

PROJECT DESCRIPTION

Overview

During the last 20 years, there has been a growing realization that sustainable development must receive a higher priority in the years ahead. There is a particular need for scientists and engineers with expertise in sustainability who can develop innovative solutions to the problem of dwindling natural resources. These students need to be able to function in a multi-disciplinary environment and need to be able to communicate technical ideas to other engineers and scientists and to those without a technical background. This proposal requests funds for nine undergraduate students each year to participate in a ten-week summer research program that will allow them to conduct research on a sustainable energy, work in a multidisciplinary research environment, develop communication skills, and learn more about current topics related to sustainability. Additionally, undergraduate researchers employed under a separate NSF EPSCOR project in solar energy will participate in many of the REU activities (seminars, field trips, research symposium); in this way, this project will impact eight additional undergraduates.

This REU site builds upon the success of an REU site in sustainable energy held at Kansas State University from 2009 through 2011. This site engaged 44 students (28 supported by the REU site and 16 by the NSF EPSCOR project) in cutting-edge research on sustainable energy. REU research led to six publications/conference proceedings[1-6] and fourteen conference presentations[7-20] (three of which received awards[8,9,16]). Of REU participants who have finished their undergraduate degree, 78% are currently attending graduate school. Students indicated that the REU program enhanced their understanding of their technical discipline, led to an improved understanding of sustainability and how to conduct research, and enhanced their interest in pursuing a research career.

The title of this REU will be “Earth, Wind, and Fire: Sustainable Energy for the 21st Century”. This title reflects the different types of renewable energy the students will be learning about (earth = biofuels, wind = wind energy, fire=solar energy) and should be instantly recognizable and interesting to undergraduate students. The goal of the program is to provide a rich research experience focused on the personal and professional development of the participants. Specific learning objectives of this project are shown in the table on the right. We also hope to enhance recruitment of students, particularly students from underrepresented minorities, into graduate studies in science and engineering.

The core of the program is the research the students will conduct on sustainable energy. These research projects will involve faculty mentors from chemistry, chemical engineering, electrical and computer engineering, biological and agricultural engineering, and grain science. In these projects, students will acquire research skills and become aware of the technical skills required for addressing challenges in sustainable

Table 1. Learning objectives for Earth, Wind, and Fire REU

Learning Objectives
1. To develop and apply knowledge and skills in the area of mathematics, science, engineering, and research methods
2. To develop an understanding of sustainability as an applied multidisciplinary field encompassing economics, science, and technology, and the social, political, and ethical issues facing contemporary societies
3. To develop a recognition of the need for, and an ability to engage in life-long learning by increasing the capacity for self-directed learning and original investigation
4. To develop skills for communicating scientific and engineering concepts to the public and to K-12 students

energy. Students will orally present the results of their research to their peers and the co-PIs once during the summer and through a poster presentation at a concluding research symposium.

In addition to their research, students will participate in weekly seminars on sustainability and professional development. The sustainability seminars will cover topics such as triple bottom line, climate change, carbon taxes and carbon trading, wind energy, solar energy, biofuels, sustainable transportation systems, energy efficiency and conservation, water, land, sustainable indoor environments, population, and sustainable food systems. These seminars will be part of a formal course, ChE 670 Sustainability Seminar, for which the students will receive one hour of academic credit. The professional development seminars will include topics such as laboratory safety, laboratory research notebooks, data management, writing a scientific paper, technical presentations, graduate education, and career paths.

A final key component of this project will be the inclusion of a team outreach project related to sustainability. In this project, groups of students will interact with the public (at the Flint Hills Discovery Center) or K-12 students (at on-campus summer camps) about a topic on sustainability of their choosing. Students will be trained in how to present technical information to a non-technical audience by the head of the Center for Science Education at K-State. This team project will enhance student communication skills, allow students to see the broader implications of their research, and see how they can positively impact society through research.

Social activities will be planned to build community among the REU students and faculty mentors. These will include weekly “brown bag” lunches on campus, field trips to unique sites at and near K-State (ethanol plant, hydroelectric plant, wind farm), and evening activities such as a hike on a nearby prairie.

Evaluation of the REU will be conducted by an evaluation expert both during and after the REU experience. Journal entries will be evaluated in terms of student learning and perspective transformation. In addition, a post-experience survey containing both qualitative and quantitative questions will be sent to REU participants 6-9 months after the experience. Finally, an existing program at K-State (CORES or the Collaborative for Outreach, Recruitment, and Engagement in STEM Program) will be utilized to track REU participants to determine whether the objective of encouraging participation in graduate studies has been met.

Students will primarily be recruited by contacting nearby colleges and universities in Kansas, all Big 12 universities, and all universities with engineering colleges within about 600 miles. Existing programs at K-State that serve underrepresented minorities will be leveraged to enhance the diversity of REU participants.

The operation of the REU will be overseen by the co-PIs, Keith Hohn and Larry Erickson. The co-PIs will be responsible for the research meetings and for organizing the social events. The weekly professional development meetings will be organized by K-State’s SUROP (Summer Undergraduate Research Opportunities Program). The sustainability seminars will be organized by Larry Erickson.

