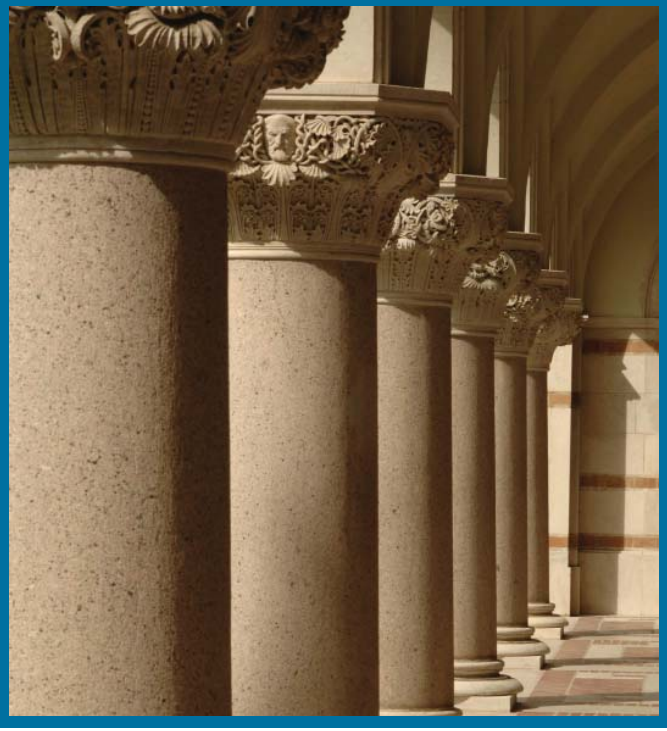

RICE UNIVERSITY
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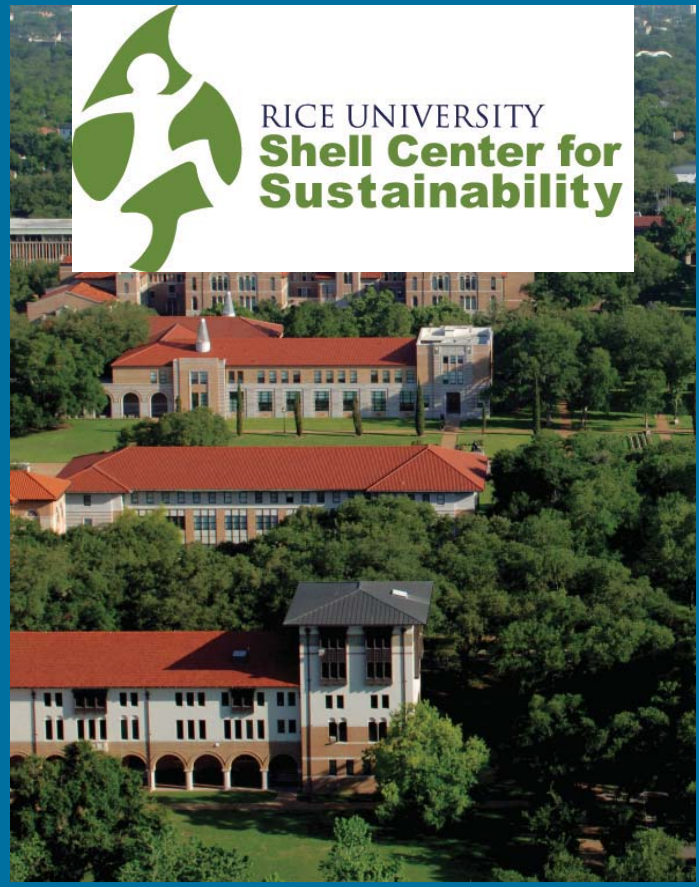

2009 Annual Report

The Shell Center for Sustainability (SCS) at Rice University is an interdisciplinary program of research, outreach, and education to address actions that can be taken to ensure the sustainable development of living standards, interpreted broadly, to encompass all factors affecting the quality of life, including environmental resources.

