FY11 MPS/ENG Energy Working Group White Paper

CLEAN SUSTAINABLE ENERGY (CSE)

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INTRODUCTION

As stated by the National Science Board in its August 2009 report, "*Building a Sustainable Energy Future: U.S. Actions for an Effective Energy Economy Transformation*, the U.S. faces a critical challenge to transform the current fossil-fuel-based energy economy to a stable and sustainable energy economy. Such a transformation must be achieved in a timely manner to increase U.S. energy independence, enhance environmental stewardship, reduce energy use, and generate continued economic growth. On a similar note, President Obama stated in his April 2009 address to the National Academy of Sciences "…in no area will innovation be more important than in the development of new technologies to produce, use, and save energy -- which is why my administration has made an unprecedented commitment to developing a 21st century clean energy economy…" This sentiment was repeated in the President's recent State of the Union Address, in which he additionally stated the need for education in this area. Continuing support has been expressed as recently as March 30, 2011, with affirmation of programs to develop alternatives to fossil fuels and in particular to petroleum-derived fuels. The global impetus to review energy politics to promote renewable energy sources has abruptly increased in light of recent disasters, most currently the Fukujima nuclear plant in Japan. The interrelationships among environmental, economic and societal impacts of are currently unfolding.

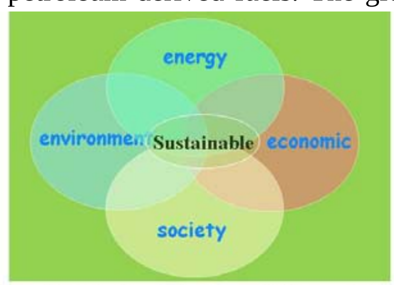

Figure 1. The National Academy of Sciences defines sustainable as: …meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems" .[3] Clean-sustainable energy cannot be realized without consideration of the interrelated environmental, economic and societal realities.

The development of an innovative research agenda in renewable and sustainable energy resources is a national and international imperative that must be addressed in multiple ways and at multiple levels. With its institutional mission of enabling basic scientific research through support of individual academic investigators and strongly interacting, collaborative multidisciplinary groups, while at the same time enhancing the training of future generations of scientists and engineers, the National Science Foundation (NSF) is uniquely positioned to facilitate the nation's progress in science, engineering, and education towards realizing a clean, sustainable energy (CSE) future. The NSF established the Science, Engineering, and Education for Sustainability Initiative (SEES) in FY10 in order to address challenges in climate and energy research and education using a systems-based approach to understanding, predicting, and reacting to change in the linked natural, social, and built (i.e., man-made surroundings) environment. The Mathematical and Physical Sciences (MPS) and Engineering (ENG) Directorates, in particular, are well positioned to address many of the fundamental and applied research questions that will enable a clean, energy economy (MPS and ENG support more than 70% of energy-related research at NSF); these Directorates will work more closely together and with other Directorates across the NSF to support research toward a clean, sustainable energy future. At the same time, the vision of the SEES Initiative cannot be achieved without an intimate relationship between communities conducting energy research and those addressing broader questions in sustainability research (i.e., linked energy, environmental, economic, societal issues). (See Figure 1.) As the MPS and ENG Directorates continue to support energy research, the goal should be to catalyze the *growth* of a CSE research (see Figure 2) portfolio and the *creation* of a new genre of scientists and engineers who work seamlessly with other disciplines, adopting a systems-level approach to address major challenges in the emerging Sustainability Research field. This multidisciplinary approach, inclusion of a strong educational component, and programmatic strength is unique to NSF thus differentiating it from other Government Agencies. The opportunity for NSF is significant, and MPS and ENG will cooperate in leading the effort to make it successful.

Please note that we are distinguishing between the terms clean and sustainable. Clean energy should have zero net anthropogenic CO_2 production and no negative environmental impact. Sustainable energy technology is not only clean, but also is based on principles and methods that do not consume resources in a manner that would prevent future generations from using that technology. For example, solar energy may be clean, but if the photovoltaic panels rely on an element that is not earth abundant and cannot be recycled, the technology is not sustainable. Energy sources based on renewable, biological resources may be clean, but if they significantly decrease food availability and increase food prices, they are not sustainable.