Nature of Student Activities

Students involved in the “Earth, Wind, and Fire: Sustainable Energy for the 21st Century” REU will be immersed in an experience that allows them to develop valuable technical skills, learn about sustainability and the tools needed to provide for sustainable systems, improve their personal skills, and develop a community with the faculty and student participants in the REU. Table 2 summarizes the activities that will help the students achieve technical competence, develop their professional skills, and form a community with each other and the faculty mentors.

Table 2. REU Activities and their relevance to program objectives

Development of Technical Expertise	Professional Development	Community Development
<ul style="list-style-type: none">• Multi-disciplinary research project on sustainable energy• Research meetings• Research Symposium• Sustainability outreach project• Sustainability seminar	<ul style="list-style-type: none">• Weekly professional development seminars• Journaling• Sustainability outreach project	<ul style="list-style-type: none">• Brown bag lunches• Field trips• Evening activities

Development of Technical Expertise

The heart of the proposed REU is to engage undergraduate students in cutting-edge research projects related to sustainable energy. Through these projects, students will gain a detailed knowledge of one aspect of sustainability, and will acquire some of the skills necessary to conduct meaningful research in sustainable energy. Listed below are the anticipated research projects.

Materials for Solar Power Generation, Fuel Cells, and Batteries (Higgins, Li, Klabunde)

Many issues related to sustainability are truly materials issues. Development of better materials will enable energy production from fuel cells, batteries, and solar cells. A number of research projects are proposed to engage REU students in materials research that will contribute to the development of sustainable energy sources.

One project will engage the REU student in developing active catalysts for hydrogen fuel cells. Typically, these fuel cells use platinum metal as the catalyst, which is a problem because of the high cost of Pt. The economics for using fuel cells would be substantially improved if a catalyst based on non-precious metals could be developed. Recently, some progress along these lines has been made with carbonaceous coated cobalt and iron particles[21]. In the past, Dr. Klabunde's group has prepared graphite/graphene coated nickel nanoparticles, and reported that these materials were effective for synthesis of pure metal carbides[22,23]. An REU student working on this project would prepare core/shell Ni/carbon nanoparticles using a vacuum codeposition method called Solvated Metal Atom Dispersion (SMAD)[24] followed by heat treatment under vacuum, test the activity and stability of the nanoparticles for hydrogen oxidation, and compare their activity to platinum and gold nanoparticle catalysts.

A second project in the area of materials will focus on the use of nanostructured materials in solar cells and electrical storage. Nanostructured materials have recently attracted extensive research interests due to their potential in providing a cost-performance balanced solution. The REU student will work under Dr. Li's supervision to develop various nanomaterials for solar cells and electrical energy storage, with a focus on one-dimensional nanowires and integration of them into energy conversion or storage devices. The main project will be on the study of arrays of vertically aligned carbon nanofibers (VACNFs) and ZnO nanowires as templates for dye-sensitized solar cells (DSSCs) and lithium-ion batteries. In addition, the synthesis of catalyst particles by solvothermal processes for photochemical watersplitting using sun light will be explored. The synthesis and fabrication processes of these materials are much cheaper than traditional semiconductor processes. They also provide the unique structures which are not available with traditional methods. The combination of these two advantages makes them very attractive for the development of new energy technologies. The REU student will evaluate the

properties of these nanomaterials and optimize them for both solar energy conversion and electrical energy storage.

Chemicals and Fuels from Biomass (Wang, Hohn, Vadlani, Anthony, Sun, Higgins)

Producing fuels and chemicals from renewable biomass, rather than finite petroleum resources, represents a possible path towards a sustainable future. Because of its status as a land-grant institution with strengths in agricultural research, Kansas State University has a number of ongoing interdisciplinary projects on biomass conversion suitable for an REU student.

Drs. Hohn and Wang are developing acid-functionalized magnetic nanoparticles to convert cellulosic materials into fermentable sugars[25]. This project involves synthesis of nanoparticles using a method developed at K-State, characterization of the nanoparticles (using x-ray photoelectron spectroscopy, infrared spectroscopy, thermogravimetric analysis, and light scattering), and testing of the materials for cellulose hydrolysis. REU students will explore how to synthesize acid-functionalized nanoparticles using different acidic ligands, how the nature of the ligand affects the nanoparticles' catalytic activity, and how the nanoparticles can be applied in different acid-catalyzed reactions for production of fuels and chemicals from biomass.

Drs. Vadlani and Anthony are studying the use of ionic liquids for extraction of chemicals from biomass. For example, they are looking at extracting zein (a major storage protein in corn that has industrial application in biodegradable plastics, films, adhesives, textiles, and cosmetics) from dried distilled grain solids using ionic liquids (organic salts that are liquids near room temperature). Ionic liquids (ILs) provide a promising opportunity to improve the extraction of zein from distiller's dried grains with solubles (DDGS). ILs can be designed with highly tunable solvation properties, making them excellent materials for both extraction processes and reactions. REU students will synthesize ionic liquids and measure their efficiency for extracting zein from DDGS.

