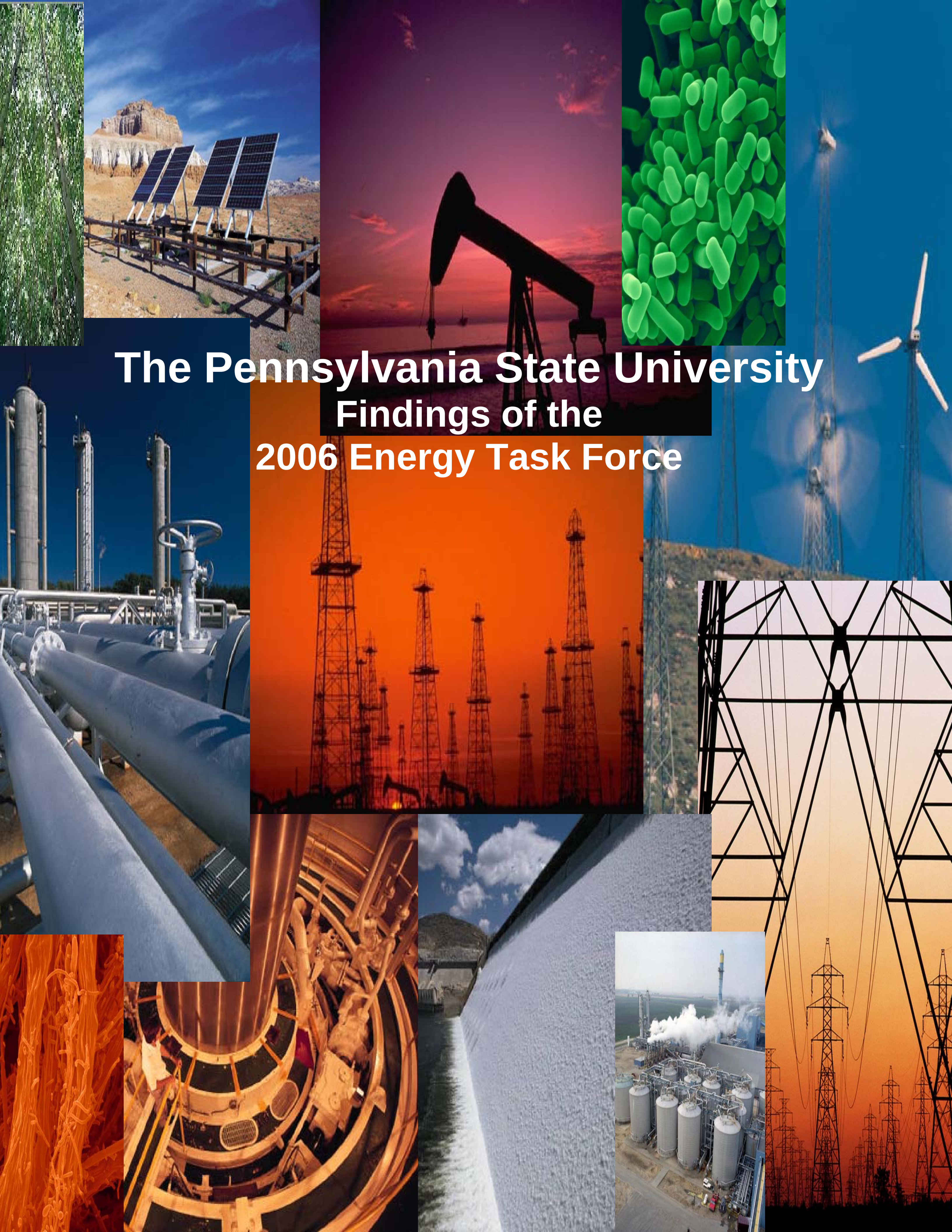

The Pennsylvania State University

Findings of the 2006 Energy Task Force

"The word *energy* incidentally equates with the
Greek word for *challenge*.
I think there is much to learn in thinking of our federal energy
problem in that light. Further, it is important
for us to think of energy in terms of a gift of life."

Thomas Carr, testimony to U.S. Senate Commerce Committee,
September 1974

"Sunlight, in its many guises, is the force that has shaped and driven the
miraculous living fabric of this planet for billions of years. It
embodies the best engineering, the widest safety margins, and the greatest design
experience we know. It provides amply for our needs, yet limits
our greed … it is safe, eternal, universal, and free. It falls justly and equitably on
South and North, East and West. It increases autonomy, fosters
diversity, and does not hurt the balance of payments.
Its quality is constant and high."

Theodore B. Taylor, *Skeptic*, March-April 1977

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A Strategic Energy Initiative for Penn State: Report of the 2006 Energy Task Force

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September 2006

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Executive Summary

Energy is the engine of technological and economic progress. Energy choices influence the environment across a range of scales, mold political alliances, and shape national defense commitments. Rapid growth of global energy consumption and slowing discoveries of new fossil energy reserves in recent years have brought the challenge of sustaining national and global energy security into sharp focus. The challenge is compounded by concerns that the combustion of fossil fuels is causing global warming and other environmental changes. Universities must step up to this challenge by training new generations of experts in energy, developing fundamental new energy knowledge and innovative applications of that knowledge, and finally reaching out to educate the public about energy issues and options.

Penn State is already a leader in many areas of energy and now is the time for the University to strengthen those areas and to invest in new areas of energy science and engineering in order to be an even stronger leader. This is the report of an intra-University Energy Task Force (ETF) charged by Senior Vice President for Research Eva J. Pell to develop a strategic vision and roadmap for energy science and engineering at Penn State.

The ETF recommends a bold new initiative in energy at Penn State that:

- develops an exciting new undergraduate and graduate curriculum in energy
- develops a visionary interdisciplinary research program in energy science, engineering, and policy
- engages scientists, engineers, stakeholders, and the public with a vigorous outreach program

Penn State has many strong energy sciences and technology assets in its colleges and institutes. Points of teaching and research excellence cover a range of topics, including: clean coal technology, efficient energy conversion and utilization, biomass fuels, energy economics and policy studies, solar energy, nuclear power, space-based systems, ultra clean fuels, hydrogen energy, and others. At present, however, these assets are not organized for optimal efficacy.

The specific recommendations of the ETF are:

For immediate payoff:

1. Establishment of one general education course in energy science, technology, and society which will be required for all undergraduate students

2. Development of upper-level integrative courses in energy across disciplines

3. Establishment of graduate minor and professional education and training certificates

4. Creation of new faculty lines to enhance research in the following areas:
   - clean coal, ultra clean fuels, carbon sequestration, and *in situ* coal extraction/conversion
   - materials and nanotechnology for energy efficiency

- genetically modified plants and microorganisms, sustainable biomass production systems, enzymatic conversion, and production of biofuels, bioenergy, and biomaterials
- hydrogen production, storage and transportation, and usage (fuel cells)
- social acceptance of nuclear power, nuclear power generation, the nuclear fuel cycle, and proliferation resistant nuclear power plants
- direct conversion of light to work with molecular transducers

For long-term payoff:

5. Development of a vigorous outreach program that targets K-12, establishes an energy extension service, engages continuing education (particularly the World Campus), and focuses on research and technology transfer opportunities

6. Creation of a new structure to facilitate the above recommendations, to be provisionally known as the *Penn State Institute of Energy Sciences and Technology* (PSIEST), with the stature and visibility of Penn State's other premier institutes. One or more donors should be sought to underwrite a new building to house this institute. To begin this initiative, the ETF recommends that the PSIE should be expanded to become the *Penn State Institutes of Energy and the Environment* (PSIEE), effectively integrating the strategic missions of the University in energy and environmental sciences and engineering. The transition to the PSIEST should occur at the earliest time when the synergy of research, University funding, and infrastructure allows.

A Bold Proposal for Energy at Penn State

The world has begun to confront a sweeping, long-term challenge to develop sustainable energy systems consonant with society's goals and the preservation of important environmental assets. Universities must step up to this challenge by training new generations of experts in energy, developing fundamental new energy knowledge and innovative applications of that knowledge, and finally reaching out to educate the public about energy issues and options. Penn State is already a leader in many areas of energy and now is the time for the University to strengthen those areas and to invest in new areas of energy science and engineering in order to be an even stronger leader. This report recommends a bold new initiative in energy at Penn State that:

- develops an exciting new undergraduate and graduate curriculum in energy
- develops a visionary interdisciplinary research program in energy science, engineering, and policy
- engages stakeholders and the public with a vigorous outreach program

The Motivation

During the period 1980-2001, global consumption of petroleum, coal, and natural gas increased by 22 percent, 27 percent, and 71 percent respectively (Chow *et al.*, 2003). Over that same period, annual global emissions of carbon dioxide from consumption and flaring of fossil fuels rose by 5.0-6.5 billion metric tons carbon equivalent. The most recent analysis from the U.S. Department of Energy (*http://www.sc.doe.gov/bes/reports/files/SEU_rpt.pdf*) estimates total global energy use at 410 exajoules per year. Put differently, this consumption level is equivalent to 13.5 billion metric tons of coal consumed per year. The International Energy Agency projects global demand for primary energy resources in 2030 to increase by 60 percent over current demand. Global annual consumption of petroleum in 2000 was 3.0 percent of proven reserves; coal was 0.5 percent of proven reserves; and natural gas consumption was 1.6 percent of proven reserves (Chow *et al.*, 2003). While exhaustion of these important resources is not imminent, it is within sight.

Hubbert (1956) noted that the production of natural resources, such as oil, seems to reach a maximum when about half of all the reserves of that resource have been extracted, leading to the notion of peak oil production. Hubbert's Peak, predicted in the 1950s, occurred in the United States in 1970. Kenneth Deffeyes, a professor emeritus at Princeton University, reasons that the world peak will come before 2009. Others say certainly by 2015 or 2020. Non-OPEC (Organization of the Petroleum Exported Countries) producers, which account for 60 percent of global oil production, will peak before OPEC producers, but even OPEC production is expected to peak by no later than 2025 (Kerr, 2005). This peaking signals tighter coupling of energy supply and demand, with potentially high economic volatility. Additionally, the impact on the Earth's biosphere of burning of hydrocarbon fuels at even current levels is of increasing concern. The impact on the Earth's greenhouse effect from the combustion of hydrocarbon fuels is indisputable.

The Intergovernmental Panel on Climate Change (McCarthy *et al.*, 2001) concludes that the Earth's climates are changing in a manner consistent with scientific expectations from the increasing concentrations of greenhouse gases in the atmosphere. Global temperature has risen on average by about 0.6°C over the 20th Century. To put that amount of warming in perspective, the Earth currently is only approximately 5°C warmer than it was during the last major ice age (the Pleistocene that ended 10,000 years BP), i.e., the warming of the 20th Century constitutes 12 percent of the warmth that distinguishes today's climate from an ice age. Rising temperatures and an accelerating hydrologic cycle have significant implications for both human and natural systems.

At the same time the United States finds itself at war in the Middle East, battling terrorists and extremists for control of a nation that is rich in petroleum reserves. A widening of the conflict in this critical region could have catastrophic impacts on world economies and societal stability. This volatile situation suggests that ensuring ready access to petroleum reserves and other resources in the region is urgent both for national economic security reasons and for purposes of equitable distribution.

With the above as a backdrop, it becomes clear to thinkers and planners at academic institutions around the country that they need to reassess how they can help the nation face this new energy challenge. Through the 1970s, energy science and technology was a major research area at universities, accompanied by significant federal support. This era ended in the late 1980s for one simple reason: oil supplies were allowed to grow faster than global demand, leading to declining real prices of oil, which removed the impetus from programs aimed at developing alternatives to petroleum. The root causes that led to this original upsurge in alternative energy research had actually not vanished—they were merely hidden by the low cost of oil on the world markets.