The Shell Center for Sustainability was founded in 2003 with funding from Shell Oil Company.

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RICE UNIVERSITY
Shell Center for Sustainability

Executive Summary

In 2009, the Shell Center for Sustainability received numerous proposals for consideration. Five faculty proposals were selected for funding. These projects included research to compare centralized and decentralized water infrastructure; industrial chemical production using microbial processes; the analysis of the use of a solar house; how climate change affects native plant mating systems; and an environmentally benign method to control water fouling.

SCS also made a commitment to fund a long-term project to develop indicators to measure urban sustainability in Houston. The project will set a baseline and measure ongoing conditions.

Research teams included Rice University faculty, undergraduate, and graduate students in diverse areas from Mechanical Engineeering and Materials Science to Architecture and Sociology. The research funded will take place in 2010.

SCS continued to partner with various entities to present speakers and events that focus on sustainability practices on campus, in the region, the U.S., and abroad.

The annual sustainability conference focused on Water In The Houston Metabolism-Water Needs and Water Quality for This Century. The event brought together more than twenty experts from the region. They focused on Growth, Environment, Health, and Policy. This year, the conference included a Visual Art component to promote local artists through a competition and exhibition, Water Effects On Life.

Through the SCS internship program, participating students held a workshop to present an experts panel that discussed funded research that promoted undergraduate participation.

Funded education initiatives were enhanced with the creation of the Energy and Water sustainability minor.

The Jones Graduate School of Business MBA Program will conduct a social enterprise case analyss project based on SCS. The study will take place in 2010 and will identify key strategies to enhance performance.

SCS will fund the SCS Independent Student Paper award for 2010. The award will promote undergraduate participation.

RICE UNIVERSITY
Shell Center for Sustainability

Research

Shell Center for Sustainability (SCS) sponsored research has generated interest among the Rice University faculty and in the Houston area. This interest is gauged by the number of inquiries received for funding. The annual call for proposals is issued in the early summer. This schedule gives potential researchers the summer to put their teams together and prepare a proposal that best meets the SCS criteria, goals and objectives.

SCS staff met with various members of the faculty and outside groups to learn about potential projects and to advise on how these projects might best align with SCS objectives. These efforts ranged from research in wind energy to religion, and architecture to electric cars.

Of the proposals presented to SCS for consideration, five new sustainable development research projects were selected in 2009. This research will be conducted during the 2010 calendar year. The projects included research to compare centralized and decentralized water infrastructure; industrial chemical production using microbial processes; the analysis of the use of a solar house; how climate change affects native plant mating systems; and an environmentally benign method to control water fouling.

SCS also funded a project to develop indicators to measure urban sustainability in Houston. The project is a long-term commitment by the Center and aims to develop a baseline which will measure change over time.

Research teams involved with SCS included Rice University faculty, undergraduate and graduate students in diverse areas from Mechanical Engineering and Materials Science to Architecture and Sociology.

SCS awarded research grants for 2010 to the following teams:

The Reliability, Efficiency and Treatment Quality of Centralized Versus Decentralized Water Infrastructure

Team

Qilin Li, Ph.D., Environmental Engineering Program, Department of Civil and Environmental Engineering, Rice University
Leonardo Dueñas-Osorio, Ph.D., Civil Engineering Program, Department of Civil and Environmental Engineering, Rice University
Isabel Raciny, doctoral student, Rice University

Project Background

Water systems in many cities date back to the early 20th century. These systems have exceeded or are approaching their lifespan. Centralized systems suffer from frequent leaks and failures, biofilm growth, and long transport distance from treatment facilities to end users. This leads to water loss, microbial and chemical contamination, disruption of service, and high energy consumption. The long hydraulic residence time in large centralized systems also leads to formation of toxic chemicals such as disinfection byproducts (DBPs). In addition, water supply demand increases rapidly with

population growth, while global climate warming leads to a decrease in water supplies. Hence there is an urgent need to improve the reliability, integrity, cost-effectiveness, and sustainability of the water infrastructure and to decrease the likelihood of failures, service disruptions and water quality deterioration so the public health is protected. This great challenge presents an opportunity to reassess century old centralized system design and consider a paradigm shift in water infrastructure.

