CENTER FOR CLEAN, SUSTAINABLE ENERGY

College of Engineering

Summary: Nobel Prize winner Richard Smalley and a host of other prestigious scientists, engineers, and policy makers have clearly stated the most important challenge of our age is to find a replacement for cheap oil – the energy source that has fueled the industrial revolution and forms the economic basis of today's society. Clean and sustainable energy tops the list of global concerns our society MUST address. Over the next twenty to fifty years we will need to replace 150-200 million barrels of oil per day in an environment of decreasing supplies of inexpensive and available energy, rapidly growing energy demand in emerging markets, and widespread concerns about pollution and global warming. Meeting the demand for large quantities of energy will require the development of ever more efficient ways of utilizing traditional energy sources (e.g. coal, nuclear) in a manner that minimizes effects on the environment, exploring new technologies (e.g. fuel cells, direct solar energy conversion devices) capable of exploiting untapped energy sources, and supporting development of new energy policies and standards.

The College of Engineering proposes to establish a *Center for Clean, Sustainable Energy* designed to address the national and global need for energy now and throughout the next century. The mission of the proposed Center is to conduct comprehensive, interdisciplinary research, education, and outreach programs that, together, result in adequate sources of clean energy in the near-, mid-, and long-term for the largest energy users – electricity generation, transportation, and industrial processes. Research on clean coal and nuclear power will lead to efficient, environmentally friendly electricity generation in the near term, and to hydrogen production in the mid-term. Research on fuel cells for stationary and mobile systems will provide the means to use clean hydrogen as an important energy source through the mid-part of this century and beyond. Breakthroughs in new technologies, such as photovoltaics and thermoelectrics, will allow us to use renewable energy sources to meet a significant portion of our nation's energy needs in the long term. Finally, research devoted to understanding the impact of these technologies, over time, on society, the environment, and the economy as well as the constraints on their development and deployment will inform energy policy and the development of codes and standards to regulate the new technologies.

Proposed research on clean coal, nuclear energy, hydrogen production, fuel cells, direct solar energy conversion, and energy policy development will build on ongoing programs at Ohio State. Much of that research is conducted in the *Mechanical Engineering* and *Chemical and Biomolecular Engineering Departments* with collaborative efforts underway in other departments including *Materials Science and Engineering*, *Electrical and Computer Engineering*, and *City and Regional Planning*. These research areas are well aligned with national priorities and are well funded by state and federal government agencies and industry. As a result, it is very **realistic** to establish the proposed Center within Ohio State's College of Engineering, and its **viability** is essentially assured. Funds requested from the College/ Department will be used to hire a Director who is well-connected and respected in the energy community and three faculty members who will be selected specifically for their **impact** on both national energy issues and the university's reputation for **excellence**. Funds from the University will provide startup packages for the new faculty and a variety of support functions (seminar programs, communications person, etc.) to ensure a rapid rise to prominence for the Center and high **visibility** for both the Center and the University.

Together these short-term expenditures will attract a larger portion of the increased funding for energy research and yield an excellent **return on investment**.

Few universities have established such comprehensive energy research centers, and the few centers that do exist, such as the one at Purdue, are new. In June of this year, MIT formed a Research Council to study the scope and feasibility of a comprehensive energy center, but a final plan has not yet been issued. A *Center for Clean, Sustainable Energy* established at Ohio State *now* would be on the leading edge of energy research and education programs critical to the nation. It would give OSU a competitive advantage to capture even more research funding and build educational programs that will bring Ohio State national recognition in an area that is destined to be of great importance over the next several decades.

Description of Proposed Center: To accomplish its missions in research, education and outreach and to ensure an impact on both Ohio State's reputation and the nation's current and future energy needs within five years of its inception, the Center will build on existing strengths within the College of Engineering and draw on expertise across the campus. The Center will be a focal point for energy research, encouraging current OSU faculty to collaborate more closely and providing the publicity that attracts more faculty, funding, and recognition. This section of the proposal outlines the Center's research, education and outreach programs. A more detailed description of the research program is in Appendix B.

