions to nuclear waste disposal, making nuclear power a major component in primary energy usage and lessening our dependence on oil. It will also further advance the goal of addressing environmental remediation needs.
Programs: SC/BES with EM

High Energy Density Laboratory Plasmas: In May 2007, the Office of Science, and NNSA jointly sponsored a workshop in HEDLP to update the scientific research agenda for HEDLP. Three scientific themes emerged from the workshop: enabling the grand challenge of fusion energy by high energy density laboratory plasmas; creating, probing, and controlling new states of high energy densities; and catching reactions in the act by ultra-fast dynamics. An important objective of the FES-NNSA Joint Program in HEDLP in the long term is to enable the broader scientific community to take advantage of the research capabilities at the major NNSA HED facilities, for example, the National Ignition Facility at the Lawrence Livermore National Laboratory, the Z-pinch pulsed power accelerator at Sandia National Laboratory and the Omega laser at the Laboratory for Laser Energetics at the University of Rochester. Another important objective of the Joint Program in HEDLP is to provide an avenue to explore the HED physics that underpins the scientific foundation for inertial fusion energy sciences.
Programs: SC/FES with NNSA

R&D Coordination Areas Proposed for Enhanced Effort in FY 2010

Three additional areas for enhanced R&D coordination for the FY 2010 budget were proposed by senior management of the basic and applied programs and is in the budget planning stage. These three areas were identified in previous portfolio reviews as areas of opportunity for increasing impact on DOE mission areas. All three areas of been the subject of technical workshops over the past two years. Programs are also planning to continue the six R&D coordination efforts initiated in FY 2009.

Materials under Extreme Environments: This focus area was the topic for the BES-sponsored workshop on Basic Research Needs for Materials under Extreme Environments. The workshop focused on the scientific challenges of materials subjected to high-radiation fluxes, high-stress, high-strain and high-strain-rate environments, temperature extremes, chemical extremes and high electric and magnetic fields. Current and future technologies for energy and national security applications will place increasing demands on materials' performance with respect to these extreme conditions. Understanding and controlling the scientific phenomena associated with these conditions is one of the most difficult challenges for materials science and engineering to date. This coordination activity will focus on failure mechanisms in materials subjected to extreme environments. In particular, there are specific environments including extremes of radiation flux, corrosion, and strain rate, separately or simultaneously, that are of interest across several program offices in DOE including the stockpile stewardship program in the NNSA; biomass, geothermal, industrial, solar, and transportation technology research, among others, in EERE; plasma facing and structural materials in SC, and on materials research related to the Advanced Fuel Cycle Initiative and Generation IV Nuclear Energy Systems in NE.

Catalysis: Catalysis for Energy was the subject of a BES-sponsored Basic Research Needs workshop in 2007 that identified the basic research needs and opportunities in catalytic chemistry and materials that underpin energy conversion or utilization, with a focus on new, emerging and scientifically challenging areas that have the potential to significantly impact science and technology related to a broad range of energy technologies. Under consideration for FY 2010 is a focus on catalysis for biofuels. A significant opportunity exists for integration between the Office of Science programs in BES and BER, and the EERE Office of Biomass Programs, in the area of biofuels other than ethanol. There are two targets for the accelerated development of non-ethanol transportation

fuels from biomass and a broad spectrum of medium-range hydrocarbons and their low-oxygen content derivatives created by advanced catalytic approaches to thermochemical conversion of biomass.

Cyber Security: The absolute integrity of information, encompassing systems, networks, and file systems is a critical requirement essential for promoting and facilitating discovery. These qualities are equally important for our nation's critical energy infrastructure. In July 2007, ASCR sponsored a workshop on Cyber Security Research Needs for Open Science in cooperation with OE. The workshop identified seven long-term, priority research long-term thrust areas that would provide a significant technological capability impact on the assured integrity of the nation's critical energy and science infrastructure. The research proposed under this effort is consistent with the interagency Comprehensive National Cybersecurity Initiative (CNCI) in which ASCR is actively engaged in. In FY 2009, ASCR initiated a new Applied Mathematics basic research program in optimization of complex systems that is strongly relevant to the interagency cyber security efforts. In FY2010, ASCR will couple applied mathematics projects initiated in FY 2009 with research related to the systems needs of one or more of the technology programs.

5. LESSONS LEARNED AND CHALLENGES TO R&D COORDINATION

The coordination between DOE's basic and applied R&D programs has been on-going since the Department was formed in 1977. The coordination processes and research integration mechanisms employed, particularly over the last decade, have provided an opportunity to identify elements that facilitate successful implementation of R&D integration efforts and can inform the development of future strategies for R&D integration.

Observations and Lessons Learned from R&D Coordination Activities

- R&D coordination activities are but one of many factors that contribute to the quality of the Department's research programs and the ability of those research programs to impact mission goals. Preserving the distinct mission focus of individual programs while exploring areas of connectivity and mutual benefit is an important goal in coordination and collaboration efforts.

- The different interests, missions, stakeholders, and external pressures of each DOE program presents challenges to sustained cooperation. Reinforcement by senior DOE management of the importance this effort encourages an environment that uses enhanced coordination for advancing DOE's mission goals. Communication and reinforcement of the importance of coordination at the highest levels within the Department is necessary for sustaining R&D integration efforts.

- There are many opportunities for R&D integration that have been identified in recent processes, such as the technical workshops and program reviews. Finite budgets require that the basic and applied programs prioritize the implementation of new coordination efforts in a strategic manner that considers other respective programmatic priorities.

- R&D coordination efforts to identify opportunities greatly benefit from seeking technical input by a broad spectrum of the S&T communities at universities, national laboratories, and the private sector.

- Program manager involvement in portfolio reviews and R&D coordination planning processes increases likelihood of successful implementation. The program managers are technical experts in their fields and respective programs and communicate regularly with the broader S&T communities. They are well equipped to identify research needs that span the basic and the applied and to develop coordinated research plans that involve effort and investment on the part of both the basic and applied research programs, consistent with respective program missions and budgets.

- R&D integration is facilitated through program cooperation at all levels and through a range of interactions – from the structured dialogue of technical workshops, to the encouragement of ad hoc and informal interaction of program managers at all levels within the Department.

- R&D coordination and collaboration efforts can be improved using processes that are a regular part of the annual budget planning, formulation, and program management and execution cycles.

- Reducing "impedance mismatches," both in technical expertise and in research portfolios between the basic and applied programs, will help ensure that the primary organizations have the capabilities to function as effective partners so that coordination and collaboration can happen in meaningful ways, and/or that the required handoffs can take place.

- Communication to stakeholders and enabling organizations such as OMB and Congress is necessary for supporting sustained efforts to implement new R&D coordination areas.

- Both the basic and applied programs need to accept some risk for failures in order to encourage innovation and transformational science and technology.

- Analytical tools and methodologies are needed to track performance and success of R&D integration efforts and enable thoughtful improvements to coordination processes and technology program evaluation.

Challenges

Bridging the gaps between basic and applied R&D is not a challenge unique to DOE. Virtually all areas of technology share the challenge of transforming basic research discoveries into technology development and, similarly, effectively tapping basic research to help overcome technological barriers. It is also a universal challenge, not unique to R&D in the U.S. The experience of the Department's basic and applied programs in executing the R&D coordination processes, as well as their experience in managing R&D portfolios over many years and budget cycles, has led to the identification of several key challenges the Department faces regarding planning for (coordinating) and implementing R&D integration efforts.

These challenges are primarily attributed to communication within DOE and among the S&T communities; to budget related issues and pressures on current program priorities contributed by stakeholders, including those with oversight responsibilities such as the Office of Management and Budget and Congress; and the absence of sustained R&D coordination planning processes that

engage all management levels. While some of these challenges are quite formidable, none should be considered insurmountable.

- Pressures by stakeholders for short-term outcomes present multiple challenges to building and sustaining collaborative R&D efforts by the basic and applied programs, and consequently can impact the integrated research efforts that those programs fund. Pressure on the applied technology programs to meet short-term technical milestones can result in the diversion of funds away from longer-term applied research areas to support technology development and deployment efforts. These shifts create greater "impedance mismatches" between the basic and applied programs and negatively impact efforts to bridge research gaps.

- None of the Department's current basic-applied R&D coordination planning processes or mechanisms is coupled to the annual budget process or allows for a regular, ongoing dialogue at all management levels focused on implementing current and future efforts after research gaps and opportunities have been indentified.

- Likewise, pressure by stakeholders on the basic research programs to support more obvious mission-relevant "use-inspired" research has the potential to erode funding for longer-term grand challenge and discovery research that challenges current understanding of matter and materials, systems and how nature works—research that leads to fundamental breakthroughs that may have much broader impacts on technology solutions of the future.

- With the exception of the some of the technical workshops, current R&D coordination processes do not enable the DOE program managers and senior management and DOE's S&T communities to learn about the successful integration efforts, related research initiatives, and practices of other large R&D organizations in the public and private sector (e.g. medical, space, information technology).

- New efforts within the Department to implement integrated and collaborative R&D efforts require regular communication to stakeholders, particularly Congress and the OMB, to gain their support, secure the funding requested, and to ensure they don't inadvertently (or intentionally) derail the Department's efforts.

- Directions from Congress and abrupt changes in funding challenge the integrity of research portfolios and strain working relationships between programs. Congress has a long history of interest in the Department's basic-applied R&D coordination efforts, but broad support has been inconsistent over the past decade. Appendix E notes some of the recent legislative and appropriation language directed at the Department related to R&D coordination. The House and Senate Appropriation Committees have implemented legislation and issued report language encouraging and directing R&D coordination efforts. In some cases, the Appropriation committees have directed funding from the basic program to applied programs or vice versa in attempt to "create" a desired program or change research directions.

- The Department does not currently have a process or appropriate set of analytical tools or methodologies for measuring progress in its R&D coordination efforts.

Measuring Progress

Developing appropriate and meaningful measures of progress of basic-applied R&D coordination within the Department to help inform decisions and improve the processes used is not trivial. The development of measures for determining whether integration research efforts are having an impact on DOE program and mission goals are even more complex and challenging. The goal of the Office of Science programs is fundamentally to gain new knowledge and understanding, the metric for this is knowledge generation and is not easily quantified. Alternatively, the applied technology programs have practical targets that focus on aspects of technology performance and more quantitative metrics targeted at milestone achievement. Coupling the two, that is to say, for example, quantifying how new knowledge gained from basic research accelerated the rate at which a technology milestone was achieved or improved an aspect of technology performance in some quantitative way is not something the Department has the tools to do yet. This is something the Department has been working on but efforts are not sufficiently developed to implement.

The Department's applied technology programs have been engaged in efforts to develop measures of progress and evaluate the benefits of the applied R&D portfolio. Progress relative to technology milestones is reported annually in the Department's Annual Performance Report and the President's Budget Request. Additionally, OMB independently tracks similar performance metrics through their Performance Assessment Rating Tool (PART) and posts that information on their public website. The Integration Working Group (IWG) initiated by R&D Council in 2006 sought to develop common analytical methods to help link R&D investments to achievement of technology program goals and provide portfolio managers with tools for improving risk-adjusted benefits analysis. Efforts initiated by the IWG have continued on some level. The Office of Science has supported projects focused on the development of indicators of scientific progress in basic research. The Office of Science is also involved in the interagency Subcommittee on Social, Behavioral, and Economic Sciences of the National Science and Technology Council's Committee on Science, which is studying the development of such indicators. These efforts need to be further developed and eventually linked to provide measures for correlating basic-applied coordination efforts to impacts of R&D integration on DOE goals. The Department's basic and applied programs use peer review mechanisms to evaluate the quality of its research programs, and the Office of Science uses its annual laboratory appraisal process to evaluate the performance of its national laboratories. While these processes look at the effectiveness of R&D efforts in impacting program and DOE mission goals, they have not looked specifically at the impact R&D integration efforts have had on program and mission goals.

Qualitative Measures of Successful Coordination

In discussing success of R&D integration efforts, the distinction must first be made between success in terms of improving coordination and collaboration efforts within the Department and its S&T communities, and success in terms of the impact pursuing integrated research efforts has had on achieving DOE mission goals. For the purpose of this paper, this discussion will focus on the former. Because there are no well-recognized, established methods or metrics for measuring progress for R&D coordination, the measures of success thus far are more qualitative. Such measures include: successful joint funding solicitations; joint contractor meetings; participation by programs managers of the technology programs in Office of Science-sponsored technical workshops; the initiation of new collaborative efforts whether structured or through less formal

processes; and open communication and good working relationships between program managers across the DOE basic and applied programs.

Another qualitative measure of success is whether the opportunities identified in portfolio reviews or technical workshops have been implemented. For example, enhanced efforts in six of the 21 areas of opportunity identified in the 2006 Program Reviews were proposed in the FY 2009 budget request. This marks an increased effort in R&D coordination and can be viewed as a success. Likewise, the Energy Frontier Research Centers proposed for FY 2009 by BES will pursue research areas identified in the ten "Basic Research Needs Workshops" focused on energy technologies. If appropriated, this would also be viewed as a major success. The Department, however, has not initiated an effort to identify and catalog all of these more qualitative measures of success.

Technology Examples

There are many cases of how knowledge transfer between basic and applied research programs have led to success in technology development and transfer to the private sector. One example is in the area of battery research. A basic research project initiated by the Office of Science at the Massachusetts Institute of Technology more than a decade ago led to the discovery of a new nanostructured cathode material for battery applications. Based on the knowledge gained, a new battery technology was developed by A123Systems of Watertown, Massachusetts. The development was further supported by a DOE SBIR grant starting in 2002 and by the Office of Energy Efficiency and Renewable Energy in 2006. Within the last three years these new batteries reached the commercial marketplace in power tools produced by North America's largest toolmaker, Black and Decker, and they currently are being implemented in hybrid and plug-in hybrid electric vehicles, among other applications. In early August 2007, A123Systems and General Motors (GM) announced the co-development of A123Systems' nanophosphate battery for use in GM's electric drive E-Flex system. This joint effort is expected to expedite the development of batteries for both electric plug-in hybrid vehicles and fuel cell-based vehicles. This successful effort testifies to the importance of long-term, broad-based fundamental research; it also serves as a model for the Department's successful transfer of basic discovery research to breakthrough technology applications which underpin globally competitive U.S. industries.