The objective of the research is to compare the reliability, energy efficiency and public health related water quality of centralized, decentralized and hybrid water systems. The research will also develop guidelines for the design of water infrastructure systems that incorporate energy and water-efficiency as well as alternative water resource management practices.

The project will:

• Study the effects of network topology on performance via numerical simulation and analytical formulations based on graph theory and system reliability, unravel the connection between water system configuration and system reliability, and determine long term sustainability of water systems.

• Modify an existing hydraulics model to allow simulation of pumping energy consumption and water quality for decentralized and

hybrid systems. The research will also consider suitable treatment technologies.

• Incorporate chemical reaction kinetic models into the distribution system hydraulics model. This chemical model will simulate the formation of DBP and trihalomethane in centralized, decentralized, and hybrid systems.

Reducing Energy Use And Carbon Dioxide While Producing Industrial Chemicals By Efficiently Engineered Microbial Processes

Team

George Bennett, Ph.D., E. Dell Butcher Professor of Biochemistry & Cell Biology, Rice University
K.-Y. San, Ph.D., E. Dell Butcher Professor of Bioengineering, Rice University
Tao Lin, Graduate Student in Biochemistry and Cell Biology, Rice University

Project Background

The objective of this project is to develop and promote greener processes for the formation of useful industrial chemicals from renewable energy sources. The processes developed would lessen petroleum and energy consumption and have a reduced environmental

footprint.

The general context for the work is the increased concern over the environmental impact of industrial processes, especially those that generate carbon emissions and hazardous waste pollution. The chemical industry seeks greener production methods for important chemicals.

Microbial conversions play an important and expanding role in chemical production. Favorable characteristics include reduction of petroleum usage and energy coupled with reduced formation of hazardous waste. The project focus has been on processes that reduce the carbon dioxide footprint. Researchers are focused on the production of large-scale chemicals with established uses and properties.

In previous work researchers developed a new bioprocess for the formation of succinate that consumes carbon dioxide while forming the product at near theoretical yield. They now seek to produce other industrially useful organic acids that can be made through microbial pathways. Among such compounds is itaconic acid, listed as one of the top 12 chemicals from biomass in a Department of Energy report of 2004. It is used directly with co-polymers, has desirable properties for the fiber industry, and serves as a precursor for a large family of 5-carbon chemicals.

Chemical synthesis is costly and inefficient. Researchers will use various feedstocks to produce the itaconic acid. The methodology

involves the modification of pathways using the tools of molecular & synthetic biology with host organisms that can perform the majority of the biosynthetic steps.

Besides laboratory research on the biochemistry and engineering of the organism, undergraduates will work with the BCM Center for Educational Outreach to promote classroom use through online and printed materials. Often, the only knowledge of microbes presented to young students is the germ relationship to disease. In this educational effort we will expand the scope of the current program by adding information on the role of microbes in the environment and for beneficial processes. Students will add modules which explain the broader impacts of microbes in the environment such as industrial microbes (food, antibiotics), biodegradation of hazardous compounds and cellulose degradation, and carbon dioxide and nitrogen fixation.

Installation, Implementation, and Analysis of the Ze-ROW Solar House

Team

Danny Samuels, FAIA / Visiting Professor, School of Architecture / Director, Rice Building Workshop.
Nonya Grenader, FAIA / Professor in Practice, School of Architecture/Assoc. Director, Rice Building Workshop.
Brent C. Houchens, PhD / Assistant Professor, Mechanical Engineering & Materials Science, Rice University.
David Dewane, Lead Architecture student, Rice University.
Roque Sanchez, Lead Engineering student, Rice University.

Project Background

Over 100 architecture and engineering students (undergraduate and graduate) have contributed to the planning, design, construction, installation, monitoring, and documentation of the Ze-Row house.