Dr. Sun conducts research to synthesize agriculturally-based rapidly-renewable materials for industrial applications as director of the Biomaterials and Technology Lab (BTL). REU students will have the opportunity to study a variety of biobased products, including soy protein-based adhesives, epoxidized soybean oil pressure sensitive adhesives, peptide nanomaterials, and poly (lactic-acid) composites. Activities include characterization of components extracted from biomass, synthesis of a product from the biomass-derived components, and testing of the product's properties, for instance testing the adhesion strength of a bio-based adhesive.

Dr. Higgins' laboratory is developing new mesoporous silica[26,27] monoliths for potential application in dewatering of biofuels[28] and organic solvents[29]. Well-aligned mesoporous silica[30-32] monoliths and surfactant gel mesophases[33] have been prepared within microfluidic channels by flowing surfactant-templated silica sols through the channels, allowing them to gel, and calcining to remove the surfactant[34]. The alignment of individual mesopores (2-10 nm diameter) templated within these materials is characterized by single molecule tracking in which widefield fluorescence videos follow the motion of nanomolar concentrations of probe dye molecules in the monolith. The results obtained are analyzed to access quantitative order parameters reflecting the local level of channel alignment[34]. An REU student will investigate aligned mesoporous silicas modified by post-synthesis grafting of organic groups (i.e. methyl, amine, and carboxylic acid functionalities) onto the pore surface by reaction with appropriate organoalkoxy- or organochloro-sulfanes to quantify the level of channel order and molecular mobility within them.

Wind Energy (Miller)

Wind energy is an important area of research at Kansas State University, and is conducted primarily through the Wind Application Center, directed by Dr. Miller. REU students will participate in wind research in a variety of ways. One project would be to acquire and analyze data for microgrid islanding modeling for the DOE-funded Resourceful Kansas project. This project seeks to build a computer model of an electrical distribution system powered partially by both conventional and renewable energy sources, where placement of wind and photovoltaic generators is determined through computer-based optimization calculations. The REU student would analyze data from real systems, including generators installed at a facility near the K-State campus, for use in the model[35] A second project, in collaboration with the Kansas Department of Transportation(KDOT), would evaluate the appropriateness of siting wind turbines at different KDOT facilities across the state. A third project would engage the REU student in the design and construction of power electronics for renewable energy generators, with consideration of maximum power trackers and power factor correction circuits and inverters[36]. A final potential project for an REU student is to analyze data from thermocouples, strain gauges, and optical sensors mounted on the wind turbines installed near the K-State campus to gain an understanding for the maintenance needs of the wind turbines.

Sustainable Energy on a University Campus (Champion, Pahwa, Miller)

There are significant financial incentives for universities to reduce the amount of power they consume. As Director of Sustainability, Dr. Champion coordinates sustainability efforts at Kansas State University, with reducing power consumption as a primary goal. An REU student will work with Dr. Champion as well as electrical engineering professors Pahwa and Miller to evaluate energy usage at K-State and devise ways to enhance energy efficiency. This project requires the student not only to devise technical solutions to a problem, but consider how those solutions can be implemented into a very complicated environment like a university. Potential tasks that the REU student may be involved with include measuring the energy consumption of different equipment on campus, devising ways that building managers, computer lab managers, and laboratory scientists can implement energy conservation strategies, and work with the K-State Energy and Environment Program to utilize new campus-wide real-time metering to study patterns in building level energy consumption and identify causes and solutions.

Small Renewable Energy Systems (Pahwa, Erickson, Miller)

Most of the homes around the world receive AC power because most traditional loads have utilized AC power. However, many of the loads in modern homes require DC. For example, computers, audio components, flat-panel TVs, and some lighting use DC supply for their operation. Since there is no DC supply available, the AC power has to be converted to DC at every load point where DC power is needed. Renewable power sources, including photovoltaics and small wind turbine, produce DC power, which must be converted back to AC for interconnection to the grid. It may be possible to directly utilize DC power produced from solar and wind energy to power DC devices in homes, which would prevent loss of energy in conversion from AC to DC and vice versa. An REU student will evaluate the technical and economic feasibility of this idea. This will involve evaluation of different AC and DC loads in homes, measuring energy loss in conversion from AC to DC, and evaluating the size of the DC source required to the home's DC load.

Production and Characterization of Algae (Erickson, Sun, Yuan)

There are a number of opportunities to use algae productively to produce food, feed, fuel, and other products. REU students will research algal growth and how to convert algae to valuable products.

Algae growth could have an environmental benefit by making use of excess nitrogen and phosphorus in waste waters. Often the algae are produced in mixed cultures in which natural populations develop. The characterization of mixed cultures and the management of them to obtain productive processes will be the focus of research by an REU student. In 2011 *Skeletonema costatum* was identified as an algal species that might be nurtured in mixed cultures that has commercial value [37]. Preliminary research studied its growth and nutrient requirements in mixed cultures. A long term goal is to develop mixed culture processes with value to society such as that reported by Adey et al. [38].

Another project related to algae is the manufacture of industrially-useful materials from biomass. Dr. Sun will lead a project to extract oils and proteins from algal biomass, and evaluate their use to produce industrial products. One example is to use algal proteins to synthesize adhesives, similar to how Dr. Sun's group has produce soy-based adhesives[39].