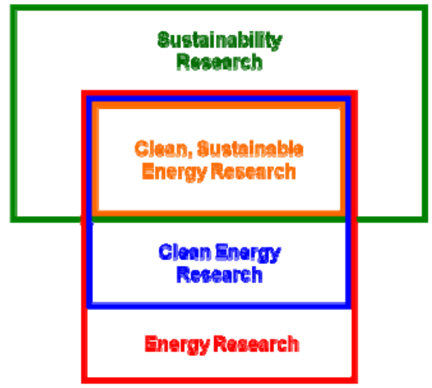

Figure 2 Depiction of different Energy Research categories and their relation to Sustainability Research (i.e. SERS). Optimally, MPS-ENG should aim to grow the Clean, Sustainable Energy (CSE) Research category

CHALLENGES

The main science and engineering challenges in CSE research have been delineated to include the need for efficient and cost-effective solutions to: 1) renewable-energy generation; 2) energy storage; 3) energy transmission, distribution and security; 4) energy use & conservation; and 5) system design and integration (i.e., integration of new technologies into existing and/or new infrastructure). While the ENG Directorate has targeted programs directly identifiable with many of these research challenges (e.g., Energy for Sustainability/CBET, Energy, Power, and Adaptive Systems/ECCS, etc.) the MPS Directorate programs are less directed (with the exception of the CHE-DMR-DMS Solar Initiative)[4]. However, current investment portfolios across both Directorates have common strength in many areas, including photovoltaics, solar fuels, conversion of CO_2 to fuel, and energy storage. More formal interactions between MPS and ENG should be developed to leverage activities in research areas related to these energy challenges. Whereas there are existing opportunities through individual investigator and centers programs for the community to address energy challenges, there are no MPS or MPS/ENG joint specific efforts to promote research in CSE. Closer cooperation between the two Directorates is also essential for accelerating fundamental science breakthroughs into innovative solutions for realizing a CSE future. Critical to this collaboration is that programmatic synergies be developed while both Directorates' identities and strengths in basic research and applied research be retained and enhanced.

A science and engineering community built around CSE requires embracing system-level thinking with respect to manufacturability, scalability, environmental impact, societal value, and practical/market viability across the entire life-cycle of the technology. A broader "Sustainability Community" needs to be fostered to develop common metrics and identify stakeholders, including industry, which will be engaged at all levels. There are many challenges to building a Sustainability Community. One of the biggest challenges is fostering stronger interactions between the MPS, ENG, and Social, Behavioral, and Economic Sciences (SBE) communities; however, it is of utmost importance for these communities to interact because realizing a CSE future cannot be achieved without considering socio-behavioral-economic realities. Information flow between communities is vital, but the data deluge is also problematic, and it is imperative to facilitate development of better data management tools, such as energy-related databases, data mining tools, and mechanisms to create "Conversation Space," not just between the MPS and ENG communities, but also across all communities vested in Sustainability Research and implementation (Government and Industry).

The joint MPS/ENG Energy Working Group (EWG) was formed to initiate coordination of energy-related efforts between MPS and ENG as a result of last year's recommendation by the MPS Energy Working Group (See Appendix A). This year, the MPS/ENG EWG held a Clean, Sustainable Energy (CSE) Retreat to address the *challenges of* and *strategies for* working together and across the foundation to advance a CSE future. The group specifically addressed science and engineering, innovation, socioeconomic and education challenges (details about the retreat can be found in Appendix B). Five themes emerged from the retreat that cross-cut all these challenges: 1) Systems-level thinking is crucial; 2) The SBE Directorate needs to be engaged as a *stronger* partner in science, engineering, innovation and education planning; 3) Better and/or new mechanisms for information flow among different communities addressing sustainable energy systems challenges are needed; 4) A sustainability research community must be developed; and 5) Training scientists and engineers to function well in diverse interdisciplinary settings not limited to science and technology, and effectively communicate with the Public and Policymakers is critical.

