Illinois Energy Research
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This paper is a description of University of Illinois' activities in energy research, including bioenergy, materials, emission reduction and energy efficiency, and the power grid. Related activities in water resources, modeling, cyberinfrastructure, and workforce training are also covered.

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Introduction

Thanks to the support we have received from both the federal government and the State of Illinois, Illinois has provided sustained leadership in energy for decades. Illinois' contributions span the entire spectrum of energy research - the design of the next generation of power grids and efficient power generation systems and their economic underpinnings; technologies for a new generation of nuclear energy and analysis of its policy implications; the science, engineering and agricultural research needed to develop bioenergy and biofuels; innovative clean coal and carbon sequestration technologies. As a world leader in computing and information technology, Illinois is uniquely positioned to bring together new technology in computer and computational sciences with broad expertise in human and environmental systems to deliver and evaluate solutions to the nation's energy challenges. One of our biggest opportunities lies in developing predictive and management capacities that can connect across various systems at the local, the national and the global scale.

An agile approach to energy research is promoted by the creation of Centers and Institutes that promote the synergistic teaming of multidisciplinary faculty groups combining policy analysts and domain experts with IT researchers to study the longer-term sustainability of current and "over the horizon" energy technologies. Examples include

- Agroecology and Sustainable Agriculture Program (ASAP)
- Center for Advanced Bioenergy Research (CABER) (described below under Bioenergy Systems)
- Energy Biosciences Institute (EBI) (see below under Bioenergy Systems)
- Environmental Change Institute (ECI)
- Initiative in Energy and Sustainability Engineering (EaSE) (see below under Educational Initiatives)
- Initiative in Social Dimensions of Environmental Policy (SDEP) (see below)
- School of Earth, Society and Environment (SESE)

These organizations promote a high level of participation by our faculty in addressing the nation's energy problems and further our influence on and partnership with global manufacturers like Caterpillar, John Deere, Boeing, Rolls Royce, Dow, ADM and Monsanto – all relating to the development of sustainable energy solutions. Illinois faculty have also been at the forefront in defining the DOE research program through the Energy Frontier Research Centers (EFRC) program, with EFRC partnerships bringing over $20M in funding to Illinois.

Any attempt to organize information on our efforts into a small number of key areas risks omitting emerging advances and innovative approaches. Nonetheless, in any discussion of energy research at Illinois, five foci emerge. These are described below.

1. Bioenergy Systems
2. Materials for energy transport, generation, conversion, and storage
3. Emission reduction and energy efficiency, including carbon sequestration
4. Power grid and energy generation
5. Water resources sustainability and management

Research in these areas is supported by a substantial state-of-the-art infrastructure, laboratories and institutes created, equipped and staffed well in advance of current economic uncertainties.

- Beckman Institute for Advanced Science and Technology (BI)
- Coordinated Science Laboratory (CSL)
- Frederick Seitz Materials Research Laboratory (MRL)
- Energy Farm
- Institute for Genomic Biology (IGB)
- Institute of Natural Resource Sustainability (INRS)
- National Center for Supercomputing Applications (NCSA)
- School of Chemical Sciences

Linkages between research and education on our campus, and the dedication of our faculty to curricular innovation have led to the development of cross-cutting programs aimed at educating the scientists and engineers who will meet the energy challenges of the coming decades. Below we enumerate key examples of our efforts to date.

Key Research Foci

1. Bioenergy Systems
A land grant university located in a major crop production region, Illinois is a major center for bioenergy research. Early success in the development of miscanthus as a bioenergy feedstock led to our inclusion in the BP-funded Energy Biosciences Institute (EBI). The Dudley Smith Foundation is funding a substantial project on rural heat and power, ranging from production of biomass to pelletizing and re-engineering of domestic stoves. The Fisher House, on the South Farms, and Christian County University Extension office are both heated by miscanthus pellets by means of this project.

Research in the production of butanol via fermentation has led to the founding of a start-up company, TetraVitae Bioscience. The $25M Integrated Bioprocessing Research Laboratory (IBRL), included in the State of Illinois budget, will use non-food sources of biomass as feedstock for biofuels, in a configurable, translational integrated facility that will allow for validation of bench scale bioenergy-related technologies at the pilot scale level.

The BP-funded **Energy Biosciences Institute (EBI)** is the most visible energy biosciences research project at Illinois. A joint effort among Illinois, the University of California at Berkeley, and the Lawrence Berkeley National Laboratory, EBI's goal is to provide the R&D needed to initiate an economically and environmentally sustainable biofuels industry, globally, without negative impacts on food production. It is noteworthy that the EBI programs at Illinois are housed in a common physical space that enables interaction among biologists, agronomists, economists, lawyers and environmental scientists on a daily basis. The initial award to UC Berkeley-U Illinois of $500M over ten years, which began in 2007, makes the EBI the largest current single investment globally in energy biosciences. The award is directed by the original PIs of this research proposal, Chris Somerville at Berkeley and Steve Long at Illinois, together with Paul Willems, from BP who serves as Associate Director. The award is now supporting almost 300 full-time graduate students, post-doctoral fellows and academic professionals, 110 of those based in Illinois. The Institute's Annual report is available at www.energybiosciences.org.

The initial focus of the Institute is elimination of barriers to the efficient production of cellulosic biofuels in order to provide alternatives to the use of food crops. This involves research in the complete supply chain from the agronomy, farm engineering and genomics of feedstock crops through biochemical deconstruction of celluloses into their component sugars through fermentation to fuels. This is coupled in a systems analysis context to research into the environmental and economic sustainability of these systems. The Institute includes a smaller effort into the application of biology to improve efficiency of oil recovery from wells.

Toward this end, eleven programs have been funded by the EBI at Illinois.

- Ecosystem Impact and Sustainability of Feedstock Production (Evan DeLucia)
- Engineering Solutions for Biomass (K. C. Ting)
- Feedstock Production/Agronomy (Tom Voigt)
- Assessing the Potential Impact of Insect Pests and Plant Pathogens on the Biomass Production of Miscanthus and Switchgrass (Michael Gray)
- Genomics-Enabled Improvement of Andropogoneae Grasses as Feedstocks for Enhanced Biofuel Production (Steve Moose)
- Biochemistry, Structure, and Engineering of Enzymes to Overcome Biomass Recalcitrance (John Gerlt)
- Engineering of Thermophilic Anaerobic Bacteria to Improve Biocatalysis of Plant Cell Wall Deconstruction. (Isaac Cann)
- Engineering a Yeast Strain that Efficiently Utilizes C5/C6 Sugars (Huimin Zhao)
- Biofuels: Law and Regulation (Jay Kesan)
- Economic and Environmental Impacts of Biofuels: Implications for Land Use and Policy (Madhu Khanna)
- Microbially Enhanced Hydrocarbon Recovery (Bruce Fouke, joint with UC Berkeley and LBNL)

Two major conference series have been founded by the EBI – the Biofuels-Law Conference, initiated in April 2009, and the Biofuels-Feedstock Conference, held on campus each January. The EBI has also involved construction of a unique Energy Farm of 320 acres, the largest of its kind, located adjacent to campus, which includes equipment ranging from state-of-the-art non-invasive wireless sensors for a wide range of measurements from plant production and machinery performance to greenhouse gas emissions and nitrogen losses in drainage water.