Faculty mentors interested in working with an REU participant will be asked to submit a brief (two-page) application by February 1st. This application will detail the research problem to be addressed, the applicability of the research towards sustainable energy, the methods used to address that problem, the faculty members and graduate students involved in the research and the resources available to the REU student. Projects will be selected by the REU co-PIs based on the intellectual merit of the proposed research, how well the research fits the sustainable energy theme of the REU program, and the extent to which the students will be involved in multidisciplinary research. The selected projects will be listed on the REU website and in information sent to prospective REU applicants. If there are more acceptable projects than REU students, student preference on projects will determine which projects ultimately receive an REU student. Table 3 lists faculty mentors and their research interests.

Table 3. Research Mentors

Name	Department	Research Interests
Jennifer Anthony	Chem. Eng.	Green Chemistry, Mesoporous Materials
Ben Champion	Geography	Sustainability
Larry Erickson	Chem. Eng.	Biochem. Eng., Environmental Remediation
John Schlup	Chem. Eng.	Materials, Spectroscopy
Keith Hohn	Chem. Eng.	Catalysis, Biomass Conversion
Dan Higgins	Chemistry	Organic Photovoltaics, Spectroscopy
Kenneth Klabunde	Chemistry	Nanotechnology, Photocatalysis
Jun Li	Chemistry	Photovoltaics, Nanotechnology
Ruth Miller	Elect. Eng.	Wind and Solar energy
Praveen Vadlani	Grain Science	Fermentation, Biomass-derived chemicals
Anil Pahwa	Elect. Eng.	Small-Scale Renewable Energy Systems
Donghai Wang	Bio. and Ag. Eng.	Fermentation, Lignocellulose hydrolysis
Wenqiao Yuan	Bio and Ag. Eng.	Biomass Conversion, Gasification
Xiushi Sun	Grain Science	Biomaterials

Students will present their research progress during research meetings throughout the ten-week program. These meetings will be facilitated by the two co-PIs, Keith Hohn and Larry Erickson. At each research meeting, three REU students will report their research progress. These meetings will help develop the ability of the students to present their research results to a multidisciplinary audience and will advance the research effects by requiring each student to think about the work that is being done, including goals, plans, methods, and expected results. Students will also attend a weekly meeting on sustainability, as part of a one-hour course, ChE 670 Sustainability Seminar. Larry Erickson will have primary responsible for the content of these seminars. Table 4 lists the seminars presented last summer.

Table 4. Sustainability Seminar Schedule in 2011

Date	Title	Presenter and Affiliation
June 3	Intro to Sustainability and Sustainable Development	Larry Erickson, Keith Hohn Chemical Engineering, KSU
June 10	Wind and Solar Energy	Ruth Miller Electrical Engineering, KSU
June 17	The Next Synthesis	Wes Jackson, The Land Institute
June 24	Sustainability Progress at KSU	Ben Champion Director of Sustainability, KSU
July 1	Climate Change	John Harrington, Ben Champion Geography, KSU
July 8	Thermal Conversion of Biomass	Keith Hohn Chem. Eng., KSU
July 15	Sustainable Communities	Huston Gibson Architecture and Planning, KSU
July 22	Algae	Vincent Amanor-Boadu, Richard Nelson Ag. Econ., Chem. Eng.
July 29	Policy Issues	Oral Saulters Cent. for Haz. Substance Research, KSU

At the conclusion of the summer program, students will present a poster at a research symposium. All of the participants from all of the multidisciplinary research teams (faculty, graduate students, and others not in the REU program) will be invited to attend and participate in the event. Students supported by the NSF EPSCOR grant will also participate in this symposium.

Professional Development

This REU program seeks to train undergraduates who are not only skilled in their technical area, but who can effectively present their research to both technical and non-technical audiences. We seek to enhance students' communication skills by engaging them in outreach activities to the general public and K-12 students. This type of approach has been demonstrated to dramatically enhance student's communication skills. In evaluating the NSF-funded G-K12 program (which had STEM graduate students teaching in K-12 classrooms), Mitchell et al. [40] reported that 75% of the graduate students interviewed cited improved communication skills as an outcome of their experience with K-12 students. These graduate students pointed to two

specific areas of improvement: (1) gauging the audience, and (2) describing scientific ideas in ways that younger students could understand. The G-K12 research fellows involved with the K-State EIDRoP Program [41] added that working with K-12 populations had strengthened their own knowledge of both science content and research methods. The very process of explaining difficult concepts or the reasons for a specific research protocol helps the graduate students develop a deeper understanding of the scientific content as well as why scientific research is done the way it is done. Evaluative data from our recently completed REU showed that participants grew in their awareness of the crucial role that scientists and engineers play in educating the public and accepted that this was a responsibility that they have now and in their future careers [6]. In order to better equip future scientists and engineers to communicate to the public about their work, we have added a learning objective and activity to intentionally develop these skills.