Numerous community partners from the Houston area (engineers, material suppliers, contractors, donors) have contributed their expertise and support.

In October 2009, a dedicated team from the School of Architecture and the George R. Brown School of Engineering participated in the Solar Decathlon. This event is a design/build competition which gives faculty and students the opportunity to partner with industry leaders in a joint effort to push the envelope on renewable energy at the scale of a single building.

The competition, sponsored by the U.S. Department of Energy and the National Renewable Energy Laboratory, includes 20 universities (international in scope) to design, build, and operate a house run entirely by solar energy. Each team must construct their house and transport it to the National Mall in Washington D.C., where all twenty houses form a "Solar Village." During the three-week period on the Mall the houses compete with each other in ten performance-based events and are open for public tours (drawing crowds well over 100,000 people).

The competition and exhibit process was a fulfilling event but the Rice team envisions their design, the Ze-Row house, as a prototype that will make a lasting contribution beyond the competition. The

objective is three fold:

--re-install the house in a Houston neighborhood with critical need for housing
--monitor the energy effectiveness of the house over the next year
--document the house, highlighting the design aspects and levels of performance

For the past twelve years, the School of Architecture, through its Rice Building Workshop (RBW), has been bringing affordable housing to the Third Ward, a vibrant and historic Houston community. The Ze-Row house will add a new level of sustainability to our affordable housing initiatives, suggesting that renewable energy belongs in every neighborhood. Rice faculty and students will work with the future inhabitant to monitor the house and its systems over the next year, and will document the results.

During this collaboration of Rice architecture and engineering departments, with numerous community advisors, the team will focus on the sustainable implementation of the Ze-Row House, research into novel and efficient energy conversion systems, and dissemination of knowledge to the Houston and scientific communities. New

data acquisition systems have been implemented via a donation from Standard Renewable Energy. Data from these systems, along with solar heating effectiveness will be investigated both quantitatively and qualitatively.

Response of Native Plant Mating Systems To Global Change

Team

Lesley Campbell, Ph.D., Ecology and Evolutionary Biology, Rice University.
Kenneth Whitney, Ph.D., Ecology and Evolutionary Biology, Rice University.
Caroline Masiello, Ph.D., Earth Science, Rice University.

Project Background

As global climate change transforms environments it has become increasingly important to understand what properties make some organisms more prone to extinction than others. Populations with more genetic diversity are able to adapt to change more rapidly than those with less genetic diversity. Species that cannot adapt to new environments will either move to new locations or become extinct.

For agricultural plant populations, low genetic diversity limits their breeding potential and makes them more susceptible to pests and

disease, reducing their usefulness as a human food source. For wild organisms, low genetic diversity increases requirements for protection via conservation programs, making the programs more expensive and extensive endeavors.

Of all traits, mating systems are most influential in structuring genetic diversity within and among populations, transmitting diversity across generations, and determining rates of loss of diversity. Plants tend to have very flexible mating systems, more so than animals, and therefore are an excellent model system to explore the plastic response of mating systems to environmental variation. Plants may mate with themselves (self-pollination) leading to relatively low heterozygosity and allelic diversity, or mate with other genotypes (outcross-pollination) producing relatively high heterozygosity and allelic diversity. Hybridization, extreme outcross pollination with another species, often leads to the incorporation of unique genetic diversity, potentially leading to novel evolutionary trajectories.

By experimentally altering soil moisture to mimic the predictions of well-accepted climate change models, the research team will measure the expected change in mating systems and hybridization rates of four well-studied, model plants in the general *Helianthus* and *Raphanus*. They will use simply inherited genetic markers to assess levels of genetic diversity mating patterns and hybridization rates. They hope to produce a predictive model to explore the relative importance of water availability, altered floral morphology, and phenology, and pollinator behavior in altering mating systems and hybridization behavior and the potential ways conservation managers could increase genetic diversity within plant populations.

