CENTER FOR
RESPONSIBLE
BUSINESS
Haas School of Business at UC Berkeley

Berkeley
UNIVERSITY OF CALIFORNIA

Sustainable Products & Solutions Program
Annual Report 2013-2014

Center for Responsible Business
Haas School of Business
University of California, Berkeley

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Greetings from the Executive Director

November 1, 2014

With this report, we present an overview of the activities and outcomes from the Sustainable Products & Solutions (SPS) program for the 2013-2014 fiscal year. Initially funded in 2008 by a generous contribution from The Dow Chemical Company Foundation, the SPS program has since engaged with leading companies and top researchers from across the University of California at Berkeley to generate leading edge sustainability-focused research.

When I arrived in my role as Executive Director of the Center for Responsible Business in August 2014, I was – and remain – firmly convinced of the importance and the incredible opportunity represented by the SPS program. The program addresses real world sustainability challenges across the entire value chain by bringing together practitioners from our partner corporations and world-leading researchers from across UC Berkeley – with the Center for Responsible Business at the center of it all. The CRB serves both as the external interface of the program to corporate partners and as the internal convener of sustainability-minded researchers. Moreover, the CRB seeks to identify researchers who may have an interest in engaging in sustainability-focused research to bring these researchers to the discussion.

As we look to the future of the SPS program, we intend to expand its capacity to provide leading companies with access to the best sustainability researchers in the world. Our activities will include convening periodic fora with our corporate partners, researchers across the Berkeley campus, and other key stakeholders. We will increase our investment in a cross-disciplinary approach to ensure that corporate sustainability challenges are addressed from multiple perspectives. I have a particular interest in using the SPS program to better connect researchers from the Haas School of Business with sustainability-minded researchers from across UC Berkeley.

SPS represents a growing community. As we reflect upon our sixth year of work, I would like to thank and commend the many faculty across the UC Berkeley campus who have contributed to the success of this program, as well as to thank our corporate partners. Together, we can more effectively address our greatest sustainability challenges than any one of us could do individually.

Are you interested in joining the SPS community? Please let me know. I would love to hear from you.

Onward!!!

Robert Strand, Ph.D.
Executive Director
Center for Responsible Business
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Overview

Housed in the Haas School of Business, the Center for Responsible Business (CRB) is an "action tank" that builds on the Haas School's culture of innovation and UC Berkeley's tradition to run–not walk–towards social progress. Building on more than a decade of research, teaching, and industry engagement, the Center for Responsible Business brings together students, company leaders, and forward-thinking faculty to redefine business for a sustainable future.

Consistently ranked among the top business school sustainability centers, the CRB promotes responsible business leadership through:

- Students, giving them the tools, strategies, and experiential learning opportunities to successfully integrate responsible and sustainable business into their daily work;
- Faculty, supporting multidisciplinary approaches to incorporating responsible and sustainable business concepts into their teaching and research; and
- Companies, supplying them with fresh perspectives on and new approaches to responsible and sustainable business leadership.

Berkeley-Haas is a signatory to the United Nations Principles of Responsible Management Education, one of whose core principles is to engage in conceptual and empirical research that advances our understanding of the role, dynamics, and impact that corporations play in the creation of sustainable social, environmental, and economic value.

The Sustainable Products and Solutions Program

A core program of the CRB since 2008, the SPS program is focused on generating business-relevant, multidisciplinary solutions to global sustainability challenges. It accomplishes this by engaging a diverse corporate community with a diverse research community to find new, innovative ways to integrate sustainability into products and business.

The program has three areas of focus:

1. **Sustainable Supply Chain Management:** Assessing the environmental, social, and economic impacts of, and encouraging good governance practices throughout, the lifecycles of goods and services.
2. **Sustainable Consumption:** Understanding resource management, the circular economy, and the value of nature and developing products and solutions to better manage world consumption.
3. **World Challenges:** Investigating overarching issues of corporate governance, finance, and society to address major social issues, including water, health, and housing, by taking scalable, market-based approaches to develop and grow sustainable communities.

SPS Sponsors

The Sustainable Products and Solutions Program is supported by generous gifts from our corporate partners. This year, we are grateful to The Dow Chemical Company, Kimberly-Clark Corporation, and Cisco Systems, Inc., for their financial sponsorship as well as for their creative input on our program.

Sustainable Products and Solutions at UC Berkeley

The SPS program provides a gateway for corporations seeking solutions to sustainability challenges that require the integration of business thought and academic research. While its home with the Center for Responsible Business is at the Haas School of Business, its expertise draws from a variety of institutions across UC Berkeley. In addition to Haas' Center for Responsible Business and the Energy Institute, we have identified partners in the following groups:

- College of Engineering: Laboratory for Manufacturing and Sustainability
- College of Natural Resources: Energy & Resources Group
- College of Chemistry: Berkeley Center for Green Chemistry
- School of Public Health: Department of Environmental Science, Policy, and Management; Berkeley Food Institute
- School of Law: Human Rights Center.