REU students will be given their choice of several outreach activities. One possibility is to work with the local science-themed Flint Hills Discovery Center (<http://www.flinthillsdiscovery.org/>, see letter of support from Bob Workman, museum director) to develop content for the museum related to sustainability energy. Possible projects include: giving a public presentation, developing an activity cart that can be checked out from the Discovery Center by K-12 teachers, or developing an exhibit for the museum. Another possibility is to make a presentation on sustainable energy to K-12 students participating in various science-themed camps at Kansas State University.

REU participants will receive specialized training to prepare them for the outreach activity. Dr. Jackie Spears, director of the Center for Science Education and Professor of Curriculum and Instruction at Kansas State University, will work with the students in the first week of the program on effective instruction. For students interested in working with the Discovery Center, museum personnel will be available to aid them in developing their materials. For students interested in working with K-12 students, a high school science teacher will be brought in to critique their presentations. Funds are included to provide compensation for this teacher.

In addition to the sustainability outreach project, students will receive professional development through an existing summer seminar organized by the Graduate School at K-State. Table 5 lists the topics covered in this seminar in 2011.

Table 5. Professional development seminars in 2011

June 7	Preparing for Research
June 14	Graduate School Application Process
June 21	Graduate Student Panel
June 28	Financial Support for Graduate School
July 5	Vita Building/Documenting Research
July 12	Effective Presentation Skills
July 19	Industry Careers

To further enhance the development of the REU participants into outstanding scholars, all participants will be strongly encouraged to present their work at a regional or national technical meeting in the academic year following their REU experience. To help make this possible, funds are included in the budget to cover all conference expenses.

Community Development

An important part of the REU experience is for the students to feel a sense of community with the other REU participants and with the faculty mentors. This collegial atmosphere is key towards creating a positive environment for student growth. It will also help in our efforts to promote research as an attractive career path for the students.

To promote a sense of community, a variety of activities will be planned. Informal “brown-bag” lunches will be held weekly, where REU participants and faculty mentors will have lunch together on campus. The lunches will not have an agenda; rather, they will encourage discussion of topics other than science and engineering. Two field trips will be held during the ten-week period of the REU program to industrial sites demonstrating different aspects of sustainable energy. The first will be to the wind farm near Concordia, KS and to the corn and sorghum ethanol plant in Scandia, KS. The second field trip will be to the Bowersock hydroelectric plant and to the wastewater treatment plant in Lawrence, KS. A research scale reactor has been constructed at the wastewater treatment plant in which the nutrients in wastewater are being used to grow algae, a possible feedstock for biofuel production. These field trips relate to the REU topic of sustainability, but will also serve to promote the development of community among REU participants. Participants in our REU will also attend an opening picnic for all REU students at K-State, hosted each summer by SUROP. SUROP also organizes two ice cream socials that our REU students can attend, and often coordinates a trip to the Cosmosphere in Hutchinson, KS. A pizza and movie night will be held at one of the PI's homes, where the selected movie will relate to sustainability. One trip to the Konza Prairie Biological Research Station (the largest virgin prairie left in the United States) will also be organized.

The Research Environment

Kansas State University (K-State) is a land-grant university located in Manhattan, Kansas with a student population of ~21,000. As a land-grant university, K-State has strong programs in agriculture and engineering to support the major industries in Kansas (agriculture, aircraft manufacture, oil and gas production).

K-State has several existing programs related to sustainability. The Center for Sustainable Energy promotes multidisciplinary research with faculty participation from several engineering disciplines and the College of Agriculture. This center was formed in recognition of the significant potential for Kansas in renewable energy production from wind energy or biofuels. Kansas State University and the Consortium for Environmental Stewardship and Sustainability (CESAS) have organized a Dialog on Sustainability for the last six years that brings together different constituents to discuss different aspects of sustainability. K-State has a director of sustainability, Ben Champion, who coordinates K-State's efforts on sustainability.

K-State has a history of strong support for REU programs, for example the NSF-funded REU programs in Grassland Ecology, Mathematics, and Physics. The Graduate School self-funds the Summer Undergraduate Research Opportunity Program (SUROP). These summer programs, as well as other academic year programs including our Developing Scholars and McNair Scholars program, comprise the *Consortium for Undergraduate Research Experiences (CURE)*. The Consortium links the undergraduate research program coordinators to sustain a University-wide undergraduate research infrastructure that makes each of the individual programs more substantive, more valuable to the students, more focused on the preparation for graduate education, and more of a pipeline into high-caliber graduate programs. The Consortium

members share best practices, resources such as workshops and assessment instruments, and endeavor to provide quality research and networking experiences for participating students.

Kansas State University has an excellent research and educational environment for nurturing undergraduate students. K-State ranks seventh nationally among universities for Rhodes, Marshall, Truman, and Goldwater Scholars and first among public universities for Rhodes, Marshall, Truman, Goldwater, and Udall Scholars. Thirteen K-State graduates have been Rhodes Scholars, and 12 have been Marshall Scholars.