Research on near-term energy supplies will focus on clean coal and nuclear power. These two sources currently supply over 70 percent of the nation's electricity, but significant advances are required if they are to satisfy the growing demand for electricity with minimal impact on the environment and to replace a significant amount of oil as a transportation fuel (possibly hydrogen for fuel cells) in the near or middle term. In addition, reliance on domestic coal and nuclear fuel sources is important to national security.

Ohio State has a long history of excellence in research on coal – a premium resource of the State of Ohio. Researchers in the *Chemical and Biomolecular*, *Mechanical*, and *Materials Science and Engineering Departments* have made many nationally notable contributions in the various areas of coal technology. This research is well-aligned with the multi-year, $1 billion US DOE initiative on *FutureGen*, a national effort to demonstrate an economical, efficient, zero-emission clean coal process for producing electricity, hydrogen and fuels. AEP, a utility based in Columbus, is preparing to build two of the world's largest electricity generating plants powered by clean coal. Funding from federal and state government programs and industry to support research at OSU related to clean coal has totaled more than $15 million over the past five years.

Ongoing research in OSU's *Nuclear Engineering Program*, and in collaboration with *Materials Science*, *Mechanical*, *Electrical*, and *Computer Engineering*, supports continuous upgrades of existing nuclear power plants enabling them to increase their generating capacity while improving an already impressive record of safety and reliability. Innovations are also being incorporated into designs for new plants which are being built around the world. Some of the most interesting research is focused on high-temperature reactors designed to generate both electricity and hydrogen. The *Nuclear Engineering Program* has an ongoing collaborative research agreement with the *Nuclear Regulatory Commission* and hosts the *Academic Center of Excellence for Instrumentation, Control and Safety of Advanced [Nuclear] Systems*. Ohio State is a partner in the *Battelle Energy Alliance*, which recently won a 10-year contract to manage *Idaho National Laboratory*, DOE's designated center for nuclear energy research. Over the past 5 years, research funding for the *Nuclear Engineering Program* has more than quadrupled.

Moving to mid-term and long-term energy considerations, fuel cells present an attractive solution to future stationary and mobile energy conversion needs. They are an environmentally friendly technology that emits only water as a by-product. The prospect of applications to passenger and commercial vehicles has generated significant R&D activities in the automotive industry. J.P. Morgan Securities estimates that the consumer market for fuel cells could reach $100 billion by 2020. Ohio wishes to create a robust cluster of fuel cell companies, organizations and academic institutions to put the fuel cell industry in Ohio in a position to have an impact on the State economy in the near term. To this end, the State of Ohio has already made a significant investment through the *Ohio Fuel Cell Initiative*, for a total of $38M over the past three years. Future plans resulting from the recent passage of Issue 1 include funding ranging from $5M to as much as $50M total to kick-start interactions between Ohio universities and existing solid oxide fuel cell companies. The Ohio State University is well positioned to advance fuel cell science and technology, thanks to a multidisciplinary research thrust housed in the College of Engineering and located in various departments and centers (*Chemical, Electrical, Mechanical Engineering* and *Materials Science and Engineering,* and *Center for Automotive Research*). Ohio State is currently conducting several millions of dollars of fuel cell research programs, sponsored by government agencies (DOE, NSF, Army, Air Force) and by private industry.

Long-term energy sufficiency is expected to rely on renewable resources, the most promising of which is sunlight. Laying the research foundation for such a technology is a very timely and meaningful goal. The recent efforts in nanotechnologies have opened several promising research directions which fit the expertise and background of faculty in *Electrical and Computer*, *Materials Science*, and *Mechanical Engineering*, including the newly appointed *Ohio Eminent Scholar in Nanotechnology*. Support for projects at OSU related to the development of devices to convert solar energy to electricity has come from a number of sponsors including DOE and NSF. It has been nearly $1M per year, and is likely to increase significantly.