Environmentally Benign Control of Biofouling Team

Team

Jun Lou, Ph.D., Department of Mechanical Engineering and Materials Science, Rice University.
Qilin Li, Ph.D., Department of Civil and Environmental Engineering, Rice University.

Project Background

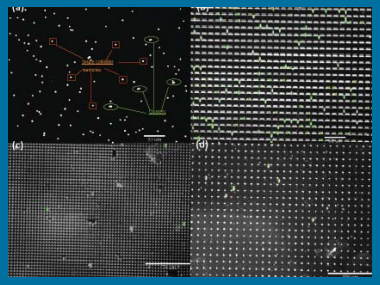
The team's objective is to develop a novel bacteria fouling control strategy using surface topographic patterning. This method does not involve use of biocides nor does it require external energy input.

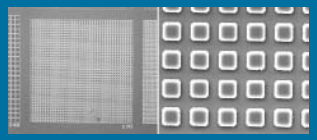
Therefore, it has the advantage of being environmentally benign compared to other control strategies.

The scale and magnitude of the environmental and economical implication of biofouling is tremendous. Its impact ranges from fouling of water filtration membranes and naval ship hulls, interference with underwater sensors, clogging and corrosion of water distribution pipelines, transport of water-borne pathogens, to contamination of food processing equipment, medical devices and biomedical implants.

The crucial step to prevent biofouling is hindrance of the initial microbial attachment to the surface and inhibition of further biological growth. Currently, the most common strategy to control biofouling is through the application of coating materials that slowly release biocides, which introduce potential environmental hazards.

Examples of highly fouling-resistant surfaces in the biological world such as shark skin and lotus leaf, both with micro- and/or nano-scale textured surfaces, suggest that surface topography may be an important factor in controlling biofouling. In addition, recent studies on both microbial (e.g., algal spores) and mammalian cells show that ordered micro- and nano-scale surface topographic structures significantly reduce cell adhesion. These results and the natural fouling-resistant surfaces suggest that manipulation of material surface topography may be a potential approach to biofouling control.





In this project, the team will first design and fabricate well-defined hierarchical topographic structures at two length scales and on different substrates to mimic natural fouling-resistant plant leaves. They will then investigate the role of micro- and nano-scale surface patterns in adhesion of biological and non-biological particles, and to elucidate the effect of scale. Short-term and long-term adhesion experiments will be conducted with non-biological particles (polystyrene latex and carboxyl modified latex), model biological particles (latex coated with extracellular polymeric substances (EPS)) and biological particles (bacteria, diatom) using the control surface, the lotus leaf and the engineered surface patterns.

The team anticipates the development of a series of hierarchical surface patterns using different materials that have the potential to control fouling by microorganisms of various sizes in the aqueous environment. They also expect to establish preliminary guidelines for design of environmentally benign surface topographic patterns for biofouling control for environmental engineering, navy and biomedical applications.

Sustainable Development Indicators For The Houston Region

Team

Jim Blackburn, Professor of the Practice, Department of Civil and Envi-

ronmental Engineering, Rice University.
Stephen Klineberg, Ph.D., Professor of Sociology and Co-Director of the Kinder Institute, Rice University.
Ellory Matzner, Student, Rice University.

Project Background

The need for sustainable development indicators was first identified in 2004, when SCS held the Houston Sustainability Scenarios Project which brought together 70 individuals representing Houston's government, NGO's, businesses, and academic community to build scenarios for Houston. As a result research was identified as being needed to define a sustainable development baseline and to measure progress in attaining sustainable development goals.

In 2009, SCS issued a call for proposals to develop a plan that identified sustainable development indicators for the Houston region. The plan included a long-term commitment by SCS to not just identify the indicators that would measure the enviornmental, economic, and social impact of sustainability in Houston are but also present a picture of these indicators over time.

Preliminary work would include development of a class to begin to identify such indicators. The class is expected to begin in the Spring of 2010.