The faculty involved in the proposed REU have had extensive experience in mentoring undergraduate researchers. The twelve senior investigators have mentored over 100 undergraduate students (many of whom are women or ethnic minority students), resulting in more than 40 presentations and more than 25 publications. Some of the undergraduates mentored have been the recipients of prestigious national scholarships, for example, Chris Baldwin, Cynthia Riemann, and Lisa Kitten (Marshall Scholars), Emily Voigt (Goldwater, NSF Graduate Fellowship, National Defense Science and Engineering Fellowship), and Jonathan King (Goldwater, NSF Graduate Fellowship)

Kansas State University has excellent research facilities in the area of sustainable energy. All of the faculty listed in Table 3 as potential research mentors maintain active research programs in or related to sustainable energy. Some specific pieces of equipment that will be useful for the proposed research includes: x-ray photoelectron spectrometer, infrared spectrometer, chemisorption apparatus, x-ray diffractometer, electron microscopes, chemical reactors, fermentors, gas, liquid, and ion chromatographs, fermentors, pyrolysis and gasification equipment.

Student Recruitment and Selection

Direct communication will be used to invite and encourage applications to the “Earth, Wind, and Fire: Sustainable Energy for the 21st Century” REU program. In addition, the website created for the previous REU site (<http://che2.engg.ksu.edu/reu>) will provide students with information on past REU activities and available opportunities in the upcoming summer. While the internet will reach out to all parts of the United States, direct communication will focus on all four year colleges and universities in Kansas and the Kansas City metropolitan area, all Big 12 universities, and all universities with engineering programs within about 600 miles of Manhattan, Kansas. We will also directly contact professionals at other colleges and universities with whom we have ongoing professional relationships. We will also include information on our REU in existing websites that compile this information, for example at the University of Connecticut (<http://www.cmbe.engr.uconn.edu/reu.html>).

A number of approaches will be taken to enhance the diversity of the REU applicants. We will work with the Multicultural Engineering Program, the Retention, Diversity and Inclusion Program and SUROP to encourage applications that enhance diversity. SUROP regularly attends events at other universities to recruit students for its programs, and has agreed to publicize our REU at these events. Another K-State resource that will aid recruitment of students from underrepresented groups is the Collaborative for Outreach, Recruitment, and Engagement in STEM (CORES) Program. CORES is a K-State funded program designed to provide databasing and tracking capabilities for participating K-12 and undergraduate outreach and education programs. CORES also facilitates connections with community colleges in Kansas and minority-serving institutions elsewhere. Both of these avenues will be valuable in helping to recruit students from underrepresented groups to the proposed REU site program.

The recruitment plan detailed above is similar to what has been used for the previous REU site. This plan has resulted in both a large number of applications (125 in 2011) and a diverse group of REU participants (25% of participants were from underrepresented groups and 43% were women). See the section on results from prior NSF support for more information.

Application to our program will be completed online at: <http://che2.engg.ksu.edu/reu>. Students will submit an application form (which includes contact information, academic background, relevant experience, ethnicity, sex, and citizenship), an essay of up to two pages on the student's interest in sustainability, research interests, and professional goals, an academic transcript, and two letters of recommendation. The completed application will be due on March 1st. The completed applications will be reviewed by the program co-PIs. The selection criteria will include merit, diversity, academic major, and professional goals. Of the nine NSF REU students, we have a goal of including at least five engineering majors and at least two majors from chemistry, physics or another field of science or mathematics who have an interest in engineering. We would also try to include at least two individuals that enhance ethnic and racial diversity, and seek to have 50% women participants. Consideration will also be given to the distribution of students among the faculty based on the listed research project interests of the students.

After receiving the applications on March 1st, the completed applications will be reviewed and ranked during the next ten days. We would expect to extend offers to the top ranked students by March 15th with their acceptance being due ten days after the date the offer is made. The students will receive a clear statement of the financial details of the program, dates for arrival and departure, and information on the details of the plan of activities for the summer. We would also alert highly ranked students that are not selected in the first round that they are still being considered as alternates, and that we will communicate with them again if we are able to make them an offer. As soon as we receive word from an applicant who has turned us down, we will make an offer to the next person on the list.

Project Evaluation and Reporting

Project evaluation will be conducted to improve the REU program and to investigate transformative learning and conceptual changes, in addition to the assessing the development of scientific knowledge and research skills. Methods for program evaluation and assessment of student learning will measure how well the learning objectives have been met. Many of the evaluation methods will be interwoven with the activities of the REU experience, for example the journaling activity. Evaluation activities will be used throughout the project to continuously improve the program and to provide a summative evaluation upon project completion. Follow-up surveys, containing a qualitative and quantitative mix of questions, will be conducted 6-9 months following the completion of the summer REU.

Tracking of students following their participation in the REU will be facilitated by the database constructed by the Collaborative for Outreach, Recruitment, and Engagement in STEM (CORES) Program at K-State. CORES is a K-State funded program designed to provide database and tracking capabilities for participating K-12 and undergraduate outreach and education programs.

An outline of the evaluation plan is shown in Table 6. Transformative learning theory[42] will be used as a guiding framework for evaluation of the REU program learning objectives. The data collected from the weekly written entries and focus groups will be analyzed in terms of perspective transformation and conceptual changes related to sustainability and the

role of scientists and engineers. Qualitative data collected from all sources will be coded and managed using QSR NVivo 8 software to create a case study database.

Qualitative data will be coded using frameworks from Mezirow [42] and the results of previous research in the area of transformative learning and sustainability [43,44] and sustainability education frameworks [45,46].