PATH FORWARD

As the main investors in energy research and innovation, MPS and ENG should establish a uniform clean, sustainable energy (CSE) strategy and implementation plan for the NSF. The MPS/ENG EWG was formed and tasked to do this. Toward this end, an effort to evaluate the current investment portfolio was launched. A science and technology Energy Topics List has been developed, and mapping of active awards is in progress. It must be made clear that NSF currently supports research in all energy research categories depicted in Figure 2, but a strategic goal will be to catalyze the growth of clean, sustainable energy research. The map will be used to identify strengths and synergies to effectively address the CSE challenges discussed above and to pursue new strategic opportunities going forward within NSF, and with other agencies. These, together with community inputs, are being used to generate a 5-year plan to frame MPS and ENG energy activities within SEES. Some elements of this plan are briefly outlined here.

Increasing awareness among MPS and ENG Program Directors of the systems-level thinking required to address CSE key challenges is important. This approach includes considering aspects from basic science, engineering, innovation, and education, through socioeconomic and environmental factors. ENG has experience in developing systems-level thinking, such as in the Engineering Research Center (ERC) Program, where a systems view of a research problem coupled with an interdisciplinary university/industry team is essential to a successful proposal. Another opportunity to develop a community is to generate solicitations, like the Sustainable Energy Pathways (SEP) solicitation currently being developed which emphasizes systems-level approaches. However, an MPS- and ENG-led energy strategy should include establishing clear definitions for clean energy and clean, sustainable energy (CSE) research, the latter falling under the general SEES umbrella. Formation of strategic partnerships addressing CSE challenges requires MPS and ENG take the lead in obtaining the different interpretations and perspectives from all these communities from the onset.

Formation of a Sustainability Research Community is critical for educating the next generation of scientists and engineers about CSE challenges. MPS and ENG should leverage existing major efforts by partnering with, for example the Science and Technology for Sustainability (STS) Program[5] at the National Academies. This program was established to encourage the use of science and technology to achieve long-term sustainable development, and involves both US and foreign agencies. Such a partnership will facilitate building stronger bridges between the physical and engineering sciences and the social, behavioral, and economic sciences.

Finally, training scientists and engineers to function well in diverse interdisciplinary settings and to effectively communicate with the Public and Policymakers is critical. Successfully addressing the challenges inherent in CSE issues requires novel approaches in education as systems-level investigation and interdisciplinary collaboration are not uniformly and widely included in current academic models. Due to its breadth of scope, NSF is well positioned to foster and promote the educational, training, mentoring and communication aspects AND couple it to the Science, Engineering and Innovation aspects all required for effectively moving toward a clean, sustainable energy future in our lifetime.

REFERENCES

1. "*Building a Sustainable Energy Future: U.S. Actions for an Effective Energy Economy Transformation,"* National Science Board, August 2009. http://www.nsf.gov/nsb/publications/pub_summ.jsp?ods_key=nsb0955 .
2. Remarks by the President at the National Academy of Sciences Annual Meeting, April 27, 2009, http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-at-the-National-Academy-of-Sciences-Annual-Meeting/.
3. www.pnas.org/site/misc/sustainability.shtml.
4. CHE-DMR-DMS Solar Initiative (SOLAR) is in its third year and has expanded to include ENG as a potential partner (i.e., ENG Program Director, George Maracas is now a member of the SOLAR management team and ENG is involved in the reviewing process and has the option to cofund projects this year. More discussions about stronger ENG role in this program in FY12 are planned).
5. Science and Technology for Sustainability (STS) Program at the National Academies can be found at http://sites.nationalacademies.org/PGA/sustainability/index.htm

APPENDIX A

FY10 MPS Energy Working Group (EWG)

The MPS Energy Working Group (EWG) was created in May 2009 and charged to:

i. serve as the MPS point of contact on energy issues;
ii. collect baseline data;
iii. stay informed on energy-related activities;
iv. talk to counterparts within NSF and at other agencies;
v. prepare and maintain working documents.

In October 2009 members of the MPS Advisory Committee were added to the EWG, and the charge was broadened to provide:

1) a high-level assessment of the needs of the MPS community in terms of energy research and specifically its relationship to climate change;

2) a plan for possible paths forward, including individual efforts, partnerships, collaborations, networks, directorates, agencies, countries, etc. and, if possible;

3) an estimate of the resources needed over the next five years in this area.