At many other major institutions, much of the science and technology infrastructure developed during this period of intensive energy research was either lost or redeployed as interest in the topic waned. At Penn State, by contrast, research in all aspects of energy—including alternative energy resources and processing—not only survived to the present, but thrived in the College of Earth and Mineral Sciences (EMS) Energy Institute and in smaller groups scattered across campus. Furthermore, as steady advances were made in the ensuing years in the life sciences and especially in molecular biology, completely new approaches to energy research, which had not yet even been conceived in the 1970s, were developed. Penn State recognized the need to strengthen research in the life sciences and created the Dorothy Foehr Huck and J. Lloyd Huck Institutes of the Life Sciences for this purpose. At the same time it was recognized that environmental sciences were also going to become increasingly important—particularly in dealing with energy-related challenges—and to position Penn State in this arena, the Penn State Institutes of the Environment was formed. *Thus, with these assets in place at Penn State, and with energy once again increasingly at the forefront of the national conscience, the time is appropriate for the University to reassess and realign its assets in all aspects of energy research.* The expected outcome of such a reassessment and realignment process is to develop the faculty, administration, and infrastructure that would allow the University to respond quickly and appropriately to rapidly changing developments in energy research and to become a local, national, and international leader in energy-related research, education, and policy development.

The Energy Task Force

In November 2005, recognizing the urgent need to provide a coherent and integrated set of recommendations for future investments in energy research, technology development, policy studies, education, and outreach, Eva J. Pell, Senior Vice President for Research, created a University-wide ETF. Deans from the colleges of Agricultural Sciences, Earth and Mineral Sciences, Engineering, the Liberal Arts, and the Eberly College of Science each appointed a faculty member to the ETF. The Associate Vice President for Research and the Director of the Penn State Institutes of the Environment served as the co-conveners. Members of the ETF are identified in the beginning of this report.

The charge given to the ETF was as follows:

1. Review the scope of current energy-related research
2. Develop a prioritized list of areas of strength at Penn State in the energy arena
3. From the list developed in number 2, identify those areas where focused effort will move Penn State into leadership positions at the state, national, and international levels
4. Identify the approaches to be taken within the areas identified in number 3 that could bring Penn State into the spotlight
5. Develop an inventory of opportunities that could support the approaches identified above through federal programs, anticipated federal programs, and industry sponsorship; suggest in which of these programs Penn State might be competitive

Drivers for Change

The ETF began with an assessment of the current context of the energy sector, the driving forces for change, the level of urgency, and the grand challenges associated with meeting society's energy needs. It was agreed that several confluent factors are necessitating a rapid change in energy policies, technologies, and research in the United States. These factors include:

- prospects for long-term increase of real energy prices
- public awareness and understanding of the imminence of Hubbert's Peak have increased
- greenhouse gas concentrations have increased resulting from fossil fuel combustion and the compelling linkage between this increase and rising global temperatures (global warming)
- international competition and contention for petroleum on a previously unprecedented (and increasing) level have been recognized
- high costs of maintaining secure access to oil and gas in the future

Because all of these factors rose to prominence in the national awareness nearly simultaneously, they have had a strong synergistic effect that has magnified their impact substantially beyond what might have been the case had they developed more slowly and asynchronously.

The Grand Challenge

Society now faces many new challenges in the energy sector. Chief among these is the grand challenge of creating an infrastructure for energy production and conversion that is sustainable, renewable, and ultimately based on solar energy with zero production rates of greenhouse gases.

The combustion of fossil fuels currently provides most of the energy we use. Fossil fuels, petroleum, coal, and related materials are energy-rich substances ultimately derived from a biological process, photosynthesis, which occurred over a timescale of billions of years. Photosynthetic bacteria, algae, and plants used solar energy to convert carbon dioxide and water into biomass while producing the oxygen-containing atmosphere that allowed all other life on Earth to develop as we know it today. The solar energy stored within these fossil fuels is released by combustion and produces carbon dioxide and water as by-products as well as pollutants, such as, oxides of nitrogen and sulfur, carbon monoxide, soot, and unburned hydrocarbons.

Energy production based upon fossil fuels is unsustainable; when these non-renewable resources approach exhaustion, their costs will rise prompting large-scale fuel substitution. Because the processes that were required to change ancient biomass into fossil fuel resources also required the input of enormous amounts of geothermal energy over nearly unimaginable time spans, these processes can only be duplicated on a very small scale in the laboratory.

As noted above, the world is presently consuming energy at a rate of approximately 410 exajoules per year. This is equivalent to a continuous consumption rate of 13 trillion watts, or 13 terawatts (TW). Because the Earth's population is projected to increase to nine billion people or more in this Century, and because of accelerating technological and economic development worldwide, even with aggressive conservation and energy-efficiency measures, energy demand is projected to double to ~30 TW by 2050 and to triple (~46 TW) by the end of the 21st Century. Much of the growth in demand will be fueled by the rapidly developing economies of China and India.

Only a few energy sources are available on Earth to meet our future energy needs: fossil fuels; nuclear energy; winds, tides, and geothermal energy; and solar energy. Fossil energy is being consumed at rates that exceed discovery of new reserves, and their consumption adds greenhouse gases to the atmosphere. To stabilize the atmosphere at even twice the pre-anthropogenic carbon dioxide level (440 ppmv versus 370 ppmv today) would require greater than 10 TW of energy from a renewable, carbon-neutral source by 2050. To produce the entire 10 TW of electricity (TW_e) from nuclear power would require the construction of one 1-GW_e nuclear-fission power plant somewhere in the world every other day for the next 50 years, and once completed, the challenge would be to provide fuel for those power plants. Various fuel alternatives are being explored and it is generally estimated that the worldwide supply of uranium ore is sufficient to fuel the deployment of about 1000 reactors over the next half century, which would cover about one-tenth of the estimated required new capacity. The practically exploitable hydroelectric potential remaining on Earth is estimated to be less than 0.5 TW_e, and the cumulative energy in tides is only 2.0 TW_e. The total amount of globally available wind energy is estimated to be 2.0-4.0 TW_e. Finally, the total geothermal energy at the surface of the Earth is estimated to be about 12.0 TW, but only a small amount of this energy could practically be extracted.

There is no single, near- and long-term option for the recovery of energy on the scale that is required to meet anticipated needs for the future. A mix of fuels, both renewable and non-renewable, will be required in the near- and medium-term. However, solar energy, both directly and embedded in biomass, is clearly the answer in the long-term. The solar constant at the upper atmosphere is 170,000 TW, of which about 70 percent (120,000 TW) reaches the surface on average. Thus, the sun provides by far the greatest energy source available, and in the long-term this is the energy source that we must learn to harvest and convert into usable energy through systems that are efficient and effective. Ultimately, we will probably collect solar energy and convert it to work directly, that is, without having to produce a combustible fuel which is then converted to other forms of energy. (This will never completely be the case, however, since stored energy or fuels will be required during those periods when sunlight is not available, e.g., at night.) We might collect this solar energy in near space, so that even more energy can be harvested per unit area than reaches the Earth's surface beneath its atmosphere.

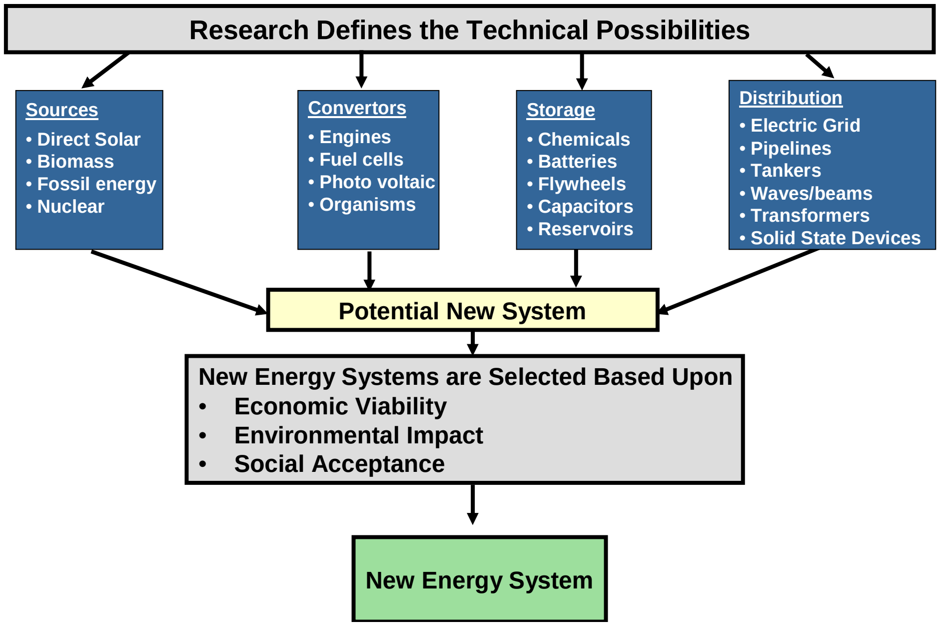
Wherever energy is ultimately harvested, direct and efficient conversion of solar energy into work will reduce greenhouse gas emissions to nearly zero and will reduce the losses that occur due to inefficiencies in each step of energy conversion. Until we can do this—and today we cannot, even with photovoltaics, photo electronics, and solar thermal methods—the next best approach will be to mimic nature by producing fuels from plants and biomass. This approach currently suffers from many of the inefficiencies inherent in extant energy production and conversion processes, and it will necessitate many advances in agriculture for energy production while maintaining food production, but it has the advantage of being sustainable and potentially carbon-neutral. Moreover, biological processes can also be developed to provide carbon-containing compounds for plastics and other materials now dependent on fossil fuels.

Given the importance and complexity of providing future energy needs, Penn State should strive to conduct a vibrant basic energy research program while simultaneously evaluating that research in the context of its potential to meet the world's energy challenges at a scale that is environmentally, economically, and socially acceptable. We must be prepared to quickly adjust to emerging research results, account for economic and environmental characteristics of proposed energy solutions, and anticipate social attitudes toward those solutions. We should actively participate in the process of providing information regarding emerging energy trends to the public and in assessing the public's reaction to those trends.

Developing New Energy Production Systems

Energy production systems consist of most, if not all, of the following elements: sources, converters, storage, and distribution. Research plays a vital role in defining and implementing the universe of technical possibilities for improving different aspects of these systems. Research also constrains the selection of new energy production systems based on economic viability, compatibility with environmental goals, and overall social acceptance. The elements that comprise the development of new energy production systems are shown in Figure 1. They provide a framework for evaluating Penn State's energy assets and the ETF's recommendations for strengthening those assets and developing new areas of strength.

Figure 1. The Development of New Energy Systems



Penn State Assets and Opportunities

The ETF examined Penn State's extant assets in energy research, technology development, and education. At the outset of the Task Force's effort, it was clear that the University has numerous assets that are either already thriving, or are in place but are not aggregated for optimal efficacy. Our assessment indicates that Penn State has numerous resources that can be brought to a new level of coordination, organization, and effectiveness to address the challenges and opportunities in the emerging alternative-energy sector. The following assets, listed in alphabetical order, are considered to be foundational to any new integrated initiative in energy:

- Applied Research Laboratory
- Center for Bioinorganic Chemistry
- Biomass Energy Center
- Breazeale Nuclear Reactor
- Electrochemical Engine Center
- Energy Institute
- Penn State Institutes of the Environment
- Hydrogen Energy Center
- Materials Research Institute
- Pennsylvania Transportation Institute
- Propulsion Engineering Research Center

These assets are at different levels of development. The Applied Research Laboratory and Breazeale Nuclear Reactor (Nuclear Regulatory Commission Rod Bundle Test Facility, Reactor Loop Test Facility, and the Energy Conversion Evaluation Facility) are each well-established with long histories of research related to energy. The Pennsylvania Transportation Institute is also a well-recognized entity that has a strong history of service to the state and to industry. Strengths in combustion science and technology are well-established across both the colleges of EMS and Engineering, which include respectively, the Energy Institute and Propulsion Engineering Research Center, among others. The Center for Bioinorganic Chemistry has a strong reputation in biocatalytic chemistry related to photosynthesis and electron-transfer reactions in biological systems. The Hydrogen Energy Center and the Electrochemical Engine Center are newer units that have already begun to have real impact and success in their respective areas of research and development. The Biomass Energy Center is emerging and will be a most welcome addition to the Penn State energy research portfolio. Finally, the Penn State Institutes of the Environment is an essential asset because problems related to the environment are among the most important drivers for new research in energy. A series of summary charts for the research strengths/priorities embedded in these and other Penn State assets are included in Appendix I.