Table 6. Evaluation Tools and Timeline

Tool/Method	Target Objective	Frequency
Sustainability Mindset Scale	2. understanding of sustainability.....	Annually (pre and retrospective pre/post at beginning and end of summer)
Journaling	2, 3. life long learning.... 4. skills for communication	Weekly during summer
Focus Group	1. develop and apply knowledge..., 2, 3,4	Annually (at end of summer)
Scientific Proficiency Checklist	1.	Annually (at end of summer)
Tracking/Documenting Student Experiences	1, 2, 3	Continuous, reported annually
Transformative Experience Survey	1, 2, 3, 4	Annually (6-9 months after completion of summer)

Emergent themes will also be included in the case study database. Data will be analyzed using a keyword phrase search derived from the aforementioned frameworks. The case study database will be utilized to conduct searches and to tabulate and manage search results.

The evaluation of the REU will build upon the successful evaluation methods used in the previous Earth, Wind, and Fire: Sustainable Energy for the 21st Century REU [6]. Focus group schedules and journaling prompts from the previous REU have been field tested and improved over the past three years. Lessons learned from the past program will inform the development and pilot testing of two new tools: the Transformative Experience Survey and Sustainability Mindset Scale that will assist in deepening our understanding of the program’s impacts, as well as further the boundaries of evaluative research. The Transformative Experience Survey is based on the work of Pugh [47,48] and will be used as a follow up-survey to measure how students have integrated their summer REU experience into their lives. The Sustainability Mindset Scale is based on work by the Cloud Institute for Sustainability Education [46], who developed a rubric for assessing sustainable habits of mind based sustainability education content standards. This rubric will serve as the basis for the development of a scale to measure changes in the students’ sustainable habits of mind and will be conducted at the beginning and end of their ten-week summer experience.

Wendy Griswold, an assistant research professor in the Adult Education Department at KSU will conduct program evaluation and prepare evaluation reports. She conducts research on transformative learning and sustainability education in higher education. Dr. Griswold has been involved in program evaluation for five years, including evaluation for NSF-funded projects.

Results from Prior NSF Support

Participants and Demographics

An REU site titled, “Earth, Wind, and Fire: Sustainable Energy in the 21st Century”, has been run at Kansas State University for the past three years. Twenty-eight science and engineering undergraduates have participated. In addition, for the past two years 16 undergraduate students supported through a separate NSF EPSCOR grant (to the Kansas Center for Solar Energy Research, NSF Award#0903806) have benefitted from the REU activities.



2009 REU Students at wind farm in Concordia, KS

These students (located at K-State, the University of Kansas, and Wichita State University) have participated in the sustainability seminars (either live or through the internet), attended field trips, and participated in the closing poster session. In this way, the REU site has impacted more people than just the 28 participants.

The “Earth, Wind, and Fire” REU site has enjoyed a high number of applicants in each year of existence: 86 in 2009, 117 in 2010, and 125 in 2011. Applicants have come from all over the United States, from small institutions to research universities. The applicant pool has

been sufficient to allow significant racial and gender diversity in the participants, as shown in Figure 1. Ethnic and racial designations were self-reported. Hispanic, Asian, and Native American designations include students who only chose this designation and those who indicated a multi-racial background. As seen in Figure 1, 25% of the REU participants are from traditionally underrepresented ethnic and racial groups, while 43% of participants were female.

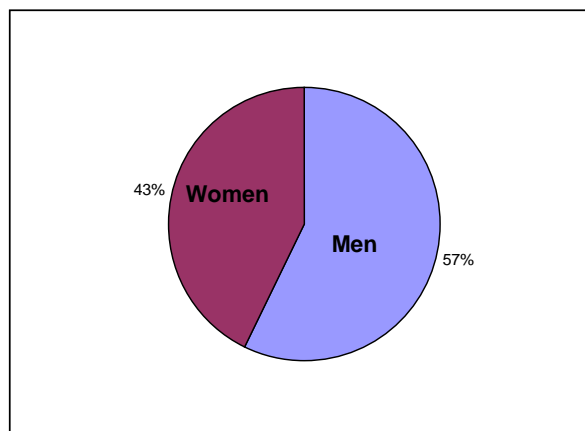
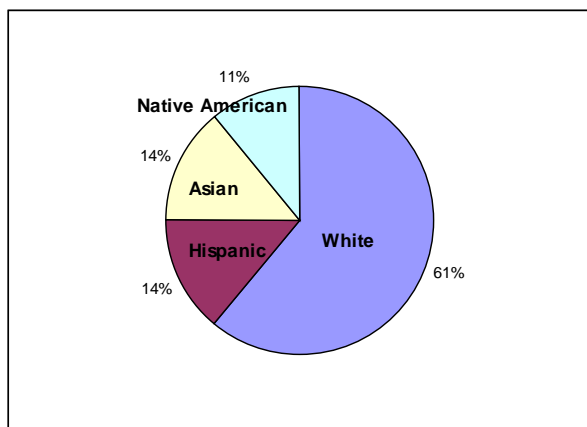


Figure 1. Demographics of “Earth, Wind, and Fire: Sustainability in the 21st Century” program (2009-2011).