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<u>MPS AC Members</u>: Theresa A. Maldonado (Chair), Daniela Bortoletto, Hector D. Abruna, Irene Fonseca

<u>NSF Members</u>: Carol A. Bessel (Chair), Linda S. Sapochak, Morris L. Aizenman, Henry A. Warchall, Robert Dunford
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The MPS EWG held weekly conference calls over several months to discuss critical areas of opportunity to advance needed technological breakthroughs in energy that should be addressed by MPS and NSF. At the same time, the EWG discussed the integral impact on society, human acceptance, and policy. The most significant challenges appear at the disciplinary interfaces, thus requiring teams of scholars with disparate backgrounds to address them. Thus, along these lines, a workshop was held on March 15, 2010 at NSF focusing on three cross-disciplinary topics which were identified to impact all sectors of the energy economy: *design of new materials*, *computational efforts in energy*, and *systems integration*.

To further engage the research community, eight selected participants from academia were invited to attend the workshop. They were:

Estela Blaisten-Barojas, Computational & Data Sciences, George Mason U.
Richard James, Aerospace Engineering & Mechanics, U. Minnesota
Hillol Kargupta, Computer Science & Electrical Engineering, U. Maryland – Baltimore Co.
Anupam Madhukar, Physics & Astronomy, U. Southern California
Clark Miller, School of Politics and Global Studies, Arizona State U.
Franklin (Lynn) Orr, Precourt Institute for Energy, Stanford U.
Keith Promislow, Mathematics, Michigan State University

Jacqueline Shanks, Chemical & Biological Engineering, Iowa State U.

General Overview of Workshop Findings

Design of New Materials (James, Promislow, Madhukar; Abruna, MPS AC)

Materials are one of the fundamental bottlenecks to sustainable energy. Richard James discussed multi-ferroic materials which can be tailored for efficient direct conversion of heat to electricity. Keith Promislow highlighted the importance of multi-scale modeling of polymeric electrolytes for advanced energy conversion. Anupam Madhukar began with a systems view of materials from the science and technology for energy (e.g., for devices such as solar cells) to the science of climate change and the environment (particulates, CO_2) – and the time evolution of the interaction of these systems. Thus, by its very nature the design of new materials covers broad areas of theory, computation, synthesis, and characterization. If any progress is made in the general area of the design of new materials, all of these aspects would need to be integrated including design, synthesis and characterization, and the appropriate feedback loops need to be developed to optimize outcomes.

Recommendations

- Facilitate (incentivize) increased cooperation between purely experimental and computational efforts in how structures form and how to control them.
- Increase and/or find a better mechanism other than EAGER to support high-risk, high impact research.
- Train the next generation of scientists to consider issues related to sustainability, the environment, climate, social, etc. when designing new energy-related materials (e.g. targeted graduate fellowships)
- Make sure that these investments are long-term and that the new relationships are sustained.

Computational Efforts in Energy (Blaisten-Barojas, Kargupta; Fonseca, MPS AC)

Data span all levels of the energy sector, from materials design to real-time (wireless) monitoring of transportation and pollution. Data is acquired from laboratory measurements, theory and modeling, dynamic systems monitoring (e.g., transportation), bibliographies and repositories, and others. Estela Blaisten-Barojas spoke at the workshop and introduced different data types as applied to the design of materials and discussed the challenges of mining the needed data from measurements, calculations, and established formal and open-source databases. Hillol Kargupta discussed related computational challenges from the materials and devices level to real-time monitoring of energy systems – both static (distributed electric power generation and storage) and mobile (vehicle emissions). Critical issues highlighted include large volumes of data, heterogeneous data sets that must be organized and/or integrated for actual use, high throughput data streams, distributed data sources, distributed users, limited bandwidth communication in monitoring applications, and the need for extracting actionable intelligence from the data. Major roadblocks to addressing these issues include the proprietary nature of of data; incomplete, costly, and non-standardized data; sustainability of datasets; and lack of mechanisms to centralize the US repository of data relevant to energy related issues (databases exist in Germany, Cambridge, and at the NIST). Needed technologies include advanced predictive learning and modeling techniques, data stream mining, distributed data mining over large networks, high performance data mining, privacy preserving data mining, and Peer-to-Peer (P2P) data mining.