FAPESP, the science research agency for Sao Paulo State, has initiated a $250 million program, BioEN, which parallels EBI in many ways. The Illinois EBI and BioEN have been developing linkages, for example, between their environmental groups, and through graduate student exchanges, and are proceeding to formalize their relationship. The first exchanges of staff and students were completed this summer.

In addition to the research being carried out within the EBI, a wide range of bioenergy related research with diverse sources of funding is being conducted by faculty across our colleges. The **Center for Advanced Bioenergy Research (CABER)** in the College of

Agricultural, Consumer and Environmental Sciences (ACES) provides a clearinghouse and communications mechanism among these diverse projects and initiatives as well as with other energy-related institutions within the State of Illinois and beyond.

CABER Global Partnerships: On the international front, CABER has developed a partnership with Brazil. CABER is a partner in a $200K FIPSE project that establishes the opportunity for graduate student exchange between Illinois and the University of Sao Paulo in Brazil. This program enables the funding of internship experiences associated with our Professional Science Master's degree in bioenergy. CABER's activities are designed to facilitate the process of capacity-building and knowledge transfer with our colleagues at the University of Sao Paulo. A collaboration has been developed which will bring together researchers from various disciplines and from two countries (USA and Brazil) to develop and implement an integrated framework for assessing critical land use and lifecycle issues associated with bioenergy systems, including the technical feasibility, economic viability, environmental sustainability and the social-political acceptability of biofuels.

CABER has also established a relationship with three universities in Korea, including Seoul National University (SNU), Korea University (KU) and Sungkyunkwan University (SKKU), with support from the Korea Science and Engineering Foundation (KOSEF).

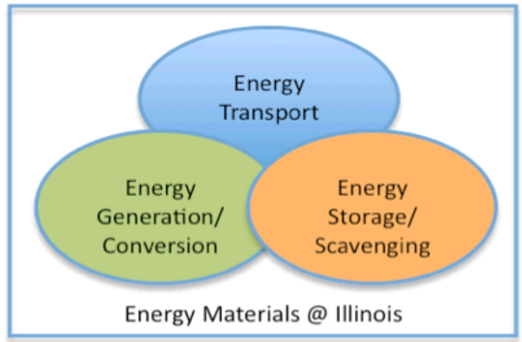
CABER Future Directions: Funding for the development of tropical maize as a new biofuel and forage crop for Illinois was just received through the Dudley Smith Initiative. Additional proposals submitted through the NSF, USDA AFRI, CFAR and BRDI also involve various faculty affiliated with the Molecular Bioengineering of Biomass Conversion theme in the Institute for Genomic Biology at UIUC, using approaches complementary to efforts in the Energy Biosciences Institute (EBI). The tools developed under this initiative will be made available to the general research and education community.

CABER is also developing plans for training and labor force development in bioenergy, including a Certificate in Renewable Energy Agriculture.

A $1 million NSF Emerging Frontiers in Research and Innovation (EFRI) project "**Interdependence, resilience and sustainability of infrastructures for biofuel development**" is being led by Ximing Cai of the University of Illinois at Urbana-Champaign (UIUC) in chollaboration with four UIUC colleagues: Atul Jain, Madhu Khanna, Gregory McIsaac, and Uyang Yanfeng. The project seeks to develop strategies to sustainably operate and expand the interdependent infrastructure systems of the emerging bio-economy. In particular, it will examine the systems used to develop biofuels from cellulosic feedstocks, including water supply, energy supply, and transportation, and their vulnerability to natural events and human factors.

The mission of the **USDA-ARS Photosynthesis Research Unit (PRU)** at the University of Illinois is to investigate critical steps in photosynthesis as well as in-plant nutrient distribution, with the goal of improving the quality and yield of US crops. By integrating experimental findings from the molecular, biochemical, and whole-plant levels, we seek to determine regulatory controls that coordinate the photosynthetic process, the influence of environmental and genetic factors on photosynthetic efficiency, molecular pathways by which nutrients are distributed within plants, factors that determine cell storage capacity, and new methods for improving plant growth by modifying gene structure and expression. This work is potentially of critical importance in the development of increasing the amount of feedstock for bioenergy that may be producted per unit area of ground. Improved photosynthetic efficiency, the core mission of the PRU, is key to allowing adequate food and bioenergy production.

2. Materials for Energy Transport, Generation, Conversion, and Storage



Meeting the energy needs of the 21st century will require new technologies for energy transmission, production, and storage with performance levels far beyond what is now possible.[1] These advances will be driven by the creation of new materials, assembly techniques, and fundamental knowledge to enable exquisite control over chemical, electrical, optical, and mechanical properties of heterogeneous functional materials.

The University of Illinois is uniquely positioned to make important contributions to our nation's energy needs. Through a long-standing partnership with the DOE Office of Basic Energy Sciences (BES), we have established a strong, multi-disciplinary research portfolio that resides partly within the Frederick Seitz Materials Research Laboratory (FSMRL) and draws on our campus' expertise in condensed matter physics, materials science, chemistry, chemical engineering, mechanical science and engineering, and related disciplines. Together, three major research areas are represented: (1) energy transport, (2) energy generation and conversion, and (3) energy storage and scavenging, with a total funding level exceeding \$10 M/year and pending requests in excess of \$10 M/year.

a. Materials for Energy Transport - Our core expertise in superconductivity will provide new insights to guide the discovery and development of the next generation of materials for a "smart grid" composed of superconducting power transmission cables. Illinois has made substantial contributions to the fundamental understanding of both conventional and high temperature (Tc) superconductors. Now, under DOE BES support, we have a dynamic research cluster dedicated to understanding "Quantum Materials at the Nanoscale," led by Paul Goldbart, and are partnering with Brookhaven National Laboratory and Argonne National Laboratory on a DOE Energy Frontier Research Center (EFRC) entitled "Center for Emergent Superconductivity," led by Laura Greene, which seeks to develop a new generation of high-performance superconducting materials for the power grid.