Success in the DOE mission rests in many ways upon discoveries made at the fundamental level that are then developed under applied programs, often with rich collaboration among the Nation's national laboratories. This was the case in the implementation of the Caustic-Side Solvent eXtraction (CSSX) process developed for removing cesium-137 from legacy high-level salt wastes such as those that have been stored for decades at DOE's Savannah River Site (SRS) and Hanford site. The CSSX process is currently being used to process several gallons per minute of High Level Waste (HLW) in the Mobile CSSX Unit (MCU) at the SRS, and it will be implemented at full scale in the Salt Waste Processing Facility (SWPF) now under construction. Research sponsored by the DOE Office of Basic Energy Sciences at Oak Ridge National Laboratory initially laid the foundation enabling the development of CSSX. Knowledge gained in this program in the 1980s and 1990s was put to use and directed toward HLW problems by applied EM funding in the period 1994-1999, leading to the conceptualization, development, and demonstration of CSSX. Additional funding by the Environmental Management Science Program provided critical insights toward overcoming technical problems and improving the technology. Scale-up and maturation of the technology occurred under EM funding in 1999-2003. Partnerships with Argonne National Laboratory and

Savannah River National Laboratory, with additional participation by Pacific Northwest National Laboratory and Idaho National Laboratory, were critical in engineering and scale-up, and hot demonstrations were carried out at the SRNL, where the locus of the majority of work has remained in connection with the SWPF. In terms of stewardship of the environment, the technological significance of the CSSX process itself is clear. Critical achievements such as CSSX could not happen without such commitment to long-range research.

Another example of successful integration of basic-applied R&D is in the area of certification of the nuclear stockpile. A broad base of science, technology and engineering capabilities is necessary to ensure confidence in NNSA's annual stockpile assessment and certification. In particular, resolution of several significant findings in the investigations of material configurations found in the nuclear warhead stockpile required an integration of R&D activities. Specific dynamic radiography tests performed at the Los Alamos National Laboratory Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility and 3-dimensional computational simulations were required to give confidence in assessment of the impact of the observed material configurations that were small but important deviations from the warhead design baseline. Without the integrated predictive capabilities developed through investments in high performance computing, modeling and simulation, unacceptable uncertainty in warhead performance would have resulted and underground nuclear tests would have remained the only alternative for verifying stockpile viability.

The R&D 100 Awards awarded to DOE sponsored projects also point to successful basic and applied integration within the S&T communities. There are a number of examples such as these, but again the Department does not keep a targeted database of these successes. The exception to this is the SBIR/STTR programs which are required to track follow-on funding and commercialization successes of funded projects.

6. STRENGTHING OUR EFFORTS TO MEET DOE & NATIONAL NEEDS

Throughout its over 30 year history, the Department of Energy's R&D efforts have led to tremendous advancements in scientific discovery and innovation, and the development and deployment of new technologies that have made significant contributions to energy security, economic development, national security, and the quality of life in U.S.

Today, the U.S. and the world face an enormous energy challenge – how to meet growing energy demands and do so without significantly impacting the environment. Some say world energy demand will double by the end of this century; others say it will triple. According to the most recent data from the Energy Information Administration (EIA, 2008), U.S energy demand will increase approximate 25% by 2030. During this time world energy will increase by almost 48%. Carbon dioxide emissions are projected to increase by almost 25% in the U.S. and 50% globally. Where will all of this energy come from, and how do we provide this energy while limiting CO_2 emissions?

This challenge comes at time when modern science has made significant advances in our understanding and control of matter, energy, and information at the molecular level, and positions scientists and engineers to apply this knowledge and new capabilities across a wide spectrum of critical technologies. A new era of science is being ushered in, enabled by the Department of Energy and catalyzed by the urgency of the challenges before us. Now more than ever, the Department is

positioned to aggressively address the energy needs of the country through a years-to-decades-to-centuries strategy. Over 30 years of scientific advancement and technology innovation, and current collaborations and partnerships with the private sector have intersected with an acute focus on a national goal that demands large-scale and rapid changes in the way we currently produce, distribute, and use energy.

The Department and the Nation face additional challenges. During the Cold War, the U.S. nuclear stockpile reached more than 30,000 nuclear weapons. Research and production of these weapons resulted in large volumes of nuclear waste and otherwise contaminated materials. During this period, the U.S. did not have the rigorous environmental protection requirements, and the environmental protection technologies, processes, and know-how that exist today to manage these materials. As a result large amounts of nuclear waste were generated, stored, and disposed of in ways that we now consider to be unacceptable, such as in single-shell underground tanks. These Cold War methods also led to the contamination of soil and groundwater at locations across the country. The sheer volume of affected soil and groundwater, the range of geologic settings, and the diversity of contaminant types make this one of the world's most complex environmental challenges.

The contaminated materials, including liquids, sludge, solids, and equipment, contain plutonium, uranium, and other radioactive elements—some of the most dangerous substances known to mankind. Some of the materials have low levels of radioactivity while others have high levels that require shielding of lead, concrete, and steel. Within the DOE complex, there are more than 1.5 million cubic meters of solid radioactive waste and 88 million gallons of radioactive liquid waste containing nearly 10 million curies of radioactivity. The total amount of nuclear waste to be safely dispositioned would fill the Louisiana Superdome. In addition to the waste, nuclear weapons research and production left a larger legacy of nuclear materials—nearly 5,000 contaminated nuclear and industrial facilities requiring decontamination and decommissioning and 10,000 areas needing remediation. There has been major progress in the cleanup of these sites, which span from Massachusetts to California. The remaining challenges, however, such as those at the Hanford and the Savannah River Site (SRS), will require unique approaches utilizing new technologies developed by an effective combination of basic science and applied research and engineering.

With the enactment of the Nuclear Non-Proliferation Treaty in 1970 and the Comprehensive Test Ban Treaty in 1996, one of the U.S.'s primary means of maintaining the safety and reliability of nuclear weapons was no longer acceptable, but the requirement to maintain a high level of confidence in weapons safety and reliability remained. Since then the U.S. has faced unique political and technical challenges as develops the means to balance the requirement to maintain its nuclear stockpile against the obligation and desire to provide strong leadership in arms control and non-proliferation. The U.S. recognizes that in a world of uncertain dangers and evolving security needs, nuclear weapons and the robust deterrent deriving from them remain fundamental to national security

The maintenance of safety, security and confidence in the nuclear deterrent, while continuing to provide global leadership in arms control and non-proliferation, requires new and innovative perspectives and processes as the stockpile becomes the oldest in the over 50-year history of the nuclear age. A decade ago the DOE and NNSA predecessor agencies faced an aging nuclear weapons complex and a legacy nuclear stockpile that was too large, lacked modern safety and

security features, did not have acceptable long-term reliability, and was poorly suited for the uncertain future of the 21st Century.

A science-based program of evaluation, assessment, and expert judgment is a primary requirement for the U.S. to meet stockpile stewardship and reliability under an environment of no testing and no new weapons. Every year, the Secretary of Energy must certify the reliability of the stockpile without conducting an underground nuclear test. Advances in science and technology, including high-performance scientific computing and experimental research in materials sciences, nanotechnology, and high energy density physics, make this feasible. An effective stewardship program will continue to require complementary efforts at the national laboratories and universities, including advances in high-performance computing; enhanced surveillance to predict aging and other defects; improved non-nuclear testing with high explosives; archiving of past design, testing and materials data; and scheduled revalidation and life-extension for the basic weapon designs in the continuing U.S. stockpile.

In addition, the convergence of heightened terrorist activities and the ease of moving nuclear materials, technology, and information across borders have made the potential for terrorism involving weapons of mass destruction (WMD) the most serious threat facing the Nation and preventing WMD from falling into the hands of terrorists is the top national security priority. The NNSA must employ more sophisticated advanced technologies to detect the proliferation of weapons of mass destruction worldwide, and eliminate or secure inventories of surplus materials and infrastructure usable for nuclear weapons.

Moving forward, improving basic-applied program coordination within the Department and research integration within the S&T communities is one area where the Department can improve the effectiveness its R&D portfolio in meeting U.S. energy challenges, and environmental stewardship and national security responsibilities. Alternative and complementary processes for improved R&D coordination are described below. The suggestions provided below incorporate lessons learned and would serve to tackle current challenges. Also discussed below is the value of establishing a common, consistent framework from which R&D portfolio analysis and coordination decisions are developed, and example frameworks are provided.

Alternative and Complementary Processes for R&D Coordination

Much progress has been made within the Department to identify research gaps and opportunities for basic-applied research coordination, establish good working relationships at the program levels, and build a strong basis of research integration within the R&D portfolio. Moving forward, the Department's basic-applied R&D coordination efforts will need to accomplish the following:

- **Improve communication** between DOE basic and applied programs and within the S&T communities
- **Understand past successes** (and failures) both inside and outside of the Department
- **Establish proactive and sustained planning processes**
- **Provide resources** to facilitate the coordination and implementation
- **Align coordination efforts with the annual budget process**
- **Remove unnecessary barriers** to coordination
- **Develop the tools to measure** progress and successes

Drawing upon the lessons learned from recent and current R&D coordination activities, the following processes, carefully planned and adequately resourced, have the potential address many of the current challenges and provide greater opportunity for improved of basic-applied research coordination in the future.

Improve communication within DOE and learn from past experiences through a DOE-wide workshop or retreat.

- A DOE-wide program manager workshop or retreat with senior management would provide a forum for obtaining broad Department input on improving coordination. The experiences and views towards recent and past R&D coordination efforts vary across programs and management levels. Creating a structured forum for senior management to exchange views with program managers and openly discuss suggestions for improvement would be a valuable first step in establishing new or more effective coordination processes department-wide. Such a forum would also serve as a means for senior management to communicate its support of R&D coordination efforts and the importance of such efforts to the Department's missions.

  This workshop could also serve as a forum to:
  - *Learn from the practices, successes and failures of other large S&T organizations*. By including presentations and discussions with representatives from leading S&T organizations in the private sector (e.g. IBM, GE, Google, Boeing) DOE can learn from their successful management practices for bridging basic-applied research gaps and facilitating collaborations between the basic and applied research communities.

  - *Evaluate how current program management authorities can be better utilized to facilitate integration.* The Department currently uses such practices as joint funding solicitations and coordinated merit reviews between the basic and applied programs. By evaluating the management tools the Department currently has within its authority, creative processes may be identified that can address key coordination management needs while avoiding the creation of unnecessary layers of bureaucracy.

Serve as a catalyst for communication between the basic and applied S&T communities

- An annual DOE R&D conference that brings the DOE basic and applied S&T communities together, along with DOE program managers, would serve to improve communication between the research communities that support the DOE mission and provide a forum for researchers to build collaborations. The conference would bring together science, applied R&D, and management leaders together each year for presentations and poster sessions on progress, promising new directions, and research capabilities. This could take the form of a single conference with parallel sessions, or series of conferences with a narrower focus of S&T topics. Some programs currently do this on a very small scale with joint contractor meetings. Such an annual forum would enable more focused exchange between DOE supported researchers and other scientists and engineers engaged in DOE relevant research than the conferences currently organized by scientific professional societies and industry

organizations. Such forums would also enable the DOE program managers to be an integral part of this exchange.

Established structured processes for sustained coordination planning

- Standing committees led by program managers from both the basic and applied programs focused on communicating and coordinating crosscutting research areas is one example of a process that could build on current efforts. The Energy Materials Coordinating Committee (EMaCC) provides a model for such committees. EMaCC is a formal structure for communicating and coordinating between 19 different program offices with distinctly different mission-related responsibilities for materials research and development. The committee has a charter defining the scope of its activities, meets several times a year, and provides an annual update on materials research efforts across the Department.

  Additional committees could be established for other crosscutting areas of research (e.g. computation and simulation, chemical transformations and catalysis, electrical energy storage, and geosciences). The committees could be charged with assessing opportunities for coordination and establishing common priorities within defined topical areas over time periods that allow thoughtful discussion, consultation with respective programs, and when needed, input from the broader scientific community through workshops or other forums. Such committees might report to the Under Secretaries or the Deputy Secretary of Energy and deliberate in a manner to support annual budget decisions on R&D coordination.

- Alternatively, a National Science and Technology Council –like structure currently used by the White House Office of Science and Technology Policy for coordinating interagency R&D activities may be a model to consider for a long-term, corporate-wide process for evaluating R&D coordination opportunities and research gaps, and identifying priorities for implementation. Each of the committees in the NSTC has several underlying subcommittees or interagency working groups that are charged with defined functions under a charter. Such a structure of subcommittees, and more detailed task groups within, led by technical program managers from the DOE basic and applied programs could provide a more sustained, deliberate, and resourced approach to R&D coordination than the previous, more ad hoc portfolio review and assessment processes of recent years.

  Useful attributes of an NSTC-like process:
  - Each subcommittee and task group has a charter defining the group's purpose, responsibilities, membership organizations, deliverables, and lifetime.
  - Participants of the subcommittees and task groups are subject matter experts representing their organizations.
  - Resulting deliverables are concurred upon by the member organizations and thus provide a consensus document.
  - The activities and deliverables of the groups inform decisions of the senior officials they report to.

  Such a structure, with leadership co-chaired by both a basic and applied program and participation by technical program managers, would provide an appropriate scientific and technical basis for analysis and development of opportunities and priorities. The

subcommittees could report to a council of the two Under Secretaries and the NNSA Administrator, or to the Deputy Secretary of Energy. Additional benefits of such a structure:

- Charges and deliverables could also serve to inform the annual budget process.
- The subcommittees and task forces could serve as a technical resource for senior management for assessing more focused research and technical topics.
- A subcommittee could be developed to focus on the development of sensible criteria and analytical methods of measuring progress in R&D program coordination and research integration.
- An institutionalized processes and documented outcomes can transparently demonstrate to DOE stakeholders, including OMB and Congress, the programmatic R&D coordination efforts and senior management's involvement.

Align coordination efforts with the annual budget process

- Establishing an integrated budget element in the annual Congressional Budget Request for basic-applied R&D coordination would serve as a driver for internal DOE planning processes and help communicate the Department's interests to stakeholders such as the S&T communities, OMB, and Congress**.** A dedicated R&D coordination section in the budget narrative of each participating DOE basic and applied program along with linked sections in the overviews would serve to develop better communication with OMB on the Department's R&D integration efforts. The narratives describing ongoing and planned R&D integration activities in the budget request would also serve as an effective mechanism for communicating the Department's plans and associated benefits to Congress, particularly the Appropriations Committees. Likewise, a dedicated section in the budget narrative would signal to the S&T communities our planned directions and funding intentions.

  The Department's effort to do this on a small scale in 2008 was viewed favorably by OMB and parts of Congress. The FY 2009 Budget Request for DOE highlighted each of the six newly initiated R&D coordination areas of research in the budget sections for each of the participating program. This was well received by the House Appropriation Committee as indicated by their extensive remarks in their FY 2009 Energy and Water Development Subcommittee mark.

Develop the tools to measure progress and successes

- The Department's basic and applied programs use peer review by recognized experts and Federal Advisory Committee reviews as valuable mechanisms to evaluate the quality of research supported within their portfolios and progress towards research program goals. These mechanisms could be expanded to include review criteria focused on how well the funded research is progressing in targeted areas that span the realm of basic and applied, and, from the overall portfolio perspective, how the research efforts are addressing technology gaps and building partnerships among basic and applied research scientists and engineers.