Recommendations:

- Create incentives for the development of computational energy networks within the US and abroad (e.g., in Europe).
- Investigate possible joint efforts and partnerships with international and other US funding

agencies (e.g. DOE, NIST) to build energy related databases (such as the NIH/NIST Protein Data Bank PDB as applied to biofuels) and to learn from precedents on how to handle proprietary issues, etc.

- Have award guidelines for which data generated through NSF supported projects should be generally accessible.
- Appoint a select Computational Energy Working Group composed of statisticians, mathematicians, computer scientists, materials and other user scientists to:
  - identify the data that is energy relevant,
  - steer dissemination and training activities such as summer schools,
  - recommend funding opportunities in this area.

Systems Integration (Orr, Shanks, Miller; Borteletto, MPS AC)

Currently, many research efforts focus on one or two components of the required alternative energy system without consideration of the entire system and its implementation into society. In this context, invited workshop participants considered the roadblocks to cross-disciplinary efforts and discussed new mechanisms for stronger interactions across the science, engineering, and social science disciplines. Lynn Orr presented his views on how to enable renewable energy sources and technologies into the energy mix, with consideration for climate, water, land use, economics, regulatory, consumer behavior, and other matters. He highlighted the future grid as an example. Jacqueline Shanks discussed transformational goals toward direct production of biological hydrocarbons for biofuels. These goals include efficient capturing of solar energy and CO_2 for the fuels while minimizing nutrient loss. Clark Miller described system integration in the context of the human and social dimensions. His definition of “energy system” as a socio-technological network went beyond the typical view of physical and cyber infrastructure. It also included individual behavior, public attitudes, risk and benefit, markets, national security, governance, and several other characteristics. Including the social science elements into the system provides a more realistic scenario for energy systems advancements and stewardship.

Recommendations:

- The science of the integration of materials into devices must be addressed. A stronger coupling with Engineering should be developed in order to have a seamless transition between the study of fundamental properties to the development of the working devices.
- NSF should leverage a partnership with the recently-funded DOE energy centers and other initiatives. For example, small groups could be supported to partner with ERCs and SBIRs. MPS should consider supplementing ERCs to support affiliate faculty.
- New PI networks, workshops and summer schools should be supported to focus on energy and to bring together groups from different disciplines.

APPENDIX B

FY11 MPS/ENG Energy Working Group (EWG)

The joint MPS/ENG Energy Working Group (EWG) was created in November 2010 and charged to:

vi. Respond to OMB budget call requests
vii. Prepare a five-year Strategic (i.e. business) plan for the Energy part of SEES
viii. Maintain updates of MPS & ENG energy-related awards and activities
ix. Maintain updated information on specific internal and external energy-related areas relevant to NSF for use by our Directorates.

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AC Members: Esther Takeuchi (MPS) and Ilesanmi Adesida (ENG)

NSF/MPS Members: Linda S. Sapochak (Co-Chair, DMR), Morris L. Aizenman (MPS), Henry A. Warchall (DMS), Jay Alexander (DMS), Colby Foss (CHE), Suk-Wah Tam-Chang (CHE), Tom Carruthers (PHY), Matt Platz (CHE), Mary Galvin-Donoghue (DMR)

NSF/ENG Members: George Maracas (Co-Chair, ECCS), Bruce Kramer (CMMI), Larry Goldberg (ECCS), George Antos (CBET, EFRI) Greg Rorrer (CBET), Darren Dutterer (ENG), Bruce Hamilton (CBET), Grace Wang (IIP), Barbara Kenny (EEC)

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The MPS/ENG EWG has at least one representative from each division within the MPS and ENG Directorates with the exception of AST in MPS. The EFRI Program in ENG is also represented. A representative from both the MPS and ENG Advisory Committees (AdComs) are also part of the EWG.