Finally, the development of new energy technologies must be accompanied by technology and environmental assessments before they are deployed. Environmental, energy and safety standards can profoundly impact the feasibility and timeliness of decisions relating to the siting of power plants, transportation and transmission of energy, and siting and operations of related facilities. Our proposed Center will couple our expertise in engineering technology and design of new facilities and technologies with the policy and impact assessment expertise of the faculty at the Knowlton School of Architecture to evaluate the overall social, environmental, and economic impacts of the new technologies.

The *Center for Clean, Sustainable Energy* will have a very active educational component. Undergraduates and graduate students, alike, will have an opportunity to participate in research and seminar programs conducted through the Center. In its first year, the Center will prepare a proposal for the NSF's *Integrative Graduate Education and Research Traineeship* (IGERT) program that will focus on preparing graduate students as leaders in energy-related research, education, and policy making. Educational benefits of the program will be extended beyond students directly involved in the Center's work through interdisciplinary courses on energy technology and policy developed and delivered by faculty affiliated with the Center.

Energy is an issue that touches every citizen. Furthermore, individual decisions on energy use have a significant collective impact on the environment, the economy, and society. Our outreach program will allow knowledge gleaned from research at the Center to be disseminated as widely as possible, not only to other scholars but also to students, teachers, the general public and policy makers at all levels.

Alignment with the Provost's Plan: To demonstrate alignment with the Provost's plan, each proposal is to answer six questions. Those questions are addressed in this section.

National Visibility and Impact

Q. Is the high priority program/department capable of achieving recognition as one of the top programs in the nation or world?

Q. How will the achievement of a top ranking for this program/department affect the university's reputation?

The two departments most heavily committed to the Center, *Mechanical Engineering* and *Chemical & Biomolecular Engineering*, are already recognized for their work in energy research, and affiliation with the Center will enhance their reputations. The departments' improved rankings along with the Center's accomplishments will build Ohio State's reputation. Well known researchers are leading the four research programs (clean coal, nuclear energy, fuel cells, and direct energy conversion) that will form the initial core of the Center for Clean, Sustainable Energy, and their work is very well funded. LS Fan, who heads the clean coal effort, is a member of the *National Academy of Engineering*. Umit Ozkan's work in catalysis which supports clean coal and hydrogen initiatives is internationally recognized. Five nuclear engineering faculty members who will be active in the Center are Fellows of the American Nuclear Society and leaders in the areas of instrumentation, control and safety. Giorgio Rizzoni, Director of the internationally known *Center for Automotive Research*, an IEEE and SAE Fellow, and member of the Executive Committee of the *Ohio Fuel Cell Coalition*, will, with Yann Guezennec, University Scholar Professor Winston Ho and others, continue their groundbreaking work in fuel cells. Joseph Heremans, the recently hired Eminent Scholar in Nanotechnology and Fellow of the American Physical Society, has a long history of research related to direct energy conversion. All of these key people have their primary appointments in the *Departments of Chemical and Biomolecular Engineering* or *Mechanical Engineering*, departments which are currently ranked 26th and 20th, respectively, according to US News &World Report. Mechanical Engineering is already in the top 10% of all ME departments and is the only OSU Engineering department to have two Eminent Scholars. Both departments are well positioned to move into the top rankings and will do so as the scope of their research expands and the public's appreciation of its importance grows.

The *Center for Clean, Sustainable Energy* is a vehicle which can bring recognition to Ohio State. Energy is going to be a very important issue for the foreseeable future. Publishers and broadcasters are already seeking news on energy. A high-profile, respected director and an effective communications program will significantly increase the likelihood that both the technical and popular press will focus attention on the work being done at the proposed OSU Center. Increased recognition of the individual departments, the cross-disciplinary efforts fostered by the Center, and Center's ability to develop energy-related technologies and policies that have a substantial impact on the nation's energy consumption patterns will have a positive effect on the university's reputation.