- Creating an institutionalized stainable R&D coordination process also enables the Department to create meaningful performance measures associated with R&D coordination and research integration. As coordination processes mature and R&D integration efforts are reviewed, it will become more feasible to develop criteria for quantitative measures for determining the impact of basic-applied R&D integration efforts on program goals, DOE mission goals, and national goals.

The processes above collectively would help ensure that the Department's R&D coordination efforts will:

- Foster integrated basic-applied Principal Investigator teams
- Create basic-applied DOE management teams
- Tap the best scientists and engineers – the innovative thinkers, receptive to new ideas and people
- Establish objectives that are innovation driven, not schedule driven
- Foster stable programs and new initiatives with reasonable assurance of appropriate duration
- Benefit from periodic review by top expert scientists/engineers outside DOE

Using Common Frameworks for R&D Coordination Portfolio Assessments

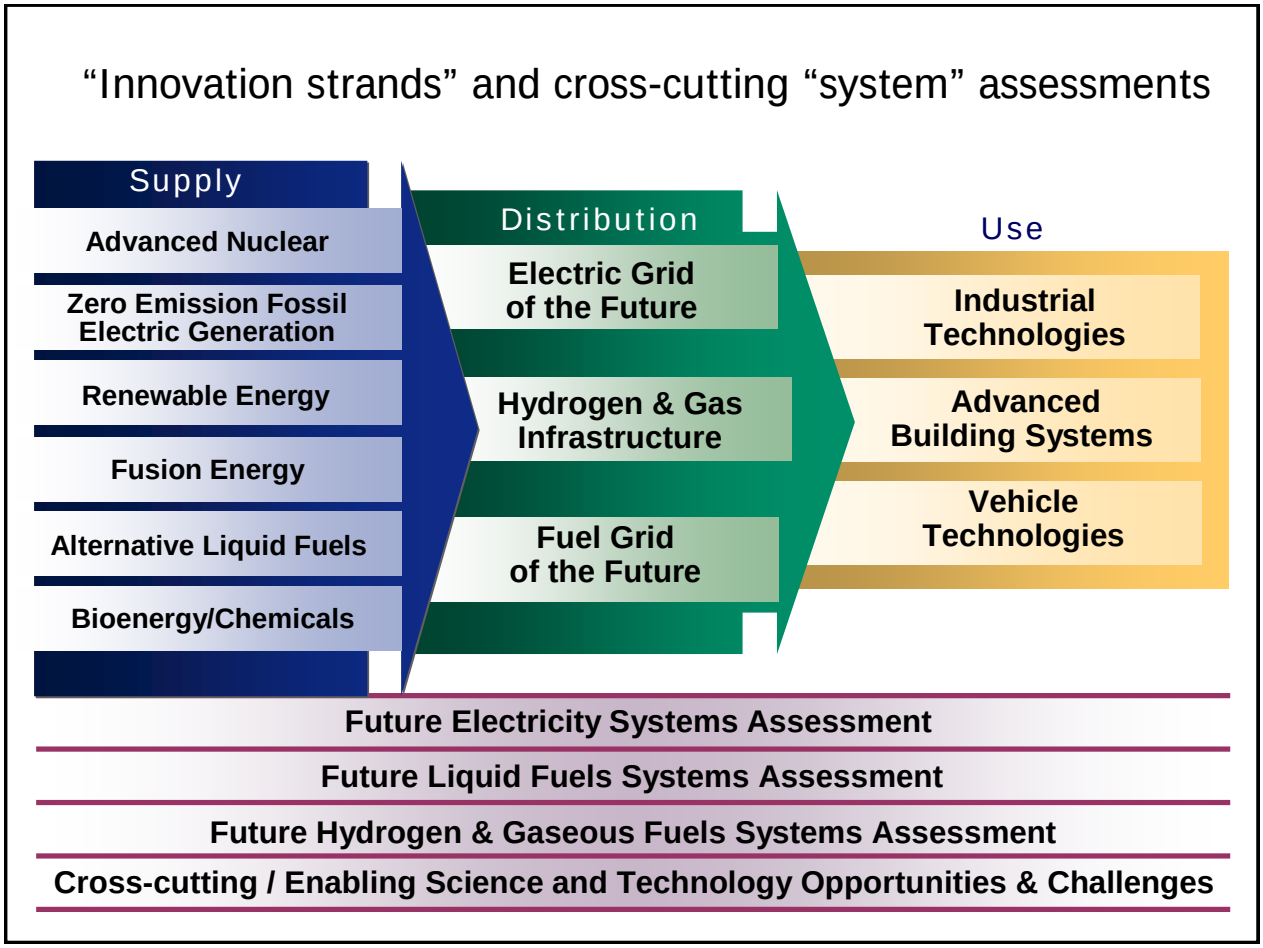
While there may never be a perfect process to ensure that the "right" scientific discoveries are made in "timely" manner to address obstacles in advancing particular technologies, better coordinated research efforts and improved communication across the S&T communities can help improve the speed and certainty that basic science will have an impact on applied research and development areas necessary to meet U.S. energy, environment, and national security challenges.

A Secure Energy Future

An important element in improving R&D integration efforts for energy is a common understanding by both the basic and applied programs of their potential contribution to the various components of the larger energy system. The 2006 S&T Portfolio Assessment process by the Laboratory Working Group highlighted aspects of this, acknowledging that mission impact requires translation from discovery to innovation to the market. Basic science creates entirely new technology possibilities. Likewise, technology efforts identify key issues requiring improved scientific understanding or new approaches. Improving technology performance, in turn, suggests new deployment opportunities. And market feedback helps set technology performance requirements.

The LWG also recognized the importance of looking at longer time horizons and basing Department R&D portfolio assessments, including assessments of R&D integration opportunities, on a common, consistent corporate view of the energy system. For the purpose of their assessment the LWG's view of the energy system consisted of energy technology sectors associated with energy supply, distribution, and use (the "innovation strands"), and the crosscutting systems, such as future electricity and liquid fuel systems and S&T opportunities that span those three innovations strands. An illustration of this energy system is provided in Figure 3.

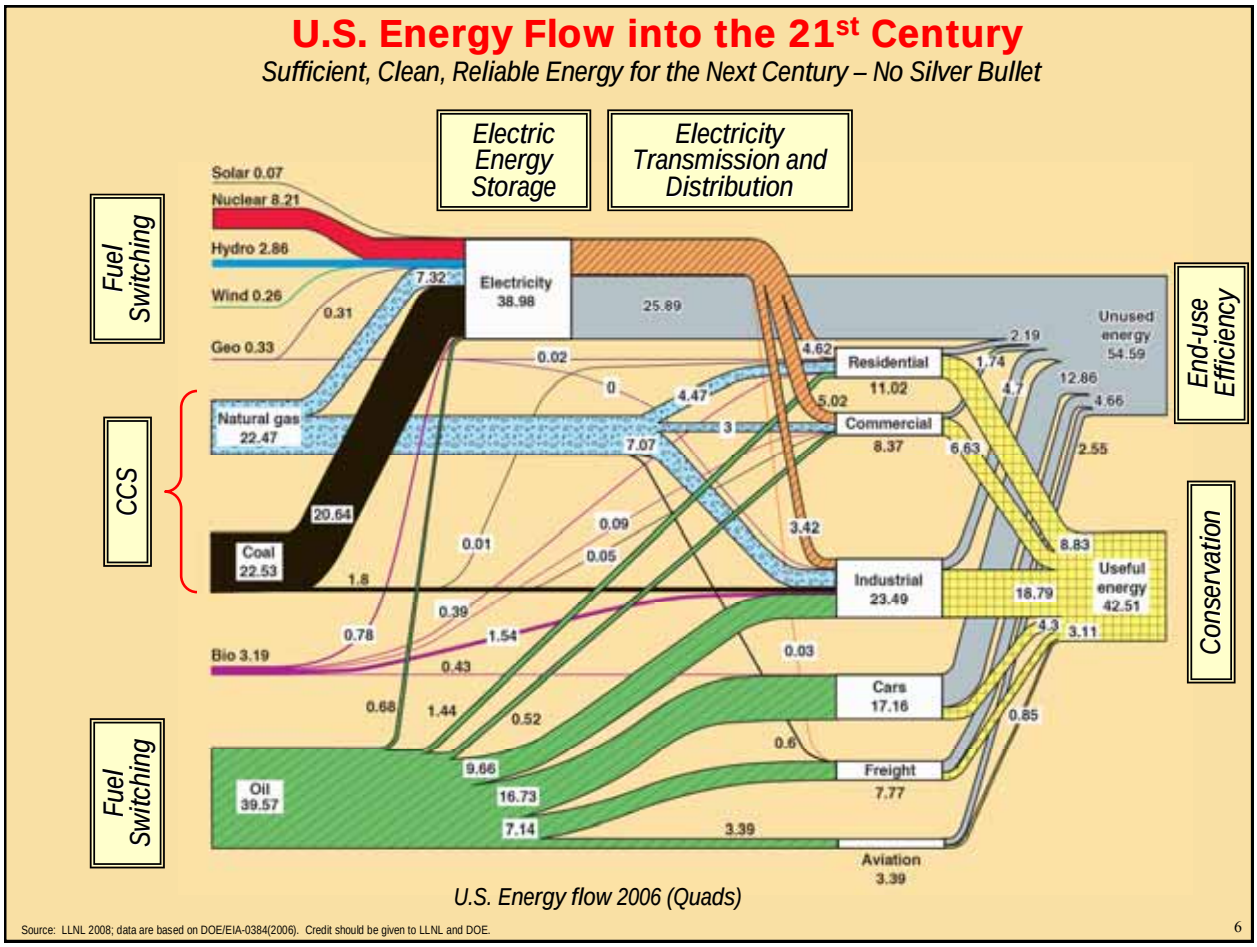
Figure 3. Energy system framework used by the 2006 Laboratory Working Group Portfolio Assessment



This energy system view gave the LWG a framework for their analysis which considered short-, medium-, and long-term time horizons and the technology gaps, and identified the basic research and technology areas and crosscutting discovery research areas that offer potential foundations for disruptive innovations in all of the "innovation strands" above.

Having a corporate view of the energy system, or framework, allows for better understanding of the systematic impacts and potential returns on R&D investments. This framework ultimately begins with an understanding current energy supply, distribution, and use in the United States. Figure 4 is one such framework that has been used for over 50 years and was developed by Lawrence Livermore National Laboratory in the 1950s. The 2006 U.S. energy flow in Figure 4 was developed with the most recent available data from DOE's Energy Information Administration. This diagram provides a single view of the country's energy system and relative contributions (shown by the line widths) of the different energy sources. The diagram also shows the connection between different energy sources, where the energy is consumed and where it is lost . These are some of the facts that can be concluded from the figure. Approximately 85% of the Nation's energy supply comes from fossil fuels. Less than 7% of the total energy supply comes from renewable sources. Approximately 40% of the total energy supply is used for the production of electricity and 30% is used for transportation. Over 96% of the energy for transportation in the U.S. comes from petroleum. And a remarkable amount of the energy put into the system, approximately 55%, is lost and goes unused.

Figure 4. Energy Flow in the United States in 2006 in Quads



Each energy source contributing to the total U.S. supply is tied in one way or another to the Nation's national and economic security, and the quality of our environment. The origin of the energy source directly affects the country's national security; generally, domestic sources provide greater security than foreign sources. The uncertainties of the energy source impact the source's affordability and thus the Nation's economic security. These uncertainties include everything from extreme weather events and infrastructure failures, to civil and international wars and terrorist attacks. Likewise, how the energy is produced and used directly affects the Nation's environmental quality. The U.S. has valuable natural resources such as coal, petroleum, and natural gas reserves, but exploiting those reserved may not come without some consequence to the environment.

Regardless of other factors such as policies, market drivers, and societal concerns, a comprehensive national energy strategy will need to address areas of energy supply (source), distribution, and use. On the supply end of the spectrum this means fuel switching. For the transportation sector, this includes biofuels, alternative liquid fuels, and electric substitution (e.g. electric vehicles). For the electricity sector means renewables, nuclear energy, natural gas, and coal. Diagrams on more detailed technology options created by the LWG assessments can be found in Appendix F. To increase energy supply without significantly increasing CO_2 emissions, carbon management

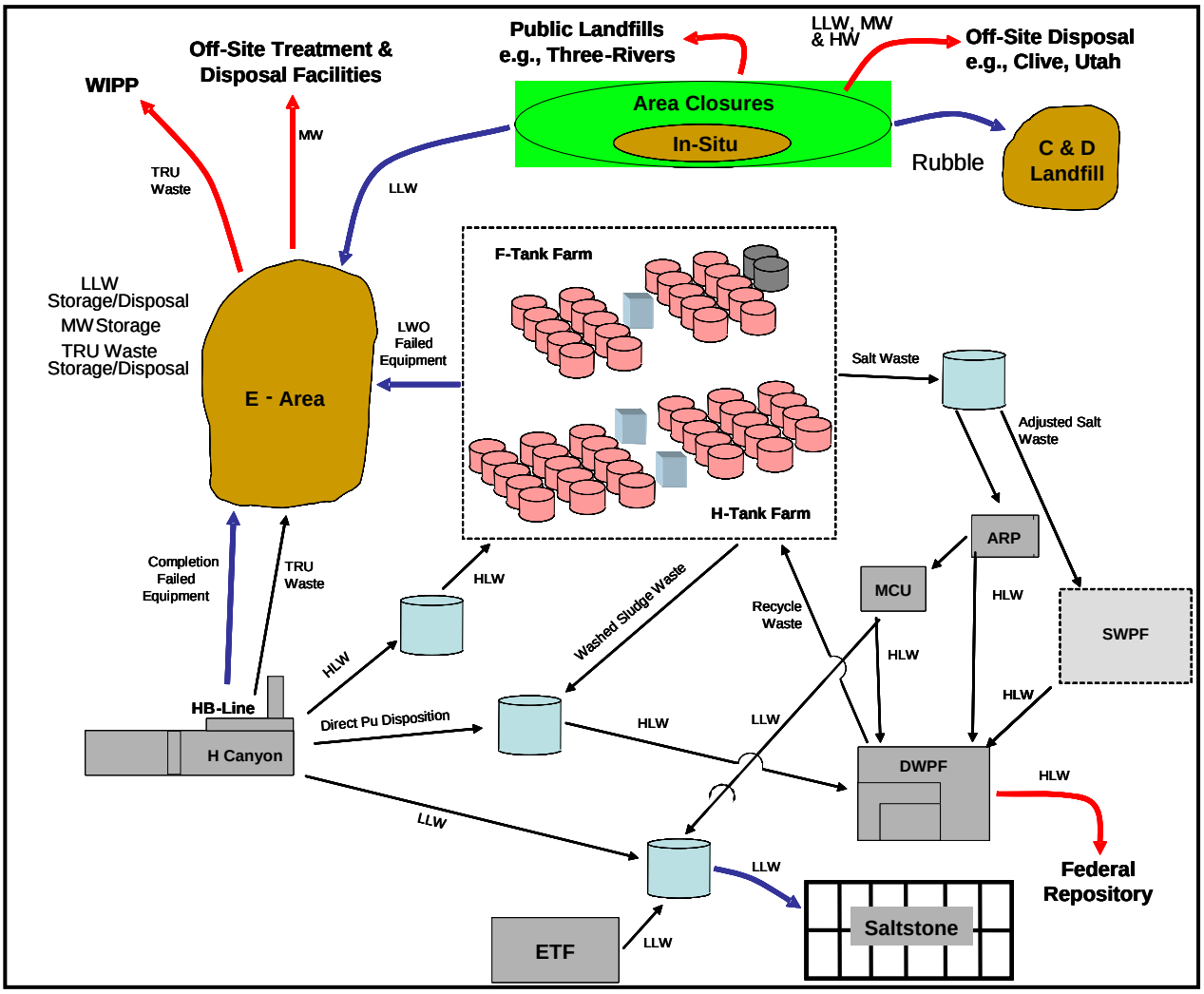
technologies would need to play a role. Given the significant loss of energy in the system, much can be gained by targeting electricity storage and distribution, and end-use efficiencies. Advanced electrical energy storage, power electronics, real-time electrical grid control can provide more efficient and reliable distribution. Likewise, more energy efficient appliances, such as solid-state lighting, reduce demand on the current energy supply.

