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 life, including environmental resources. The Shell Center for Sustainability was founded in 2003 with funding from Shell Oil Company.

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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.

The Energy and Water Sustainability minor funded by the Center was enhanced with the creation of workshops to present an opportunity to discuss and develop solutions to sustainability issues.

Research continued to focus on urban sustainability policies through a conference titled "Urban Sustainability: Policy and Practice". The conference included a virtual panel discussion on sustainable urban planning, focusing on case studies from around the world. The conference also included workshops on green building design and the use of renewable resources.

Research funding will take place in 2010 and will identify key strategies to enhance performance. The Center also made a commitment to partner with Rice University to develop indicators to measure urban sustainability in Houston. The project will set a baseline and measure ongoing conditions.

The Center continued to partner with various entities to present speakers and events that focus on sustainability practices on campus, in the region, and internationally. These events included the annual sustainability conference, which focused on "Sustainability in the Workplace" and "Sustainability in the Global Economy".

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Research

Shell Center for Sustainability

Mechanical Engineering and Materials Science to Architecture and Urban Planning and Graduate degrees in diverse areas from

Research teams involved with SCS included Rice University faculty, outside groups, and graduate students.

SCS also funded a new research 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. This project will be conducted in the 2010 calendar year. The project is a long-term commitment by the Center and aims to develop a baseline which will measure change over time.

Of the Proposals Presented to SCS for consideration, two new sus-

The seven proposals that were funded in 2009 included research in various fields and included Rice University faculty, undergraduate and graduate students in diverse areas from Mechanical Engineering and Materials Science to Architecture and Urban Planning.

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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 Urban Planning.

Annual Report 2009
SCS awarded research grants for 2010 to the following teams:

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

  - 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, disruption of service, and high energy consumption. The long hydraulic residence time in large centralized systems also leads to the 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 resources. Therefore, there is an urgent need to improve water system reliability, efficiency, and sustainability.

  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 programs. The project will also focus on:

  - Studying the effects of network topology on performance via numerical simulation and analytical formulations based on graph theory and system reliability.
  - Unraveling the connection between water system configuration and system reliability, and determining long term sustainability.
  - Modifying an existing hydraulic model to allow simulation of pump- station behavior.
  - Improving and refining models of water systems.

  The project will:

  - Develop management procedures to improve water efficiency and water reliability as well as alternative water resource management programs.
  - 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.
  - Determine long term sustainability of water systems.

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  - Develop an existing hydraulic model to allow simulation of pump-station behavior.
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  - Determine long term sustainability of water systems.

**Team**

- **Centralized Versus Decentralized Water Infrastructure**

  SCS awarded research grants for 2010 to the following teams:

  - 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
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.

**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 petrochemical usage 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 industrial chemicals. Favorable characteristics include reduction of petroleum usage and energy coupled with reduced formation of hazardous waste.

Microbial conversions play an important and expanding role in chemical production. Promising characteristics include reduction of environmental impact and contribution to the broad production of useful compounds with established uses and properties. Microbial processes for the production of succinate were developed in previous work. The project focuses 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 production 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, which can be made through microbial fermentation. Researchers are also exploring pathways to produce other important compounds from carbohydrates and other feedstocks.

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

**Microbial Processes**

- **Reducing Energy Use and Carbon Dioxide While Producing Industrial Chemicals That Have Established Uses and Properties**

- **Shell Center for Sustainability**

- **Annual Report 2009**
involves the modification of pathways using the tools of molecular & synthetic biology with host organisms that can perform the major-
ity 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

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

Installation, Implementation, and Analysis of the Ze-ROW Solar House
The objective is threefold:

-- reinstall 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, 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**

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

**Project Background**

As global climate change transforms environments, it has become increasingly important to understand what properties make some environments better able to support diversity than others. Populations with higher levels of genetic diversity are better able to adapt to changing conditions, whereas populations with lower diversity are more prone to extinction. Understanding how these processes work in these environments will either move to new locations or become extinct.

Environmental change will either move to new locations or become extinct. Those with higher genetic diversity, species that can adapt to new environments, will be better able to do so, thus creating more 'genetically rich' habitats. Populations with lower genetic diversity are more prone to extinction. Understanding these processes make some environments better able to support diversity than others.
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 novel species, often leads to the incorporation of unique genetic material to the recipient species, leading to a greater range of diversity within and among populations. These larger diversities may, however, be at risk of being lost due to severe bottlenecks or excessive hybridization.