The transport of hydrogen fuels represents another emerging area of importance. Hydrogen is a potential medium in which to carry energy for both static and mobile applications. Although storage in static systems does not present a major materials challenge, the same cannot be said for light-weight metallic on-board regeneration systems for transportation applications. Currently, no material system meets the stringent

[1] *New Science for a Secure and Sustainable Energy Future*, DOE BESAC Report (2008).

performance requirements established by the DOE. A team of materials researchers, funded by the DOE Energy Efficiency and Renewable Energy (EERE) Metal Hydride Center for Excellence (Project Lead, Ian Robertson), is engaged in discovery of the atomistic processes governing the uptake and release of hydrogen from candidate systems and in identifying the catalytic processes that will enable these materials to meet system targets. Another project aimed at the hydrogen economy is related to delivery of hydrogen from the production facility to the end-user station in a safe and economically viable manner. A candidate distribution system is the existing natural gas pipeline system. Building on past experience with hydrogen in metals, a team of researchers, funded by DOE EERE, is tackling issues related to hydrogen embrittlement of steels, while simultaneously building a robust predictive model that can accelerate the design and assess the performance of structural materials used in the delivery of hydrogen.

b. Materials for Energy Generation and Conversion - Our core expertise in flexible electronics is enabling the production of flexible, transparent, and inexpensive solar micro-cell arrays.[2] John Rogers is a pioneer in this field, recently named a MacArthur Fellow. His work on “stretchable silicon” was selected as one of the Top 10 emerging technologies by MIT’s Technology Review (2005). Now, a research team, led by Rogers and funded through the DOE Solar America Initiative, is developing low-cost, concentrator photovoltaic arrays via automated printing techniques in collaboration with Semprius, a start-up company spun off by Rogers and his colleagues. This team is partnering with Caltech and UC Berkeley on a DOE EFRC project entitled “Light-Material Interactions in Energy Conversion” led by Atwater (Caltech), and has recently collaborated on another project, “NSF Engineering Research Center for Material-Scale Heterogeneous Functional Integration in Products.”

In the DOE EFRC project, “Emerging Materials for Solar Energy Conversion and Solid State Lighting,” Jim Coleman is working with colleagues at the University of Southern California to explore simultaneously the light absorbing and emitting properties of hybrid inorganic-organic materials for solar energy conversion and solid-state lighting.

Thin film photovoltaic cells utilize micrometer-thick semiconductor layers and can be deposited onto large sheets of glass for building integrated power generation. Angus Rockett investigates compound semiconductor materials and John Abelson is an expert in amorphous silicon materials. Both have worked extensively with the photovoltaic manufacturing industry under the sponsorship of EPRI and NREL.

There is a concerted effort on campus to produce fuels through the design of novel catalysts. For example, Andy Gewirth and his collaborators are pursuing novel cathode catalysts for fuel cells through a DOE-BES funded project. Tom Rauchfuss, who is credited with discovering biomimetic catalysts for the production of hydrogen, is participating in a DOE EFRC project with Northwestern University on coupling photosynthesis to hydrogen production, reflecting the considerable international interest in hydrogenase enzymes.

By combining expertise in materials science, nuclear, and mechanical engineering, researchers are developing materials for next generation nuclear energy systems. Under

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[2] http://www.sc.doe.gov/News_Information/speeches/2008/Oct%209.html

DOE BES and DOE Nuclear Engineering (NE) support, these researchers are focusing on nuclear fuel design and optimization, using irradiation to create far-from-equilibrium structures that self-heal against further irradiation, discovery of fundamental mechanical degradation processes, and development of predictive models for accelerating the design, assessment and deployment of new material systems. A dynamic research team led by Robert Averback is participating in a DOE EFRC project entitled "Extreme Environment Tolerant Materials via Atomic Scale Design of Interfaces," in partnership with Los Alamos National Laboratory, building upon their fundamental knowledge of ion beam interactions with materials, in situ transmission electron microscopy, and mechanics of materials. Pascal Bellon is working with colleagues from Oak Ridge National Laboratory on the EFRC, "Energy Frontier Center for Defect Physics in Structural Materials," which is aimed at enhancing our fundamental understanding of defects, defect interactions, and defect dynamics that determine the performance of structural alloys in extreme radiation environments. Faculty in Nuclear, Plasma and Radiological Engineering collaborate with these and other groups to conduct research on the performance of materials for nuclear systems, focusing on extreme irradiation and temperature environments.

c. Materials for Energy Storage and Scavenging – research is now underway to create "self healing" batteries. This pioneering effort builds on the work of Scott White, Nancy Sottos, Jeff Moore, and their colleagues in self-healing materials, which has been recognized as a Top 10 Innovation in Science by Popular Science (2001) and by a SciAm50 Award by Scientific American (2008). A research team (led locally by Gewirth) is partnering with Argonne National Laboratory on a DOE EFRC project entitled "Center for Electrical Energy Storage".

As part of the FreedomCAR initiative, ANL and FSMRL staff scientists worked together for nearly a decade to investigate the chemical mechanisms that limit the life of high-power lithium-ion batteries for vehicular applications. Together, they have recently focused on developing the next generation of lithium-ion cells and ultracapacitors, using low-cost nanostructured battery electrodes produced by novel techniques developed within the FSMRL.

To summarize, our campus has a vibrant research portfolio funded by DOE BES, EERE, and NE that extends from basic energy materials research to applied science and engineering. Our outstanding cadre of scientists and engineers is playing a leading role in energy transport, generation, conversion, and storage/scavenging through their funded partnerships with DOE, other federal agencies, and the national labs, as well as through the creation of start-up companies that foster their fundamental discoveries to desired technological impacts. Our campus also serves a critical role in defining the national research agenda; for example, by participating in several DOE BES-sponsored workshops held as part of their "Basic Research Needs Workshop Series"[3], and by serving on the Basic Energy Sciences Advisory Committee (Laura Greene) as well as the DOE BES Long Range Planning Committee for the Materials Sciences and Engineering Division (Ian Robertson).

3. Emission Reduction and Energy Efficiency, Including Clean Coal

[3] http://www.sc.doe.gov/BES/reports/list.html

Until alternative sources of energy are readily available, the future of life on our planet is dependent upon strategies to contain or reduce emissions from sources of fossil fuel and the efficient utilization of energy resources.