Today's current energy technologies and infrastructure are rooted in 20th Century technologies and 19th Century discoveries, namely the internal combustion engine and incandescent lighting. These two technologies are largely responsible for driving the development of our current transportation system and electricity infrastructure. We know that current technologies cannot meet the energy challenges we now face. And incremental changes in current technologies will not suffice. Looking forward it is unlikely that there will be a silver bullet technology that will meet our energy needs in the way that the petroleum did in the past. That is why the Department's R&D portfolio is investing in basic science and applied research supporting multiple technology options in energy supply, distribution and storage, and end-use. The energy technologies of the 21st Century will be driven by a new era of science and technology, one rooted in our ability to direct and control matter down to the molecular, atomic, and quantum levels. A secure energy future for the Nation begins with a ***years-to-decades-to-centuries strategy***. And a central part of this strategy is ensuring that the transformational discoveries in basic science are translated into the revolutionary technologies the Nation needs.

Environmental Legacy and Stewardship

Cleaning up the nation's nuclear weapons complex remains one of the most technologically challenging and financially costly problems facing the Department. Safety, cost, and technological challenges have often delayed progress in retrieval, processing, and final disposition of high-level waste, spent nuclear fuel, and challenging materials. Some of the issues result from the difficulty and complexity of the technological issues; others have programmatic basis, such as strategies that may provide undue focus on near-term goals or difficulties in developing and maintaining stakeholder confidence in the proposed solutions. The complexity and interdependency of the environmental management challenges are illustrated in Figure 5, which can serve as a type of framework for EM's R&D portfolio needs. The different processes, systems, and requirements illustrated in Figure 5 can be categorized into three focus areas: Waste Processing, Groundwater and Soils, and Deactivation and Decommissioning. There are significant scientific and engineering needs by EM in each of these focus areas.

Figure 5. Environmental Management schematic for the Savannah River Site



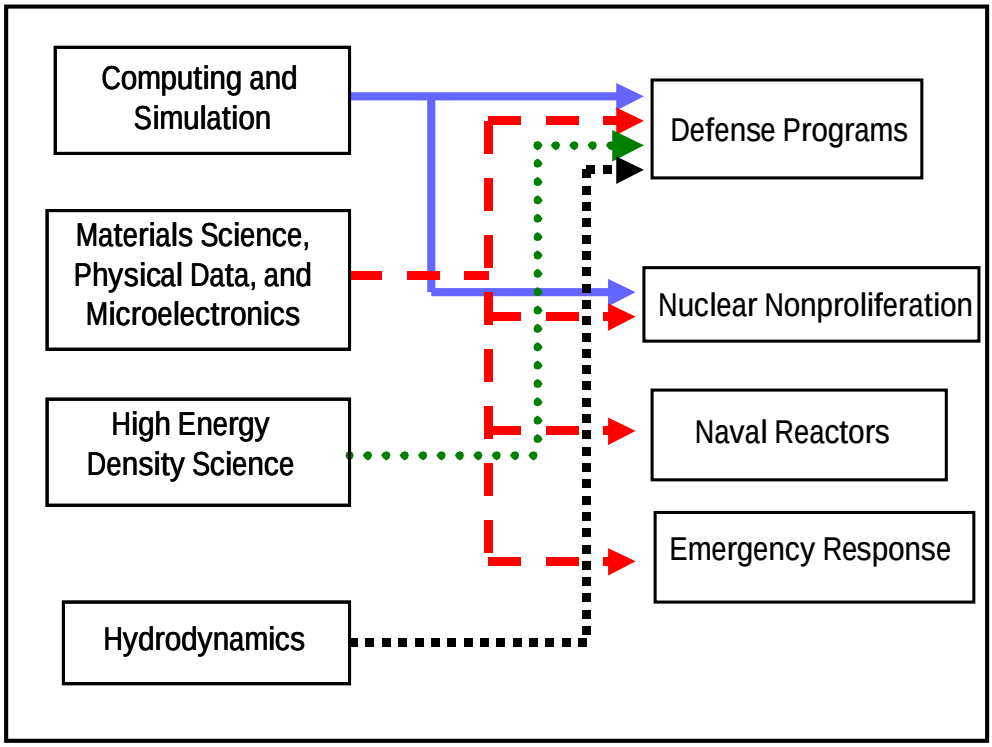
The Office of Environmental Management's (EM) Roadmap, *U.S. Department of Energy – Office of Environmental Management Engineering & Technology Roadmap* (Roadmap), defines the Department's intent to reduce the technical risk and uncertainty in its cleanup programs. The unique nature of many of the remaining facilities will require a strong and responsive engineering and technology program to improve worker and public safety, and reduce costs and environmental impacts while completing the cleanup program. The EM Roadmap is a springboard for the development and deployment of discoveries coming out of many basic science avenues such as the Office of Science and Laboratory Directed Research and Development. There are continued discussions between EM and the Office of Science in many areas. One area of emphasis in EM's science needs is in support of the cleanup efforts at the nuclear weapons sites. A recent publication, P. Bredt, *et al*., *Scientific Opportunities to Reduce Risk in Nuclear Process Science* (2008), endorses independent basic fundamental science research, addressing the full cleanup life-cycle, and identifies opportunities to help address these challenges by providing 1) scientific insight into the fundamental mechanisms involved in currently selected processing and disposal options, 2) a rational path to the

development of alternative technologies should the primary options fail, 3) confidence that models that predict long-term performance of different disposal options are based upon the best available science, and 4) fundamental science discovery that enables transformational solutions to revolutionize the current baseline processes.

Nuclear Stockpile Stewardship

The mission of the National Nuclear Security Administration (NNSA) is to strengthen national security through the military application of nuclear energy and by reducing the global threat from terrorism and weapons of mass destruction. A major goal of this effort is to transform the Nation's nuclear weapons stockpile and supporting infrastructure to be more responsive to the threats of the 21st Century. Figure 6 illustrates four of the NNSA's mission focus areas and the scientific pillars that underpin NNSA's ability to meet its mission goals.

Figure 6. Four scientific pillars underpinning NNSA mission focus areas



Four scientific pillars illustrated in Figure 6 underpin NNSA's ability to perform its missions: High-performance computing and simulation; materials science, physical data, and microelectronics; high-energy-density science; and hydrodynamic testing. Together, these scientific pillars form the basis for the development of predictive capabilities. Improved fundamental models of materials behavior and other physical data, as well as revolutionary advances in computer architecture and simulation capabilities over the past decade have enabled the development of these predictive capabilities.

The NNSA's Defense Programs is focused on keeping the U.S. nuclear weapons safe, secure, and reliable in the absence of underground nuclear testing. NNSA uses and oversees a wide-range of breakthrough science experiments, engineering audits and high-tech computer simulations, including

extensive laboratory and flight tests of warhead components and subsystems, to keep the existing warheads reliable, secure and safe. The Programs' activities also focus on transforming and revitalizing the entire nuclear weapons complex to be smaller, safer, more secure and more efficient. NNSA must be better able to quickly respond to technical problems in the stockpile and be able to rapidly respond to unforeseen national security needs. NNSA's broad-based and comprehensive set of science, technology, and engineering (ST&E) capabilities ensure confidence in its annual stockpile assessment and certification. Without integrated predictive capabilities, unacceptable uncertainty in warhead performance would drive a need for underground nuclear tests to ensure stockpile reliability.

NNSA's Nuclear Nonproliferation goal is to detect, prevent, and reverse the proliferation of weapons of mass destruction (WMD). The NNSA provides policy and technical leadership to limit or prevent the spread of materials, technology, and expertise relating to weapons of mass destruction; advance the technologies to detect the proliferation of weapons of mass destruction worldwide; and eliminate or secure inventories of surplus materials and infrastructure usable for nuclear weapons – in short, to detect, secure, or dispose of dangerous nuclear material. Two key scientific areas that underpin the NNSA's ability to accomplish this are highlighted in Figure 6.

The focus of the NNSA's Naval Reactors program is to provide the United States Navy with safe, military effective nuclear propulsion plants and ensure their continued safe and reliable operation. The program is responsible for all naval nuclear propulsion work, beginning with reactor technology development, continuing through reactor operation, and ending with reactor plant disposal. The Emergency Response program provides the capabilities to respond to and mitigate nuclear and radiological incidents worldwide as the U.S. government's primary capability for radiological and nuclear emergency response. Basic and applied research in materials science, physical data, and microelectronics are essential for meeting these responsibilities.

Future R&D portfolio assessments and other efforts by the Department to identify and address research gaps and opportunities for better basic-applied R&D coordination and collaborations will benefit from being done within the context of consistent frameworks describing the system, whether it be for energy, environmental legacy waste management, or stockpile stewardship. Such frameworks that are independent of policy factors, market drivers, and particular societal interests will enable processes that are science and innovation driven and the promote consistency needed to effectively manage research portfolios over time frames needed to see impacts.

7. CONCLUSIONS

As with other large R&D organizations, DOE faces the challenge of translating new concepts that arise out of basic research to the conceptual stage and targeted R&D. The Department and its S&T communities recognize that advances in basic sciences create entirely new technology possibilities. Likewise, technology efforts identify key issues requiring improved scientific understanding or new approaches. Central to bridging R&D gaps between the basic and applied research communities is leadership by the Department's senior management and program managers in improving communication and coordination between DOE programs in headquarters, and, through these coordination efforts, provide opportunities for the basic and applied scientists and engineers in the field to collaborate and build integrated R&D efforts that target DOE mission needs.

Since its inception, the Department of Energy has engaged in efforts to coordinate its basic and applied R&D programs and some of the processes carried out in recent years were described above. Through these processes many S&T opportunities have been identified that, if pursued, have the potential to accelerate mission goals for energy and national security, and environmental stewardship. Tables I, II, and III above highlight many of these S&T opportunities and identify the corresponding basic and applied programs that would pursue those collaborative efforts. Some of these opportunities build on current efforts, while others such as those listed in Table III were previously unidentified opportunities for mutual collaboration. Six of these areas were proposed for initiation in the FY 2009 budget request, and the planning for three additional areas in FY 2010 is currently underway.

There were also many lessons-learned by the Department regarding what is required to promote successful coordination and collaboration efforts. Namely:

- Ongoing communication and collaboration between the basic and applied programs is essential through both structured dialogue and informal interactions between program managers.
- Strong support by senior management and bottoms-up approaches led by program managers, with engagement of the scientific community, provide greater potential for successful implementation.
- R&D coordination is one of many factors in program planning and the management of research portfolios that impact mission goals. Preserving the distinct mission focus of individual programs while exploring areas of connectivity and mutual benefit is an important goal in coordination efforts.
- Communication to stakeholders such as OMB and Congress is necessary for supporting sustained efforts to implement new R&D coordination areas.

Looking to the future, much can be harvested from this recent work both in terms of implementing S&T opportunities identified and establishing alternative mechanisms that replace or are complementary to current practices. The technical workshops, for example, presented a broad range of S&T opportunities that are still ripe for pursing. Table IV lists the technical workshops conducted over the past six years and maps the research priorities and opportunities resulting from those workshops to where they impact elements of an energy system, and the EM and NNSA mission focus areas discussed in the previous section.