Affiliated Researchers

The thought leadership of the SPS program is performed by its affiliated researchers across the Berkeley campus. This network of researchers is the single greatest asset of the SPS program.

Some of our affiliated researchers are noted below.

Sara Beckman

Earl F. Cheit Faculty Fellow, Haas School of Business
Chief Learning Officer, Jacobs Institute of Design Innovation, College of Engineering

Professor Sara Beckman is Chief Learning Officer of the recently founded Jacobs Institute of Design Innovation within University of California, Berkeley's College of Engineering. Her 25 years of experience teaching product and service design and innovation-related topics at the Haas School of Business culminated in a course, Problem Finding, Problem Solving, which draws from design thinking, critical thinking and systems thinking literature. She once offered a class, jointly with the College of Environmental Design, on the Post-Dilbert Workplace. Her recent research focuses on the role of learning style diversity on design teams and on the pedagogy of teaching design. Dr. Beckman received her B.S., M.S. and Ph.D. degrees from Stanford University in industrial engineering and engineering management.

Dr. Beckman was a member of the founding faculty of the Berkeley Institute of Design and has supervised a number of Ph.D. students in the Institute. She co-founded the Cal Design Lab, a studio-style teaching space within the College of Environmental Design that serves the need for multi-disciplinary teaching across the Berkeley campus. In addition to her work at Berkeley, Dr. Beckman is active in executive education, running the Haas School's highly successful Product Management Program and teaching in a variety of other programs. She also actively consults with a range of companies on innovation and design.

Douglas S. Clark

Dean, College of Chemistry

Professor Douglas Clark's research is in the field of biochemical engineering, with particular emphasis on enzyme technology, biomaterials, and bioenergy. Current projects include the structural characterization and activation of enzymes in non-aqueous media, the development of metabolic biochips for high-throughput catalysis and bioactivity screening, protein design and assembly for the development of advanced biomaterials, and enhanced conversion of lignocellulosic feedstocks to biofuels.

Dr. Clark is currently Dean of the College of Chemistry and Professor in the Department of Chemical and Biomolecular Engineering at the University of California, Berkeley. He is also the Co-Director of the Synthetic Biology Institute, Faculty Scientist at Lawrence Berkeley Laboratory, and holds the

endowed G.N. Lewis Chair. He is currently Editor-in-Chief of *Biotechnology and Bioengineering*. He received his B.S. from the University of Vermont and his Ph.D. from the California Institute of Technology.

Lucas Davis

Faculty Director, Energy Institute at Haas
Haas School of Business

Professor Lucas Davis' research focuses on energy and environmental markets, and in particular, on electricity and natural gas regulation, pricing in competitive and non-competitive markets, and the economic and business impacts of environmental policy. His work appears in leading academic journals including the *American Economic Review*, the *RAND Journal of Economics*, and the *Journal of Political Economy*.

Dr. Davis is an Associate Professor at the Haas School of Business, and, prior to joining Haas in 2009, he was an Assistant Professor of Economics at the University of Michigan. He received a B.A. from Amherst College in 1996 and a Ph.D. in economics from the University of Wisconsin in 2005.

David Dornfeld

Director, Laboratory for Manufacturing and Sustainability
College of Engineering

Professor David Dornfeld leads the Laboratory for Manufacturing and Sustainability (LMAS; lmas.berkeley.edu) with research activities in several fields of manufacturing engineering: green and sustainable manufacturing; monitoring and analysis of manufacturing processes (e.g., cleanability, burr formation and micromachining); precision manufacturing; and intelligent sensors and machine interoperability for process monitoring and optimization. He has published over 400 papers in these fields, authored three research monographs, contributed chapters to several books, and has seven patents based on his research work. He is a consultant on green and sustainable manufacturing, mechanical design, manufacturing productivity, sensors, automation, and process modeling and the associated intellectual property issues. He writes a blog on green manufacturing at http://green-manufacturing.blogspot.com/.

Dr. Dornfeld holds the Will C. Hall Family Chair in Engineering and currently serves as the Chair of the Mechanical Engineering Department. He is a Fellow of the CIRP (The International Academy for Production Engineering), Vice-President Elect and Chair of the Working Group on Energy Efficiency and Resource Effectiveness. Dr. Dornfeld received his B.S., M.S. and Ph.D. degrees in mechanical engineering from the University of Wisconsin-Madison in 1976 in the area of production engineering.

> "We are delighted to partner with the Haas School of Business to insure our work has a solid business context and can consider the broad enterprise challenges to insure a truly sustainable business model."
> – Professor David Dornfeld

Ganesh Iyer

Edgar F. Kaiser Professor of Business Administration
Haas School of Business

Professor Ganesh Iyer is the Edgar F. Kaiser Professor of Business Administration at the Haas School of Business, University of California, Berkeley. His research uses economic theory to study marketing strategy problems. His areas of research are the coordination of product distribution, marketing information, Internet strategy, strategic communication, and bounded rationality in marketing strategy. His research has won the Little Award in 2000 for the best paper published in *Management Science* and *Marketing Science*, and he has been a finalist for this best paper award on four other occasions (1998, 2003, 2005 and 2012). Two of his papers have also been finalists for the 2012 Informs Society of Marketing Science Long Term Impact Award.