The EWG met approximately weekly between November 2010 through March 2011. Initial meetings discussed the charge to the group as directed by Ed Seidel (AD MPS) and Tom Peterson (AD, ENG). An Energy Topics List was developed and plans were initiated to generate a baseline MPS-ENG Energy Awards Portfolio. The group was asked to identify where they thought MPS/ENG Energy efforts with respect to SEES should be in five years. This was discussed at several meetings and the basic elements were determined to be: a) creation of a single office staffed with cross-Divisional and cross Directorate members with a mission clearly differentiated from other Agencies; b) promotion of inter-Agency interactions, c) a significant science and engineering component that does not compromise but enhances the core basic and applied research activities at NSF, and d) a strong social component (including workforce, community, education, economic and commercialization).

The EWG held a Clean, Sustainable Energy Retreat on March 15, 2011. The purpose of the Retreat was to identify the science & technology, innovation, socioeconomic, and education challenges toward achieving a clean, sustainable energy future and develop strategies for MPS & ENG to address these challenges. The results of the Retreat will be used to develop a 5-year plan (5YP) for how the two Directorates can best integrate energy-related activities into the wider Science, Engineering, and Education for Sustainability (SEES) Initiative.

In order to engage the outside community in this process, the EWG AC members solicited input to four specific questions (see below) from experts in the field:

1) What are the top few scientific/engineering challenges and opportunities toward achieving sustainable energy within the next decade (short term)? Within the next 50 years (long term)?

2) What are the major areas of innovation needed toward implementing a Clean Energy Future?

3) How should the science and engineering research community consider and engage the socio-economic issues?

4) How should the next generation of scientists and engineers be prepared so they can address these issues?

The survey was sent to ~ 30 members of the outside community identified as leaders in fields related to clean, sustainable energy and 16 responses were received. The external respondents were:

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John Abelson, Cornell University, Chemical & Biomolecular Engineering

Robert Brown, Iowa State University, Bioeconomy Institute

Emily Carter, Princeton University, Director, Andlinger Center for Energy & the Environment

Franklin Hadley Cocks, Duke University, Mechanical Engineering

Frank DiSalvo, Cornell University, Director, David R. Atkinson Center for a Sustainable Future

Declie Durham, University of Southern Florida, Mechanical Engineering

Dan Kammen, UC Berkeley, Engineering

Trung Nguyen, University of Kansas, Chemical & Petroleum Engineering

Daniel A. Scherson, Case Western University, Director, Ernest B. Yeager Center for Electrochemcial Sciences,

Cliff Singer, University of Illinois –UC, Nuclear, Plasma, and Radiological Engineering

Chris Somerville, UC Berkeley, Director, Energy Biosciences Institute

John Sutherland, Purdue University, Environmental & Ecological Engineering

Esther Takeuchi, SUNY at Buffalo, Chemical & Biological Engineering

Jeff Tester, Cornell, Associate Director, David R. Atkinson Center for a Sustainable Future

Eric Wachsman, University of Maryland, Director, Energy Research Center

Jay Whitacre, Carnegie Mellon, Engineering and Public Policy

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In addition, each member of the EWG was asked to work with their respective Divisions and gather input for the same four questions listed above, and for the following three NSF-internal questions:

a) What can MPS and ENG do to achieve the Goals and what linkages between ENG & MPS are necessary to achieve them most effectively?

b) What linkages between other Directorates (GEO, BIO, SBE, etc) and Offices (Polar Programs, Integrative Activities, etc) are necessary to achieve them most effectively?

c) What differentiates NSF from other agencies with respect to the proposed activities in part a) and b)? Are there activities proposed that compliment what other agencies are doing in Clean Sustainable Energy?

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Goals of the Retreat

Morning – Combine External Community and ENG/MPS inputs on the Challenges

Distill the External Community and internal-NSF inputs for a Scientific/Engineering Roadmap (including major societal issues needing to be addressed, time it will take to achieve, Sci/Tech roadblocks, what innovation are necessary and when, etc).

Afternoon – Planning for Five Year Plan (5YP) Goals and Milestones

Combine all attendee's inputs and identify where NSF will be in 5 years with respect to MPS/ENG Clean Sustainable Energy within SEES and how we will get there.