Table IV. Technical workshops and where the opportunities identified can impact DOE mission elements

Office of Science Workshops	Research Strategy for Energy Security					Environmental Management			National Security			
	Energy Efficiency	Fuel Switching	Carbon Management	Energy Storage	Distribution & Delivery	Waste Processing	Groundwater & Soil Remediation	Deactivation & Decommissioning	Defense Programs	Non-Proliferation	Nuclear Reactors	Emergency Response
Basic Research Needs to Assure a Secure Energy Future October 2002)	X	X		X	X							
Basic Research Needs for the Hydrogen Economy (May 2003)		X		X								
Basic Research Needs for Solar Energy Utilization (April 2005)		X		X								
Basic Research Needs for Superconductivity (May 2006)	X				X				X			
Basic Research Needs for Solid-state Lighting (May 2006)	X											
Basic Research Needs for Advanced Nuclear Energy Systems (July 2006)		X				X			X	X	X	
Basic Research Needs for the Clean and Efficient Combustion of 21st Century Transportation Fuels (October 2006)	X	X										
Basic Research Needs for Geosciences (February 2007)		X	X				X					
Basic Research Needs for Electrical Energy Storage (April 2007)	X			X								
Basic Research Needs for Materials Under Extreme Environments (June 2007)	X	X	X	X	X	X	X	X	X	X	X	
Basic Research Needs: Catalysis for Energy (August 2007)	X	X		X								
Nanoscience Research for Energy Needs (March 2004)	X	X	X	X	X	X	X		X			
Advanced Computational Materials Science: Application to Fusion and Generation IV Fission Reactors (March 2004)		X									X	
The Path to Sustainable Nuclear Energy: Basic and Applied Research Opportunities for Advanced Fuel Cycles (September 2005)		X				X			X	X	X	

Office of Science Workshops	Research Strategy for Energy Security					Environmental Management			National Security			
	Energy Efficiency	Fuel Switching	Carbon Management	Energy Storage	Distribution & Delivery	Waste Processing	Groundwater & Soil Remediation	Deactivation & Decommissioning	Defense Programs	Non-Proliferation	Nuclear Reactors	Emergency Response
Workshop on Simulation and Modeling for Advanced Nuclear Energy Systems (August 2006)		X				X	X	X	X	X	X	
Nuclear Physics and Related Computational Science R&D for Advanced Fuel Cycles Workshop (August 2006)		X				X	X		X	X	X	
Biomass to Biofuels: Breaking the Biological Barriers to Cellulosic Ethanol [and other biofuels] Workshop (December 2005)		X	X									
Mathematical Research Challenges in Optimization of Complex Systems Workshop (December 2006)	X	X	X	X	X		X		X			
Computational Subsurface Sciences Workshop (January 2007)			X				X					
Computational Research Needs in Alternative and Renewable Energy (September 2007)	X	X		X								
Cyber Security Research Needs for Open Science (July 2007)					X	X			X			
Workshop on Research Needs for Wind Energy Characterization (January 2008)		X										
Workshop on the Nations Need for Isotopes: Present and Future (August 2008)		X				X	X	X	X			
Opportunities for High Energy Density Laboratory Plasma Science (May 2007)		X							X			

Several possible alternative and complementary mechanisms for enhanced basic-applied R&D coordination that would serve to build on lessons learn and address current challenges were described above. These proposed mechanisms are centered on accomplishing the following:

- Improve communication within DOE and learn from past experiences
- Serve as a catalyst for communication between the basic and applied S&T communities
- Established structured processes for sustained coordination planning
- Align coordination efforts with the annual budget process
- Develop tools to measure progress and success

Improving basic-applied R&D program coordination within the Department and research integration within the S&T communities is integral to the Department efforts to improve the effectiveness its R&D portfolio in meeting U.S. energy challenges, and environmental stewardship and national security responsibilities. Taken in sum, recent coordination efforts have been widespread and have contributed greatly to DOE's capabilities and impact on mission goals. While these efforts have identified many new opportunities, helped establish good working relationships between program managers, and allowed for the initiation of a few new key research areas, the Department could benefit from more deliberate, sustained, and appropriately resourced planning processes and structured communication efforts with its stakeholders. This becomes increasingly important as the Department develops new strategies for meeting the current and future challenges we now face.

8. APPENDICES

Appendix A. References

DOE Technical Workshop Reports:
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Basic Research Needs for the Hydrogen Economy, May 2003, http://www.sc.doe.gov/bes/reports/files/NHE_rpt.pdf
Nanoscience Research for Energy Needs, March 2004, http://www.sc.doe.gov/bes/reports/files/NREN_rpt.pdf
Workshop on Advanced Computational Materials Science: Application to Fusion and Generation IV Fission Reactors, March 2004, http://www.sc.doe.gov/bes/reports/files/ACMS_rpt.pdf
Basic Research Needs for Solar Energy Utilization, April 2005, http://www.sc.doe.gov/bes/reports/files/SEU_rpt.pdf
The Path to Sustainable Nuclear Energy, September 2005, http://www.sc.doe.gov/bes/reports/files/PSNE_rpt.pdf
Biomass to Biofuels: Breaking the Biological Barriers to Cellulosic Ethanol, December 2005, http://genomicsgtl.energy.gov/biofuels/b2bworkshop.shtml
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Basic Research Needs for Advanced Nuclear Energy Systems, July 2006, http://www.sc.doe.gov/bes/reports/files/ANES_rpt.pdf
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Basic Research Needs for Electrical Energy Storage, April 2007, http://www.sc.doe.gov/bes/reports/files/EES_rpt.pdf
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Basic Research Needs: Catalysis for Energy, August 2007, http://www.sc.doe.gov/bes/reports/files/CAT_rpt.pdf

Computational Research Needs for Alternative and Renewable Energy, September 2007, http://www.sc.doe.gov/ascr/WorkshopsConferences/CRNARE.htmlAppendix D

Additional References:

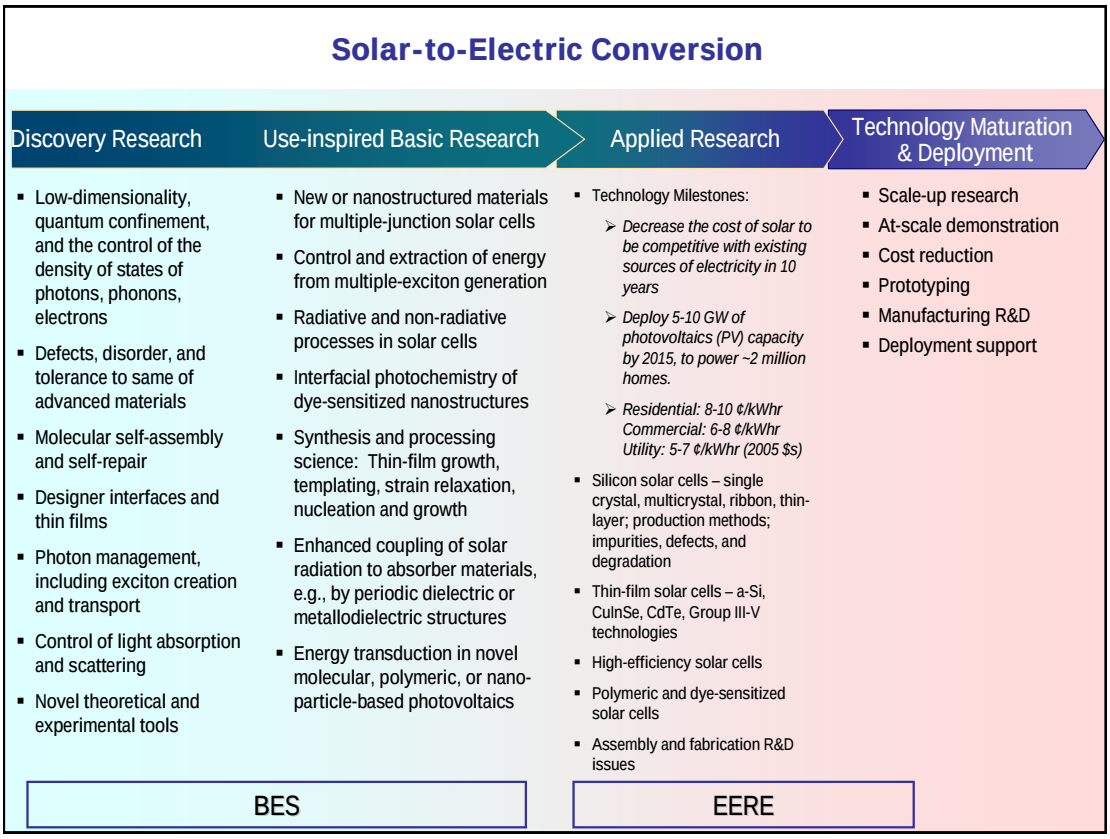
P. Bredt, A. R. Felmy, P. A. Gauglitz, D. Hobbs, S. Krahn, N. Machara, M. McIlwain, B. A. Moyer, A. P. Poloski, K. Subramanian, J. D. Vienna, B. Wilmarth, *Scientific Opportunities to Reduce Risk in Nuclear Process Science*, Pacific Northwest National Laboratory Report 17699, July 2008.

Report of the Interagency Task Force on High Energy Physics, August 2007, National Science and Technology Council Committee on Science Interagency Working Group on the Physics of the Universe.

Appendix B. Four-Column Charts from the "Basic Research Needs" Workshops

One way to describe the focus of the Department's basic research programs compared to those of the applied technology programs is illustrated the four column charts representing the continuum of research, development, development and deployment. These particular examples below are from the Office of Science's Office of Basic Energy Sciences "Basic Research Needs" workshop reports, but similar illustrations could be developed for research areas in all of the Office of Science programs. The first of two columns on the left is Discovery Research described as basic research for fundamental new understanding on materials or systems that may revolutionize or transform today's technologies for energy, environment, and national security. Use-inspired basic research focuses on fundamental new understanding, usually with a goal of addressing showstoppers on real-world applications in the energy or environmental technologies. The Grand Challenges study by the Basic Energy Sciences Advisory Committee described the basic research areas aimed at addressing fundamental limitations of current theories and descriptions of matter in the energy range important to everyday life—typically energies up to those required to break chemical bonds. Grand Challenges research would fall in a far left column, as illustrated in Figure 1 of this paper.

The two right-hand columns describe the research, development, and deployment activities undertaken by the Departments applied technology programs, in some cases in partnership with industry. Applied research can be generally described as research with the goal of meeting technical milestones with and emphasis on the development, performance, cost reduction, and durability of materials and components or on efficient processes. It also includes research on proof of technology concepts. Technology maturation and deployment efforts include scale-up research, at-scale demonstration, cost-reduction strategies, prototyping, manufacturing R&D, and deployment support.



Solar-to-Fuels Conversion

Discovery Research	Use-inspired Basic Research	Applied Research	Technology Maturation & Deployment
▪ Charge transfer and separation in natural and bio-inspired photosynthetic systems ▪ Nano-architectures for coupling light-harvesting and catalytic functions ▪ Self-organization and controlled-assembly of complex structures ▪ Robust, functional catalysts that mimic biological processes ▪ Ultrafast imaging of electron dynamics ▪ Multi-scale theoretical and computational approaches	▪ Novel photoelectrode materials and molecular configurations for efficient photoelectrolysis ▪ Biomimetic multi-electron catalysts and proton-coupled electron transfer for solar water splitting ▪ Photocatalytic cycles for CO_2 reduction to alcohol fuels ▪ Multi-scale control of reactivity in hybrid molecular materials ▪ Defect formation mechanisms and self-repair in solar-to-fuels pathways ▪ Hierarchical organization of molecular constructs for artificial photosynthesis	▪ Technology Milestones: ➢ *2010 to 2012: Laboratory-scale demonstration of solar driven high-temperature thermochemical hydrogen production that projects to a cost $6.00/gge (ultimate target: $7.00/gge delivered)* ➢ *2015 to 2018: Laboratory-scale photo-electrochemical water splitting system to produce hydrogen at a 10% solar-to-hydrogen efficiency. Laboratory-scale photobiological water splitting system to produce hydrogen with 5% efficiency.* ▪ Accelerate and expand research on the low-cost solar production of hydrogen: ▪ Component development and systems integration to enable electrolyzers to operate from inherently intermittent and variable-quality power derived from solar sources ▪ Solar-driven high-temperature chemical cycle water splitting ▪ Photoelectrochemical systems ▪ Thermochemical conversion of biomass ▪ Photolytic and fermentative microorganism systems	▪ Scale-up research ▪ At-scale demonstration ▪ Cost reduction ▪ Prototyping ▪ Manufacturing R&D ▪ Deployment support
BES		EERE	

Superconductivity

Discovery Research	Use-inspired Basic Research	Applied Research	Technology Maturation & Deployment
▪ Complete determination of interaction functions generating HTS ▪ Predictive understanding of strongly correlated superconductivity ▪ Room-temperature superconductor ▪ Nano/meso-scale superconductivity ▪ Vortex matter ▪ Materials by design ▪ Manipulation of structure and properties on the atomic scale ▪ Tuning competing interactions	▪ 100K isotropic SC ▪ 3-d quantitative determination of defects and interfaces ▪ Intrinsic and intentional inhomogeneity ▪ "Pinscape engineering" in-situ manipulation of pinning centers ▪ Achieve theoretical limits of critical current ▪ Next generation SC wires	▪ Technology Milestones: ➢ *2G coated conductor carrying 300 A x 100 m (2006)* ➢ *In-field performance for 50 K operating temperature* ➢ *Electric power equipment with ½ the energy losses and ½ the size* ➢ *Wire with 100x power capacity of same size copper wires at $10/kiloamp-meter* ▪ Assembly and utilization R&D issues ▪ Materials compatibility and joining issues	▪ Scale-up research ▪ At-scale demonstration ▪ Cost reduction ▪ Prototyping ▪ Manufacturing R&D ▪ Deployment support
Office of Science BES		Technology Offices EDER	

Solid State Lighting

Discovery Research	Use-inspired Basic Research	Applied Research	Technology Maturation & Deployment
▪ Rational design of SSL lighting structures ▪ Control of radiative & non-radiative processes in light-emitting materials ▪ New functionalities through heterogeneous nanostructures ▪ Innovative photon management ▪ Enhanced light-matter interactions ▪ Precision nanoscale characterization, synthesis, and assembly ▪ Multi-scale modeling – quantum excitations to light extraction	▪ Unconventional light-emitting semiconductors ▪ Photon conversion materials ▪ Polar materials and heterostructures for SSL ▪ Luminescence efficiency of InGaN ▪ Managing and exploiting disorder in OLEDs ▪ Understanding degradation in OLEDs ▪ Integrated approach to OLED fundamentals	Technology Milestones: By 2025, develop advanced solid state lighting technologies with a product system efficiency of 50 percent with lighting that accurately reproduces sunlight spectrum. ▪ Materials and components for inorganic and organic light-emitting diodes research for improved efficiency and cost reduction ▪ Strategies for improved device light extraction ▪ Low-cost fabrication and patterning techniques and tools & manufacturing R&D ▪ Product degradation and reliability issues	▪ Developing national standards and rating systems for new products ▪ Commercial adoption and support ▪ Industrial partnership ▪ Legal, health, market, and safety issues ▪ Cost reduction ▪ Prototyping

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Advanced Nuclear Energy Systems

Discovery Research	Use-inspired Basic Research	Applied Research	Technology Maturation & Deployment
▪ Accurate relativistic electronic structure approaches for correlated f-electron systems ▪ Integration of multi-physics, multi-scale computational models: atomistic to continuum ▪ Reactivity, dynamics, molecular speciation and kinetic mechanisms at interfaces ▪ Utilize microstructure control to impart radiation resistance to structural materials for ANES ▪ Innovative experimental methods for dynamic, *in situ* measurements of fundamental properties	▪ Predict microstructural and chemical evolution in actinide fuel, cladding and structural materials during irradiation ▪ Identify self-protective interfacial reaction mechanisms capable of providing universal stability in extreme environments ▪ Improve understanding of coordination geometry, covalency, oxidation state, and cooperative effects of actinides to devise next generation separation methods. ▪ Predict the behavior of waste forms over millennia	▪ Rational design and development of reactor fuels ▪ Verified and validated modules for reactor-level multi-scale simulations ▪ Develop 3D fuel performance code ▪ Laboratory-scale sample fabrication and characterization with relevant post-irradiation examination of samples ▪ Demonstrate new separation systems at bench scale ▪ Demonstrate at-scale waste- form performance in deep geologic laboratory	▪ Demonstrate the scaling to production-scale by process prototyping ▪ Develop and validate fuel licensing code for design and safety basis ▪ Fabricate and characterize lead test assemblies (LTAs) ▪ Irradiate lead test assemblies in prototypic environment ▪ Couple waste-form performance to design and performance of a repository.