Excellence

Q. If a high priority program/department has received central investment through selective investment and/or academic enrichment, the results of that investment will be considered. After that central investment, was the reputation of the department/program enhanced?

Q. Is there evidence of the impact of that improved reputation on the university?

Neither *Chemical and Biomolecular Engineering* nor *Mechanical Engineering* received selective investment or academic enrichment funds. However, both departments have built successfully on prior investments to develop excellent programs. Furthermore, investment in the

proposed *Center for Clean, Sustainable Energy* can promote excellence and improve the reputation of the college and the university.

Excellence can be defined in many ways, but it is often measured using US News & World Report rankings. In engineering, those rankings are based on an assessment by peers and recruiters, student selectivity, number of NAE members on the faculty, doctoral degrees awarded, and research expenditures (both total and per faculty member). The next paragraph describes how the proposed Center can lead to improvements with respect to each of these assessment criteria and thus to a higher ranking for the College of Engineering.

The Center will house programs that contribute to the solution of immediate energy problems and programs that provide the theoretical underpinning for technologies that will produce long-term energy solutions. This mix of programs will improve the College of Engineering's standing both with peer institutions and with recruiters wishing to hire people who can help position their companies to be important players in energy technology. Energy is clearly important to society, and many of the best and brightest students seek a place where they can make contributions to society. A properly structured Center, with appropriate advertising of opportunities for students, will attract large numbers of students interested in helping to find "energy solutions". This will allow the College of Engineering to be quite selective when admitting students to work at the Center. It will also result in larger number of Ph.D. degrees awarded. Opportunities to do cutting edge work attract top notch faculty as well, possibly leading to more NAE members. Government agencies, private corporations, and foundations have all recognized the importance of energy to society and are allocating funds to support research in that area. Energy-related research at Ohio State is already well-funded, and the visibility provided by the Center will increase research expenditures. Thus, establishing the *Center for Clean, Sustainable Energy* can lead to improved scores on all of the criteria used to determine the US News & World Report ranking for engineering schools, leading to recognized excellence in Ohio State's College of Engineering and improved reputation for the University.

Viability

Q. Is it realistic? If the plan is implemented, how likely is it to have an impact on the university's reputation?

The proposed Center is very realistic. As noted earlier, the College of Engineering already has strong programs in clean coal, nuclear power, fuel cells, and direct energy conversion. While the key people named in this proposal are primarily affiliated with the Chemical and Mechanical Engineering Departments, they are working in conjunction with faculty members from almost all other departments within the College. Over the years, engineering departments, the university, federal and state government agencies, and corporate sponsors have invested in an infrastructure that supports energy research at Ohio State. Examples of some of the more significant facilities include the *Center for Automotive Research*, the *Gas Turbine Laboratory*, the *Nuclear Reactor Laboratory*, and the *Wright Fuel Cell Group*. Decades of investment in people and facilities involved in energy research makes the College of Engineering an ideal location for the *Center for Clean, Sustainable Energy*. The energy-related programs described in this proposal have attracted millions of dollars of research funding to Ohio State, and that funding is growing. With the proposed Center in place, Ohio State will be in a position to attract a growing share of that funding. The results our talented faculty will be able to achieve with the additional funding will certainly enhance the University's reputation.

Cost/Benefit

Q. How will the effort benefit the university relative to the cost of the proposal?

With the world-wide demand for energy increasing, oil supplies becoming more uncertain, and public concern about the environmental impacts of energy consumption broadening, both government and industry are increasing their long-term investments in research required to ensure abundant supplies of clean energy. Faculty and staff at Ohio State have an excellent track record with sponsors of such research. The University's investment of $1 million per year over 5 years could easily result in research exceeding $10 million per year at the *Center for Clean, Sustainable Energy*.