Retreat Breakout Groups & Instructions

Question 1 **Science & Engineering**	**Question 2** **Innovation**	**Question 3** **Socioeconomic**	**Question 4** **Education**
Esther Takeuchi (MPS) - Lead	Barb Kenny (ENG) - Lead	Mary Galvin-Donoghue (MPS) - Lead	Ilesanmi Adesida (ENG) - Lead
Bruce Kramer (ENG)	Grace Wang (ENG)	Colby Foss (MPS)	Hank Warchall (MPS) Haiyan Cai (MPS)
Suk-Wah Tam-Chang (MPS)	Morris Aizenman (MPS)	George Antos (ENG)	Darren Dutterer (ENG) Bruce Hamilton (ENG)
George Maracas (ENG)	Greg Rorrer (ENG)	Wendell Hill (MPS)	Linda Sapochak (MPS)
Charles Ying (MPS)	Kathy Covert (MPS)		Samir El-Ghazaly (ENG)
			Maura Borrego (OIA)

- Each Breakout Groups (BG) consisted of a Lead and Scribe.
- The four BGs addressed their assigned question (Q1-4) and encouraged to address the others. All BGs addressed all Qa-c in the context of their assigned Q1-4.
- Leads presented the results from their BG after the Morning and Afternoon Sessions.

BG tasks were to:

<u>Morning Session – Scientific Community and NSF contributions to Q1-4</u>

1. Distill the top five points for assigned question using external and internal inputs–Lead coordinated
2. Generate bullets and 1-2 paragraph description for each point – Scribe & BG
3. Present PowerPoint slides to the whole EWG - Lead
4. Revise bullets and/or ideas from feedback during the Lead's presentation – Scribe & BG

<u>Afternoon Session Qa-c NSF contributions to Qa-c – EWG and other NSF invitees</u>

1. Distill the top five points for assigned question using external and internal inputs–Lead coordinates
2. Generate bullets and a 1-2 paragraph description for all Qa-c with respect to assigned Q1-4 (answers may overlap one or more questions) – Scribe & BG
3. Revise bullets and/or ideas from feedback during the Lead's presentation – Scribe & BG

<u>Summary Session (30 min)</u>

Recap of morning and afternoon sessions. This session was open to all NSF Associate Directors, Deputy Directors and Division Directors.

<u>Retreat Deliverables from each BG:</u>

One PowerPoint file containing final output from morning and afternoon session in the form:

> The top 5 bullet points and 1-2 paragraph description of their assigned question (Q1, 2, 3 or 4) and ALL questions Qa-c

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General Overview of Retreat Findings

Question 1: Science & Engineering Challenges and Strategies for Addressing

Clean, Sustainable Energy research should use earth-abundant, environmentally-benign, sustainable resources in an economically viable way and ensure security and safety across the entire life-cycle. Required enablers include interdisciplinary expertise, positive public opinion, multi-scale design and understanding made possible by advanced computational and experimental methods, manufacturing scale up and improved communication.

Key challenges broadly speaking included:
1. Renewable energy generation (electricity and fuels);
2. System design and integration of alternative energy sources (examples: electric grid, energy efficient building management and control, vehicles, etc.);
3. Energy storage;
4. Energy transmission and distribution;
5. Energy use and conservation (buildings, transportation, and industrial processes)

Strategies:
1. MPS and ENG should have more formal interactions (e.g., joint solicitations, reviews) in current areas of overlap (PV, solar fuels, CO_2 to fuel, energy storage).
2. Interactions with other NSF Directorates in specific key areas, such as BIO (biomass), GEO (land use, impact CO_2), CISE (smart grid, energy conversation/management, cyber security), and EHR (public education, curriculum development).

Question 2: Innovation Challenges and Strategies for Addressing

Innovation is defined as the introduction of new or significantly improved products (goods or services) processes, organizational methods, and marketing methods in internal business practice of the marketplace.

Key challenges:
1. How to integrate market pull into research push? Information flood is problematic, need to create an accessible knowledge pool.
2. Development of a common frame of metrics for sustainability to enable innovation. For example, operating costs, primary energy consumption, water usage, greenhouse gas emissions, etc.
3. Foster system-level thinking with respect to sustainability, including manufacturability, scalability environmental impact, societal value, and practical/market viability.
4. Foster strategic partnerships including cross-division, -directorate, and –agency, as well as international.
5. Government policies affecting all aspects of sustainability (e.g., CO_2 tax, environmental regulations, subsidies, IP handling).