A careful analysis of current and expected future needs in the energy research and technology development sector, and a mapping of Penn State strengths and assets onto these needs, was another part of the ETF's overall consideration of opportunities in the energy sector. To summarize this effort, we created a series of seventeen "quad charts" to help map out where near-, medium-, and long-term opportunities likely will be for the University. Each quad chart (see Appendix I) includes descriptions of the Research Priority, Research Clusters and Opportunities, Needs, and Rationale. The topics (in alphabetical order) are:

1. Advanced Power Generation
2. Biomass Conversion Technologies
3. Biomass Feedstock Production
4. Coal
5. Economics and Tax Policy
6. Efficient Combustion, Energy Conversion, and Utilization
7. Energy Extension and Outreach
8. Energy from Space-Based Systems and Sources
9. Energy Systems Science
10. Environment (not covered in other topics)
11. Hydrogen Energy
12. Materials
13. Nuclear Energy Technologies
14. Nuclear Fuel Cycle
15. Social and Policy Studies
16. Solar Energy
17. Ultra Clean Fuels

Recommendations

The primary objective of the ETF's work was to provide the University's administration with a coherent set of recommendations for current and future investments in energy that would address needs for near-, medium-, and long-term solutions to energy problems. We chose to structure recommendations along the lines of the University's main goal, which is to be the best in the country at the integration of learning, discovery, and engagement. Therefore, the ETF makes the following recommendations in education, research, and outreach activities related to energy:

Learning (via Education)

- Establish a general education requirement for ALL Penn State undergraduates (see Appendix II)
  - One basic (required for all) course in energy science, technology, and society
    - From fossil energy to sustainable energy
    - Interdisciplinary and team-taught by social, biological, physical scientists, and engineering faculty
- Develop upper-level integrative courses on energy across disciplines through new faculty lines co-funded by interdisciplinary research programs and colleges
  - Engineering
  - Agricultural , Chemical, Life, and Physical Sciences
  - Business and Social Science
  - Economics and Policy
- Establish a graduate minor and professional education and training certificates
  - Integrative Energy Research and Graduate Studies (iERGS)

Discovery (via Research)

For immediate payoff:

- Enhance research on clean coal, coal-based fuels, carbon sequestration, and *in situ* coal extraction/conversion as well as on materials and nanotechnology related to increasing energy efficiency through new faculty lines co-funded by the research office-funded interdisciplinary units and colleges.

For long-term payoff:

- Enhance research in the following areas through new faculty positions co-funded by the research office-funded interdisciplinary units and colleges:
  - Genetically modified plants and microorganisms, sustainable biomass production systems, enzymatic conversion, and production of biofuels, bioenergy and biomaterials
  - Hydrogen production, storage and transportation, and usage (fuel cells)
  - Social acceptance of nuclear power, nuclear power generation, the nuclear fuel cycle, and proliferation resistant nuclear power plants
  - Direct conversion of light to work with molecular transducers
  - Extraterrestrial harvesting, collection, and transfer of solar energy
    - solar collector satellites in geosynchronous orbit

Engagement

- Outreach
  - Initiate K-12 education by faculty and graduate students
    - Summer camps for K-12 teacher development
    - K-12 curriculum development

  - Create Energy Extension Service
    - County-level professional staff to translate Penn State's energy knowledge and expertise to the general public, businesses, and government in the Commonwealth's 67 counties
- Continuing Education
  - Involve World Campus (e-Penn State on the WEB)
    - Develop courses, certificates, and degrees in energy technology and policy
  - Develop Executive and Professional Education
    - Emerging energy issues and technological solutions
- Research and Technology Transfer
  - Expand programs in industrial and small business research for economic development
  - Develop public-private partnerships to accelerate innovation and technology deployment
  - Exploit state and federal funding sources including SBIR programs in DOE, NSF, and USDA; PEDA, PA Energy Harvest, PENNTAP, and the Ben Franklin Technology Center of Central and Northern PA, Inc.

Restructuring Energy at Penn State

The structure of an organization should be such that it both reflects the organization's purpose and facilitates the achievement of its goals. In order for Penn State to be even more fully recognized as a premier "Energy University" in the United States and overseas, this initiative must ultimately lead to a *Penn State Institute of Energy Sciences and Technology* with the stature and visibility of Penn State's other premier institutes (Environment, Life Sciences, Materials, and Social Science). In light of the probable increase in society's efforts to secure adequate energy supplies in the future, the ETF believes that a signature Energy Building should be sought to house this new institute. Potential donors to the Energy Building concept should be approached immediately—this should be a high priority of Penn State's Development Office. However, in recognition of the benefits of beginning an energy initiative quickly and with minimal administrative start-up costs, the ETF recommends that a two-stage implementation process be adopted (see Appendix III). Initially, the PSIE should be expanded to become the *Penn State Institutes of Energy and the Environment* (PSIEE), effectively integrating the strategic missions of the University in energy and environmental sciences and engineering. This will strengthen ties between the environmental and energy communities at Penn State, which will broaden our capacity to work on problems in this important cross-over area. *The creation of a PSIEE with concomitant expanded funding (see next section) should happen immediately*.

We anticipate that the energy component of the PSIEE will grow in stature rapidly. The transition to an independent PSIEST should be made when a synergistic balance of research accomplishments, financial resources, and physical plant is achieved. At that time, the PSIEE would be expected to revert back to the Penn State Institutes of the Environment, with its former mission and scope. The creation of PSIEST would foster interdisciplinary research, support the development of the proposed Integrative Energy Research and Graduate Studies (iERGs) program, and serve as the intellectual and organizational center of outreach and technology transfer activities. Given the immediacy of the research needs as well as the window of opportunity for advancing Penn State to a leadership position in this area, the ETF recommends that this transition to independence should be put on a fast track to occur within a five-year period.

Building the Capacity to Lead

The ETF gave strategic thought to the resources that will be required to develop, and in some cases extend, Penn State's leadership in key topical areas. It was considered wise to build on current models in the existing institutes. We recommend that resources be made available to co-fund new faculty lines across the colleges in areas that this report has highlighted. Doing this in an organized fashion, with annual allocations of resources being made on the basis of a competitive grants basis, is the best approach we can imagine for creating new momentum in energy research at Penn State. Other funds will be used to fund seed grants for research or course development, especially for interdisciplinary teams that join energy and environmental issues together intellectually. We are not in a position to know what magnitude of funding might be available, but we developed a rough-cut recommendation based upon faculty lines and associated start-up costs. Our basis was to assume that 33 FTEs will be added in energy-related research in the near-term (3-5 years) and that the Office of the Senior Vice President for Research will provide the Director of the new energy structure with funds for half of the salaries and start-up for these faculty as outlined in Table 1. We strongly recommend that an expansion of faculty FTEs should be accompanied by a vibrant graduate fellowship program.

The annual costs for the Energy Institute would be approximately $1,785,000 for ongoing salary sharing and the capital for start-up would be approximately $8,250,000.

In the long-term (5-10 years), Penn State must continue to invest in new positions in addition to those listed for near-term development. Areas that will require further expansion of faculty lines include biomass fuels, solar energy, nuclear energy, fuel cells, and environment particularly in the area of carbon-cycle science and management. Energy outreach will also require additional lines. We must be cognizant of emerging strengths within an area, hence concentrate new hiring in order to leverage those strengths toward building a world-class reputation. This has worked well in other cross-disciplinary areas at Penn State, such as, infectious disease ecology. Moreover, some of these new faculty lines should go toward hiring individuals working in novel, high-risk areas. This hiring maximizes Penn State's potential to lead the way in developing innovative energy concepts.

A doubling of new positions in the long-term over those requested for the near-term is indicated if we are to compete with other leading institutions, such as, MIT, Stanford, Purdue, Rice, and Georgia Tech to name a few. Some of the long-term growth can be expected to derive from recycled positions from other, less strategic areas.

Table 1. Resources Needed to Begin an Energy Initiative

Topical Areas for Near-Term Development	**FTE***	**Areas to Hire Into**	**Relevant Quad Charts**
Efficient Fossil Energy Conversion and Utilization including Environmental Challenges	4	catalysts (2) combustion & emissions *in situ* underground processing	Coal Efficient Energy Conversion/Utilization Environment Economics Ultra-Clean Fuels
Biofuels Production/Conversion including Economics	7	agro-ecosystem modeling biomass production technologies plant biotechnology biocatalysis chemical catalysis separations bioprocess modeling & scale-up industrial ecology of biomass & biofuels	Biomass Feedstock Production Environment Economics Social & Policy Studies
Hydrogen Production and Storage	2	gas & electron production & storage	Hydrogen Economics
Nuclear Power and Fuel Cycle	4	fuel cycle analysis waste storage/disposal novel systems & reactor engineering	Nuclear Fuel Cycle Social & Policy Studies
Solar Energy and Space-Based Systems	8	molecular conversion (5) photovoltaics (2) space-based platforms	Solar Energy Energy from Space-Based Systems & Sources Economics
Social – Political – Economics	8	integrated assessment modeling public acceptance environmental economics/biomass production international security/proliferation cap & trade	Economics & Tax Policy Social & Policy Studies
TOTAL	**33**	**Half of Start-Up for 33 FTEs**	
*16.5 Central/OSVPR + *16.5 Colleges			
Fellowship/Traineeship Program	$300,000		
Annual Costs		**Notes**	
$1,785,000	FTEs	Half of a 36-week salary basis of $90,000 for 33 FTEs plus 10 fellows @ $30,000/fellow	
$8,250,000	Capital	Half of start-up of $500,000 for 33 FTEs	

Summary and Conclusions

At this early point in the 21st Century, a technological shift is upon us that will be as historic in its impact as was the first industrial revolution. This country, Western Europe, and eventually the rest of the world have no choice but to begin to wean their societies off expendable cheap energy sources that have been stored in the Earth for eons. Expanding the living standard enjoyed in the industrialized west over the last 200 years by relying on non-renewable hydrocarbon energy sources is a goal as unachievable as it is unsustainable. Our systems for the inter-conversion of stored energy and for the release of that energy to do work are simply too inefficient when considered in light of our actual levels of stored energy resources. This problem is social and political as well as technological, and it will become increasingly intensified as the world population grows to a predicted global level of 9-12 billion people by the end of this Century. Hence, there is an unprecedented urgency for research to find and to develop truly new means of capturing and storing renewable energy resources that will not be diminished with time; this urgency will grow rapidly as fossil fuels are depleted and the population and demand grow.

Compounding the problem of filling the looming energy gap is the need to avert environmental degradation. One of the great challenges of this Century will be stabilizing greenhouse gas concentrations in the global atmosphere, thus slowing the rate of climate change. The natural processes for removal of carbon dioxide from the atmosphere are incorporation into plant biomass and absorption into the ocean. Both are relatively slow processes compared to the production of carbon dioxide by fossil fuel combustion in the unprecedented quantities anticipated in the near future. It is the source side of the CO_2 problem that we can address by providing alternates to fossil fuel to produce energy.

All of this is evidence of the need to do more research into energy—conservation, inter-conversion processes, resources, allocations, alternatives, and the effects on our environment of energy decisions that societies will make in the ensuing decades. Energy and the environment are tightly coupled now and will be even more so in the future. Concern for the environment motivates the development of new means to achieve cleaner fossil energy sources. Carbon dioxide sequestration at the downstream end of combustion systems will only be implemented when it is mandated because of concern for the environment. Similarly, the drive toward fossil fuels with no sulfur and high H/C ratios has as its rationale a cleaner environment. When we seek to produce combustible fuels from plant matter, we do so because we know that the carbon dioxide produced by their combustion will be biologically sequestered into new plant matter. While this will not reduce the bolus of carbon dioxide we have already placed and are continuing to place into the atmosphere, it will not add to it either. The environment and the expendability of our supplies of fossil energy are co-equal drivers for change in our technology now and for the future. We should seek a clean, safe, and stable energy environment.