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Combustion Science for 21st Century Fuels and Engines

Discovery Research	Use-inspired Basic Research	Applied Research	Technology Maturation & Deployment
• Reaction chemistry of large molecules at high pressure • Heterogeneous combustion and soot chemistry • Turbulent reacting flows with a large range of chemical time scales • Liquid fuel spray chemistry and dynamics • Multi-scale modeling: from quantum to continuum scales • High-fidelity computational approaches (DNS, LES) • 4-D diagnostics at high pressure and under multi-phase conditions	• Automatic generation & reduction of chemical kinetics models of 21st Century Fuels • Soot formation, composition, morphology, oxidation and atmospheric evolution • High-fidelity CFD for complex and deformable engine geometries • Elucidating combustion dynamics for control strategies • Uncertainty quantification in multi-scale modeling • Development of novel diagnostics for molecular characterization at high pressure • Data and simulation framework built upon collaboratory and cyber-infrastructure tools • Modeling of turbulent sprays and turbulent multi-mode combustion	• High-fidelity CFD for device scale research: Virtual Engine Simulators (VES) • Application of VES to engine design, optimization, and real-time control • High-resolution optical diagnostics for device scale research • Device scale research on the impact of alternative fuel properties on novel combustion and emission processes • Exploration of high pressure engine combustion • Joint optimization of alternative fuel formulation and engine design • Smart vehicle strategies and sensor development	• New generation of vehicles with alternative fuels: achieving high efficiencies with emission compliance • Enable realization of next-generation efficiency and emissions standards • Smart vehicles with VES-based control systems

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Applied Energy Offices
EERE

Electrical Energy Storage

Discovery Research	Use-inspired Basic Research	Applied Research	Technology Maturation & Deployment
▪ Understand and predict interfacial charge transfer and multi-body effects ▪ Predict and control dynamics of phase transitions ▪ Control of chemistry and its dynamics at electrified interfaces ▪ Determine consequences of dimensionality ▪ Physicochemical consequences of nano-dimensions ▪ Fundamentals of solvation dynamics and ionic transport ▪ Revolutionary tools for *in situ* structural and dynamic studies over broad spatial / temporal regimes	▪ Retrosynthetic approaches to high performance new materials ▪ Design of new materials capable of multi-electron storage per redox center ▪ Understand design criteria for electrolytes that enable higher voltages ▪ Tailor nanoscale electrode architectures for optimal transport ▪ Novel chemistries for scavenging impurities and self-healing ▪ Generation of knowledge and computational and experimental tools to predict properties, performance evolution, and lifetime of materials	• Develop and apply material models and computational tools for component and system design and diagnostics • Identify, develop, evaluate materials, electrodes, cells, and advanced electrochemical systems • Develop and apply novel material processing technologies • Design and develop device and system architectures • Assemble/test devices with respect to energy storage system requirements—high power, high energy density, long lifetime, rapid recharge, deep discharge, reliability, safety, low cost.	▪ Demonstrate energy storage systems in advanced vehicle applications. ▪ Support the establishment of domestic manufacturing capabilities for components and systems ▪ Assist development and deployment of high capacity storage systems for centralized and distributed power sources ▪ Develop long-life, low cost, reliable, environmentally friendly, recyclable energy storage for portable and stationary energy storage

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BES

Technology Offices
EERE and OE

Materials Under Extreme Environments

Discovery Research

- Dynamics of excitation and relaxation under extreme flux
- Fundamental limits of dielectric performance
- Bond-energy-charge relationships over relevant conditions
- Complex chemistry and physics of degradation
- Multi-dimensional in-situ characterization tools
- Extreme environments as probes of materials behavior
- Self assembled multi-paradigm algorithms for understanding materials performance
- Atomic level understanding of dynamic behavior
- Fundamental knowledge of non-equilibrium systems
- Novel states of matter in extreme magnetic fields
- Design and synthesis of transformational materials

Use-inspired Basic Research

- Achieving stable, non-reacting surfaces
- Exploit kinetically states far from equilibrium
- Mitigating materials degradation under extreme conditions
- Simulating and measuring dynamics at the same length and time scales
- Understanding dynamic behavior across interfaces
- Enabling a new generation of non-traditional materials for extreme environments
- Development of highly robust materials for extreme environments
- Harnessing extreme conditions to create new materials with revolutionary functionality

Applied Research

- Application of models and computational tools for system design and diagnostics for energy technologies requiring high strength and temperature
- Material evaluation and process development for radiation resistant materials for use in solar thermal, defense, nuclear reactors, and waste storage
- Improve long-term stability under extreme temperature, cyclic loads, pressure, chemical reactivity and electromagnetic field for energy generation and use
- Develop and apply novel materials processes and manufacturing technologies
- Proof of technology concepts with improved performance and reduced cost for use in extreme conditions

Technology Maturation & Deployment

- Demonstrate energy production and utilization systems operating at high efficiency
- Support the establishment of domestic manufacturing capabilities for highly robust components and systems
- Development and deployment of reliable, high-capacity distribution and storage systems for centralized and distributed power sources
- Develop long-life, low-cost reliable, environmentally friendly recyclable processes for energy applications
- Computer validation of multifunctional materials performance for applications in extreme environments

Catalysis for Energy Applications

Discovery Research

- Understand mechan-isms and dynamics of catalyzed reactions at the molecular level
- Understand and describe kinetics of complex reaction networks in multiphase systems
- Synthesize uniform catalytically active sites
- Develop instrumenta-tion with enhanced spatial, temporal, & energy resolution for studies of functioning catalysts
- Develop theoretical and computational methods for complex catalytic systems

Use-inspired Basic Research

- Design catalysts for biomass deconstruction and conversion to targeted fuels
- Discover catalysts for selective removal of heteroatoms from fossil and biomass feedstocks
- Discover catalysts for CO_2 reduction and for H_2O splitting using solar and electrical energy
- Discover catalysts for selective synthesis complex molecules
- Synthesize catalysts with multiple active sites to mimic nature

Applied Research

- Develop catalytic systems that exploit nonequilibrium conditions for fuel production
- Demonstrate viability of catalytic systems for converting CO_2 to fuels
- Develop advanced catalytic systems for hydrogen management to use in selective heteroatom removal from fossil and biomass feedstocks

Technology Maturation & Deployment

- Improve overall efficiency & robustness for economically viable energy conversions
- Implement technology for production of hydrocarbons from biomass, coal, and heavy crude oils
- Implement carbon-neutral energy conversion systems
- Implement scalable systems to harness solar energy for conversion of CO_2 to fuels
- Use sustainable domestic sources of fuel with minimal environmental impact

Appendix C. Priority Areas for Research Integration Identified in 2006 DOE Program Reviews from the report *DOE Strategic Research Portfolio Analysis and Coordination Plan*

HIGHLY CROSSCUTTING

1) Radiation-Resistant Materials

Implications: There is a significant opportunity to respond to multiple departmental (and national) mission challenges by capitalizing on the advances in materials science to understand and design materials for the challenging, extreme conditions of radiation environments. The DOE has multiple challenges from the standpoint of stockpile stewardship; challenges for design and safety assurance of next generation and advanced reactor concepts (including fuel cycle issues); challenges in waste storage, treatment and containment issues for materials; and even DOE's basic research programs are challenged in the design and operation of many facilities, including, perhaps, the ultimate challenge of designing a fusion power facility that can withstand the intense radiation fluxes, temperatures and pressures of a sustained burning plasma. Outside the Department, NASA, DOD, and others are faced with no less a daunting challenge. Significant advances in materials science, computational science, and other related disciplines provide the launching point for a broad-based national program that can respond to these mission challenges with collective focus and effort. Such a program will not only help reduce uncertainties in predicting long-term performance, but will undoubtedly deliver new classes of materials with greatly improved performance for those many applications where needed.

Promising focus areas: Current processes of "cook and look" with regard to materials synthesis and processing need to give rise to more predictive understanding of materials properties under extreme conditions and many research opportunities are now possible with improved materials science, computational algorithms, and 200 Teraflops sustained computational speeds that are now achievable. There is opportunity to develop quantum calculations for bond strength in real time, and building simulations from atomic scale effects to the bulk properties of materials under extreme radiation and other conditions. There is interest in low atomic weight materials, silicon carbides, and more generally, in inherently radiation-temperature-chemically resistant materials.

2) Energy Storage

Implications: Energy storage for a wide range of power levels and mission duty cycles is needed.
Large scale electricity storage will benefit the grid in cost effective applications by making it more reliable, reduce system transmission congestion, help manage peak loads and shift from expensive peaking to more efficient base-load generation, and make many renewable electricity sources more viable. At the mid-scale, there are significant implications for hybrid and plug-in electric vehicles, as well as innovative concepts for an integrated vehicle-based battery grid storage system. Advanced battery technology developed for hybrid and plug-in vehicles will likely benefit hydrogen fuel cell vehicles as well. Widespread commercialization of hydrogen-powered vehicles will support our national security interests by reducing and ultimately eliminating our reliance on foreign oil. On-board vehicle hydrogen storage is one of the critical barriers to the viability of hydrogen-powered vehicles. At the small to micro scale, independent power supplies for electronics and sensors are needed. Other forms of energy storage are also important, including potential forms of concentrated solar-thermal storage and hydrogen storage.

Promising focus areas: Opportunities for fundamentally new materials and integrated designs to achieve high cycle life, high energy capacity storage materials. In particular, there are now opportunities to create designer materials at the molecular level that would usher in a new class of high-cycle, high-density electric batteries that could revolutionize the transportation sector and the grid. Miniature, high density power supplies for personnel would support some of the DOE's safeguards and security needs.

3) Advanced Mathematics for Optimization of Complex Systems, Control Theory, and Risk Assessment

Implications: DOE's large scale computation efforts have historically focused on the techniques required for solving partial differential equations in areas such as fluid dynamics, material characterization and magneto hydrodynamics. But the math required for combining these and other models into complex systems, and for control theory and risk assessment are fundamentally different than what DOE has historically pursued and further development would benefit DOE in many of its other complex systems challenges. Examples include: the control and stability of the electric power grid, optimization of combustion systems and industrial processes, and full lifecycle optimization of nuclear fuel cycles with recycling. In support of the many integration efforts defined below that are dependent on advanced computation and simulation, this particular area of cooperation is foundational for those others and will help to advance progress on those many mission-related fronts.

Promising focus areas: Opportunities for breakthroughs in the behavior and mathematics of complex systems and multi-scale analysis. These breakthroughs would enable fundamentally new computational methods for modeling such systems. These complex systems that would be modeled include the national electricity grid, nuclear fuel cycle, fusion burning plasmas, carbon sequestration and methane hydrate risk analysis, and smart sensors.

4) Building Synergies With Work-for-Others, Laboratory Directed Research and Development (LDRD), and DOE University-Sponsored Research

Implications: There is considerable investment at our national laboratories by non-DOE entities, such as other agencies. There is also significant investment of discretionary money by the operators of the national laboratories, and the DOE invests significant resources in universities in support of its mission-related research. Recently, the Department has taken steps to improve it view of the DOE sponsored work at its laboratories in context of the labs operating as a system. An important next step in the progression is to expand this systems-oriented perspective to other work underway at the labs and to the DOE's other sponsored research providers, that is, the nation's universities, to explore the linkages and opportunities for collaborations and broader synergies among the various interests and players.

Promising focus areas: An inventory and portfolio analysis of all related work within a context of integrated core competencies and from the standpoint of potential synergies across sponsors and research providers.

ENERGY

5) Superconductivity

Implications: Realizing a 100-fold increase over the capacity of conventional copper wires at a comparable cost will enable the transmission of more power through a smaller footprint, shrink the size of high temperature superconducting power equipment (smaller motors, etc.), and offer improved energy management capabilities (e.g., fault current limiters). There are particularly promising applications for urban settings for power distribution and for long-distance transmission.

Novel, extremely strong and highly conductive wires constructed from nano-materials show considerable promise to revolutionize the grid.

Promising focus areas: Methods to reduce costs and control quality of superconducting wires require basic research. Some areas to consider include control of nano-defects and interfaces, filament development, high temperature superconducting film deposition rates, and more. For motors, generators, and other devices, work is needed on high voltage dielectrics.

6) Power Electronics/Switching

Implications: For the electric grid, advances will allow precise and rapid switching and control of electric power to support long distance transmission. Such advances are needed to more rapidly respond to system disturbances and allow the system to operate with lower margins and fewer constraints. There are broad implications for other energy-related applications such as hybrid electric vehicles, consumer electronics, industrial processes, solar energy, wind energy, buildings applications, as well as military-related applications. Power electronics that can withstand high temperatures, pressures, corrosive environments, and other challenging circumstances are needed for industrial technology processes, geothermal down-hole activities, and elsewhere.

Promising focus areas: This area is ripe for both basic and applied research, with properties of new materials observed such as silicon carbides and diamond-graphite nano-materials that, in the latter case, can deliver switching speeds that are 3x faster than present materials. Such materials must also withstand extremely high temperatures and harsh environments. The five Office of Science sponsored DOE Nanoscale Science Research Centers can help facilitate the needed breakthroughs. These breakthroughs will enable new, higher power systems to be implemented across the grid, improving control and grid efficiency. Additionally, work by the basic research community in high energy physics on power modulators for a next generation particle collider, such as an International Linear Collider, is likely to be relevant.

7) Grid Control

Implications: Significant improvements are needed to improve grid reliability and efficiency, increase utilization of assets, reduce vulnerabilities, and accommodate expected significant changes and adaptations to changing energy supplies/demands. Efforts are needed for much more rapid and reliable detection of disturbances and prevention of widespread outages and cascading blackouts while providing real-time information during energy emergencies. Development of renewable energy resources and accommodation of decentralized energy sources will require a systems perspective and modeling approach.

Promising focus areas: Mathematics underlying these complex, interconnected systems is poorly developed and does not support predictive understanding, modeling, and control. Further development of the math and models of such complex systems is critical to improving the speed and effectiveness of grid management control systems. Similarly, improved visualization techniques will help in the human interface with such control systems.

8) Wind Power

Implications: Although wind power is one of the more mature renewable technologies, there remain significant opportunities to improve cost and performance, particularly in low wind-speed regimes, as well as technical uncertainties associated with wind patterns, both at a micro- and macro- scale that could impact not only siting decisions, but many other operating and design features. Both areas could benefit from increased science attention.
Promising focus areas: Continuing to reduce the cost of wind energy and enabling the cost-effective use of more wide-spread but lower-speed wind resources will require further improvements in the efficiency of wind turbines and reductions in their capital cost by reducing the material required in their construction as well as improved knowledge of wind patterns. To address these needs will require further collaborations to better characterize the fundamental aerodynamics of rotating airfoils, especially effects caused by inflow turbulence; this can help optimize turbine rotor efficiency and mitigate loads, reducing materials requirements. Characterizing wake mixing, and downstream impacts, aero-acoustics, and developing better and higher resolution wind models that integrate with long-term assessments of potential changes in wind patterns are also important. Current wind resource assessments could greatly benefit from application of advanced modeling and computational methods and work in climate modeling and prediction.