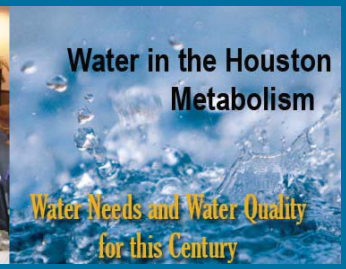
Outreach

Various activities were supported by SCS to reach out with the sustainable development message. These activities included:

- *Sustainable Development Innovations: Japan's Effort to Unite Against Climate Change*, a presentation by Associate Professor in Sustainability Science, Masaru Yarime, from the University of Tokyo. The event was hosted by SCS, the Baker Institute Student Forum, and the Consulate General of Japan.

- *Water In The Houston Metabolism-Water Needs and Water Quality for This Century*, the SCS annual sustainability conference, took place in the fall. The event was co-sponsored with the James A. Baker III Institute for Public Policy Health Policy Forum and Science & Technology Policy, the Visual Arts Program for the Student Center, Rice University, and Shell Oil Company.

  The conference focused on Water and Houston's Growth, Houston's Natural Environment, Water and Health, and included a Policy Discussion. Overall, the conference offered over 20



speakers and moderators in an intense one-day event.

- The water conference concluded with the *Water Effects On Life Art Competition Awards and Exhibit opening*. The art component of the annual sustainability conference featured the work of 16 regional artists, in support of local art. The artists were:

Rebecca Benitez	*Becky Brocato*
Hebe Brooks	*Hana Case*
Howie Doyle	*Mary Fuller*
Natascha Gotesky	*Kelly Halbach*
Sarah Hazel	*Sarah Kitagawa*
Victoria Lewelling	*Jackie Liddell*
Nicola Parente	*Milam Schverak*
Belinda Smith	*Luigino Alessandro Taboada*

The Award recipients were *Mila Schverak*, First Place; *Jackie*

Liddell, Second Place; and *Mary Fuller*, Third Place. Images of the artwork, along with presentations and video recordings of the day's events can be viewed at the SCS Web site, under the Outreach link at *http://shellcenter.rice.edu*.

- There was extensive national interest about the results of the SCS projects on biofuels and biodiesel that were conducted in 2008.

- Over 250 international science students visited Rice University to hear from SCS researchers and Shell experts in the areas of energy, engineering and environment, as part of the *International Sustainable World Energy Engineering Environment Project Olympiad (ISWEEEP) 2009* international science fair held in Houston.

- The James A. Baker III Institute for Public Policy and SCS presented *Energy for Sustainability Development in Africa, a lecture by Bryan Wilson, Ph.D.*, as part of the course on Integrated Approaches to Sustainable Development taught by Amy Myers Jaffe, the Wallace S. Wilson Fellow in Energy Studies at the Baker Institute, and Rebecca Richards-Kortum, Ph.D., the Stanley C. Moore Professor, in Electrical and Computer Engineering.

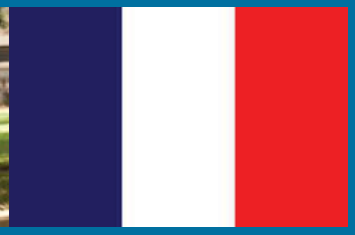
- SCS Operating Committee member, Debra Marshall, Shell, and SCS researcher and Professor Jim Blackburn were featured speakers at the Rice University Environmental Club's 16th Annual Conference, *Green Pays: Environmental Responsibility In The Business World*.

- *Sustainability Research & Opportunities*, a workshop featuring 5 SCS research leaders discussed their projects and what they look for in participating students. Lila Holzman, the SCS intern, organized the event. (Read more under Education).

- SCS partnered with the Center for Houston's Future for the annual *Quality of Place Report and Symposium*. The event is targeted to people that can make a difference in the Houston area.

- SCS continued to partner with the *Center for the Study of Environment and Society* as a board member and to sponsor lectures and colloquiums on climate change. The events are offered at no cost to students, faculty and the community.

- On campus, SCS also advised and met with various students and student organizations as part of its outreach efforts. These organizations included Engineers without Borders, the Bicycle Committee, and The Rice Thresher.