He received his Ph.D. from the University of Toronto, and he was previously on the faculty at the Olin Business School, Washington University in St. Louis. He has served as the Associate Dean for Academic Affairs and Chair of Faculty of the Haas School of Business from 2008-2010 and as the Chair of the Haas Marketing Group from 2010-2011. He is currently chair of the Haas School's Policy and Planning Committee. He is currently a Senior Editor for *Marketing Science* and has been an Associate Editor for *Marketing Science*, *Management Science*, and *Quantitative Marketing and Economics*. He is also a member of the board of the Informs Society for Marketing Science and serves as Secretary of the Board.

Daniel Kammen

Director, Renewable and Appropriate Energy Laboratory
Energy and Resources Group

Professor Daniel M. Kammen is the Class of 1935 Distinguished Professor of Energy at the University of California, Berkeley, with parallel appointments in the Energy and Resources Group, the Goldman School of Public Policy, and the department of Nuclear Engineering. He was appointed by then Secretary of State Hilary Clinton in April 2010 as the first energy fellow of the new Environment and Climate Partnership for the Americas (ECPA) initiative.

Dr. Kammen is the founding director of the Renewable and Appropriate Energy Laboratory (RAEL; http://rael.berkeley.edu) and Director of the Transportation Sustainability Research Center. He has founded or is on the board of over 10 companies, and he has served the State of California and U.S. federal government in expert and advisory capacities. Dr. Kammen has served as a contributing or coordinating lead author on various reports of the Intergovernmental Panel on Climate Change since 1999. The IPCC shared the 2007 Nobel Peace Prize.

Dr. Kammen was educated in physics at Cornell (BA 1984) and Harvard (MA 1986; PhD 1988), and held postdoctoral positions at the California Institute of Technology and Harvard.

Marty Mulvihill

Executive Director, Berkeley Center for Green Chemistry
College of Chemistry

Dr. Marty Mulvihill is committed to meeting the challenges of global sustainability by pioneering interdisciplinary approaches to research and education—and especially the subsequent integration of this newly expanded understanding in social, political and business practices. Since 2010 Dr. Mulvihill has been the Executive Director of the Berkeley Center for Green Chemistry (BCGC) while continuing as a researcher in both Public Health and Environmental Engineering. He received his Ph.D. in 2009 from the University of California, Berkeley in chemistry and nanoscience. Subsequently, Dr. Mulvihill completed a postdoctoral fellowship at Lawrence Berkeley National Laboratories doing research in the materials science and earth science divisions.

Dr. Mulvihill's current work focuses on developing technologies that help provide access to clean drinking water and the creation of safer chemicals. He has a number of publications and patents related to the detection of arsenic in drinking water and he is currently partnering with students in Environmental Engineering to develop safe and affordable technology to remove excess fluoride from drinking water in India. He also works with professors in toxicology to design and produce safer chemicals including oil dispersants, catalysts, and bio-based platform chemicals. At Berkeley, Dr. Mulvihill has developed new green chemistry curricula for introductory chemistry as well as interdisciplinary graduate classes which incorporates the principles of green chemistry and sustainability by grounding them in the context of broader social challenges, such as access to energy or clean water. He also coordinates a new NSF fellowship program which uses green chemistry to guide a systems approach to green energy development.

Dara O'Rourke

Associate Professor, College of Natural Resources

Professor Dara O'Rourke studies the environmental, social, and health impacts of global supply chains. As both a professor and a practitioner, Dr. O'Rourke teaches environmental and labor policy at the University of California, Berkeley and is co-founder and Chief Sustainability Officer of GoodGuide, the leading source of information on the health, environmental, and social performance of products and companies. Under Dr. O'Rourke's leadership, GoodGuide has been named: one of the world's "50 Most Innovative Companies" by *Fast Company*; the *New York Times* "App of the Week"; and the TechCrunch startup "Most Likely to Make the World a Better Place." Dr. O'Rourke has consulted to organizations such as the World Bank, the United Nations Development Programme, and the Organization for Economic Cooperation and Development. Dr. O'Rourke was previously a professor at MIT and holds an M.S. and Ph.D. from the University of California, Berkeley.

> "We need Sustainable Products and Solutions more than ever today! The SPS program is at the forefront of efforts to bring scientists and innovators together from across disciplines to work on some of our toughest sustainability challenges. I remain very excited about the potential to conduct research on sustainable consumption through the SPS program - and ultimately to get research from UC Berkeley out in the world to help advance sustainability."
>
> – Professor Dara O'Rourke

Omar Romero Hernandez

Haas School of Business

Dr. Omar Romero Hernandez is a chemical engineer with graduate studies in economic policy and government and a PhD in process economics and environmental impact from Imperial College, London. He has worked for a diverse range of public and private organizations such as Procter & Gamble, PEMEX, Accenture, and Mexico's Ministry for the Environment and Natural Resources. From 2012 to 2014 he served as director of the Sustainable Products and Solutions Program at the Center for Responsible Business at the UC Berkeley's Haas School of Business. In 2010 he was appointed leader of Mexico's Business Summit task force on Economic Growth and Low Carbon Emissions, which delivers recommendations to the President.