In the area of **Geological Carbon Sequestration**, the Illinois Geological Survey (ISGS) has held one of seven Regional Carbon Sequestration Partnerships, led by Robert Finley, funded by the U.S. Department of Energy (DOE), since 2003. The ISGS has one of the top geological carbon sequestration research groups in the nation. They obtained the first Underground Injection Control permit for a 1 million metric ton saline reservoir injection demonstration under Phase III of the regional partnership program. This test is taking place in collaboration with ADM in Decatur, Illinois and involves the capture and storage of carbon dioxide from ADM's ethanol plant in Decatur. The drilling of a 7,230 ft deep injection well is completed. The $84.3 million project is funded by $66.7 million from the U.S. Department of Energy over a period of seven years, supplemented by co-funding from ADM, Schlumberger Carbon Services, and other corporate and state resources. ISGS researchers are participating in a World Resources Institute-State Department-funded technical exchange with China.

The cost of carbon capture is being addressed through separate U.S. DOE funding. ISGS researchers have developed a patent-applied for process to remove carbon dioxide from dilute power plant flue gas streams at lower energy cost than current systems. Further work is underway to demonstrate the process. This process addresses the most costly part of the sequestration process, that of the capture of the carbon dioxide.

In a new DOE supported study, an ISGS-URS Corporation team is investigating a concept in which a dry sorbent technology is configured to combine the water-gas-shift (WGS) reaction with CO_2 removal for coal gasification systems. In the proposed process concept, a solid sorbent bed removes CO_2 at conditions designed to improve WGS efficiency, subsequently eliminating the need for a catalyst. It also enables CO_2 capture and regeneration at high temperature and pressure, thus improving energy efficiency at the treated IGCC plant.

Projects based in Chemical Engineering also examine **novel fuel cell designs** for a variety of applications. One key idea is to replace hydrogen in the hydrogen economy with a liquid fuel that would fit into within the existing fueling infrastructure. Workers at UIUC have pioneered the use of **formic acid** as a fuel for fuel cells. Formic acid is relatively safe, environmentally benign and much less flammable than for example gasoline or hydrogen. Workers at UIUC have shown that formic acid has the same fuel cell characteristics as hydrogen. Thus there is the possibility of quickly switching transportation to fuel cells without building a new transportation infrastructure.

Another key advance is to find ways to eliminate one of the most expensive parts of the fuel cell, the membrane. Workers at UIUC have demonstrated that a **laminar flow fuel cell** can produce almost as much power as a conventional fuel cell but at lower cost. This advance shows the potential of lowering the cost of a fuel cell to be competitive with an internal combustion engine.

Formic acid fuel cells are being commercialized by a start-up company, Tekion, while the laminar flow fuel cells are being commercialized by another start-up company, INI Power Systems, under ARO and NSF support.

Another DARPA funded project in chemical and biomolecular engineering aims to develop new sensor systems that can be used to **improve the efficiency of power plants** running on natural gas. Natural gas is actually a mixture of components; its heating value can fluctuate by 10% over a course of minutes. Present day gas turbines are designed to run at the minimum heating value, since there is no way to measure the instantaneous heating value. Workers at GE have estimated that the efficiency of existing power plants could be improved by perhaps 5% by developing sensors that could measure the heating value instantaneously. Researchers at UIUC are working with GE and DARPA to develop such sensors. A new company, Cbana Laboratories, has been started to exploit these advances. Cbana has received funding from DARPA and ARO.

Moshe Matalon and colleagues are developing technology for environmentally sound coal energy, aimed at the improving the efficiency and reducing the emissions from coal combustion. A host of other projects are underway to mitigate the emissions and pollution that can be caused by fossil fuel combustion. For example, the Illinois State Geological Survey has been the lead agency assisting with siting of the FutureGen project with respect to the geological carbon sequestration that is an integral part of this advanced coal gasification project. The site at Mattoon, IL overlies excellent geology for carbon sequestration, and this site is the only one of the four finalists (two in Illinois, two in Texas) where on-site carbon dioxide injection could take place.

Coalbed methane (CBM) research has been focused on coal adsorption properties, gas origin and chemistry, and on determining how much gas is in place in the largest bituminous coal reserve in the country. The current ISGS DOE Regional Sequestration partnership has an enhanced CBM recovery pilot test underway that is examining the potential to recover CBM with the injection and underground sequestration of CO_2 in a coal seam. CBM research has been supported by DOE and by the State of Illinois.

New methods for the removal of sulfur and nitrogen (the sources of acid rain) are critical to the clean utilization of all fossil fuels and especially of coal. Novel approaches to the preparation of heterogeneous catalysts now take on a special urgency, given the recent EPA mandates for a ten-fold reduction in the permissible sulfur content of fuels. Professors Rauchfuss and Suslick in the Department of Chemistry have developed a new class of nanostructured heterogeneous catalysts with extremely high activity for hydrodesulfurization (HDS) and hydrodenitrification (HDN).

In the area of **fly ash utilization**, an ISGS scientist has recently filed a technology disclosure related to the inclusion of significant amounts of fly ash, a waste from coal-burning power plants, in autoclaved aerated concrete (AAC) blocks, an underutilized, energy-saving, building construction material. Until recently, this research was supported by DOE. Coal-burning utilities have an interest in this product as its use in block is a far more “sustainable” use than sending the ash to a landfill. In fact, the energy saved because of the superior insulating properties of this material when used in construction can exceed the amount of energy generated by burning the coal that supplies the ash (while drastically reducing the number of dangerous ash landfill sites, such as the recently breached TVA site, by using the landfill material as a resource to produce AAC).

Mercury control is a key issue for coal-fired power plant operation. ISGS researchers have developed and are now testing novel carbon sorbents to remove mercury from flue gas streams. A unique aspect of their approach is the production of the sorbent directly from the coal being utilized at the plant to reduce the cost relative to commercial activated carbon supplies.

Enhanced Oil Recovery (EOR) is another Illinois research focus relating to energy. The ISGS is providing key data on the location of oil fields suitable for enhanced oil recovery and the volumes of unrecovered oil resource that could be accessed using carbon dioxide oil recovery processes. A carbon dioxide pipeline study recently was completed with the Illinois Office of Coal Development. ISGS is also supporting private entities seeking to understand near-surface geological conditions impacting the cost of pipeline construction in Illinois

Enhanced oil recovery research in the ISGS has focused on an alkaline surfactant polymer technique and on a CO_2 injection technique, both of which have planned and current field demonstration tests that have been supported by the DOE. Neither technique has yet been applied to the Illinois Basin where there is potential to recover tens of millions of additional barrels of oil from known oil fields.