Strategies
1. Create "Conversation Space" – Mechanism to bring industry (third party) and researchers (physical/social/economic/geo sciences and engineering) together to identify academic/industry/society needs and guide academic research towards a Market-driven (addressing societal needs) impact.

2. Create a "Sustainability Community" who defines common metrics, consisting of researchers, investors, policy makers, and industry. This must be done within NSF (among Directorates) and outside, where NSF serves as an unbiased and neutral participant/sponsor.
3. Incorporate systems-level thinking into solicitations related to sustainability and promote this way of thinking by educating reviewers and the general research community.
4. Top-down incentives (from AD level) to encourage strategic partnerships across the Foundation. For example, availability of matching funds. Or alternatively, create an "Office of Strategic Partnerships" which focuses on fostering internal and external partnerships (industry, federal and private funding agencies, etc).
5. Establish a strong collaboration between MPS/ENG and SBE to garner better understanding of government policy issues affecting all aspects of sustainability.

Question 3: Socioeconomic Challenges and Strategies for Addressing

Key Challenges:
1. Creation of a "Sustainability Research Community" that includes physical / social /economic /geo sciences and engineering.
2. Promotion of systems-level awareness in developing research and education programs to address sustainable energy issues. (Need internal NSF education, as well as education of research communities, students and postdocs).
3. Education and promotion to the public of the acute need for sustainable energy solutions. Public is misinformed about issues and lacks confidence in the scientific /engineering communities. This perception must be overcome in order to gain public acceptance of new clean, sustainable energy technologies.

Strategies:
1. Solicitation for Sustainability Research Community Centers (5-7 total nationwide, multi $M, ca. 5 yrs) that focus on a sustainable energy problem (e.g., non-petroleum based fuels, physical-economic model development, etc.) and involve all directorates (MPS/ENG/SBE/BIO/GEO/EHR).
2. Support sustainability research in individual investigator programs, but include annual reporting meetings to bring all PI's together to help create a community.
3. Internal NSF education on system-level thinking through targeted special seminar series.
4. NSF representatives should present and lead discussions about sustainability at professional meetings.
5. Ask PI's to "teach" with their highlights rather than create "hype".
6. MPS and ENG should work with SBE to sponsor a workshop addressing how to better interact with the Public – how can scientists and engineers do a better job "teaching" the public?
7. Revise Broader Impact requirements to emphasize "reality" on the technical side and "quality" (effectiveness) on the education/outreach side.
8. Create an "NSF Science Central" website maintained by professionals targeting grades 3-6 with energy science articles/games. This site should be linked to like-minded sites and be publicized as tools for teachers/schools.

Question 4: Education Challenges and Strategies for Addressing

Key Challenges:
1. Integration of the socio-behavioral-economic realities affecting a clean, sustainable energy future into the Science & Engineering students' mind sets.
2. Training Science & Engineering students to communicate better to the public.

3. Balancing depth with breadth in clean, sustainable energy undergraduate and graduate training/education programs.
4. Incorporation of clean, sustainable energy topics into K-12 and undergraduate education curricula.
5. Understanding the needs of industry, government, non-profit entities when designing clean, sustainable energy curricula.

Strategies:

1. Explicitly demonstrate and acknowledge SBE roles with MPS/ENG. For example, MPS/ENG should consider participating in Coupled Natural Human Systems (CNH) and Decision Making Under Uncertainty (DMUU) programs (i.e., collaborate on shaping the solicitations).
2. Increase the number of coupled collaborations between MPS and ENG funding systems-level problems (e.g., energy critical elements and carbon capture and storage) will provide training of graduate students in system-level thinking.
3. Collaborate with other Agencies to sponsor popular events where students participate intensively (e.g. DOE Solar Decathlon).
4. MPS/ENG should work with EHR to address new curriculum development in sustainability.
5. Support the SEES postdoc fellowship program as an excellent approach to train future leaders in this area.
6. Create an REU program specifically for science education majors; improving the training of K-12 science/math teachers.