Research Quality and Productivity

One of the hallmarks of the “Earth, Wind, and Fire” sustainable energy REU is that it has engaged students in research that spans multiple academic disciplines, often requiring them to consider issues other than technical ones. For example:

- Emily Reinhard (2010) worked with Noel Schulz, professor of electrical engineering, and Ben Champion, Director of Sustainability at Kansas State University, to measure the power consumption of computers in different modes and to evaluate the potential cost savings for Kansas State University to implement energy-saving procedures.
- Kara Walker (2010) worked with Philip Ugorowski, professor of mechanical engineering, and Praveen Vadlani, associate professor of grain science, to evaluate the potential for small-scale production of ethanol from waste starches produced in food manufacture. To develop this idea, Kara conducted research in fermentation with Dr. Vadlani, and then performed engineering calculations with Dr. Ugorowski on whether waste heat from the cooking process could be used for purification of the ethanol/water mixture resulting from the fermentation.
- Christopher Maher (2010) and Joseph Alfaro-Stone (2009) worked on wind energy projects with Ruth Miller. These projects required the students to acquire and analyze wind data and perform simulations of the data to determine potential wind energy at different locations. Christopher and Joseph were also engaged in the DOE-funded “Wind for Schools” project that places wind turbines in schools throughout Kansas to educate students about wind energy. This project required Christopher and Joseph to visit these schools and interact with the teachers and who would be teaching the students about wind energy.
- Karen Tietzen (2009) and Alisha Multer (2011) worked with Keith Hohn, chemical engineering, and Praveen Vadlani, grain science, to develop a hybrid process (combining fermentation and catalytic steps) to convert biomass to chemicals. These students performed research both on fermentation of biomass to an important intermediate chemical (2,3-butanediol) and catalytic dehydration of 2,3-butanediol to methyl ethyl ketone.

REU research projects have resulted in fourteen presentations at regional and national meetings [7-20] (three of which have received awards[8,9,16]) and six publications and conference proceedings(this includes both submitted and accepted manuscripts)[1-6]. We anticipate that at least three more publications will result from the research from the summer 2011 REU.

Assessment of Program and Learning Objectives

To evaluate whether we have met our learning objectives(for the previous REU these were the first three objectives listed in Table 1), students kept a journal documenting their experiences throughout the ten-week experience, and also completed two surveys (one quantitative and one qualitative) at the end of the experience. All results suggest that students are benefiting immensely from the REU program. Table 7 shows the quantitative results for 2009 and 2010 related to the specific learning objectives. Students reported substantial improvement in all areas, with average scores always greater than 7 and most greater than 8.

Table 7. Results from quantitative survey of student objectives. Students were asked to self-assess their own improvement in the area specified on a ten-point scale with 10 being the highest improvement

Objective Measured	2009	2010
Interest in conducting research	8.6	7
Interest in graduate school increased	8.5	7.6
Understanding of sustainability	8.6	8.8
Understanding of how to do research increased	7.8	8.3
Understanding of a particular technical area	8.4	8.3

We have been particularly successful at encouraging students to pursue an advanced degree in science and engineering. Out of the 19 students who participated in 2009 and 2010, eleven are currently attending graduate school, while five are still completing their undergraduate degrees, and three are working in industry. This means that over 78% of students who have participated in our program who have received their B.S. degrees have pursued an advanced degree.

Perhaps the best evidence for the impact of the Earth, Wind, and Fire REU site are student journal entries. These indicate that the REU program was instrumental in helping students make decisions on their career path, in teaching them about research and sustainability, and in their personal development. A few comments are given below.

“This summer has definitely impacted the way I view research and sustainability, but my perspectives and beliefs have changed the most about graduate school and my career. Before this experience, I had no intention or desire to go to graduate school for chemistry. However, after the SUROP seminar on graduate school, my ideas about graduate school changed. I realized that it would be the best for my career and my future to attend graduate school. I also realized, through the research I was involved in, that I would really enjoy graduate school. Now, I am looking forward to being part of a research community and getting my PhD.” **Student O, 2010**

“As I continue to do more and more lab work and especially this first week of working in a lab full time, I find myself enjoying the work. I am a slow, methodical, and patient person who likes to do things precisely: a perfect fit for working in a lab atmosphere. I have been contemplating going to graduate school, and work like this has encouraged me more than anything to pursue my graduate school goals.” **Student B, 2009**

“Before this I had a lot of experience in industry and I was pretty sure that was the way I was going to go...I wasn’t sure I would be any good at it, because I’d never done it before. That was one main thing...I was really glad I came here and that was one of my main goals, to figure out if I want to go into industry and become a regular engineer or spend a few more years in graduate school. From this experience I realized that material science is what I want to do and one way to do that...is to go to graduate school. I’ve already committed to doing this in signing up for the GRE finally...This ten weeks has helped me a lot in determining that.” **Student R, 2010**

“When looking back this summer, I have gained so much from this sustainability REU, and I feel that I have truly grown as a person. I have learned while here that incorporating sustainability in the world today is not solely a technical problem, but will take social approaches, as well.” **Student M, 2010**