He is the author of three books: *Renewable Energy Technologies and Policies, Industry and the Environment* and *Introduction to Engineering – An Industry Perspective* and several international publications on engineering, business, and sustainable development. Dr. Romero Hernandez was the recipient of the 2010 Franz Edelman Award, the world's most prestigious award on operations research and management science.

Robert Strand

Executive Director, Center for Responsible Business
Haas School of Business

Dr. Robert Strand is the Executive Director of the Center for Responsible Business at the Haas School of Business at the University of California, Berkeley. He also maintains formal affiliation with the Copenhagen Business School as Assistant Professor of Leadership & Sustainability. Dr. Strand's research and teaching focuses on the strategic aspects of sustainability which includes the role of the Chief Sustainability Officer, corporate governance of sustainability, comparing global approaches to sustainability with particular focus on U.S. and Scandinavia, and theory of the firm with a focus on ethics of the corporation. He is a frequent contributor to popular and academic venues including the *Financial Times* and the *Journal of Business Ethics*.

Dr. Strand completed a Ph.D. from the Copenhagen Business School focused in corporate social responsibility (CSR), an MBA from the University of Minnesota focused in international business, and a B.S. in industrial engineering from the University of Wisconsin. He was a U.S. Fulbright scholar to Norway, during which time he explored sustainability and CSR across Scandinavia. Prior to joining academia, Dr. Strand spent a decade in industry with IBM and Boston Scientific in a range of roles that include manufacturing, supply chain, marketing, strategy, and investor relations.

Terry Taylor

Milton W. Terrill Associate Professor of Business Administration
Haas School of Business

Professor Terry Taylor's research interests include contracting and coordination in distribution channels, the marketing/manufacturing interface, and operations management. His work has explored the role of ongoing relationships in supply chains, contract renegotiation, outsourcing, forecasting, and product line design. He has consulted on marketing and/or operational issues in the retail, high-tech, banking, and telecommunications industries. He is an associate editor of *Manufacturing and Service Operations Management*, *Operations Research*, and *Production and Operations Management*. Dr. Taylor received Columbia Business School Dean's Award for Teaching Excellence in 2003 and the UC Berkeley Cheit Award for Excellence in Teaching in 2009.

> "The Sustainable Products & Solutions Program provides a terrific bridge connecting faculty to companies facing sustainability challenges. These connections help faculty to frame and pursue their research in a way that it will have the most impact: addressing real problems and developing insights useful to a broad set of firms."
> – Professor Terry Taylor

Dr. Taylor is an associate professor in the Haas School of Business. Prior to his position at Berkeley, Dr. Taylor was a professor at Columbia University's Graduate School of Business and Dartmouth's Tuck School of Business. Prior to his academic career, Dr. Taylor was a consultant for McKinsey & Company. He received his Ph.D. and B.S. from Stanford University.

Candace Yano

Professor and Chair, Operations and Information Technology Management Group
Haas School of Business

Professor Candace ("Candi") Yano's primary research interests are production, inventory, and logistics management, particularly on how to deal with various sources of uncertainty in these contexts, as well as interdisciplinary problems involving manufacturing and marketing. She has authored or co-authored over 70 articles and book chapters on these subjects and is the recipient of several National Science Foundation grants.

She is a Professor in the Department of Industrial Engineering and Operations Research (IEOR) and in the Haas School of Business at the University of California, Berkeley. She holds an A.B. in economics, a M.S. in operations research, and a M.S. and Ph.D. in industrial engineering from Stanford University. Prior to joining the University of California, she held positions as a member of the technical staff at Bell Telephone Laboratories and as a faculty member in the Department of Industrial and Operations Engineering at the University of Michigan.

Dr. Yano was the recipient of a Chancellor's Professorship at UC Berkeley from 1997 to 2000, and is a Fellow of the Institute for Operations Research and the Management Sciences as well as the Institute of Industrial Engineers.

Summary of 2013-14 Research Projects

This report contains summaries of research projects performed by the affiliated faculty of the SPS program for the fiscal year 2013-2014, which runs from July through June. Previous versions of this report have not followed a fiscal year format, so, as indicated, some projects may also have been represented in last year's annual report.