The EBI's Program on Microbially Enhanced Hydrocarbon Recovery includes participation by Bruce Fouke from the Department of Geology.

Efficient, low-emissions diesel engines utilizing conventional fuels or biofuels are the target of research by faculty in Mechanical Science and Engineering and Agricultural and Biological Engineering. Faculty members from the two departments collaborate in the Illinois Graduate Automotive Technology Education (GATE) Center of Excellence that is supported by DOE and has produced pioneering work in low-temperature combustion, biofuel oxidation for in-cylinder conditions, and electrostatic fuel atomization. Accurate numerical codes and precise laser diagnostics have been developed with a particular emphasis on modeling and measurements of critical emissions such as NO_x and soot. A particular strength of the Illinois approach lies in bringing experts on both the mechanical and biological issues of biofuel combustion together so that an effective coupling of upstream and downstream biofuel technologies is achieved.

Novel energy conversion and combustion technologies have been studied by researchers in Mechanical Science and Engineering with a wide variety of theoretical, experimental, and computational tools. Catalytic oxidation at intermediate temperatures has emerged as a particularly interesting process that occurs in a wide variety of energy conversion modules ranging from solid oxide fuel cells (SOFCs) to low-emission gas turbines. "Micro"-combustors have been demonstrated that will be the building blocks of grid-independent power sources with power density superior to state-of-the-art batteries. Novel fuel cell designs have been proposed in collaboration with colleagues in Chemical and Biomolecular Engineering. The interaction of chemical kinetics with turbulence, which is ubiquitous in contemporary power generation, has been studied with high-fidelity computer codes and advanced experimental tools, such as laser diagnostics.

An ARPA-E award to a group led by Sanjiv Sinha will fund the development of a novel thermoelectric waste heat harvesting device based on large area arrays of 1-D concentric silicon nanotubes which can be inexpensively printed as stacked thermoelectric junctions. This thermoelectric technology holds promise for providing low cost harvesting of energy now lost in the form of waste heat in settings ranging from electricity generation to automobiles to massive data centers.

Energy efficient building technologies have been developed in the Air Conditioning and Refrigeration Center in the Department of Mechanical Science and Engineering. This includes better and efficiently controlled heating, air conditioning and ventilation systems; as well as co-generation of electrical power with either heating or cooling. Particular emphasis has been placed on the study of environmentally friendly refrigerants with a special focus on the increasingly interesting carbon dioxide. In parallel, research has been performed on radiation and efficient use of solar energy, which included the award of second place to an Illinois team in the "Solar Decathlon" competition in Washington D.C. in 2009.

In Electrical and Computer Engineering, researchers have developed a plan for a Center for Energy-Smart Building Technologies (CBEST), focused on energy efficiency, recycling, and lighting. Among other technologies, **programmable windows** are in development that are transparent to heat in the winter, but block it in the summer, promising to provide gains in the efficient use of energy for heating and cooling the built environment.

The **Smart Energy Design Assistance Center** (SEDAC) in the Department of Architecture is designed to encourage building owners, designers, and users to incorporate renewable energy systems and energy conservation practices. SEDAC accomplishes this by providing information and design assistance in the practices and implementation of components of energy conserving design, specification, construction, and education. SEDAC also provides support for the Illinois Energy Code, assists with the financial strategies needed for project implementation, and provides assistance for more broadly defined sustainable design initiatives.

4. Future Concepts for Electrical Energy Processing

Electricity and the electric grid will play a crucial role in our transition to a sustainable energy infrastructure. Over 90% of non-fossil-fuel energy is used in the form of electricity. Non-fossil sources such as nuclear, hydro, bio-mass, and wind are the primary sources for this energy, and as a transition is made to sustainable energy, electricity will be the main tool for delivering these resources.

Integrating a significant percentage of renewable energy sources into the nation's energy mix, and delivering it through electric transmission and distribution systems is a major research challenge since these sources are less controllable than the fossil-fuel-based generation they will displace. Strong wind and solar resources are often distant from urban areas. Their growth will require large national investments in transmission infrastructure, but also brings technology challenges such as large-scale superconducting energy grids. Solar energy can be produced with dispersed small-scale generators, even to the level of an individual residence. Wind, tidal, and ocean wave resources are also dispersed. Dispersed generation requires a shift in control from the generation sources to the distribution system and the loads, a major driver behind the development of what is being called the Smart Grid. At the other end, making the best possible use of energy is crucial. In more advanced Smart Grid concepts, certain loads such as air conditioning and ventilation interact with the rest of the system to help track variable renewable generation. Individual loads can have assigned priorities that ensure continued function of the most important equipment when something goes wrong. Consumers need to be able to take control of their energy use and costs. Appliances, buildings, and other energy consumers must be as efficient as is economically feasible.

Development of the electric system of the future will require expertise in a number of different disciplines including electric power systems, power electronics, information technology and security, materials, urban planning and sociology, control systems, economics, transportation engineering, reliability, the implementation of electric and hybrid transportation, and many others. These are areas of established strength for Illinois and ones in which we are uniquely positioned to take the lead.

Research in the Power and Energy group at Illinois is focused in three main areas: electric power systems, electric machinery and power electronics. Throughout each of these research areas, two highlights of the Illinois program have been close collaboration with industry, and active collaboration across disciplines. Example research projects include the development of power system visualization techniques that are now integrated into electric utility control rooms, power flow and optimal power flow algorithms that are used in software throughout the industry, evaluation of battery performance in hybrid vehicles, and novel techniques for electric machine analysis and design. Associated with this research, Illinois faculty participate in three world-class centers: the Grainger Center for Electric Machinery and Electromechanics, the Power Systems Engineering Research Center, and the Information Trust Institute (ITI). Finally, the faculty have founded two start-up companies: PowerWorld Corporation, which develops power system analysis and visualization software, and SolarBridge Technologies, which specializes in the development of power electronics to enable cost-effective solar energy.

Over the last five years one key and growing area of research has been in the area of electric power grid cyber security. Together with colleagues in computer engineering and computer science, power and energy faculty are addressing the challenge of how to protect the nation's power grid by significantly improving the way the power grid infrastructure is built and operated, making it more secure, reliable, and safe. This is being accomplished through a National Science Foundation-funded project, with support from the Department of Energy and the Department of Homeland Security, known as Trustworthy Cyber Infrastructure for the Power Grid (TCIP). TCIP's research plan is focused on securing the low-level devices, communications, and data systems that make up the power grid, to ensure trustworthy operation during normal conditions, cyber-attacks, and/or power emergencies. Simulation and evaluation techniques are then employed to analyze real power grid scenarios and validate the effectiveness of the TCIP designs and implementations. TCIP has also developed interactive and open-ended applets for middle-school students, along with activity materials and teacher guides to facilitate the integration of research, education, and knowledge transfer by linking researchers, educators, and students. TCIP has recently been funded for another five years by the DOE.