9) Catalysis for Energy Efficiency and Renewable Energy

Implications: Although there is good cooperation in catalysis work, there remain significant opportunities to apply the energy savings potential of catalysis to energy supply and demand challenges. There are also important implications for other departmental missions, but clearly one of the high priority initial thrusts should reflect the significant opportunities to impact energy related processes and technologies that will remain cost-prohibitive until breakthroughs in areas of catalysis are realized. Advances in catalysis are now possible through new facilities that can examine in real-time, chemical interactions at the molecular scale and at extremely fast intervals.
Promising focus areas: Significant opportunities exist in industrial technologies, transportation, energy supply and conversion (including biomass), and more.

10) Nuclear Fuel Materials and Design

Implications: Current materials synthesis efforts here, too, are driven by a "cook and look" approach. Basic research could help significantly with the design and predictive modeling and evaluation of various nuclear fuel materials and configurations. Such work is critical to next generation reactor concepts and designs, as well as for verification and its associated costs and uncertainty.
Promising focus areas: There are many areas where basic research could be helpful. Some areas of high interest include high temperature and corrosion resistant materials, helium contaminants and impacts, sulfur iodine in H2 production, cladding interactions, and performance characteristics of high temperature liquid salts.

11) Catalysis for Hydrogen Production from Nuclear Energy

Implications: As part of advanced concepts for commercial hydrogen production, there are many unanswered questions and technological uncertainties that could benefit from science investigations. Research is needed to develop catalysts and membranes that would improve hydrogen production efficiencies and make the technology cost effective. Catalysts and membranes employed thus far in laboratory demonstrations are either excessively expensive to produce or provide too short a service life for future commercial applications.
Promising focus areas: Current platinum catalysts sinter at high temperatures and the platinum is lost. Research is needed not only to address this problem but to explore new and/or alternative catalysts that have the desired properties and can function in these hostile, high-temperature conditions. In addition, membranes for a variety of applications including improving equilibrium conversions, difficult chemical separations, dewatering, and hydrogen purification will improve hydrogen production efficiency and cost effectiveness. Improved catalysts and membranes are also required for the electrolyte steps in thermochemical cycles.

12) Risk Assessments for Geologic Carbon Sequestration

Implications: There are reasonably good models for the geologic performance of oil fields spanning a 30-40 year period. However, detailed understanding and models for other geologic storage reservoirs is insufficient to allow for long term risk assessment predictions. A challenging question is how to predict the performance of geologic sequestration of CO2 spanning periods of 100 years or more. There are complex chemistry and geosciences issues that must be studied further and factored into models. And there is a need to correlate small, focused tests with model development. Ultimately, our ability to use fossil fuels may be constrained by our ability to pursue one or more carbon sequestration pathways and, thus, our ability to predict the performance of engineered sequestration pathways, such as geologic carbon sequestration, takes on a real sense of urgency.
Promising focus areas: Basic research is needed in all aspects of geosciences and geology.
Additionally, advanced modeling and simulation are critical areas of basic research need, including risk assessment in complex systems which are driven by non-linear dependencies. Further areas of basic research needs include trapping mechanisms, including pore trapping, chemical reactions, and lab-field reconciliation. The chemistry of cement-based materials is also of critical interest given the expected dependency on concrete caps that will need to withstand the complex chemistry of contaminants and CO2 for considerably long times. Also beneficial for risk assessment in geologic carbon sequestration will be DOE's efforts to understand, model, and predict fundamental subsurface biogeochemical processes, including collaboration with DOE's SciDAC program in the context of contaminant mobility. One of the SciDAC projects in subsurface modeling will have specific applicability to geologic carbon sequestration.

13) Gasification and Combustion Modeling and Computational System Dynamics

Implications: There are significant technical issues in understanding and optimizing the fundamental, basic mechanisms associated with coal gasification and combustion that will benefit from supporting basic research.
Promising focus areas: Areas of basic research need include: reactive flows and combustion, both requiring a finer "grid" size and model scaling; problems associated with the high flame speeds of hydrogen; and the need for better codes to model combustion and turbine dynamics. In particular, efforts undertaken within the Innovative and Novel Computational Impact on Theory and Experiment program may be helpful, and modeling from the micro to the macro will undoubtedly yield benefits for Future/Gen.

14) Advanced Sensors and Controls for Gasification and Combustion Systems

Implications: For a broad range of future coal gasification and combustion systems, they will need to respond rapidly, and in real-time, to changes in combustion and fuel quality to balance such factors as performance with emissions, addressing contaminants such as mercury and others. It isn't just research into advanced sensors that is required, but research into the algorithms that underpin intelligent control systems that can respond instantaneously to sensor data.
Promising focus areas: There are opportunities to further develop and apply capabilities in scaling and reduced order modeling. The Department is faced with some of the same challenges in grid control, that is, how and where to deploy smart sensors and how to deploy mathematics simplification techniques to separate noise from real changes in control systems - responding at very rapid speeds. Additionally, there is room for further development of smart sensors that can withstand harsh, corrosive and high temperature environments.

15) High Performance Materials for Advanced Fossil Energy Processes

Implications: Although there is considerable scientific work underway within DOE to develop materials that can withstand harsh conditions, there are particular needs in fossil energy due to the temperatures, pressures, and corrosive and abrasive environments posed by fossil fuel processing, conversion, and combustion. Additional basic research to support those applied energy challenges will help improve existing systems, and deliver the new fossil energy systems that will improve efficiency and reliability of the next generation plants.
Promising focus areas: There is particular opportunity to explore fractures, cracking, corrosion, atomic displacement and scaling.

NATIONAL NUCLEAR SECURITY

16) Innovative Materials for Safeguards and Security

Implications: There are myriad technical challenges in safeguards and security that would benefit considerably from advances in materials science. Such new materials would enable more rapid threat detection, enhance and harden communications, protect personnel, and isolate and protect special nuclear materials.
Promising focus areas: New materials are needed for lightweight armor, high efficiency filtration (chem/bio filters), physical barriers, perimeter sensors and more.

17) Nuclear Test Detection

Implications: Presently, there are reasonably good detection systems and processes for aboveground tests although there is room for improvement. Detection of below-ground tests, however, is more challenging and is handicapped by limitations in seismic and geologic models and characterization, as well as the ability to discriminate from the background noise of natural seismic disturbances. Especially for low-yield testing, close proximity to underground tests is required, posing a significant obstacle when attempting to monitor rogue nations. Space-based nuclear explosion monitoring poses some challenges as well.

Promising focus areas: Research is needed in seismic analysis, earth models, and the space weather environment.

18) Remote Sensing and Analysis of Radioactive Materials and Nuclear Weapons

Implications: Preventing the proliferation, production, diversion, transport, and assembly and use of radioactive weapons and detection and tracking of significant radioactive materials is a critical responsibility of the DOE and a scientific and technological challenge. With the expansion of terrorism, and the ability of developing nations to produce such materials, the challenges have never been greater, and the risks higher. There is opportunity for the DOE's basic research communities to work together to further strengthen our nation's sensing and analysis capabilities. A critical challenge is the ability to "see" highly shielded HEU, where even gammas see little or no penetration.

Promising focus areas: Research is needed in materials science and large, defect-free crystal growth for detectors; simplifying computational algorithms for analyzing gigabytes to terabytes of data from hyper-spectral analyses; hierarchy of decay of higher energy lines of isotopes and resulting cross-sections; neutrino detection for nuclear plants.

19) High Energy Density Physics

Implications: From nuclear physics to stockpile stewardship and fusion energy sciences, understanding of high energy density physics is a critical component. The NNSA has maintained a broad-based set of computational capabilities and experimental facilities (e.g. NIF at LLNL, the Z-pulsed power accelerator at SNL, and the Omega laser at the Laboratory for Laser Energetics at the University of Rochester) supporting high energy density physics. The SC Office of Fusion Energy Sciences (FES) scaled back investments over several years due to budget constraints, resulting in a loss of critical capability and the lack of a coherent, mutually supportive DOE program by the end of 2006. Following the development of an interagency report on High Energy Density Physics in 2007, SC and NNSA developed a joint program in High Energy Density Laboratory Plasmas to leverage scientific cooperation and expertise from both organizations and engage the scientific community from universities and national laboratories to developing a path forward for compelling research that supports the FES and NNSA missions.

Promising focus areas: Specific needs are being developed through joint SC-NNSA workshops with broad participation from the scientific community. The general area of increased experimentation and in particular, studies on fast ignition that could involve FES are viewed as promising. In general, advancing the linkages between SC's basic research with the inertial confinement fusion program within NNSA is deemed a promising initial step.

ENVIRONMENTAL MANAGEMENT

20) Chemistry and Separations for Radioactive Waste

Implications: There are critical unanswered scientific questions that must be addressed to facilitate the stabilization, long-term storage, treatment, and ultimate disposal of radioactive waste. The chemistry underlying these wastes is extremely complex and separations processes designed to split the highly problematic fractions of the waste from other portions is poorly understood. Many of these wastes are merely prepared for long-term stabilization at this time. Significant cost savings will only be made possible through improved scientific understanding of these complex chemical interactions.

Promising focus areas: There are many complex chemistry issues of interest, ranging from modeling separations and chemical reactions (similarities between waste management and advanced fuel cycle work within DOE), to understanding the interaction of radioactive wastes and soils, to the behavior of low level waste grout over hundreds or even thousands of years. In addition, there are material science issues associated with the long-term performance of aging storage tanks and with potential grouts for those tanks. Fossil energy applications could also benefit from understanding the chemistry of concretes, especially when subjected to radiation environments. Similarly, transuranic chemistry is all but terminated in the Department and it provided an important foundation for work in

waste management, nuclear energy, and other mission areas within DOE. Fundamental science in the area of monitoring and sensors is needed to provide tools for the long-term stewardship of these materials and their storage environments.

21) Modeling, Simulation, and Scaling Issues for Environmental Management

Implications: Consistent with the current joint attempts at groundwater modeling at Hanford by DOE's basic research and environmental management communities, there are numerous other areas within the latter community that would benefit from the application of advanced understanding of subsurface transport processes, computation and scaling methods to provide insights into the processes and designs for treatment and disposal, and ultimately, for validation of the same.

Promising focus areas: Evaluation of subsurface fate and transport, disposal forms and stability, interaction with the environment, and predictive validation of performance are just some of the opportunity areas.

22) Predicting High Level Waste System Performance over Extreme Time Horizons

Implications: Predicting the performance of combined engineered and natural containment barriers as part of a systems perspective for high level waste management is a challenging task when asked to examine performance over tens of thousands or even a million years. It is entirely possible, however, to design for such long time horizons if conservative assumptions are made at each step of the way. There may be opportunity to apply areas of science to reduce the uncertainty associated with the full system performance. This could translate into less costly approaches.

Promising focus areas: Particularly promising areas include application of lessons learned and synergies between the DOE's radioactive waste programs and DOE's science communities on studies of the subsurface transport of materials, basic energy sciences work on materials corrosion, including corrosion properties of new advanced materials; synthesis compositional approaches to developing new radiation-high temperature-chemically resistant materials for use in long-life monitoring sensors; high temperature materials properties such as might be presented by magma intrusion; understanding of nuclear cross-sections; access to nuclear data that could be useful for further validating the unlikelihood of criticality; and enhanced understanding of climate variability (including paleoclimate and future predictive modeling).

Appendix D. Funding requested for newly initiated R&D coordination areas in the FY2009 budget request.

Summary Funding Table
Basic and Applied R&D Collaborations

	FY 2007	FY 2008	FY 2009	FY 2009 vs. FY 2008	
Advanced Mathematics for Optimization of Complex Systems, Control Theory, and Risk Assessment					
Energy Supply and Conservation					
Energy Efficiency and Renewable Energy					
Vehicle technologies	——	——	500	+500	——
Nuclear Energy					
Research and development					
Advanced fuel cycle initiative	10,000	19,410	55,000	+35,590	+183.4%
Science					
Advanced scientific computing research	——	1,900	2,000	+100	+5.3%
Total, Advanced Mathematics	10,000	21,310	57,500	+36,190	+169.8%
Electrical Energy Storage					
Energy Supply and Conservation					
Energy Efficiency and Renewable Energy					
Vehicle technologies	——	——	2,000	+2,000	——
Electricity Delivery and Energy Reliability					
Energy storage and power electronics	——	——	13,403	+13,403	——
Science					
Basic Energy Sciences	——	——	33,938	+33,938	——
Total, Electric Energy Storage	——	——	49,341	+49,341	——
Carbon Dioxide Capture and Storage					
Fossil Energy Research and Development					
Carbon sequestration	97,228	118,908	149,132	+30,224	+25.4%
Science					
Basic energy science	5,915	5,915	10,915	+5,000	+84.5%
Advanced scientific computing research	——	976	976	——	——
Biological and environmental research	16,841	16,874	17,374	+500	+3.0%
Total, Science	22,756	23,765	29,265	+5,500	+23.1%
Total, Carbon Dioxide Capture and Storage	119,984	142,673	178,397	+35,724	+25.0%
Characterization of Radioactive Waste					
Energy Supply and Conservation					
Nuclear Energy					
Research and development					
Advanced fuel cycle initiative	37,190	53,722	59,000	+5,278	+9.8%
Science					
Basic energy sciences	——	——	8,492	+8,492	——
Biological and environmental research	——	——	1,500	+1,500	——
Nuclear physics	200	200	6,603	+6,403	+3,201.5%
Total, Science	200	200	16,595	+16,395	+8,197.5%
Defense Environmental Cleanup					
Technology development	2,100	2,100	9,500	+7,400	+352.4%
Total, Characterization of Radioactive Waste	39,490	56,022	85,095	+29,073	+51.9%

Predicting High Level Waste System Performance Over Extreme Time Horizons					
Science					
Basic energy sciences	——	——	8,492	+8,492	——
Defense Environmental Cleanup					
Technology development	500	500	1,500	+1,000	+200.0%
Total, Predicting High Level Waste System Performance	500	500	9,992	+9,492	+1,898.4%
High Energy Density Laboratory Plasmas					
Science					
Fusion energy sciences	15,459	15,942	24,636	+8,694	+54.5%
Weapons activities					
Campaigns					
Interial confinement fusion ignition and high yield campaign					
Joint program in high energy density laboratory plasmas	7,000	3,152	3,147	-5	-0.2%
Science campaign					
Dynamic materials properties	3,000	9,143	7,000	-2,143	-23.4%
Total, Weapons Activities	10,000	12,295	10,147	-2,148	-17.5%
Total, High Energy Density Laboratory Plasmas	25,459	28,237	34,783	+6,546	+23.2%
Total, Basic and Applied Research Collaborations	**195,433**	**248,742**	**415,108**	**+166,366**	**+66.9%**
Recap by Organization					
Science	38,415	41,807	114,926	+73,119	+174.9%
Energy Efficiency and Renewable Energy	——	——	2,500	+2,500	——
Electricity Delivery and Energy Reliability	——	——	13,403	+13,403	——
Fossil Energy	97,228	118,908	149,132	+30,224	+25.4%
Nuclear Energy	47,190	73,132	114,000	+40,868	+55.9%
Environmental Management	2,600	2,600	11,000	+8,400	+323.1%
National Nuclear Security Administration	10,000	12,295	10,147	-2,148	-17.5%

Appendix E. Congressional Legislative and Report Language on DOE R&D Integration Efforts

- House Report 107-112, Energy and Water Development Appropriations Bill, 2002, June 26, 2001. This report directed the department "to identify ways in which coordination can be improved and research conducted which is mutually beneficial and to report to the Committee….on the Department's strategy for ensuring that the basic research programs also focus on energy technology needs."