Penn State is well-positioned to be a leader in the development of new knowledge needed to train energy professionals, develop energy technologies, manage energy resources, and implement energy policy. Combined with our heritage of education and engagement, our agricultural, engineering, and science research excellence provides underlying strength in all aspects of the energy challenge. We are well-equipped and ready to lead society into new directions through research, teaching, and outreach. To do so we must act now: we must invest quickly, and we must be prepared to sustain our support for energy science, technology, education, and policy even as the waves of political reversal and cultural vicissitudes wash over us in the coming decades. As an institution, Penn State should pursue this course in energy not simply because it may be opportunistic to do so now, but because it is our responsibility to serve the people of Pennsylvania and the United States.

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Appendix I

Opportunity Quad Charts

(alphabetical order)

1. Advanced Power Generation
2. Biomass Conversion Technologies
3. Biomass Feedstock Production
4. Coal
5. Economics and Tax Policy
6. Efficient Combustion, Energy Conversion, and Utilization
7. Energy Extension and Outreach
8. Energy from Space-Based Systems and Sources
9. Energy Systems Science
10. Environment (not covered in other topics)
11. Hydrogen Energy
12. Materials
13. Nuclear Energy Technologies
14. Nuclear Fuel Cycle
15. Social and Policy Studies
16. Solar Energy
17. Ultra Clean Fuels

Research Priority

1. Advanced Power Generation

Description

Electrical power generation represents ~40% of US energy consumption. Currently that energy is produced from coal combustion (~50%), natural gas combustion (~20%) and nuclear reactors (~20%). Significant changes are expected over the next 15-20 years as advanced power generation systems are developed that operate on coal-derived syngas and hydrogen, and have very high efficiencies and near-zero carbon emissions. These systems will require new technologies for low-emissions combustion, hydrogen combustion, coal gasification, fuel synthesis, high-efficiency turbines, fuel cells, high-temperature materials and CO_2 sequestration. Penn State has proven expertise in nearly all of these areas and therefore is capable of making significant contributions to this effort.

Research Clusters	Opportunities
High Efficiency Turbomachinery COE researchers are known nationally for their work on aero thermal processes in power generation turbomachinery. This work is supported by DOE, AFOSR, and gas turbine manufacturers. ***CO_2 Capture and Sequestration*** Researchers in the EMS Energy Institute (CO_2 capture through carbonate storage, removal from stack gas, in-bed removal) and CoAS (carbon sequestration with innovative crop management such as switch grass and tillage techniques) are nationally known. ***High-Temperature Components*** Researchers at MRI, COE, and EMS have a broad range of expertise relating to this topic in the areas of advanced materials and coatings. ***Probabilistic Design Methodologies*** There is considerable expertise in the COE, although currently not focused on problems of interest to the power generation industry. ***Advanced Combustion Processes*** COE and EMS researchers are known nationally for their work on fundamental and applied combustion processes in gas turbine systems. This work is supported by DOE, AFOSR, and gas turbine manufacturers. ***Advanced Numerical Methods*** Researchers in COE have developed state-of-the-art computational facilities and are well-recognized in the power generation industry.	Advanced power generation systems that operate on coal-derived syngas and hydrogen, have very high efficiencies, and produce near-zero carbon emissions are the focus of DOE's *FutureGen* and *Vision 21* Programs. These are cross-disciplinary programs based on the successful development of a number of advanced technologies, including: - coal gasification systems with feedstock flexibility - hybrid technologies that combine coal combustion and coal gasification - combined-cycle gas turbines and high temperature (>1700°C) gas turbine cycles - CO_2 sequestration technology In addition to federally funded programs, opportunities for state funding are expected in the area of advanced power generation. Furthermore, advanced power generation is closely coupled to the development and use of coal-derived syngas and hydrogen, thus there is a strong tie-in to Pennsylvania's coal industry.

Needs

- To establish a focused interdisciplinary research effort devoted to the development of advanced power generation systems. This effort should address both technical and policy issues affecting the successful development of such systems.
- To establish an industrial consortium involving gas turbine manufacturers, coal suppliers, companies with coal gasification capabilities, the power-generation industry, and DOE Laboratories.
- To establish a critical mass of research expertise in the area of coal gasification.
- To focus existing expertise in probabilistic design methodologies to address research issues of relevance to the power-generation manufacturers.
- Application of biological solutions to clean fuel production

Rationale

- Electrical power generation will continue to represent a significant fraction of US energy needs. Therefore the transition to high-efficiency, environmentally acceptable advanced power generation systems is essential for continued social, economic, and political stability in the US. The successful development of advanced power generation systems will require a broad spectrum of resources that the State of Pennsylvania and Penn State are well positioned to provide.

Research Priority

2. Biomass Conversion Technologies

Description

Biomass can supply much of our transportation fuel demand, produce electricity and heat, and is the only renewable source of carbon for chemicals and materials. Successful integrated biorefinery systems will require innovative research on a range of conversion technologies.

Research Clusters	Opportunities
Microbial Fuel Cells Internationally recognized program includes collaboration among Engineering, Science, EMS, and Ag Sciences.	This technology has the potential to revolutionize wastewater treatment and tap natural systems for power at remote sites. Strong continued funding potential from DOD, NSF, EPA, and DOE.
Cellulosic Ethanol Strong program in Ag Sciences, with collaboration expanding to include Engineering, Science, and EMS.	Cellulosic ethanol will play a critical near-term role in increasing energy security. Increasing support from DOE, NSF, USDA, state agencies, and industry.
Combustion and Gasification Strong program in EMS, with emergent collaboration with Ag Sciences. Integrates well with Penn State strengths in fossil-fuel combustion.	Established and rapidly expanding industry in Pennsylvania. Increasing DOE and state support for thermochemical biomass conversion processes.
Biodiesel and Bio-oils Well-developed collaboration among Engineering, EMS, Ag Sciences, and OPP. Student entrepreneurs supply biodiesel to Penn State farms and OPP.	Moderate funding from USDA, commodity groups and EPA for soybean and oilseed conversion, use, and air emissions research. Limited support from DOE.
Anaerobic Digestion Strong outreach and modest research program in Ag Sciences. Currently expanding to include Engineering.	Strong potential for support from state agencies. Penn State OPP planning to build an anaerobic digester that could also serve as an applied research and demonstration facility.
Hydrogen from Biomass Strong collaboration between Engineering and Ag Sciences, expanding to include Science	Successful track record with federal funding likely to continue as long as DOE and NSF continue to prioritize hydrogen.

Needs

- Scientific and engineering expertise in systems integration, sensors and controls, nanobiotechnology, and biocatalysis.
- Expanded outreach linkages with industry and state agencies.
- Partnerships with the Commonwealth and federal agencies to develop a Biomass conversion pilot-plant for research, teaching, and outreach.

Rationale

- The US, including Pennsylvania, is blessed with a wealth of biomass resources, which can provide the foundation for a sustainable bio-based economy in the 21st Century.
- Penn State has strong research programs on the conversion of biomass to electricity, transportation fuels, stationary power and heat through thermal, chemical, and biological mechanisms.
- Environmental benefits of these technologies include reduced use of fossil fuels, carbon-neutral energy, and reduced vehicular and industrial air emissions.
- Inherent synergies between biomass energy, life sciences, environmental and materials research can strengthen multiple Penn State initiatives.
- This research area is a priority for the federal government. DOE biomass research budget proposed to increase by 80% this year. NSF, DOD, and EPA are all increasing funding opportunities as well.
- State and federal funds are available for industry partnerships. Targeted federal programs include SBIRs and Rural Development funds. Pennsylvania programs include Energy Harvest grants and loans.
- Emerging industries need opportunities for hands-on learning and demonstration. A pilot plant facility would position Penn State as a regional center of excellence.
- Other industries will benefit from this research. A bio-based oil platform can also produce hydraulic fluids, lubricants, and precursors for plastics, textiles, and coatings. Lignocelluloses and sugar platforms will produce high-value chemicals, pharmaceuticals, fibers, and biocomposite materials. Basic research will benefit biotechnology, food, pharmaceutical, and other industrial sectors.

Research Priority

3. Biomass Feedstock Production

Description

The DOE and USDA estimate that there is over one billion tons of biomass available annually in the USA. Large-scale production of bioenergy will require development of new crops and appropriate production, harvest, and storage strategies.

Research Clusters	Opportunities
Crop Production Penn State's 14,000 acres of agricultural land includes dedicated research programs in perennial grasses, biomass tree crops, oilseeds and grains. The USDA-ARS's biomass crop systems scientist is housed at Penn State.	The USDA and DOE have prioritized biomass feedstock production in several recent RFPs. Penn State has the strongest crop research/extension program in the Northeastern US.
Harvest Technology Strong programs in traditional crop-harvesting systems. Existing nationally ranked programs in forage handling directly translate to biomass crops.	Materials handling and transport costs are the primary constraint on biomass feedstock procurement. Strong funding from USDA, and little competition in the northeastern US.
Biomass Storage and Pretreatment Penn State researchers pioneered the lowest cost strategy for biomass storage. World-class experts in Ag Sciences, Science, and Engineering collaborating to address pretreatment needs.	Many biomass crops are only harvested once per year, making year-round storage a critical system component. Current funding from USDA and DOE, with little competition nationally.
Plant Biotechnology The Schatz Center for Tree Molecular Genetics performs research on hybrid poplar, chestnut, and other potential biomass crops. Strong programs in agricultural crop genetics.	Advances in plant biotechnology offer opportunities to increase biomass yield, and improve conversion efficiencies. Strong funding from USDA, commodity groups and industry.
Feedstock Characterization Strong programs in Ag Sciences and EMS working to characterize biomass quality, geographic distribution, and potential yields.	Essential complement to other biomass program areas. Strong potential for support from state agencies and in collaborative federal grants.

Needs

- Integration of biomass production with existing agricultural and silvicultural systems to maximize economic and environmental benefits.
- Development of infrastructure of extension educators and technical specialists to assist large numbers of landowners with varying assets and goals.
- Partnerships with state agencies and industry to meet 50% cost share on many federal funding programs.

Rationale

- Biomass resources can provide a foundation for both energy and materials, and are the only renewable source of carbon for fuels and chemicals.
- Pennsylvania has the most diverse and productive agricultural and natural resource system in the Northeastern US.
- Penn State has very strong research programs in agriculture and silviculture, with research expertise in the diverse crops and cropping systems appropriate for the region.
- Penn State's exceptional integration of research and extension outreach is the envy of the region.
- Development of a bio-based economy will require a major transformation of rural landscapes and communities. The success of this transformation will depend on coordination between farmers, foresters, communities, and industrial enterprises. Penn State has the expertise and infrastructure to catalyze this sort of sustainable economic development in Pennsylvania and the region.

Research Priority

4. Coal

Description

Coal is a secure, abundant domestic energy resource. Coal is one of only two options—the other being nuclear—for base load electricity generation in the next 25 years. Existing and emerging technologies offer ways to convert coal to liquid transportation fuels. Coal can also be a rich source of chemicals and premium carbon materials.

Research Clusters	Opportunities
Combustion and Emissions	Improved cycle efficiency in coal combustion systems; development of multifuel or flexifuel combustors; emissions control (e.g., Hg); CO_2 capture and sequestration.
Clean Liquid Fuels	"Refinery ready" coal-based fuels (e.g., JP-900); catalysis for direct liquefaction or downstream liquid treatment.
Carbon Materials and Chemicals	"Commodity carbons" such as graphite and activated carbon; specialty premium carbons—fibers, foams, nanocarbons, etc. New routes to valuable aromatic compounds, e.g. high-tech polymer precursors.
Catalysts	Use of coals directly as catalysts for various reactions, including "green oxidations" with hydrogen peroxide.
Underground (in situ) Processing	Development of technologies to use coal without mining it; reduction or elimination of workplace hazards and/or environmental issues.
Beneficiation	Improved tailoring of coal properties for specific applications or reduction/removal of targeted potential emissions.
Medical Geology	Control of hazardous emissions in domestic heating/cooking in developing nations.