The power and energy faculty have teamed with colleagues in other departments, such as aeronautical and mechanical engineering, and several other universities to establish the

Center for Integrated Wind Energy Systems (CIWES). Given that wind energy is projected to produce as much as 20% of U.S. electricity by 2030, the goal of CIWES is to transform the current paradigm of wind energy by developing fully integrated, commercially viable technologies by 2020 consistent with a 20%+ grid penetration by 2030. There are many system-level barriers that can prevent this goal from being realized including: inefficient power grid integration with dynamic inputs, problems in up-scaling current turbine concepts, and insufficient resolution of atmospheric data for fully coupled control systems. Overcoming these challenges will require an unprecedented fusion of interdisciplinary research across the entire spectrum of wind energy in an interdependent fashion. CIWES will focus on four multi-disciplinary thrusts based on energy availability, energy harvesting, energy distribution, and energy economics. These thrusts will support three transformative test beds, including morphing turbines, controllable wind energy systems, and an extreme-scale virtual wind energy platform. This integrated approach takes advantage of unique resources and experts at the CIWES national and international institutions. It also leverages strong commitments from a wide variety of wind energy industry and innovation partners to coordinate system requirements and to ensure technology transition to commercialization.

In all of the various power and energy research efforts at Illinois, industry interactions play an important role in both guiding research activities and aiding the effective transition of research results. More than 50 industry partners are involved in TCIP, CIWES, PSERC and other major efforts. These partners represent major vendors, grid operators, regulatory and oversight entities all over the country. As an example of successful interactions, several software tools in TCIP have recently been field tested at site facilities of TCIP industry partners.

5. Water Resources

The development of alternative energy technologies, especially those related to biofuels, has important linkages to the quantity and quality of water resources. All major current energy production processes are intensive users of water and the availability and quantity of water is directly linked to weather and climate. The development of alternative energy technologies will create jobs and help to improve the economic foundation of the state and U.S. by supplementing other sources of energy and in time reducing our dependence on fossil fuels, especially oil. However, new energy production systems such as biofuels create new dynamics relating to water management, and there is a risk that energy dependence may be translated to water dependence. At the same time, the solution of water problems such as diversion, desalination, and waste water treatment can significantly increase energy demands and have adverse impact on ecological systems. The university has substantial strength in alternative energy development focused on agriculture (biofuels) and also considerable expertise in water treatment and water resources science, engineering and management, as well as sustainability issues connected to industrial agricultural and urban growth and their reliance upon surface water and groundwater.

At Illinois, the **Center of Advanced Materials for the Purification of Water with Systems (*WaterCAMPWS*)**, a National Science Foundation Science and Technology Center funded at $4 million annually, focuses on the development of revolutionary new materials and systems to purify water safely, economically, and sustainably for human use, with the goal of a drastic reduction in the necessary chemical and energy use. Projects include new methods for desalination and water reuse, with the recovery of minerals, nutrients, and energy, new sensors to detect trace contaminants and monitor purity, disinfection without the disadvantages of strong oxidants or high energy consumption, and the use of remote sensing and communication technologies to collect data that can be used in probabilistic forecasting and risk management, utilizing Illinois' unique petascale computing resources. Two new programs within the *WaterCAMPWS* are recovery of the more than five megaJoules (MJ) of energy in every 1000 liters of municipal wastewater (in which we now spend over 9 MJ of energy to covert to CO_2 and H_2O), and in conjunction with the EU, simultaneously generation of *both* electrical energy and freshwater (from seawater cooling water) using concentrated sunlight.

The *WaterCAMPWS* is leading many national and international efforts to find the scientific and policy solutions to the coming water crisis through organized symposia sessions in collaboration with technical societies, industrial organizations, and government agencies. The American Chemical Society, the American Institute of Chemical Engineers, and the Materials Research Society are key partners in this regard. The Center has also testified to the U.S. Congress on pending water related legislature and to NGOs such as the Clean Water American Alliance, the Water and Wastewater Equipment Manufacturers Association and the Organization for Economic Cooperative Development (OCED. At the invitation of the State Department and the NSF Director, the Center addressed a meeting of 30 world ambassadors in Washington aimed at developing a memorandum of understanding to create a capacity building program on clean water in Sub-Sahara Africa.

Reduction in water consumption is another research theme at Illinois. Power plant water consumption can be reduced by potentially using lower grade resources. Staff in the Illinois State Geological Survey are characterizing non-potable waters for power plant use and defining the issues, such as corrosion, that must be addressed when using water either from enhanced oil recovery projects or from coalbed methane production. Both consumptive and cooling needs are being addressed. Preliminary research is also being conducted in creating zero-discharge processes with mineral recovery from produced waters in enhanced oil recovery, and waters extracted in coal-bed methane and refract waters used for increasing natural gas production.

Prediction and decision support under uncertainty for water quantity and quality as well as air quality is another area of strength at Illinois. The **Institute for the Sustainability of Intensively Managed Landscapes (ISIML)** studies the interaction between water, carbon and energy cycle dynamics to predict the impact of climate change; hydrologic synthesis to understand the integrated response of water, biochemical and ecological functioning in watersheds; drought prediction and mitigation at the sub-seasonal to longer time scales using regional climate models; the dynamics of bioenergy production and best management practices; the health of Great Lakes ecosystems; etc. Jointly with the Institute for Advanced Computation and Technologies (IACAT) at NCSA, a group is developing technologies for a Virtual Observatory for Sustainability of Intensively Managed Environmental Systems to understand entire watershed functions in a virtual environment. Our campus has significant strength in applications of satellite remote sensing data, climate modeling, and spatial computing for integration of a variety of data systems and multiscale predictions.

An NSF-funded project, "Interactions between Water, Energy and Carbon Dynamics as Predictors of Canopy to Ecosystem Scale Vegetation Pattern and Function in a Changing Environment," has developed and validated a multilayer canopy process model that accurately predicts the increase in canopy temperature due to biophysical changes. In particular we are studying the response of crops with regard to water and energy balance, their adaptation to droughts, and the impact that the ecophysiological changes have on the atmospheric boundary layer development.