Collaborations: As indicated in the description of the proposed Center's activities, almost all departments in the College of Engineering are already involved in some aspect of energy research. The proposed center will promote collaboration among those departments and with faculty members in other colleges, interdisciplinary programs, and centers. For example, faculty members in physics and chemistry (MAPS) study the underlying physical phenomena upon which many of the energy technologies are based. Faculty members from FAES study renewable energy sources, environmental impacts of large energy-producing or energy-consuming facilities, and energy/environmental policy. The Environmental Science Graduate Program involves faculty from 5 different colleges, several of whom specialize in energy production, utilization and policy areas.

In addition, the *Center for Clean, Sustainable Energy* can complement work of other Centers proposed under the Provost's Targeted Investment Initiative. For example, MAPS has discussed proposing a center that studies the "impacts of energy consumption on climate and water." While the Center for Clean, Sustainable Energy focuses on clean energy production and technologies that use the energy efficiently, the MAPS center would take the next step, looking at the global impact of the emissions on climate and water.

Resource and Staffing Issues: A detailed budget and a budget justification are provided in Appendix A. This section outlines what resources are required, how they will be utilized, and the contributions requested from the University, College, and Departments. The total amount requested in an average of $1 million per year with ~$500 K from the University, $250 K from the College and $250 K total from the participating departments. Salaries and benefits for personnel - a director, three faculty members, and an administrative associate- are requested from the College and Departments. Funds to cover all other costs are requested from the University. Those costs include (1) startup packages for new hires, (2) release time for current faculty to build research teams, prepare proposals and develop interdisciplinary courses based on Center research, (3) salary for a communications person to establish and maintain a website, prepare promotional materials and news releases, and help with proposals, (4) operating expenses for the Director's office, (5) matching funds, if required, for early proposals, and (6) travel, seminar series, and a conference, all of which promote collaborative, interdisciplinary efforts, and enhance Ohio State's visibility

Proposed faculty and staff hires and responsibilities for their costs among are:

- Director – a systems person with experience leading an energy research organization and extensive connections in the field – to develop specific long-term plans to carry out the Center's mission and vision, and foster internal and external relationships. Salary/benefits: ½ from the College, ¼ each from Mechanical and Chemical Engineering.
- Senior faculty member – nuclear engineer specializing in instrumentation and control systems. Salary/benefits: ½ from the College and ½ from Mechanical Engineering
- Junior faculty member - reactions person (catalysis and non-catalysis) in Chemical Engineering with courtesy appointment in Mechanical or Materials. Salary/benefits: ½ from the College, ½ from Chemical Engineering.

- Junior faculty member – fuel cells specialist with an appointment in Materials and possibly a joint appointment in Chemical or Mechanical Engineering. Salary/benefits: ½ from the College, ½ from Materials Science and Engineering.
- Administrative Associate – experienced administrative person to support the Director. Salary/benefits: same distribution as for the Director.

APPENDIX A

Center for Clean, Sustainable Energy Supplies and Utilization

Budget Estimate – Revised Dec. 21, 2005

All costs given in thousands

Cost Category	Year 1	Year 2	Year 3	Year 4	Year 5
Personnel					
1. Director					
Annual Rate*	$ 120	$240	$180	$120	$ 60
Start-up	$ 50	$100	$100	$ 50	$ 0
2. New senior faculty					
Annual Rate*	$ 70	$140	$145	$150	$155
Start-up	$ 50	$100	$100	$ 50	$ 0
3. New jr/sr faculty					
Annual Rate*	$100	$200	$200	$200	$200
Start-up	$100	$200	$200	$100	$ 0
4. Faculty release time (proposals)	$100	$100	$ 50	$ 50	$ 25
5. Communications	$ 0	$ 45	$ 40	$ 35	$ 30
6. Admin. Assoc.*	$ 60	$ 62	$ 64	$ 66	$ 68
7. Faculty release (course devel.)	$ 0	$ 25	$ 25	$ 25	$ 25
Other Costs					
1. Operating Exp.	$ 55	$ 15	$ 15	$ 15	$ 15
2. Seminars	$ 10	$ 10	$ 10	$ 10	$ 10
3. Travel/host	$ 40	$ 40	$ 20	$ 40	$ 20
4. Matching funds	$ 50	$ 50	$ 50	$ 40	$ 30
5. Conference	$ 0	$ 10	$ 60	$ 10	$ 60
Total – University	$ 455	$ 695	$ 670	$ 425	$ 215
Total – Coll./Dept.	$ 350	$ 642	$ 589	$ 536	$ 483
GRAND TOTAL	$ 805	$1,337	$1,259	$ 961	$ 698

From University: $2,460 From College/Department: $2,600 Total: $5,060

* Funds from College/Department. All other funds from University.