- SCS began to broaden exchange with other centers and institutes on the Rice University campus to expand communication among the organizations and to identify potential opportunities to work together.

- SCS participated in activities sponsored by the Greater Houston Partnership, the Galveston Houston Association for Smog Prevention, the Hispanic Chamber of Commerce, and conducted presentations to the Houston-Galveston Area Council Natural Resources Advisory Committee and other organizations to expand awareness and understanding of SCS.

- SCS met with various in-house and outside experts such as representatives from the U.S. Business Council for Sustainable Development and visiting faculty from France to discuss sustainability issues, SCS goals, and to explore potential joint efforts.

- SCS hosted the U. S. State Department-led Australian delegation to discuss various aspects of sustainability. Rice faculty was invited to participate.

- A video featuring the SCS funded *Monitoring Engineered Nanoparticles In The Environment* project, conducted in 2008, was completed. The video features the project team members and

was launched on YouTube.

- Redesign of the Shell Center for Sustainability Web site was completed. The redesign included adopting a new hosting system to enhance system management.

Education

Course Funding

The Rice University Faculty Senate unanimously approved the new interdisciplinary minor offered by the George R. Brown School of Engineering, the Wiess School of Natural Sciences, and the School of Social Sciences. This minor includes the SCS funded course in *Energy and Water Sustainability* selected for funding in 2008.

SCS Study

Rice University *Jones Graduate School of Business* MBA's will work with SCS to develop a Houston oriented social enterprise case analysis project. The research will be based on the Shell Center for Sustainability and will identify key strategies to enhance performance. Work will begin in early 2010.

Measuring Sustainability

A course based on the sustainability indicators project funded by SCS will be developed and offered in 2010 by a team of faculty members representing environment, economics, and society. This

course will serve to develop sustainability indicators for the Houston region. (Read more under Research).

Internship

Once again, SCS partnered with the City of Houston and other area organizations to offer students interested in sustainability, hands-on opportunities to work on area projects focused in different areas of sustainability.

In her second internship with SCS, Lila Holzman developed and implemented a plan to increase student participation and awareness of the work carried out by SCS. This action built on the previous semester's work by Holzman and another SCS intern.

In the spring semester, Holzman, a senior double majoring in Engineering and Policy Studies, participated in outreach and education activities for the Center and carried out a combined plan by organizing an Expert Panel to generate student interest in SCS sponsored research. Several project researchers were invited to present information on their currently funded projects. The researchers answered questions from students and other attendees, including representatives from Shell Oil Company.

The event also provided an informal opportunity for students, faculty and potential partners and collaborators to talk about what it takes to participate in a research project. The event was successful and

several students were invited to join some of the research teams.

Student Research Award

A new SCS Award was funded for an undergraduate Rice University independent student paper on sustainable development. The call will be issued in early 2010. This effort focuses on generating greater participation by undergraduate students in SCS activities. The award will be presented at the end of the 2009-2010 academic year.

Operating Committee

Dr. John Anderson
Dr. Walter Chapman
Ms. Kimberly Corley
Ms. Mary Margaret Hamilton
Dr. Peter Hartley
Dr. Christopher Hight
Dr. Stephen Klineberg
Ms. Debra Marshall
Dr. Lyn Ragsdale
Dr. Doug Schuler
Dr. Evan Siemann
Dr. Robert Stein
Ms. Marybeth Savicki
Ms. Sharon Bashouri

Management Committee

David W. Leebron, Rice University
Marvin Odum, Shell Oil Company

Acknowledgements

The work done by the Shell Center for Sustainability (SCS) during this year could not have been possible without the people and organizations who participate in the work funded by SCS. We we thank the members of the Operating Committee and the Management Committee for their short and long-term leadership.

We thank the research teams, made up of faculty, graduate, and undergraduate students, and other partners, who proposed new research and education initiatives in sustainable development.

We also thank our many on and off-campus partners, sponsors, and collaborators for joining us in our effort to achieve our objectives for 2009.