SPS research falls into three general themes. Given the breadth of the topics, there is inevitably overlap among these themes. For the purposes of reporting, they are categorized as follows:

Sustainable Supply Chain Management

- Supplier Evasion of a Buyer's Audit
- Improving Reverse Logistics for Recycling Post-consumer Polypropylene (PP) for Sustainable Products
- Energy Efficient Models for Manufacturing Processes
- Biomimicry, 3D Printing, and the Future of Green Manufacturing
- Biomimetic Durable Finishes for the Textile Industry

Sustainable Consumption

- Consumer Decision-Making and Sustainable Products
- Social Responsibility and Product Innovation
- Regression Discontinuity Evidence for the Demand for Energy-Efficient Products
- The Role of Packaging in Reducing Food Waste in the US
- What Will Post-Consumer Waste Streams Look Like in 2025?

World challenges

- Locally Appropriate Energy Strategies for the Developing World: A focus on Utility Scale Clean Energy Opportunities in Sarawak, East Malaysia
- How Does Leakage Affect the Role of Natural Gas in a Carbon-Constrained Grid?
- Information and Communication Technologies to Enable Energy Access

The full text of each report is available on the CRB website, http://responsiblebusiness.berkeley.edu.

Sustainable Supply Chain Management

Project: Supplier Evasion of a Buyer's Audit
SPS Project Lead: Professor Terry Taylor
Haas School of Business

Many brands have recently been tarnished by the publicity of their suppliers' labor and environmental violations and have responded by increasing their auditing efforts. Anecdotal evidence suggests that "hiding" – supplier efforts to pass an audit through deception or corruption – is prevalent.

Under that condition, analysis shows that increasing auditing backfires, because it increases suppliers' motivation to hide and reduces their efforts to comply with labor and environmental standards. Increasing a supplier's margin (by paying a higher price or providing training that improves its productivity) and the increasing attempts by NGOs to publicly expose violations also promote hiding and reduce compliance efforts. To promote compliance, NGOs and buyers should collaborate to make hiding more costly and difficult for suppliers.

More generally, the research provides guidance for a buyer on how the optimal level of auditing varies with 1) a supplier's hiding and compliance capabilities, 2) both firms' contribution margins, 3) the likelihood that an NGO will publicize a violation, and 4) other salient aspects of the business environment.

Full project report

This project built upon research presented in the previous SPS annual report.

Project: Improving Reverse Logistics for Recycling Post-consumer Polypropylene (PP) for Sustainable Products

SPS Project Lead: Professor David Dornfeld
Laboratory for Manufacturing and Sustainability, College of Engineering

Packaging is the highest market demand for plastics, polypropylene specifically, comprising almost 35% of demand. According to the EPA, it is the second highest resin collected by municipal solid waste systems but has the lowest recycling/reuse rate of any of the resins collected. There is a strong desire among some leading companies to source up to 100% post-consumer recycled (PCR) plastic for their packaging wherever possible. These companies intend to design packaging to be recyclable at its end-of-life by selecting resins that are collected in the majority of recycling streams. However most of the packaging is not yet fully optimized.

This research investigated how companies can further their packaging sustainability goals in the form of a case study in collaboration with a local cleaning products company. The company already sources recyclable resins and up to 100% PCR plastic when possible; however some components, such as their refill pouches or their pumps and triggers, are not recyclable or eligible for PCR content because of their use of multiple layers of different plastics and stringent design/manufacturing requirements, respectively. Locating PCR sources of clear, un-dyed polypropylene proved to be a significant challenge, despite clear polypropylene parts being a critical design feature of the company's products.

This difficulty stems from the lack of sorting during polypropylene recycling, and plastics recycling in general. Often mixed plastics are baled and "downcycled" into bulk products such as plastic lumber. Partnerships with other companies that can provide un-dyed polypropylene waste, such as polypropylene cups from airlines, stadiums, and hotels, may provide an option for this company.

This case study illuminated several findings about polypropylene in general:

- There is a lack of material collection and sorting infrastructure for polypropylene, which makes sourcing specific versions of it troublesome.
- The lack of collection and sorting infrastructure is driven by polypropylene's low value compared to other materials in material recovery facilities.
- Until such infrastructure exists, manufacturers will continue to encounter some tradeoffs between ideal design/aesthetics and sustainability for polypropylene packaging.

Full project report

Project: Energy Efficient Models for Manufacturing Processes
SPS Project Leads: Dr. Omar Romero Hernandez, Professor Sara Beckman
Haas School of Business

The industrial energy efficiency market has experienced rapid change over the last four decades. In the late 1970s, energy was supplied by a utility at a rate set by the public utility commission; the only option for efficiency upgrades was direct purchases. Since then, the utility market has experienced significant deregulation. These changes have led to the proliferation of new business models, technologies and best practices to navigate, exploit and profit in the new environment. Still, manufacturers do not always grasp how business models affect the feasibility of energy efficient projects. This research is organized to deliver a framework for understanding and evaluating different options for business financing and implementing industrial energy efficiency projects. It focuses on both financial and non-financial key performance indicators. The project provides an overview of the industrial energy efficiency market by describing its size in both relative and absolute terms, its history, and key stakeholders.