Active collaborations also exist between university faculty and scientists at the U.S. Geological Survey's Water Science Center, which is located on campus. A focus of this collaborative research includes efforts to understand how extreme weather events and changing climate affect flooding, channel change and ecosystem dynamics along major rivers, such as the Mississippi, Illinois and Wabash, and urban hydrology, especially in downtown Chicago. These collaborative projects involve the application of state-of-the-art modeling and field data-collection techniques to better understand how variable natural processes and human-induced environmental changes influence water quantity and quality.

Researchers at the Advanced Energy Technology Initiative of the Illinois State Geological Survey (ISGS) are conducting research on the critical issues of water consumption and pollution in the energy sector. A DOE project is evaluating the potential feasibility of reusing three types of non-traditional water sources for cooling or process water for existing and planned coal-based power plants in the Illinois Basin. The three type of non-traditional water sources are: (1) produced water from carbon dioxide enhanced oil recovery; (2) coal-bed methane recovery; and (3) active and abandoned underground coal mines. The project will focus on evaluating the quantity and quality of produced water from these sources, identifying and developing suitable technologies for treating the produced water to different quality levels, estimating cooling/process water demand for coal-based power plants in the Illinois Basin, estimating the cost of treated water, and optimizing the cost of pipeline distribution network for water transportation.

Modeling and Decision Support Capabilities

Resource, climate, and environmental modeling is a general area of strength. Modeling of climate change is well established nationally, and Illinois has been a noteworthy player, particularly through the participation of Don Wuebbles and others in Atmospheric Sciences (Jain; Baidya Roy; Schlesinger; He). The Department of Nuclear, Plasma, and Radiological Engineering is cooperating with Hamburg University on extrapolation of carbon dioxide emissions and their implications for nuclear and other energy systems and climate change. Illinois' modeling studies of climate are distinctive because of our well-established capabilities in chemistry climate interactions, regional climate impacts assessment, statistical downscaling of climate, regional climate modeling, carbon cycle analyses, and integrated assessment analysis. Developing capabilities include wind power meteorology and biosphere-climate interactions.

Illinois' distinctive capability is based on the computing capacity and data systems and mining capacity of NCSA and the Blue Waters project to coalesce a broad-scale development of integrated local and regional modeling that can achieve greater precision and more directly address the needs of policy makers.

In addition to the strong modeling capability in Atmospheric Sciences, very substantial strengths have been brought into the campus with the formation of the Institute for Natural Resource Sustainability (INRS) which is integrating the state geological, water, natural history and waste management surveys within the university. Groups there lead the national atmospheric deposition program monitoring the nation's chemical climate, the state water and atmospheric resources monitoring and modeling program, and several programs focused on local and regional modeling of specific energy-relevant resources, with particular strength in regional water resource modeling and modeling for enhanced resource recovery. Strengths in the Department of Civil and Environmental Engineering and the School of Earth, Society and Environment bolster and extend these capabilities. Distinctive clusters of expertise are also present for modeling technologies and technologies integrating large scale field data collection, management and mining. These are of course also core NCSA strengths. Geographic Information Systems expertise is significant across multiple campus units (e.g., Andrew Isserman, Urbana & Regional Planning; Shaowen Wang, NCSA and Geography).

An important dimension of this capacity in regional modeling is early-stage development of a network of international collaborations that could establish the basis for consolidation of a major leadership position in regional modeling. These collaborations include: NCSA and Atmospheric Sciences engagement with the newly forming Cyprus Institute on environmental modeling in the Eastern Mediterranean (led by Wuebbles); Liang Xin-Zhong's (INRS) leadership in collaboration with the Chinese Academy of Sciences to develop China's integrated regional modeling capacity; early-stage engagement of INRS scientists with environmental sciences researchers in Singapore exploring the potential for useful collaboration on regional, policy-enabling modeling in SE Asia (with National University of Singapore); and NCSA's engagement with Brazil's Instituto Nacional de Pesquisas da Amazonia in Manaus on data mining and modeling of Amazon basin environmental impact. Combining the campus' infrastructure capacity to be created by the Blue Waters project, our extensive capacities in energy-related resource and environmental impact monitoring, and our depth in regional modeling can be focused and integrated both for advancing knowledge and sharply strengthening decision support.

Energy and Sustainability Decision Support Capabilities are another strength at Illinois. In conjunction with our national laboratory and industrial partners, Illinois has available analyses of (1) energy sources, including conventional, nuclear, and renewable; (2) delivery infrastructure, including the power grid and transportation systems, and the information technology resources that manage these systems; (3) hydro-meteorological and climate analyses that forecast impacts on energy use and changes in renewable resources and their distributions, and anticipates environmental effects of energy use and related demands on water resources; and (4) econometrics providing probability distributions for outcomes that can be sampled to obtain reasonably likely outcomes in addition to the most probable one. These tools can be used to inform policy decisions based on details but summarized in manageable overviews.

The multidisciplinary team we have assembled has the ability to integrate these capabilities to provide comprehensive, end-to-end analyses that consider energy production, energy transportation, policy, effects on climate and environment, and economic policy. A goal is to engineer a sustainable energy *system* by enabling the prediction of energy use and production on daily, weekly, seasonal, annual, and decadal time scales with concurrent modeling of weather patterns and climate change, costs, and energy resource availability included. This approach is capable of bringing together existing analyses of electrical grids, transportation systems, renewable energy systems, information technology, and micro-scale process models that impact energy use efficiency, embedded in the context of the national and global energy models. Our current capabilities include rapid analysis of particular energy systems, a solid base for further development of decision support analysis tools in 1–5 year time frames, and sustained support for continuing evolution of decision support analysis. Specific focus areas include:

- The power grid (operations, reliability, and security)
- Renewable energy (biomass, wind, photovoltaics)
- Nuclear energy (production and spent fuel management)
- Atmospheric sciences (modeling and measurement both local and global)
- Coupled human and natural systems (economics, policy, and biosphere)
- Construction of a resilient system-wide information technology energy infrastructure
- System-wide decision and control
- Connections to national and international policy makers both public and private
- Techniques for multi-level, scalable modeling, simulation, and analysis

These capabilities link to our strong computational science and engineering programs, along with the Blue Waters petascale computer soon to be installed on campus. All of this interacts with strong research efforts on creating and evaluating the next generations of technologies relevant to energy systems and their sustainability.