Needs

- Strongly enhanced modeling and understanding of reactivity and properties related to composition and structure.
- Improved understanding of variability of coal properties, e.g., within seam or within given geographic region.
- Fundamental exploration of unusual coal properties that could have huge payoff—e.g., anthracites are semiconductors.
- R&D in support of "coalfinery" for multiple products.
- Accurate reassessment of US coal resource base.
- Development of sustained financial support base for coal research comparable to universities of Kentucky and North Dakota.

Rationale

- US has enormous reserves of coal; historically price has been very stable compared to wild swings of oil and gas; coal could supply base load electricity and transportation fuels for decades if need be.
- Government support for coal R&D is highly cyclical. The previous resurgence of coal research (70s to early 80s) was aided greatly by development of sophisticated analytical instruments in 60s and 70s. The next "wave" will be aided by sophisticated computational methods for structural and reactivity modeling of large molecules (e.g., proteins) developed in recent decades.
- Penn State's Energy Institute remains recognized worldwide as a leading institution for coal research.
- Coal remains an important industry in some segments of the Commonwealth. Coal R&D dovetails with the land-grant mission of the University.
- The unstable geopolitical situation surrounding oil means that it would be very prudent to position coal to make a quick comeback as a provider of the nation's energy.
- The likely continued, and potentially increased, use of coal, whether in Pennsylvania or elsewhere, demands a focus on increased efficiency (lbs CO_2/Btu) and CO_2 capture and sequestration methods.

Research Priority

5. Economics and Tax Policy

Description

A wide range of policy responses to changes in the energy field will be driven by economics and cost factors. Indeed, much of the demand for new knowledge of energy production and distribution systems will be driven by economic considerations. At present, Penn State is not well-positioned to take on integrated economic and energy technology modeling. We simply do not have the faculty members in sufficient numbers for critical intellectual mass.

Research Cluster	Opportunities
Pricing and Consumer Response	How will mass consumers respond to various levels of energy prices, changing their behavior in what ways in response to what price levels? There is some localized strength in EMS.
Taxes, Incentives, and Government	What mix of increased taxes and targeted tax incentives will be effective in spurring conservation and technical innovation?
Market Mechanisms (especially in the area of carbon trading)	How can market mechanisms such as cap-and-trade markets be used? This is particularly important in implementing carbon trading schemes. This is an area of strength at Penn State, including faculty in EMS and CoAS. Funding opportunities are strong at NSF, DOE, USDA, and EPA.
Industrial Development Opportunities (especially in the area of nanotechnology)	What new economic opportunities will be developed and who will recognize them? How can this be encouraged / incubated? There is limited capacity in the CoE to approach issues of nanotechnology as it relates to the overlap of energy and environmental economics. There is untapped potential in the CoLA—Economics.
Distributed Energy Production	What is the feasibility and future of highly decentralized energy production facilities, at the scale of a single household? What are implications for large energy utilities? Are there implications for environmental justice? There are small clusters of faculty in the CoAS, CoLA, and EMS working on these issues. Funding opportunities are not immediately apparent.
Life Cycle Analysis in Economics	Economics of mass and energy flows and the associated costs using principles of mass balance. This is an emerging area of strength, mostly within EMS. Potential funding sources include NSF and EPA.

Needs

- There is a need to recruit economists specializing in energy at Penn State. New positions in areas such as cap-and-trade mechanisms and life-cycle analysis should be considered.
- There is a need for structured approach that has a core mission to bring together existing experts in energy economics to coordinate on research with technical experts.
- Involvement of theoretical and applied economists in team projects involving technical specialists would be helpful, especially in bringing strengths in industrial management/economics.

Rationale

- Current concerns over energy supplies are partly prompted by economic forces.
- Economic forecasting and studies of consumer and industrial response to rising energy costs and energy alternatives at various price points.
- Evaluations of tax-incentive policies are crucial to charting appropriate policy incentives.

Research Priority

6. Efficient Energy Conversion/ Utilization

Description

The effective use of energy by combining improved efficiency and use of fuel-flexible technologies is the most promising near-term approach to reduce the growth rate of energy use in the US. Research to improve the efficiency of energy-related technologies involves a wide range of expertise including combustion, fuel science, transportation, building design, and social policy. As alternate fuels such as biodiesel, syngas, and LNG become available, current and future combustion systems must be able to operate efficiently using this wide range of fuels. Penn State is well positioned to provide technical and social-policy leadership in the implementation of efficient energy conversion and utilization.

Research Clusters	Opportunities
Transportation Internationally recognized research in the Energy Institute, COE, Ag Sciences and the PTI allow Penn State to address energy utilization starting from in-cylinder combustion processes to vehicle-level innovations for internal combustion engine-based transportation. Coupled with expertise in the social sciences, Penn State can provide the assistance to consumers needed to adjust to new transportation scenarios.	State (DEP) and federal (DOE, AFOSR, ONR) agencies' interest in fuels such as hydrogen, biodiesel, and coal-derived alternatives to petroleum-based fuels requires a broad-based research approach. Penn State's current strengths in combustion, fuel science, and agriculture provide an opportunity to cement our leadership position in the production and utilization of alternative fuels.
Electric Power Generation Nationally recognized strengths in gas turbine engines and fuels expertise allow comprehensive research on coal gasification and LNG as applied to electric power generation. Collaborations currently exist from which cross-disciplinary programs can develop to include environmental issues also.	The re-emergence of coal as a critical energy technology heightens the need for research on production and combustion of syngas to assure it is competitive with natural gas for electric power generation. Cost increases are driving interest in alternative fuels from coal and Penn State is in a strong position to take advantage of these opportunities.
Residential-Commercial Energy Use Collaborations involving existing strengths in the Indoor Environment Center, fuel science, combustion, and the social sciences provide another opportunity to comprehensively approach needed research.	State and federal agencies as well as industry realize that as energy costs rise using resources wisely is a sound policy. With its outreach mission Penn State is poised to lead efforts in this area.

Needs

- Increase efficient use of energy across the spectrum; residential, commercial, industrial, and transportation to reduce the rate of growth of US energy demand over the near-term (2006-2025).
- Coordinated program that includes science, engineering, and policy expertise to implement advanced technology and identify high payoff areas for research.
- Partnerships with the state and with federal agencies to develop research, teaching, and outreach that push the state-of-the-art forward and encourage user buy-in.

Rationale

- The combustion of hydrocarbon fuels (natural gas, oil and coal) along with the development of alternate fuels (biodiesel etc.) will continue to be the primary source for meeting energy needs. The efficient use of these fuels is the most effective way to reduce the growth in the demand for energy. Penn State has strong research programs in fuel science, combustion, residential energy use, transportation, and alternative fuels activities to draw upon.
- Energy and the environment are synergistically linked and both are areas of strength for Penn State. Collaborations that address both energy and environmental issues provide an intrinsic advantage in proposing comprehensive programs.

Outreach Priority

7. Energy Extension and Outreach

Description

Innovative energy systems and associated business models need to be developed and demonstrated for Pennsylvania residents, businesses, and industry. Knowledge-driven partnerships with diverse stakeholders can catalyze the implementation of new technologies and provide a vital service for the state.

Outreach Clusters	Opportunities
Technology Transfer Full-service programs in Industrial Research and Small Business Development, experience with intellectual property issues, and economic development expertise.	Public-private partnerships can accelerate innovation and technology deployment. State and federal funding sources include SBIR programs in DOE, USDA, and NSF, PA Energy Harvest, PENNTAP, and Ben Franklin.
Cooperative Extension Nationally recognized program has educators and economic development specialists throughout the state with strong connections to local communities, chambers of commerce, and the agricultural and forest industries.	There is increasing demand for demonstrations, workshops, and short courses to provide hands-on experience for entrepreneurs. Innovative programs can attract support from local, state, and federal agencies.
Energy Extension A recently-established office at The Energy Institute for providing energy outreach. The intent is to broaden it to a state-wide program through federal and state assistance.	There is a demand for technical assistance, energy courses, and information by homeowners, farmers, and industry to identify technologies and fuel options and to use and manage energy more economically and efficiently.
College of Engineering COE offers distance-education programs in Nuclear Engineering, Power Engineering, and Visible Emissions.	Demand for distance education is rapidly expanding in response to continuing education needs and increasing career flexibility and mobility.
World Campus Penn State offers relevant graduate degrees in Oil and Gas Engineering Management, GIS, and Business Administration.	Additional certificate and degree programs can provide pathways for career transitions and develop a highly skilled energy workforce for the future.

Needs

- Expanded outreach linkages with citizens, business, government agencies, and industry.
- A statewide network of technical specialists with energy expertise.
- An energy demonstration center showcasing new technologies.
- Partnerships with economic development agencies for energy technology development and deployment.

Rationale

- The energy industry has been crucial to economic development in Pennsylvania for over one hundred years. State government has signaled strong support for advancing next-generation energy business and industry.
- Penn State has a proven track record in industrial research and technology transfer, with over six billion dollars of direct economic impact in the Commonwealth.
- Penn State has the most robust and effective Cooperative Extension program in the Northeast, which could serve as a model for new Energy Extension Service.
- Penn State is recognized internationally, nationally, and locally as a leader in fundamental and applied energy research and development and energy education, making it the ideal home for a state-wide energy extension service.
- Public acceptance of new energy systems and technologies will require broad participation from all sectors of society. Citizen concerns about social and environmental impacts must be addressed with unbiased information.
- The established network of statewide campuses, distance education courses, and World Campus certificate and degree programs offer a platform for expanded offering of energy-related education programs.
- This effort would dovetail with ongoing work underway in the Center for Sustainability.

Research Priority

8. Energy from Space-Based Systems and Sources

Description

Space-based systems and sources offer the potential of near limitless, clean power. Power can be provided to remote regions of the Earth. Resources scarce on Earth are found in abundance on other celestial bodies. Obtaining energy economically via space-based systems and sources will require significant reduction (~10-100×) in launch costs.

Research Clusters	Opportunities
Space Power Satellites Strong research programs in amorphous solar cell technology (EE, MRI), antennas (EE, ESci), microwave propagation (EE), space systems (CSRP), autonomous systems (ARL)	Collected via solar cells and beamed via microwaves to Earth where energy is collected via a rectenna. Ability to beam energy to remote parts of the earth, quickly reconfigure where energy is sent, and provide solar-derived energy on the dark side of the Earth. Repair will require autonomous robots.
Helium 3 Mining Strong mining research in EMS, strong chemistry program, strong nuclear engineering program	Can be mined from Moon regolith. (One Space Shuttle load, 25 tons, can power US for year.) May provide the necessary fuel for fusion reactors on Earth. (Over-unity fusion itself must be developed.)
Derived Technologies from Space Programs Strong culture of tech transfer (Outreach) and cross-disciplinary collaboration, role as trusted agent	Extensive research by NASA and DOD in systems to make hydrogen, use nuclear power safely in space. Transferring technology to private sector offers many opportunities.
Solar Wind Strong ionospheric/plasma research capabilities (CSSL in EE), strong Astronomy program	Particles in solar wind travel at ~450 km/sec, but low density ~5/cc. May be better to support in-space systems.
Power from the Electrojet Current Strong ionospheric/plasma research capabilities (CSSL in EE)	Using electrojet and auroral currents to generate power on Earth. Developing methods to extract power from diffuse current densities is key.

Needs

- Scientific and engineering expertise in space systems integration, solar cell technology, large space structures, mining, fission/fusion, autonomous systems, and plasmas.
- Research to provide paradigm-shifting capability for low cost launch.
- Partnerships with NASA, DOE, and private space investors are key.
- Legal landscape for using/owning resources from space must be clarified.

Rationale

- Penn State has many strong programs for these highly interdisciplinary systems. Many other universities may only have a piece.
- Penn State has Center for Space Research Programs, which can tie together researchers across colleges and ARL to implement the large and complex systems needed to harness space-based energy sources.
- Energy from space offers one of the few sources of “limitless clean power.”
- Space power can leverage huge US strategic investments in space-program infrastructure.
- Space power provides flexibility in delivery location and low barrier for wide-spread use since limited Earth-based infrastructure needs to be built (e.g., beamed energy can be connected to existing power grids and retasked depending on needs).
- Investments made now during critical window produce long-term payoffs (high risk–high payoff).
- Private investment in space is increasing and will move space away from a government-only game.