The research provides a framework for technology adoption which highlights the steps for evaluating both individual investments and overall technology strategy. Researchers also reviewed the standard ISO 50001, which provides a more specific method for evaluating energy management systems. The second phase of the project focuses on the application of frameworks to various technologies. It investigates some of the most common industrial efficiency products including the largest providers, standard business models, and payback periods. A result of this research is a book chapter, "Energy Efficient Models for Manufacturing Processes," part of an upcoming book on *Energy Efficiency and Manufacturing* by John Sutherland, David Dornfeld, and Barbara Linke.

Full project report

This project also appeared in the previous SPS annual report. It is published here in order to capture all work from the fiscal year of July 1, 2013, through June 30, 2014.

Project: Biomimicry, 3D Printing, and the Future of Green Manufacturing
SPS Project Leads: Dr. Martin Mulvihill, Dr. Omar Romero Hernandez
College of Chemistry, Berkeley Center for Green Chemistry, Haas School of Business

This project examined the current state of additive manufacturing technology and assessed the opportunities for bio-based materials and biomimetic design. Manufacturing processes in nature rely heavily on additive process. Plants and animals gather nutrients and energy from their environment, and using chemical processes and self-assembly they create the complex structures of the natural world. Wood, seashells, and butterfly wings all started out as carbon dioxide. Using energy from sunlight, biochemical processes transform the carbon dioxide transform via an additive process, guided by self-assembly to produce intricate biological materials.

There is currently a wide range of additive manufacturing technologies in use, and the number continues to grow. For biological materials, one popular method is to additively create a porous scaffold in the approximate shape of the objective shape of the tissue, then place cells in the scaffold. The cells will grow into a tissue around the scaffold, and the scaffold itself would ideally be excreted over time, leaving just the new tissue behind. Because of the inherent complexity of the scaffold geometry, this would not be possible without additive manufacturing. Current research is focused on identifying biocompatible materials that can be used in additive processes.

Another area of potential impact for additive manufacturing in the biological materials field is custom implants and surgical guides. Because there are little to no economies of scale with additive manufacturing, apart from the part design, making one part costs the same per part as making one hundred parts. This lowers the financial barrier to making custom implants and individual surgical guides available to patients in need. In addition, the complex geometries involved in biological parts are more easily manufactured with additive processes than any conventional manufacturing technique.

Full project report

Project: Biomimetic Durable Finishes for the Textile Industry
SPS Project Leads: Dean Douglas S. Clarks, Dr. Martin Mulvihill
College of Chemistry & Berkeley Center for Green Chemistry

During the Fall 2013 semester, 10 students worked in interdisciplinary teams as a part of the Berkeley Center for Green Chemistry Greener Solutions Program to evaluate potential replacements for current crosslinking chemistry in the textile industry. The goal of the collaboration was to identify biologically inspired opportunities to modify crosslinking technologies currently used in their wrinkle-resistant and water repellent finishes, motivated in part by the chance of eliminating the hazardous chemicals that are typically associated with these treatments, such as formaldehyde and diisocyanates. Formaldehyde is used in the conventional wrinkle resistance treatment process, and in addition to being carcinogenic; it can cause nasopharyngeal irritation and sensitization. Diisocyanates, conventionally used to impart water resistance, can cause respiratory tract irritation, occupational asthma, and possibly cancer.

The crosslinking strategies employed by nature are particularly rich sources of inspiration for alternative approaches. Biomimicry is the process of using inspiration from nature to solve a technology challenge. It draws upon thousands of years of engineering and refinement by nature, utilizing materials that are safe for the biological systems in which the processes occur. The students began with twelve examples of crosslinking found in nature, and after translating them into potential chemical solutions they estimated the potential performance and safety of each biomimetic strategy. From all of the potential solutions identified, there was one strategy in particular that warranted further lab-based technical evaluation. This solution, inspired by the enzyme catalyzed polymerization of lignin, had the potential to provide a benign solution that could scale in the textile industry if it could meet certain performance benchmarks.

Upon experimentation with the enzyme and a variety of small molecule inputs, the enzyme crosslinked small molecules into colored, insoluble molecules. While fabric-scale crosslinking did not occur based on standard tests in the textile industry, the results of this experiment show promise for another application in the textile industry – the production of alternative and inherently less hazardous dyes. As is often the case in science, the pursuit of one goal led to a discovery elsewhere as a byproduct. The enzyme produced a range of reds, yellows, and browns colors in the fabric, and further research can be done to expand the color palette and enhance the colors' stability.

Full project report

Sustainable Consumption

Project: Consumer Decision-Making and Sustainable Products
SPS Project Lead: Professor Dara O'Rourke
Environmental Science, Policy, and Management, College of Natural Resources

This project conducted research on actual consumer decision-making to evaluate root drivers of consumption decisions, how changes in sustainability information influence behaviors, and what might be learned from successful experiments in advancing behavior change. This project is unique in that moves beyond surveys and small-scale experiments to large-N empirical data on actual consumer decision-making. Anonymized data was accessed from http://GoodGuide.com, which has over 600,000 consumers per month using its web and mobile applications.