Social Dimensions of Environmental Policy
This strategic initiative involves the Beckman Institute and the School of Earth, Society and Environment (SESE). The initiative will: 1) conduct research on the human dimensions of environmental change and policy; 2) serve as a forum for collaboration among social and natural science faculty within SESE and across the UIUC campus; and in the long run 3) link UIUC researchers with policy makers and policy-making processes in Illinois, across the US, and globally. An example of the research involved in the initiative is Jesse Ribot's study of the equity aspects of production and distribution systems for wood fuel in the West African Sahel. The initiative will help set the national and global agenda for environmental policy research, develop its own nationally and globally recognized research initiatives, and become renowned as a source of reliable evidence-based policy guidance. Its ultimate goal is to apply rigorous social-science research to the making of just and sustainable environmental policy. It will provide a platform for public outreach and help SESE attract top-notch policy faculty and students.

Datasets on Plant and Animal Resources: It is noteworthy that the Illinois Natural History Survey is in possession of some of the longest term datasets on the distribution of plant and animal resources among the states (maybe better than anyone else in the world, however, USGS, Biological Resources Division might argue the point), and therefore is very well-positioned to contribute to efforts to assess the impacts of climate change and energy development, and develop mitigation strategies for those impacts.

Carbon Registry: The new Institute for Environmental Change associated with the Colleges of ACES, Business, and Law is developing a new carbon registry program as part of the introduction of cap and trade policy and consumers/business seeking to purchase carbon credits to offset their environmental impact. The institute will serve as a clearing-house for research proposals, publications, and other resources on global warming.

Illinois in Washington: In order to make the best research in energy policy available to policy advisors in Washington DC, the University of Illinois is planning a conference in January 2010, jointly with the University of Chicago and Resources for the Future (RFF). The U. of I. sponsorship involves the Environmental Change Institute (ECI), the Center for Business and Public Policy (CBPP), the Institute of Government and Public Affairs (IGPA), and the office of the Vice Chancellor for Research (VCR). The first annual conference will be held January 20-21, at the RFF (1616 P St., NW, Washington DC), and it will feature ten papers about "The Distributional Effects of Energy Policy." Authors include researchers at UIUC, the U. of Chicago, RFF, Tufts, and UC Santa Barbara. Their research will look at the effects of carbon taxes or cap and trade legislation on the cost of production in each industry, the increase in the price of each product, which consumer groups spend the most on those carbon-intensive goods, and generally who will bear the burden of higher energy costs.

Computing and Information Technology Infrastructure

Key elements of the computing and IT infrastructure needed for energy research include the Blue Waters Petascale computing project, the Cloud Computing Initiative, and the Information Trust Institute.

The University will receive a total of $208 million to acquire and make available the Blue Waters petascale computer, which is 500 times more powerful than today's typical supercomputers. The system is expected to go online in 2011. Blue Waters will reside at Illinois where it will be operated by the National Center for Supercomputing Applications and its academic and industry partners in the Great Lakes Consortium for Petascale Computation. The system may be used, for example, to study the behavior of complex biological systems, design catalysts and other materials with application to fuel and power generation, conduct regional modeling of climate and ecosystem impact, simulate complex engineered systems like the national power grid, and model human-nature interactions to allow the development of sustainable energy solutions. While much of Illinois' previous work in parallel computing has focused on scientific issues, the combination of Blue Waters and numerous applications projects will provide a unique framework that will position Illinois to create large scale models of the societal impact of energy technologies, a significant tool for policy makers and analysts.

Other parallel computing projects on the Illinois campus will contribute to our efforts, for example, the recently announced Cloud Computing Testbed (CCT), a joint research endeavor in collaboration with Hewlett-Packard, Intel, and Yahoo!. This global partnership will result in the establishment of a globally distributed, Internet-scale testing environment, bringing together distributed computing, network, and data resources. By coupling this research with Illinois parallel computing expertise, it will be possible to develop advanced computer simulations operating on distributed resources in areas to model complex, distributed systems such as the energy economy.

Illinois' Information Trust Institute (ITI) addresses the challenge of trustworthy computing for mission-critical applications relating to energy and sustainability, such as the power grid, telecommunications, and transportation, all of which must operate reliably in real-time.

Educational Initiatives

To fulfill the demands of the global workforce, there exists a growing need for education and training in the areas of energy and sustainability engineering. An effective preparation for the student is to acquire a rigorous background in a core discipline, combined with an interdisciplinary understanding of the energy and sustainability challenges and a deeper understanding of a chosen sub-topic. The University of Illinois is well positioned – by virtue of faculty expertise, available coursework, and research opportunities – to provide the mixture of core, breadth, and depth that will allow the graduate to tackle problems in research, planning, development, and implementation of advanced technologies, as well as the interface between technology and society. Our goal is to make Illinois the "go to" university at which ambitious undergraduate and graduate students will develop the foundation for a successful career in the energy and sustainability areas.

For example, interdisciplinary faculty expertise and available coursework cover all phases of bioenergy – from the agricultural generation of biomass, to the biomolecular conversion of feedstocks into fuels, to the economic and social dynamics. A *Professional Science Master's degree in Bioenergy* (PSM) has been launched by the Center for Advanced BioEnergy Research (CABER, www.Bioenergy.Illinois.edu) and enrolled its first cohort of students in Fall 2009. The PSM program requires three semesters plus an internship, includes both science and business classes, and requires no thesis. New course offerings include Bioenergy Systems and Advanced Bioenergy Topics.

In *Nuclear, Plasma, and Radiological Engineering*, we are educating a cohort of students who are committed to a future of safe, clean nuclear energy. Our University has the only nuclear engineering department in the State of Illinois, which has eleven operating reactors.

The *Initiative in Energy and Sustainability Engineering* (EaSE, http://EaSE.Illinois.edu) in the College of Engineering (CoE) promotes research, education, industrial outreach and student engagement, and serves as a bridge between the CoE and complementary efforts on campus. A *Graduate Option Program in EaSE* will launch in January 2010. The option includes a new core course, consisting of a seminar series plus a theory and methods class, and seven areas of specialization – *Biomass Energy Resources, Geologic Energy Resources, Energy Markets, Energy Conversion and Transmission, Energy Safety and Security, Sustainable Environmental Systems*, and *Energy and Sustainability in the Built Environment*. The EaSE option is open to master's and Ph.D. students who are enrolled in an existing departmental degree program and have a background in the natural sciences. It has been designed to facilitate enrollment of graduate students outside of the CoE, including SESE, FAA, and others. A *Master of Engineering in Energy Systems* is under development. This future offering will allow the student to combine any undergraduate degree in Engineering from our campus with a greater depth of course work chosen from two of seven EaSE specialization areas.

We expect future developments at the undergraduate level, such as a minor or option in energy and sustainability.