Research Priority

9. Energy Systems Science

Description

A sustainable energy future demands strong interdisciplinary research linking energy, environment, and human systems. New tools and emerging disciplines are evolving to address such complex systems, with intellectual ramifications for many conventional disciplines. Energy can serve as a unique and critical focus for applying fundamental systems science to a pressing societal need.

Research Clusters	Opportunities
Carbon Cycle Science Internationally recognized program includes collaboration among Engineering, Science, EMS, and Ag Sciences.	The global carbon cycle drives an increasing amount of energy and environmental research. Funding sources include NSF, NASA, EPA, NIH, USDA, and DOE, with strong potential for increased support from all agencies.
Industrial Ecology of Energy Existing programs in Engineering, EMS, and Ag Sciences on material and energy flow. Enhanced collaboration and expanded participation can help provide a broader systems view.	NSF, DOE, USDA, state agencies, and leading companies are making industrial ecology and life-cycle assessment central components of integrated projects, regulatory analysis, and new product development.
Multifunctional Agroecosystems Strong programs in Ag Sciences, with collaboration with USDA-ARS Pasture Systems and Watershed Management unit on campus. Interaction with Engineering and EMS should increase.	Increasing production of biomass along with conventional food crops will challenge our ability to maintain ecosystem services, cycle nutrients, and retain biodiversity. NSF, USDA, and DOE funding is likely to increase.
Sustainability Science Existing programs in Engineering (STS, Center for Sustainability), Earth and Mineral Sciences (ESSI), Ag Sciences (ENRI), and the Liberal Arts (Rock Ethics Institute) provide a basis for exploring the interaction of ethics, environment, society, and technology. Greater synergy among these programs on energy is needed.	Coupled human-environment interactions require integration of science, social science, and the humanities. NSF's Biocomplexity Initiative incubated the development of a vast array of new tools for system analysis. Future NSF initiatives are likely to do the same.

Needs

- Greater interaction among social scientists, engineers, ethicists, and biophysical scientists to identify and understand multidisciplinary issues of sustainability.
- Research expertise in life-cycle, energy, and material-flow analysis.
- Expertise in coupled human-environment interactions applied to energy systems.
- Increased collaboration with industry, government, and NGOs to identify and address emerging issues of energy sustainability.

Rationale

- Many of the grand challenges for our future energy supply are systems issues, and addressing them will require strong collaboration among biophysical scientists, social scientists, engineers, and the humanities.
- Penn State has a national reputation and strong capability in integrating energy and environmental research.
- Developing energy systems that are environmentally, economically, and socially sustainable is not intuitive. Integrating multidimensional quantitative and qualitative methods is essential to generating information and results that are robust and useful.
- The expertise, methods, and tools developed to address issues of energy sustainability will have broader application to other critical issues at the interface of environment, technology, and society.

Research Priority

10. Environment (not covered in other areas)

Description

Residuals from energy production and consumption, including land cover change, greenhouse gas emissions, and emissions of primary and secondary air pollutants (outdoors and indoors), all affect ecosystems, economies, quality of life, and human health. Also under this priority are strategies for alleviating these problems, some of which are discussed in other sections of this report (see e.g., biomass energy, hydrogen energy).

Research Clusters	Opportunities
Carbon Cycle Science Internationally recognized program includes collaboration among Engineering, Science, EMS, and Ag Sciences.	Research in this area includes marine and terrestrial carbon fluxes, methods for estimation of greenhouse gas emissions, land-change science, and economic modeling of carbon-trading strategies. Funding already received from NSF, NASA, EPA, NIH, USDA, and DOE. Strong funding potential for the future from these agencies.
Plant and Human Health Effects of Air Pollution Strong existing programs on plant health in CoAS and an emerging program on human health in EMS, CoAS, and HMC.	Monitoring infrastructure and research on the effects of tropospheric ozone and acid deposition on crops and trees are highly recognized. Ozone effects on pulmonary disease are an emerging strength. Strong funding potential from PA DEP, EPA, NIH, and DOE.
Understanding and predicting anthropogenic climate change Internationally recognized program in mostly in EMS and CoAS, with strengths in CoE. Several well-funded research projects underway.	World-class research on detecting climate change signals in ice core records, and tracking of mass balance of major ice sheets. Also, impacts of climate change on ecosystems and human systems. Current and future funding potential is high with NSF, DOE, NASA, and EPA.
Indoor Environment Tightly coupled collaborative projects already funded in IEC in CoE. Includes faculty from ECoS andCoAS. Has strong Homeland Security potential.	Group is beginning to focus on connections of indoor environment with human health. Funding opportunities seem good for NSF, DOE, EPA and, further on, with NIH.
Geophysical monitoring Major new project supported by NSF called AfricaArray provides capability of monitoring seismic conditions that may be a threat to on- and off-shore oil production facilities. Mostly an EMS initiative.	Has attracted significant attention and interest at NSF and appears to have large upside growth potential, with funding coming from international groups in addition to NSF.

Needs

- Stronger linkage between energy and environmental science/engineering faculties.
- Stronger linkage of HMC and UP faculty on energy and environmental health.
- Restoration of excellence in climate modeling.
- Investment by industry.

Rationale

- Energy production and consumption and environmental stewardship are inextricably linked and best studied and taught in integrated fashion. The majority of grand challenges in the environmental sciences and engineering can be traced to some facet of energy production and/or use.
- Penn State is a world leader in many facets that fall at intersections of energy and environment, including renewable energy production such as hydrogen, wind, solar, and environmental change such as global warming and related carbon cycle science, air quality, and environmental health. Joining these strengths together is likely to add uniqueness and leverage research/teaching firepower.
- Energy-linked environmental research is a major component of federal and state R&D and is projected to be a growth area in agencies such as DOE, NSF, EPA, NIH, and USDA at the federal level and PA DEP, DCNR, PAD, DECD among others at the state level.

Research Priority

11. Hydrogen Energy

Description

Hydrogen energy development has the potential to have major impacts on increasing efficiency, reducing greenhouse gases (GHG) and minimizing the air pollution from energy utilization. It involves hydrogen production, storage, delivery, and utilization via fuel cells or advanced combustion systems.

Research Clusters	Opportunities
H_2 Production Fossil fuels (natural gas, coal, and petroleum) represent the major energy sources for H_2 production. Some recognized programs in EMS and COE with federal, state and industrial funding, including H_2 Refueling Station by Air Products and DOE.	Demand for hydrogen is increasing rapidly due to the growing needs for clean fuels, chemical processing, and fuel cell applications. More funding opportunities on H_2 production from liquid fuels and coal from DOE and DOD.
H_2 Production Renewable sources such as solar energy, biomass, and organic waste are sustainable. Some work including microbial H_2 production internationally recognized.	Alternative sources of energy and renewable H atom source such as water could contribute to a sustainable H_2 production system. Strong potential for increased funding from DOE and NSF.
H_2 Storage Storage of hydrogen in boronated carbon, carbon nanotubes, metal and chemical hydrides, and light-weight compounds. Strong programs in COS, EMS, and COE with federal, state, and industrial funding.	The use of hydrogen fuel cells for transportation requires the means of on-board or on-site storage of hydrogen at sufficiently high energy density. Potential for continued funding for the DOE Grand Challenges.
Fuel cells Polymer electrolyte fuel cells (PEFC), solid oxide fuel cells (SOFC), microbial fuel cells (MFC), membranes, modeling and system integration. Well-recognized in multiple areas involving COE, EMS, COS, and AG.	Development of more durable and affordable fuel cells is a key technology need involving both experimental and computational electrochemical studies. Strong potential for continued funding from DOE, NSF, and DOD agencies.
Advanced Combustion One way to introduce hydrogen to the current energy system is combustion of blends of H_2 with methane (Hythane) or CO (Syngas). Moderate program on-going.	Combustion in IC engines and turbines related to advanced power generation technologies. Potential for continued funding from federal agencies.

Needs

- The US and the world are consuming enormously large amounts of hydrocarbon resources that are converted at lower life-cycle efficiencies (<35 % for power plants and <25% for automobiles) with significant amounts of pollutants and large amounts of GHG emitted.
- A fundamental shift in thinking is needed that invokes new conversion devices which are intrinsically far more efficient and decouple the link between energy utilization and pollution.
- There are major needs for more efficient hydrogen production using either hydrocarbons or renewable sources (biomass, wind, and solar) at both small and large scales.
- New materials for hydrogen storage and new methods for hydrogen delivery are needed for achieving the major weight/volume density targets for transportation.
- More efficient and affordable fuel cells hold the key to more effective and practical hydrogen utilization in transportation sector.

Rationale

- Research and development towards hydrogen energy have the potential to improve energy efficiency and decouple the seemingly natural link between the current energy uses via combustion and environmental pollution due to SO_x and NO_x and particulate matters.
- It is still an early stage for the industrialized nations to develop hydrogen energy systems, so Penn State could play a leading role in this area of clean energy development.
- Hydrogen production is still very expensive, so more efficient production methods using available resources such as heavy hydrocarbons, coal, biomass, and solar energy could pave the path forward for overcoming the barriers.
- Research on hydrogen production and storage as well as utilization will stimulate and promote advanced materials research at Penn State.

Research Priority

12. Materials

Description

Environmental and geopolitical trends are driving the need to develop renewable energy production, storage, and utilization on the scale of ten terawatts over the next few decades. New materials for solar energy production, catalysis, fuel cells, batteries, hydrogen storage, lighting, and energy conversion will be needed to meet this technological challenge.

Research Clusters	Opportunities
Nanomaterials New kinds of devices and improved performance will be enabled by control of matter at the nanoscale. Internationally recognized programs including collaboration among ECoS, EMS, and COE.	Nanoscale materials have the potential to revolutionize solar energy conversion, thermoelectrics, solid-state lighting, fuel cells, and catalysis. Strong continued funding potential from NSF, DOE, DOD, and industry.
Electrochemical materials Improved materials for batteries, fuel cells, and corrosion protection will be needed in energy technologies. Internationally recognized programs in ECoS and EMS.	Electrochemistry continues to be a focus in interdisciplinary energy research involving materials science, chemistry, and engineering. Strong funding potential from DOE, DOD, and industry.
Polymers/hybrid materials Research will enable lightweight high performance composites, polymer photovoltaics, and biomimetic assemblies for energy conversion. Internationally recognized programs include ECoS, EMS, and COE	Polymeric, hybrid, and bio-inspired functional materials represent an interdisciplinary growth opportunity for Penn State. Potential funding from NSF, DOE, DOD, and industry.
Catalysis Better catalysts are essential for fuel processing, fuel cells, and solar conversion. Internationally recognized program include ECoS, EMS, and COE.	Efficient energy conversion requires the design and use of advanced catalysts. Continued funding from DOE, NSF, DOD, and industry.
Materials Characterization and Theory Imaging, analysis, and simulation of new materials guide synthesis and applications. Internationally recognized programs include ECoS, EMS, and COE.	New imaging and analytical tools, and increasing computational power create opportunities in energy-related research. Potential funding from NSF, DOD, DOE, and industry.

Needs

- Emerging energy-related technologies (solar power, hydrogen storage, fuel cells, thermoelectrics, solid-state lighting, and lightweight structural materials) will require breakthroughs in materials synthesis and nanoscale assembly in order to achieve high performance at low cost.

- Fundamental research in nanoscale materials, polymers, hybrid organic-inorganic nanostructures, biomimetic materials, catalysis, and electrochemical materials science is needed to provide a scientific basis for next-generation energy conversion technologies.

- The shift to renewable energy utilization will dramatically change the infrastructure of energy production, distribution, and use requiring new materials for energy storage and transmission.

- Better atomic-scale imaging and analytical techniques, and computational modeling, will be needed to inform the design and understand the properties of functional and hybrid materials.

- A national center for energy-related materials that maintains a graduate education, research, and technical outreach program is needed.

Rationale

- Clean, renewable energy will become increasingly important over the next few decades because of environmental, economic, and national security imperatives. The shift to renewable energy will be largely technology-driven, and the scale of the problem is vast.