Energy, Environment, Sustainability Subcommittee
Supporting Comments for Budget Estimates

Personnel

- Annual rate includes 9-month salary for faculty (12-months for Director) and benefits
- Each new person's startup package of $300K will be evenly distributed over 3 years
- Director and the new senior faculty member will take some time to find and will be on board only half of Year 1 (best case estimate)
- 2 junior faculty members will be hired (1 in Year 1 and 1 in Year 2) with an average 9-month salary plus benefits at $100K
- After Year 2, an increasing portion of the Director's salary will be covered by indirect costs or direct appointment to projects rather than by annual rate

- Funds under "Faculty release time (proposals)" will be for current faculty who want to write proposals for interdisciplinary work to be done within the Center.
- "Communications" refers to a full-time person who handles such responsibilities as news releases, brochures, and web site development, and also helps to polish proposals. An increasing portion of this person's time will be charged to indirect costs or as a direct appointment to projects.
- "Administrative Associate" is a full-time person who supports the Director and faculty working at the Center.
- "Faculty release (course devel.)" provides funds for faculty members to develop cross-disciplinary courses that will allow students to learn from the research conducted at the Center and will prepare students (primarily graduate students) to make more significant contributions to the Center's research.

Other Costs

- "Operating expenses" include rent for the Director's office, office supplies, phone, fax, and furniture/equipment to set up the Director's office in the first year. The Director's office will have space for the Director, Administrative Associate, and Communications person.
- "Seminars" are expected to be quarterly interdisciplinary seminars by well-known researchers not currently working at Ohio State or the proposed Center.
- "Travel/host" funds will provide the Director and researchers with the wherewithal to visit potential collaborators and sponsors or host their visits to OSU.
- "Matching funds" are for proposals to organizations that require a match.
- "Conference" is a biennial national, and perhaps international, conference on Energy/Environment/ Sustainability hosted by Ohio State

APPENDIX B

Description of Proposed Center's Research Program

To accomplish its missions in research, education and outreach and to ensure an impact on both Ohio State's reputation and the nation's current and future energy needs within five years of its inception, the Center will build on existing strengths within the College of Engineering and draw on expertise across the campus. This section of the proposal will describe the Center's research program and outline the education and outreach programs. It will note the existing strengths in key departments and opportunities to promote interdisciplinary efforts.

Four inter-related research thrusts will be conducted in parallel at the Center for Clean, Sustainable Energy. They will explore technologies for near-term, mid-term, and long-term energy supplies along with development of energy policy and standards to regulate the various energy technologies.

Research on near-term energy supplies will focus on clean coal and nuclear power. These two sources currently supply over 70 percent of the nation's electricity, but significant advances are required if they are to satisfy the growing demand for electricity with minimal impact on the environment and to replace a significant amount of oil as a transportation fuel (possibly hydrogen for fuel cells) in the near or middle term. In addition, reliance on domestic coal and nuclear fuel sources is important to national security.