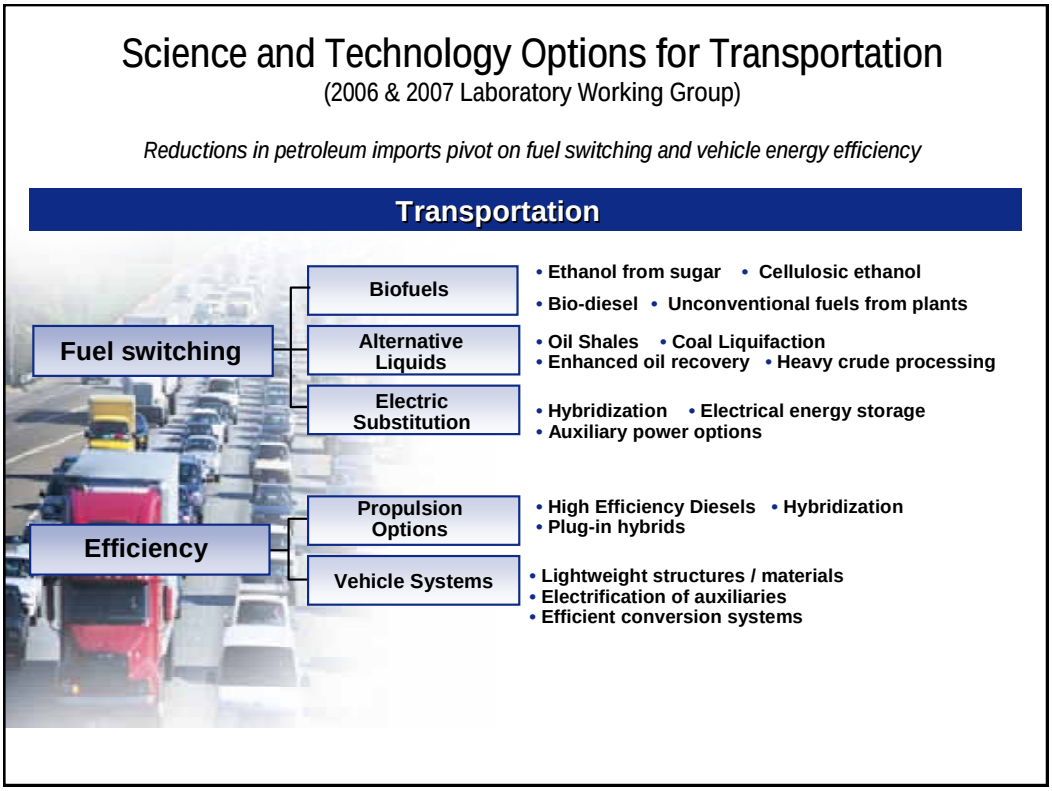
- The Energy Policy Act of 2005 (Public Law 109-58, dated August 8, 2005), Section 994, requires the Department to periodically review the science and technology activities of the Department in a strategic framework that takes into account both the frontiers of science to which the Department can contribute and the national needs relevant to the Department's statutory missions. EPAct 2005 also requires the Department to establish a coordination plan to improve coordination and collaboration in research, development, demonstration, and commercial application activities across the Department organizational boundaries.

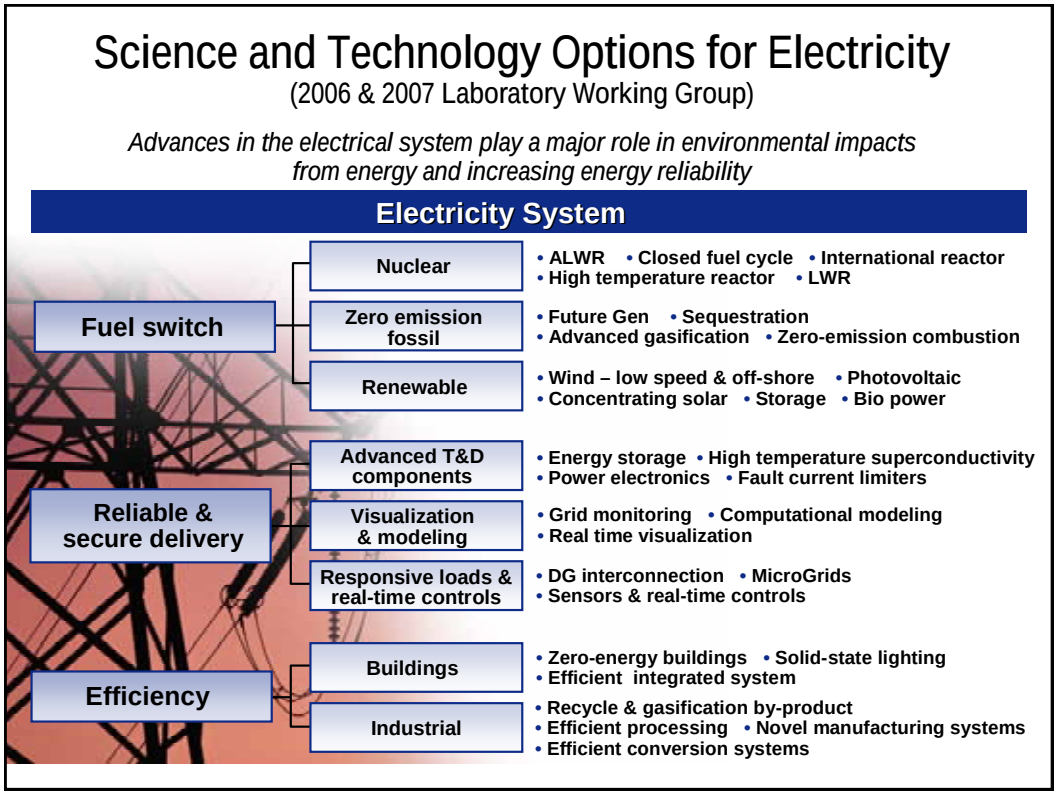
- June 29, 2006. Senate Report on Energy and Water Appropriations Bill, 2007; Senate Report 109-274; page 134. *Report on Scientific Cooperation*.—The Department is directed to prepare a report supported by the Office of Science and the Office of Energy Supply and Conservation regarding the specific steps the Department is taking to ensure cooperation between the two offices in identifying broad research objectives and goals as well as specific R&D priorities required in the short term. This report should contain information as to how the various Department of Energy laboratories are supporting these activities and budget projections in the next 5 years.

- July 9, 2007. Senate Report on Energy and Water Appropriations Bill, 2008; Senate Report 110-127; page 143 – bottom: *Report on Scientific Cooperation*.—The Department is directed to prepare a report supported by the Office of Science and the Office of Energy Supply and Conservation regarding the specific steps the Department is taking to ensure cooperation between the two offices in identifying broad research objectives and goals as well as specific R&D priorities required in the short term. This report should contain information as to how the various Department of Energy laboratories are supporting these activities and budget projections in the next 5 years.

- FY 2009 House Appropriations Energy and Water Development Subcommittee Mark, June 2008, "…One of the issues that this Committee raised repeatedly in recent years of the lack of coordination among these programs[SC and EERE, FE, NE, and OE] to ensure that mission-critical science needs and opportunities that span multiple programs are being appropriately addressed. The Committee is pleased to note that the Department has taken some encouraging steps in this direction, including the completion of twenty planning workshops arranged by the Office of Science in consultation with the applied technology programs in order to address the scientific barriers to progress in applied technology missions; integrated budget documentation for six key research and development areas of significant interests to the missions of multiple programs; and the proposal to fund over two dozen Energy Frontier Research Centers (EFRC) to tackle many of these critical science needs."

Appendix F. Fuel switching and efficiency technology options highlighted in the 2006 and 2007 LWG Portfolio Assessments.





Appendix G. The "use-inspired" basic research, applied research, and technology maturation and deployment needs for Environmental Management Challenges. While these tables were not developed during a technical workshop, the basic and applied research needs identified below were informed by multiple technical workshops.

Research and Development for Environmental Management

Use-inspired Basic Research for Waste Processing	Applied Research	Technology Maturation & Deployment
• Understanding of the fundamentals of corrosion resistance and chemical behavior of materials under extreme radiation, chemical, and temperature conditions to design more resistant materials. • Develop fundamental understanding to design ligands to enable recognition and separation of unusual chemical complexes. ▪ Understanding of behavior of reactive chemical complexes in radioactive and high temperature environments. ▪ Expand the fundamental understanding of separatng anions from multiple chemical complexes.	▪ Improved Waste Storage Technology ▪ Reliable and efficient Waste Retrieval Technologies ▪ Enhanced Tank Closure Processes ▪ Next-generation Pretreatment Solutions ▪ Enhanced Stabilization Technologies ▪ Spent Fuel Storage ▪ Spent Fuel Stabilization ▪ Disposal Packaging Preparation ▪ Challenging Materials Storage, Stabilization and Disposal	▪ Improved understanding of corrosion chemistry ▪ Develop suite of retrieval technology ▪ Develop characterization and quantification techniques for measuring heels ▪ Develop near tank pretreatment methods ▪ Develop next generation stabilization technologies ▪ Improve monitoring techniques for fuel safety ▪ Develop advanced characterization, monitoring and inventory analysis methods

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Research and Development for Environmental Management

Use-inspired Basic Research – Groundwater and Soils	Applied Research	Technology Maturation & Deployment
▪ Understanding the fundamental science underpinning the speciation, bonding and reactivity of actinides and fission products in contaminated groundwater and soils near HLW tanks. ▪ Exploring the basis of radiolytic processes in heterogeneous geohydrologic environments. ▪ Basic research leading to conceptual and numerical models of the fate and transport of low-level contaminants. ▪ Understanding the biogeochemical processes influencing radioactive contaminant mobility at the nanoscale.	▪ Improved Sampling and characterization strategies ▪ Advanced predictive capabilities ▪ Enhanced remediation methods ▪ Adapted technologies for site-specific and complex-wide D&D applications ▪ Enhanced long-term performance evaluation and monitoring	▪ Develop advanced sampling and characterization technologies and strategies for multiple contaminants ▪ Use basic and applied research to gain better understanding of contaminant behavior in the subsurface ▪ Develop advanced models that incorporate chemical reactions, complex geologic features and /or multiphase transport for multiple contaminants ▪ Develop and demonstrate advanced in-situ and ex-situ remediation methods ▪ Improve understanding on in-situ produced chlorinated organics ▪ Provide technical basis for use of monitored natural attenuation of organics, radionuclides and metals

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Appendix H. List of Acronyms

AFCI	Advanced Fuel Cycle Initiative
APS	Advanced Photon Source (at Argonne National Laboratory)
ARP	actinide removal process
ASCR	Advanced Scientific Computing Research (of the Office of Science, DOE)
BER	Biological and Environmental Research (of the Office of Science, DOE)
BES	Basic Energy Sciences (of the Office of Science, DOE)
BESAC	BES Advisory Committee
CO_2	Carbon dioxide
CRF	Combustion Research Facility
CSSX	Caustic-Side Solvent eXtraction
DARHT	Dual-Axis Radiographic Test facility (at Los Alamos National Laboratory)
DOD	Department of Defense
DOE	Department of Energy
DWPF	Defense Waste Processing Facility
EERE	Office of Energy Efficiency and Renewable Energy (of the DOE)
EIA	Energy Information Administration
EM	Office of Environmental Management (of the DOE)
EMaCC	Energy Materials Coordinating Committee
EPAct	Energy Policy Act of 2005
EPSCoR	DOE Experimental Program to Stimulate Competitive Research
FE	Office of Fossil Energy (of the DOE)
FY	Fiscal year
FESAC	Fusion Energy Sciences (of the Office of Science, DOE)
FES	FES Advisory Committee
FOA	Funding Opportunity Announcement
GNEP	Global Nuclear Energy Partnership
HEDP	High Energy Density Physics
HEDLP	High Energy Density Laboratory Plasmas
HEP	High Energy Physics (of the Office of Science, DOE)
HEU	highly enriched uranium
HLW	high level waste
HP-CAT	High Pressure Collaborative Access Team beamline at APS
IWG	Interagency Working Group
LEDs	Light-emitting diodes
LLNL	Lawrence Livermore National Laboratory
MCU	Mobile CSSX Unit
NAS	National Academies of Science
NASA	National Aeronautics and Space Administration
NE	Office of Nuclear Energy (of the DOE)
NETL	National Energy Technology Laboratory
NIF	National Ignition Facility
NNSA	National Nuclear Security Administration (of the DOE)
NSTC	National Science and Technology Council
NOx	Nitrous Oxide
NP	Nuclear Physics (of the Office of Science, DOE)
NSF	National Science Foundation
OLEDs	Organic light-emitting diodes
OE	Office of Electricity Delivery and Energy Reliability (of the DOE)
OET	Office of Energy and Technology (of the Office of Environmental Management, DOE)
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
OSTP	White House Office of Science and Technology Policy
PART	Program Assessment Rating Tool
RW	Office of Civilian Radioactive Waste Management (of the DOE)

R&D	Research and development
SBIR	Small Business Innovative Research Program
SC	Office of Science (of the DOE)
SciDAC	Scientific Discovery through Advanced Computing (of the Office of Science, DOE)
SNL	Sandia National Laboratory
SOx	Sulfur Oxides
SRS	Savannah River Site
SSA	Office of Security and Safety Performance Assurance (of the DOE)
STTR	Small Business Technology Transfer Program
S&T	science and technology
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
ST&E	science, technology and engineering
SWPR	Salt Waste Processing Facility