- Breakthroughs at the basic research level, including the discovery and exploitation of new physical phenomena and emerging synthetic techniques, will be needed to achieve high efficiency at low cost.

- Energy-related technologies now entering the market (hybrid, electric, and hydrogen powered vehicles, solar photovoltaics, solid-state lighting) require improved catalysts, electrochemical materials, polymer composites, and nanoscale materials.

- Breakthroughs in thermoelectric, electroluminescent, and super-conducting materials have the potential to change the landscape of energy transmission and utilization.

- Penn State has clusters of faculty members in ECoS, EMS, and COE, with research activities on several critical aspects of energy-related materials.

Research Priority

13. Nuclear Energy Technologies

Description

Nuclear energy is derived from nuclear reactions and has the potential to supply the nation's electrical power and process heat needs without the emission of carbon dioxide, particulates or acid rain-producing chemicals.

Research Clusters	Opportunities
Radiation Science Breazeale reactor is longest operating research reactor in US. Provides safe nuclear analytical and testing facility for research and education.	Can provide a wide range of research and academic services to university, government, and corporate sponsors.
NRC Rod Bundle Facility Operated jointly by COE and ARL for the investigation of heat transfer and fluid flow in simulated reactor cores. Funded by the NRC.	Basic heat transfer and fluid flow investigations for existing and proposed new reactors. Potential for support from NRC, DOE, and commercial fuel vendors.
Reactor Dynamics and Fuel Research Group in M&NE that performs research on reactor physics, nuclear safety, and fuel management.	Support DOE and NRC in research on new reactor concepts and performance and safety analyses for licensing reactors.
Pump Loop Facility ARL facility to perform research on pumps, control valves, and other devices in reactor cooling loops. Funded by US Navy.	Research on flow and hydro acoustic characteristics of reactor coolant loop components. Potential for DOE, DOD, and industrial support.
Synthetic Environment Application Lab Immersive, three-dimensional visualization facility. Operated by ARL and used by industry, government and University collaborators.	Potential for application to plant designs and analyses of alternative configurations. Potential sponsorship from industry, DOE, DOD, and NRC.

Needs

- Science, technology, and facilities for a mine-to-waste-storage nuclear fuel cycle that addresses proliferation issues.
- Advanced power plant designs that are passively safe, efficient, and complimentary to hydrogen production.
- An education and outreach program that encourages and enables public engagement in the plant-licensing and site-selection processes.

Rationale

- Nuclear power is carbon-free.
- Nuclear power is delivered economically on a large-scale worldwide.
- Long-term fuel supplies are available with current fuel cycles; renewable fuel supplies are possible with advanced fuel cycles.
- Research opportunities are anticipated in fuel-cycle development, advanced plant designs, safety and non-proliferation assurance, and public education and acceptance.
- Changes in the US licensing regulations increased federal funding for nuclear power, and foreign orders for nuclear plants will increase the research and development efforts on nuclear power.
- The environmental, sociological, and technical issues associated with nuclear power require the kind of broad-spectrum expertise that Penn State possesses to shape the role of nuclear power in our energy future.

Research Priority

14. Nuclear Fuel Cycle

Description

The use of nuclear power to meet the Nation's energy needs requires that nuclear fuel can be produced, used and disposed of in a manner that is economical and environmentally acceptable.

Research Clusters	Opportunities
Radiation Science Breazeale reactor is longest operating research reactor in US Provides safe nuclear analytical and testing facility for research and education.	Can provide a wide range of research and academic services to university, government, and corporate sponsors.
Reactor Dynamics and Fuel Research Group in M&NE that performs research on reactor physics, nuclear safety and fuel management.	Support DOE, NRC and DHS in research on the performance and safety of fuel cycle options.
Materials Research Institute Coordinates, supports, and sponsors important and significant advances in materials science and engineering technology.	Development of materials and processes that enable an economical and environmentally acceptable nuclear fuel cycle.
Penn State Institutes of the Environment Conducts multi-disciplinary environmental research with participation by governmental stakeholders.	Assessment of the environmental impact of potential nuclear fuel cycles.
Social Science Research Institute Conducts research encompassing skills and perspectives that are needed to solve complex social problems.	Define approaches to encouraging public engagement on the issues identified for proposed nuclear fuel cycles.

Needs

- Definition of a common, economical nuclear fuel cycle, and the alignment of government resources to achieve it.
- The incorporation of technical and political features in the fuel cycle to address proliferation issues.
- An education and outreach program that encourages and enables public engagement in defining an acceptable nuclear fuel cycle.

Rationale

- Increased use of nuclear power depends on the development of an economical, environmentally acceptable, and proliferation-resistant nuclear fuel cycle.
- Potential fuel cycles have technical, environmental, economic, and social issues associated with them.
- Multidisciplinary efforts are required to characterize and resolve the specific issues associated with various fuel cycles.
- Public acceptance of proposed fuel cycles is of paramount importance and depends upon presenting the information to the public in a manner that encourages their engagement.
- Penn State has a strong collection of institutes and research activities capable of performing comprehensive research on the nuclear fuel cycle.

Research Priority

15. Social and Policy Studies

Description

Energy policies in the future will be affected by the social acceptability of various technologies, domestic political choices, and international events such as war. Government response to global climate change may be extremely volatile, with resistance to any change giving way to a cascade of dramatic policy changes in the future. Energy policy in the US will be transformed.

Research Clusters	Opportunities
International War and Conflict Penn State is a major hub for the study of the causes of war; resources available concerning all previous wars and their economic and social contexts.	Linking the study of war to their possible energy-related causes and consequences.
Government Energy Policies Policy agendas project and other resources allow for tracking of government response. Various policies pose new opportunities for research and development of associated technologies.	Volatility of government response means both challenges related to disinvestments as well as tremendous opportunities related to reinvestment strategies. Many policies will be indirect rather than direct, as when environmental or tax-code changes create new incentives or cost structures.
Public Acceptability Public discussion of complex issues is always affected by powerful framing effects. How energy options are presented affects the response.	Public opinion research on risk acceptance, trade-offs, and the NIMBY phenomenon. Survey capabilities in hand.
Political Dimensions of Energy Policy Various energy options have different geographic impacts, and political responses often follow from these.	Drafting effective energy policy will require sensitivity to geographic impact.
International Aspects of Energy Policy International agencies and treaties will likely play an important role in the future over both energy and environmental aspects of policy.	Global climate change will increase pressure for coordinated international response. Trade negotiations and other aspects of foreign policy will be affected. Anti-internationalist stances will also be apparent.

Needs

- Penn State can invest more in infrastructure of policy analysis and public policy monitoring. The core skills are already on campus but can be expanded.
- Linking scholars doing policy-relevant basic research to energy applications and collaborations with energy-focused researchers.
- Greater presence in Washington energy policy circles, i.e. think-tanks, congressional staffers, and agency contacts to help shape policy.
- Quadrennial Energy Forecast and Assessment for policy and technology with a Penn State brand name.

Rationale

- Wars and international conflicts over energy resources will have great impacts on energy supplies and transportation.
- The public acceptability of various energy options is unknown but will determine the future. Nuclear power may or may not lead to elaborate public concern with waste and proliferation. Farmers may or may not be interested in biomass fuel production. Consumers may or may not be willing to pay much higher purchase prices for energy-efficient cars and appliances.
- Previous periods of intense governmental concern with energy policy, in the 1970s, were short-lasting but led to intense investments in some few areas of energy policy. The next wave of attention to these issues will be much more dramatic and far reaching. Government, social, and public response will hinge on a mixture of the economics of the competing solutions as well as on their environmental impacts and public reaction to technology.
- International pressures will also increasingly affect public opinion on environmental issues. This affects both climate-change responses and international negotiations over trade and carbon taxes.
- Penn State is a leading institution nationally in the study of climate change; we have strong faculty strength in international relations, conflict, and trade; we have a survey research center with faculty strength in the study of public opinion and the infrastructure to do large-scale studies of public acceptability of new technologies; we have nationally known faculty in the study of public policy and agenda-setting.

Research Priority

16. Solar Energy

Description

Sunlight provides by far the largest of all potential energy sources for the Earth. More energy from sunlight strikes the Earth in one hour (4.3×10^{20} J) than all the energy consumed on the planet in a year (4.1×10^{20} J). Solar energy conversion systems fall into three broad categories according to their primary energy product: solar electricity, solar fuels, and solar thermal systems.

Research Clusters	Opportunities
Materials Research The Materials Research Institute brings together some of the very best scientists in this area and includes many internationally recognized researchers.	Nearly every aspect of improved solar energy conversion is dependent upon improvements in materials and the development of novel materials. Additional hiring of faculty targeting solar energy conversion could lead to even greater prominence in this area.
Nanotechnology Penn State has an NSF-sponsored Materials Research Science and Engineering Center, whose research themes include molecular nanofabrication, complex inorganic materials, nanoscale motors, low-dimensional electronic nanostructures, and integrated optical metamaterials.	DOE, NSF, and DOD support for nanomaterials is likely to increase as pressure to develop solar solutions to energy needs increases. Penn State is well-positioned to take advantage of such opportunities.
Plant Biotechnology The Schatz Center for Tree Molecular Genetics performs research on hybrid poplar, chestnut, and other potential biomass crops. Strong programs in agricultural crop genetics.	Advances in plant biotechnology offer opportunities to improve solar energy conversion efficiencies and to increase biomass yield. Strong funding from USDA, DOE, commodity groups, and industry.
Photosynthesis The Center for Bioinorganic Chemistry includes internationally recognized scientists with expertise in photosynthesis.	Genetically engineer cyanobacteria and other phototrophic bacteria to produce hydrogen and other potential bio-derived fuels. Funding opportunities will likely expand beyond that currently available from DOE, DOD, and NSF.
Artificial Photosynthesis Members of the MRI are investigating photocatalysts for direct photolysis of water.	DOE has made this a priority research direction, and funding will expand in this area.

Needs

- Reduce the cost/watt of delivered solar electricity by a factor of 5-10 to compete with fossil and nuclear electricity and 30-fold to compete with primary fossil fuels.
- New photovoltaic materials, including new inorganic- (silicon, other) and organic-based materials, thin-film photovoltaics, light concentration schemes, and photoelectrochemical storage cells.
- Genetically engineer plants to improve solar energy conversion into biomass by a factor of 10 as well as improve biomass interconvertability.
- Genetically engineer photosynthetic bacteria to produce solar-derived fuels (e.g., H_2, CH_4, methanol, ethanol, etc.).
- Replicate the essential components of photosynthesis in a completely artificial system to obtain a robust, cost-effective system and produce solar-powered catalysts.
- Construct entirely man-made chemical components that mimic photosynthesis to convert sunlight into chemical fuels such as H_2 or CH_4 in an efficient, robust, scalable, and cost-effective manner.
- Identify cost-effective methods to convert sunlight into storable and efficiently utilizable thermal energy.
- Develop high-efficiency thermoelectric materials, nanostructured metallic and dielectric materials, thermophotovoltaics, and scalable manufacturing processes applicable to many geometries.

Rationale

- Solar energy is environmentally friendly, carbon-neutral, and renewable upon sunrise each day.
- Solar biofuels and agriculture already account for ~12% of the total world energy budget. Expansion to ~50% requires only a 4-fold expansion over the current situation.
- Advances in photovoltaics, artificial photosynthesis, and solar thermal approaches are all highly dependent upon advances in materials, one of Penn State's greatest strengths.
- Penn State has existing strength in photosynthesis, molecular genetics of phototrophic bacteria, methane-producing archaea, and general microbial physiology and metabolism.
- Penn State has strength in molecular plant physiology, plant engineering, (including cell wall structure and lignin degradation), forestry, and agriculture.
- Scalability and improvements in efficiency and cost reduction require advances in engineering processes. Penn State has strength in all areas of engineering.

Research Priority

17. Ultra Clean Fuels

Description

There are major challenges and thus new opportunities for research on more efficient production and utilization of ultra-clean transportation fuels from hydrocarbon resources and biomass in the foreseeable future, due to the ever increasing demand for liquid fuels, heightened concerns for cleaner air and higher efficiency, and more stringent regulations for auto-exhaust emissions.