Ohio State has a long history of excellence in research on coal – a premium resource on the State of Ohio. Researchers in the Chemical, Mechanical, and Materials Engineering Departments have made many nationally notable contributions in the various areas of coal technology including combustion, gasification, sorbent and membrane technologies, catalysis and flue/fuel gas pollution control. New clean coal processes such as OSCAR and CARBONOX have been invented, demonstrated and licensed to industry. Research within the Center will continue these ongoing programs, focusing on such areas as reaction and separation chemistry that help to eliminate pollutants and catalysis which improves process efficiency. This research is well-aligned with the multi-year, $1 billion US DOE initiative on FutureGen, a national effort to demonstrate an economical, efficient, zero-emission clean coal process for producing electricity, hydrogen and fuels. AEP, a utility based in Columbus, is preparing to build two of the world's largest Integrated Gasification Combined Cycle (IGCC) electricity generating plants powered by clean coal. Funding from a variety of federal and state government programs and industry to support research at Ohio State related to clean coal has totaled more than $15 million over the past five years.

One hundred and four nuclear power plants in the U.S. generate 20% of the nation's electricity at a competitive price while emitting zero air pollutants – no CO_2, SO_2, NO_X, mercury, or particulates. Ongoing research supports continuous upgrades of existing plants enabling them to increase their generating capacity while improving an already impressive record of safety and reliability. Innovations are also being incorporated into designs for new plants which are being built around the world and are expected to be ordered for US utilities in the coming year. Some of the most interesting research is focused on high temperature reactors to provide process heat needed to generate hydrogen. Ohio State's Nuclear Engineering Program, in collaboration with Materials, Mechanical, Electrical, and Computer Engineering, has ongoing research in several areas that impact current and future reactors. Because Ohio State is one of a

small number of universities with a research reactor, our faculty and students typically conduct both theoretical and experimental studies.

Research areas proposed for the Center build on current research and include: (1) Instrumentation and controls and human-machine interface – sensor development, control system design, and improved human-machine interfaces. (2) Safety and reliability – development and application of probabilistic risk assessment methodologies to identify operating procedures and plant design features that improve plant efficiency and safety. The methodologies can be applied to other energy-related facilities as well. (3) Thermal-hydraulics – improved understanding of two-phase flow and heat exchanger design, with particular emphasis on compact, high-efficiency, durable, heat exchangers made of materials that can withstand high temperatures and pressures. Such devices will also be valuable in hydrogen production and coal gasification facilities. (4) Waste management – recycling and reusing nuclear fuel, using resources efficiently, reducing the volume of waste requiring storage or disposal, and minimizing the chances of theft. (5) Advanced energy system design – focusing on using nuclear power to produce electricity and hydrogen, providing energy for transportation regardless of whether the nation eventually settles on hybrid/electric or hydrogen fuel cell powered vehicles.

The Nuclear Engineering Program has an ongoing collaborative agreement with the Nuclear Regulatory Commission to conduct research in many of the areas listed above. In addition, the Program hosts the Academic Center of Excellence for Instrumentation, Control and Safety of Advanced [Nuclear] Systems. Ohio State is a partner in the Battelle Energy Alliance, which recently won a 10-year contract to manage Idaho National Laboratory, DOE's designated center for nuclear energy research and the revitalization of nuclear engineering education. Over the past 5 years, research funding for the Nuclear Engineering Program has more than quadrupled.

Moving to mid-term and long-term energy considerations, fuel cells present an attractive solution to future stationary and mobile energy conversion needs. They are environmentally friendly technology that emits only water as a by-product. Co-generation through solid-oxide fuel cells can achieve outstanding energy conversion efficiency; further, the prospect of applications to passenger and commercial vehicles has generated significant R&D activities in the automotive industry. Breakthroughs in these applications will require scientific as well as engineering and manufacturing advances. J.P. Morgan Securities estimates that the consumer market for fuel cells could reach $100 billion by 2020. The potential growth of the fuel cell market appears substantial, ranging from $61 million in 2001 to more than $7 billion by 2009. The State of Ohio has developed a very pragmatic and focused approach in support of fuel cell technology development. Ohio wishes to create a robust cluster of fuel cell companies, organizations and academic institutions to put the fuel cell industry in Ohio in a position to have an impact on the State economy in the near term. To this end, the State of Ohio has already made a significant investment through the Ohio Fuel Cell Initiative, for a total of $38M over the past three years. Future plans resulting from the recent passage of Issue 1 include funding ranging from $5M to as much as $50M total to kick-start interactions between Ohio universities and existing solid oxide fuel cell companies.