This research analyzed how different types of information, delivered at different stages in the consumption process, influence consumer decision-making. It involved examining:

- Does information about a product or company's environmental, social, or health performance has an influence on purchasing decisions? What information (health vs. environmental, etc.) has the most influence? When in the purchasing process?
- Does information change behavior if it is delivered closer to the moment of purchase (i.e., near the "buy now" button online or via a mobile phone in a store)?
- How does price and quality information interact with (or trump) environmental, social, and health information?
- What is the impact of presenting different types of information? Pass/fail information versus detailed ratings? Only positive information vs. positive & negative?
- What are the most effective types of "feedback" loops in consumption information? Is it possible to create a "Prius screen" for purchases to show consumers the impacts of their decisions?

A multivariate statistical analysis was conducted on over forty thousand GoodGuide online purchase interactions and found a significant impact of certain types of sustainability information on purchase intentions, varying across different types of consumers, issues, and product categories. Health ratings in particular showed the strongest effects compared with social and environmental ratings, and considerable differences appear in the influence of ratings across different categories, pointing to the need for heterogeneous strategies and approaches across the many types of consumer products. A particularly interesting finding is that direct users – those who intentionally sought out sustainability information – were most strongly influenced by sustainability information, while such information, on average, had no impact on non-direct users. Thus, simply providing more, or even better, information on sustainability issues will likely have limited impact on changing mainstream consumer behavior unless it is designed to connect with real-world decision-making processes.

Full project report

Project: Social Responsibility and Product Innovation
SPS Project Lead: Professor Ganesh Iyer
Haas School of Business

In many markets, consumers care about consuming products that are socially responsible or environmentally friendly. This project examines the incentives of firms to invest in product innovations that respond to social responsibility concerns and connects the existence of the markets for socially responsible innovations to the presence of intrinsic and extrinsic social responsibility preferences. In addition to deriving economic value from the product, there are two distinct dimensions for consumer social responsibility preferences. First, they recognize intrinsic costs for consuming a product which is socially/environmentally unfriendly, and they are heterogeneous in these costs. Second, consumers also have social comparison preferences, which are endogenous to the nature of their market interactions. They enjoy a social comparison benefit if their consumption decision is environmentally more responsible than that of a consumer that they meet in a social interaction. Conversely, they face a social comparison cost if they meet someone whose consumption is more responsible than theirs.

The analysis reveals a robust result pertaining to innovation incentives across monopoly and competitive markets. When the economic value of the product is relatively small and there exist non-buyers in the market, the incentive to innovate decreases as social comparison costs and benefits increase. In contrast, when the economic value of the product is sufficiently large, increases in social comparison costs and benefits increase the incentive to innovate. The analysis of competition also shows that social comparison benefits can act to soften price competition, while social comparison costs can exacerbate price competition. Finally, this project also identified market conditions where a monopoly invests more or less compared to a firm facing competition.

Full project report

Project: Regression Discontinuity Evidence for the Demand for Energy-Efficient Products
SPS Project Lead: Professor Lucas Davis
Haas School of Business

Interest in energy efficiency has surged over the last several years, in large part due to unprecedented levels of public support. This increased attention to energy efficiency represents a substantial opportunity for manufacturers and retailers of energy-efficient products. The market is unusual, however, in that it involves a high level of cooperation between the private and public sector. With many energy efficiency programs, manufacturers and retailers work together with utilities to offer and administer rebates and other forms of direct incentives.

This study aimed to study the demand for energy efficient products by using a regression discontinuity (RD) analysis. Data was used from a large-scale energy-efficiency program that provided incentives for households buying energy-efficient refrigerators and air conditioners.

Overall, the graphical evidence provides a strong indication that program participation increases with higher subsidy amounts. Although the differences in participation rates are relatively modest, it seems quite clear that the subsidy amount was a strong factor in the decision to make a replacement. These preliminary results suggest that demand may be relatively inelastic beyond a certain incentive level. They also have potential important implications for product marketing of energy efficient or "green" goods, suggesting that other factors, in addition to price, are playing an important role in driving consumer behavior. This sector is unusual in the scope of non-price factors playing a substantial role. In future work, it would be interesting to combine quantitative analyses like this with qualitative evidence from consumer surveys.

Full project report

This project also appeared in the previous SPS annual report. It is published here in order to capture all work from the fiscal year of July 1, 2013, through June 30, 2014.

Project: The Role of Packaging in Reducing Food Waste in the US
SPS Project Lead: Dr. Omar Romero Hernandez
Haas School of Business

According to the United Nations, approximately one-third of the food produced worldwide is lost due to spoilage, bad handling, poor operational practices and a lack of a holistic perspective of the food supply chain. One significant factor of the problem lies in a misunderstanding of the potential benefits of better packaging systems, as many current businesses and consumer attitudes have not yet addressed this issue. Food systems need to be more resilient, healthier, and allow for broader and fairer distribution. This project is a literature review and preliminary opportunity analysis focusing on the research question: *Where can packaging improvements have the greatest impact on reducing food waste?*

First, this project investigated the role of packaging in reducing food waste and identified where food losses are most impactful in the supply chain. In the U.S., this is often at the consumer level. Next, specific food products were narrowed down that were most voluminous and valuable food waste. For example, certain fruits, vegetable, and a variety of meats have some of the largest impacts. The next part of the project summarized innovations in packaging, and some high level suggestions were proposed to the industry about where research and development is most needed to further reduce the food waste issue.