Research Clusters	Opportunities
Ultra Low-Sulfur Fuels Deep removal of sulfur and nitrogen from hydrocarbon fuels by new adsorption and new catalytic approaches. Internationally recognized program including collaboration among EMS and COE.	New approaches to deep desulphurization have the potential to revolutionize the way clean fuels are produced worldwide. Strong continued funding potential from DOE, EPA, DOD (Navy, Army, Air Force), and industry.
Engine Combustion Studies Ultra-low sulfur fuels, oxygenated fuels, bio-fuels, and new blends of fuels require combustion studies for their performance and emission control. Internationally recognized program in COE and EMS.	This area continues to be a focus in inter-disciplinary energy research involving fuel science, mechanical engineering, and materials science. Strong continued funding potential from DOE, EPA, and industry.
Alternative Fuels Non-conventional fuels such as jet fuel from coal, bio-diesel, DME, liquids from natural gas (FTS), bio-ethanol, Hythane, and syngas fuels. Internationally recognized program including EMS and COE.	Alternative fuels represent a growth opportunity for Penn State as more and more attention is being paid to them. Potential funding from DOE, industry, and international funding agencies.
Catalyst and Adsorbent Nano-porous catalytic and adsorption materials for fuel processing, conversion, and pollution prevention. Internationally recognized program including COE, EMS, and COS.	Processing and utilization of fuels as well as pollution control require the design and use of advanced functional materials. Continued funding from DOE, NSF/EPA, DOD, and industry.
Heavy Oil Upgrading Conversion of heavy oils and non-conventional heavy resources such as coal, petroleum residue, and tar sands. Current program funded by DOE and industry in EMS.	Far more resources of non-conventional and lower-quality conventional resources such as heavy oils, tar sands, and coal. Potential funding from DOE, industry, and international funding agencies.

Needs

- Scientific and engineering expertise needed for developing new approaches and novel processes for more efficient production and utilization of ultra clean transportation fuels.
- Ultra clean fuels need to be produced from heavy crude oils through advanced refining including deep desulphurization, from natural gas via reforming and catalytic synthesis, from coal via gasification or liquefaction, and from biomass for various bio-fuels.
- The use of ultra low-sulfur fuels is required by various fuels cells being developed for stationary, transportation, commercial/residential, and military applications, which call for alternate approaches other than those used in the current industry.
- Rapidly changing fuel formulations also create needs for product engineering, advanced combustion, and fuel reformation studies that also involve catalysts and adsorbents materials.
- A national center for ultra clean fuels is needed that maintains a graduate education, research, and technical outreach program.

Rationale

- Crude oils refined worldwide are becoming increasingly higher in sulfur and heavier in gravity, while the world is demanding more and more light and clean liquid fuels in increasingly larger quantities.
- Conventional high-temperature high-pressure refining technologies using high-pressure hydrogen are reaching diminishing returns for ultra-clean fuels.
- Heightened concerns for cleaner air and increasingly stringent federal regulations call for new approaches in clean fuels development.
- Work on upgrading and utilization of heavy oils and non-conventional fuels such as tar sands bitumen and bio-fuels are important for mid-term to long-term transportation fuels.
- Penn State has a cluster of faculty members in EMS, COE, and AG with research activities on some critical aspects of liquid hydrocarbon fuels and bio-fuels.

Appendix II

Education Program Plan

A major objective of this Institute is to impact the pool of talent at both the graduate and undergraduate level who are trained to address and solve the energy challenges described earlier in this report. An important first step is to enhance the visibility of energy research at Penn State to attract highly qualified students. Undergraduate involvement will include academic year and summer research opportunities along with a summer minority-student research program. The Institute will impact graduate students through their research experiences and classroom activities.

1. **Graduate Student Recruitment**. Attracting the very best students requires a well-planned recruiting package. Two types of student support are envisioned: Energy Fellows and Graduate Research Assistants. Special efforts will be made to recruit women and underrepresented minorities in both categories. The recommended recruiting package includes four parts:
   - an attractive financial stipend
   - an appropriately named fellowship
   - a selection of interesting research topics for dissertation research
   - an opportunity to choose one's faculty advisor

   The Fellowships will be restricted to the very best undergraduate applicants. These financial packages will be awarded by the Institute, tenable in any college or Graduate Program, to work on Institute projects of interest to the student with any faculty associated with the Institute. The annual stipend for these fellowships will initially be set at $26,000 plus tuition.

   Experience indicates that providing an attractive stipend along with the freedom to choose their research advisor and project will be beneficial to the student, the faculty, and the Institute. The Graduate Research Assistantships will be awarded by faculty using either their Institute funding or external grants. These financial stipends will provide for student research on programs of interest to the faculty member. Special minority add-ons from the Institute will be used to encourage participation from women and underrepresented minorities in the graduate assistantship program.

2. **Minority Program**. A summer research program for undergraduate minority students will be implemented to stimulate interest in energy science, engineering, and policy research. The program will place undergraduate students in a one-on-one situation with faculty for their research assignments. One goal of this program will be to recruit the best of these undergraduate students to graduate school. The ten-week program will provide housing and attractive stipends to the students. Active participation of the Women in Science and Engineering Research (WISER) and the Minority Undergraduate Research Experience (MURE) programs will also be pursued.

3. **Classroom Program**. Penn State has many existing courses at both the undergraduate and graduate levels that provide effective classroom learning experiences related to energy topics. Despite this breadth we anticipate that the Institute will stimulate selected specialized courses at the graduate and undergraduate level. A special focus of the Institute is the introduction of courses using web-based communications.

4. **Certificate Programs and Short Courses**. The Institute will also establish Certificate Programs in specific areas of energy science, engineering, and policy for practicing professionals in government and industry. The Certificate Programs will consist of nine to twelve credit hours of classes via the Web or on campus, as well as residence programs. Certificate Programs do not require or imply admission to Penn State, but credits could be applied toward a degree should the participant choose to pursue one. In addition, the Institute will establish one-week refresher courses for practicing professionals or for disseminating the latest information in the field. The short courses will use both resident faculty and experts from other universities, government, and industry.

Appendix III

Organization and Management Structure

The proposed management structure is designed to be effective and responsive to faculty and students. It stresses individual creativity and promotes research excellence.

1. **Management Structure**. The proposed management structure facilitates the primary functions of the Institute and focuses on high-quality research; selects worthy projects to fund; increases the number of trained students; reviews Institute-supported peer research; recruits high-quality students with diverse backgrounds; measures performance; and manages growth. Through proper focusing of activities and dissemination of results, the Institute will generate an exciting environment that attracts highly qualified students, post-doctoral fellows, and faculty who might otherwise pursue other areas of study. Through the proper selection of faculty, projects, and students, the Institute will be assured of success that highly leverages University support for the Institute.

   The Institute will use a management approach that incorporates three elements to achieve results and oversight while maintaining a high degree of autonomy. The elements are the Policy Advisory Board (PAB), the Director, and the Faculty Review Board (FRB). The PAB along with the Director have specific responsibility for setting the mission and operation of the Institute. It establishes research priorities and assists in program philosophies, evaluates research progress, and identifies new development opportunities. Semi-annual meetings of the PAB will involve formal presentations by Institute investigators and one-on-one interactions with faculty and students. The PAB comprises outstanding individuals from Penn State, industry, and government agencies.

   The FRB reviews proposals submitted by Institute researchers and allocates internal research funds. These individuals provide a balance between the technical disciplines involved in energy research activities to assure a fair evaluation of these proposals.

2. **Operation of the Institute**. In their deliberations, the PAB sets guidelines for allocation of Institute funds using two sets of constraints. One set is structured according to a balance of research topical areas, while the second is structured according to the type of research activity.

   Topical Funding Allocations: Topical areas are described in our recommendations. As the first step, this technical program will be reviewed by the PAB. An appropriate distribution of funds to the various projects will then be effected by the Faculty Review Board.

   Three specific funding categories have been identified, viz., Core Research Program, Exploratory Research, and Matching Funds Research.

   The **Core Research Program** will be the largest in the early days of Institute operation. Such programs are to be in areas designated as high-priority activities by the PAB. These will typically be of three years duration and have a nominal funding level of $150,000 per project per year. This level of funding is based on experience that the development of significant research results on major technology problems requires a commitment of three years at this funding level.

Projects that involve multi-disciplinary groups of faculty working together will be emphasized, and interactions with faculty in other universities will be encouraged. Each project will be closely monitored by the FRB with the understanding that programs can be modified at the discretion of this Board. Approximately 15 core projects will be initiated in the first year with one or two more to start in the next two years. As these initial Core Projects are completed, Matching Projects will be emphasized.

Matching Funds Research represents those funds allocated to individual researchers who can acquire equal funding from resources other than the Institute. This category stimulates growth and self-sufficiency as the Institute matures. Funding levels are designated at $75,000 of Institute funding per project per year for three years subject to obtaining external funds. The initial number of Matching projects will be small, but will increase with time. By the fifth year, such projects will dominate Institute activities.

The **Exploratory Research** category is for smaller awards, around $40,000, for embryonic studies in newly relevant areas. Successful exploratory activities will evolve into Matching Funds or Core Research activities. These awards are designed to last for one year, with the potential for a one-year renewal upon demonstration of objectives at the end of the first year.

3. **Institute Expansion**. As mentioned in the main body of this report, both initial and subsequent faculty hiring is recommended in the key areas identified by the ETF. With the growth in faculty, the funds provided to the Institute must also grow to provide core, matching, and exploratory research programs. The growth in Institute funding for both faculty hiring and programmatic efforts should be tied to the research funding directly generated by the Institute and its associated faculty. The Institute should not interfere with the normal process for F&A return to colleges and departments. Rather, funds from the central administration should be provided based on two principles. First, the amount of additional University funds provided to the Institute should be based on the total research funds generated by the Institute using a fixed ratio of external funding to University support. Second, the magnitude of this ratio should increase with time as the Institute matures and gains wider recognition; for example, this ratio could vary over time from 5 to 1 initially to 20 to 1 as the Institute matures. This approach assures that sufficient resources are made available based on performance and the expectation that a mature Institute will provide a larger share of its staffing and operating costs.

Appendix IV

Glossary

AFOSR	Air Force Office of Scientific Research (US)
Ag (Sci) or CoAS	College of Agricultural Sciences
ARL	Applied Research Laboratory
CoE	College of Engineering
CoLA	College of the Liberal Arts
CSRP	Center for Space Research Program
CSSL	Communications and Space Sciences Laboratory
DCED	Department of Community and Economic Development (PA)
DCNR	Department of Conservation and Natural Resources (PA)
DEP	Department of Environmental Protection (PA)
DOD	Department of Defense (US)
DOE	Department of Energy (US)
(E)CoS	(Eberly) College of Science
EE	Department of Electrical Engineering (CoE)
EESI	Earth and Environmental Systems Institute (EMS)
EMS	College of Earth and Mineral Sciences
ENRI	Environmental and Natural Resources Institute (CoAS)
EPA	Environmental Protection Agency (US)
ESci	Department of Engineering Sciences (CoE)
ESSI	Energy Self-Sufficiency Initiative (EMS)
GIS	Geographic Information Systems
HMC	Hershey Medical Center
Huck	Huck Institutes of the Life Sciences
IEC	Indoor Environmental Center (CoE)
LNG	Liquefied Natural Gas
MNE	Department of Mechanical and Nuclear Engineering (CoE)
MRI	Materials Research Institute
NASA	National Aeronautics and Space Administration (US)
NIH	National Institutes of Health (US)
NRC	Nuclear Regulatory Commission (US)
NSF	National Science Foundation (US)
ONR	Office of Naval Research (US)
OPP	Office of the Physical Plant
PENNTAP	Pennsylvania Technical Assistance Program
PSIE	Penn State Institutes of the Environment
PTI	Pennsylvania Transportation Institute (CoE)
SBIR	Small Business Innovation Research
SSRI	Social Science Research Institute
STS	Science, Technology, and Society
USDA-ARS	United States Department of Agriculture Agricultural Research Service