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 genera 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 behaviors and the potential ways conservation programs might be affected.
Therefore, it has the advantage of being environmentally benign compared to other control strategies. The scale and magnitude of the environmental and economical implications 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 animal examples of micro- and nano-scale textured plant and lotus leaves indicate that such structures may be an important factor in controlling biofouling. Therefore, in this project, the team will 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 topography in controlling adhesion of biofouling agents. 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 environmental engineering, energy and bio-medical applications.
Project Background

Ellory Matzner, Student, Rice University.

K. Richard Lujan, Rice University, Professor of Sociology and Co-Director of the Community Engagement Rice University.

Outreach

Policy Discussion: Overall, the conference addressed issues related to environmental and social sustainability. The conference aimed to develop a plan to begin in the spring of 2010 to identify sustainability indicators for the Houston region.

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

- Sustainable Development Innovations: Japan’s Efforts to Unite Against Climate Change
- Water in the Houston Metabolism: Water Needs and Water Quality
- Policy Discussion: Overall, the conference addressed issues related to environmental and social sustainability. The conference aimed to develop a plan to begin in the spring of 2010 to identify sustainability indicators for the Houston region.

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The Farmington 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.

2008 SCS workshops on biofuels and biodiesel that were conducted in Houston and regional international science fair held in a Sustainable World Engineering Environment Project were featured on television and environmental as part of the International Science, Engineering and Social Studies Fair held at Rice University.

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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 colloquia for a broad audience and to support research and career opportunities in the field. SCS continued to work and collaborate with the Greater Houston Partnership, the Galveston Houston Association for Smog Prevention, the Hispanic Chamber of Commerce, and the Houston-Galveston Area Council Natural Resources Advisory Committee to expand awareness and understanding of SCS.

On campus, SCS also advised and met with various students and student organizations as part of its outreach efforts. These efforts included exchange with other centers and institutes on the Rice University campus to expand communication among the organizations and to identify potential joint efforts. SCS sponsored and supported the Rice University Environmental Club's annual conference, *Green Pays: Environmental Responsibility in The Business World*. SCS also hosted the U.S. State Department-led Australian delegation to discuss various aspects of sustainability. Rice faculty and U.S. government officials hosted the Australian delegation to discuss sustainability issues. SCS met with various in-house and outside experts such as Dr. John M. Buyers from the University of Houston to discuss climate change and sustainability issues.

The 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 partners in the Environmental project, conducted in 2007, was presented at the SCS Funded Monographs Group Online conference.

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was launched on YouTube.

Redesign of the Shell Center for Sustainability Web site was completed. The redesign included adopting a new hosting site.

A course based on the sustainability indicators project funded by Rice University’s Jones Graduate School of Business M.B.A.s will work with SCS to develop a Houston oriented social enterprise case study.

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

Measuring Sustainability

The course will begin in early 2010.

Education

Course Funding

SCS Study

The 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.

In the second internship with SCS, Holzman developed and carried out a Student Research Award. A new SCS Award was funded for an undergraduate Rice University student to participate in a research project. The award was successful and led to potential partnerships and collaborations to link student work with local projects.

Student Research Award

Several students were invited to join some of the research teams.
Acknowledgements

For 2009, collaboration for joining us in our effort to achieve our objectives and research and education initiatives in sustainable development. We thank the members of the Operating Committee and the Management Committee for their short and long-term leadership. We also thank our many on and off-campus partners, sponsors, and the research teams made up of faculty, graduate, and undergraduate students and other partners, who proposed new initiatives and helped us understand the challenges and opportunities. We thank our many on and off-campus partners, sponsors, and the research teams made up of faculty, graduate, and undergraduate students and other partners, who proposed new initiatives and helped us understand the challenges and opportunities.

The work done by the Shell Center for Sustainability (SCS) was possible. We also thank the members of the Operating Committee and the Management Committee for their short and long-term leadership. We also thank our many on and off-campus partners, sponsors, and the research teams made up of faculty, graduate, and undergraduate students and other partners, who proposed new initiatives and helped us understand the challenges and opportunities.

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- David W. Leebron, Rice University, Chair
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- Dr. Rether Stenn, Shell
- Dr. Evan Shemen, Shell
- Dr. David Shuler, Rice University
- Dr. Tim Kretschmer, Rice University

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