The Ohio State University is well positioned to advance fuel cell science and technology, thanks to a multidisciplinary research thrust housed in the College of Engineering. Current activities are located in various departments and centers (Chemical, Electrical, Mechanical Engineering and Materials Science and Engineering, and Center for Automotive Research). The research conducted at OSU ranges from nanoscale (heterogeneous catalysis, high-definition

inorganic materials, organic membranes) to large scale systems, including hydrogen production, and stationary, portable and automotive systems. These activities range from basic science, including strong modeling and multi-scale simulation capabilities, to experimental characterization, to design, to system integration, and are supported by computational and experimental facilities that include catalysis, membrane, and reactor laboratories in Chemical Engineering; material synthesis and characterization facilities in Materials Science and Engineering and Mechanical Engineering; and system integration and balance of plant laboratories at the Center for Automotive Research, where a prototype fuel cell vehicle and a hydrogen refueling station are located. Ohio State is currently conducting several millions of dollars of fuel cell research programs, sponsored by government agencies (DOE, NSF, Army, Air Force) and by private industry, making Ohio State a very strong player in this developing area.

Long-term energy sufficiency is expected to rely on renewable resources, the most promising of which is sunlight. Actual data indicate that the average solar energy incident onto a horizontal surface averaged over the US is 4 kWhr/m^2/day. A conversion technology with a system efficiency on the order of 10% would enable the energy demand of the country to be satisfied while maintaining the land use to a few hundreds of km^2. Laying the research foundation for such a technology is a very timely and meaningful goal. The recent efforts in nanotechnologies have opened several promising research directions, two of which fit the expertise and background of faculty in Electrical and Computer, Materials Science, and Mechanical Engineering, including the newly appointed Ohio Eminent Scholar in nanotechnology. They are (1) photovoltaic solar cells, and (2) the direct photocatalytic production of hydrogen by splitting water on catalytic semiconductor nanoparticles. Both topics are mentioned as areas of research opportunity by the Office of Science of the US Department of Energy. Photovoltaic cells are the subject of research in the Electrical Engineering Department. A new program on the development of two new classes of photo catalysts for water splitting, delafossites and tungsten oxide, is being set up that combines the complementary expertise in three departments: the electronic transport properties measurements on the nanometer scale structures (Mechanical Engineering), synthesis of nanometer particles of ceramics (Materials Science), and measurements of the energy band structures of wide-gap semiconductors (Electrical Engineering). Renewable energy production, and energy conversion and conservation (through waste heat recovery) with nanomaterials are also the object of research programs on nanoscale thermoelectric devices and materials, and will draw on expertise in organic semiconductors.

Finally, the development of new energy technologies must be accompanied by technology and environmental assessments before they are deployed. Currently environmental, energy, safety, and related codes and standards can profoundly impact the feasibility and timeliness of decisions relating to the siting of plants, transportation and transmission of products, and siting and operations of related facilities. Our proposed center will couple our expertise on the engineering technology and design of new facilities and technologies with the policy and impact assessment expertise of the faculty at the Knowlton School of Architecture to evaluate the overall social, environmental, and economic impacts of the new technologies. The resulting interdisciplinary team will offer a unique and highly competitive approach to the analysis of future energy technologies.

The importance of this aspect of energy development was recently recognized by the U.S. Department of Energy (DOE, 2005) as they released a request for proposals to study the codes

and standards required to for the hydrogen economy. The RFP notes that codes and standards can often delay deployment for six years or more as codes are proposed, reviewed, revised, and finally implemented. It seeks parallel development and evaluation of codes and standards along with hydrogen fuel energy development to help expedite the potential implementation of these new technologies.

As responses are developed to this and other research opportunities, faculty from the Colleges of FAES and Social and Behavioral Sciences may also be able to play a significant role with additional expertise in technology and environmental impact assessment.