Full project report

Project: What Will Post-Consumer Waste Streams Look Like in 2025?
SPS Project Lead: Dr. Omar Romero Hernandez
Haas School of Business

The aim of the project was to examine how waste processing technologies, policy, consumer behaviors, and other megatrends influence long-term changes in our waste streams. This project investigates waste trend predictions for 2025 and analyzes the current and potential impacts of waste drivers including technology, corporate activity, policy, and consumer behavior.

Currently 1.3 billion tons of post-consumer solid waste are generated each year globally, and this is expected to grow 70% by 2025 as a result of rising urban populations, incomes, and urbanization. This project analyzed the potential future impact of four key factors:

- Technology
- Corporations
- Consumer attitudes
- Policy

Technology solutions do not transfer easily and thus will be slow to achieve scale. Corporations have a mixed effect, as some are adopting sustainable design and/or are playing an active role in recycling and recovery. Consumers view waste as a concern, but it is unclear how much their behaviors are based on sustainability issues. Policy is the strongest driving factor, and it is most poised to affect waste production between now and 2025.

Full project report

World Challenges

Project: Locally Appropriate Energy Strategies for the Developing World: A focus on Utility Scale Clean Energy Opportunities in Sarawak, East Malaysia
SPS Project Lead: Professor Daniel Kammen
Energy and Resources Group

Southeast Asian nations, along with China and India, are shifting the center of gravity of the global energy system. Since 1990, the region's energy demand has expanded two-and-a-half times and will increase over 80% between today and 2035, a rise equivalent to current demand in Japan. The power sector is fundamental to the energy outlook for Southeast Asia, and within it coal emerges as the fuel of choice. This leaves a significant space for exploring clean energy technologies. Emblematic of states pursuing rapid economic expansion, the Malaysian state of Sarawak, which is currently one of the world's largest producers of palm oil and timber, is embarking on a large industrialization project, the backbone of which is a series of up to 50 hydroelectric dams with a capacity of 20,000 Megawatts (MW). Despite these large-scale energy developments, most of these rural villages in East Malaysia are not grid-connected, and they rely heavily on high-cost diesel fuel for all electricity and transportation needs. The Sarawakian economy, based on large-scale agriculture and primary extractive industry, represents an ideal case study for exploring whether synergies between clean energy technology and abundant exploitable natural resource exist. Given the pace of growth of similar states in the Southeast Asian region, a study of this potential is timely.

The Renewable & Appropriate Energy Laboratory (RAEL) at UC Berkeley studied this local and large-scale energy service debate in villages along the Baram River in Sarawak, where electricity from diesel effectively costs 2.24 RM/kWh ($0.70/kWh), compared to a 0.31 RM/kWh ($0.10/kWh) domestic electricity tariff for state utility customers. Using a hybrid energy resource optimization framework, RAEL explored optimal configuration for these villages based on cost and resource availability. They found the least cost options for energy services to come from a mixture of locally managed small-scale hydroelectricity, biogas generators, and accompanying batteries instead of a claim of service provision based on large-scale regional electrification. A range of different renewable energy service scenarios are consistently 20 percent, or less, than the cost of diesel energy scenarios, without the social, economic, and environmental disruptions that would come with a large-scale hydropower plan for the river basin. The results of this study are currently being published.

Full project report

Project: How Does Leakage Affect the Role of Natural Gas in a Carbon-Constrained Grid?
SPS Project Lead: Professor Daniel Kammen
Energy and Resources Group

Natural gas plays a critical role in most low-emission grid planning scenarios. Natural gas generators are relatively flexible, emit half as much carbon as coal, and recent advancements in fracking technologies have driven down the price of fuel. Between now and 2030, natural gas can reduce emissions by displacing coal power while enabling a greater penetration of intermittent renewable resources. However, the emission reduction relative to coal could be swamped by leakage of natural gas at many points in the supply chain. Fracking provides a cheaper source of gas, but also has higher rates of leakage relative to traditional gas wells. Incorporating supply-chain NG leakages into long-term low-emission grid planning is vital to ensure we meet emission targets.

This project incorporated recent estimates of natural gas leakage into SWITCH, a state-of-the-art systems planning model for low-cost and low-emission power grids. Then a number of scenarios were run to understand how the optimal deployment of natural gas generators is impacted by various leakage rates and to determine if widespread deployment of more leakage control technologies is cost-effective. Current leakage rates from natural gas systems favor coal to natural gas substitution. Additionally, climate benefits from using natural gas in transportation are uncertain (for gasoline cars) or unlikely (for heavy-duty diesel vehicles).

Full project report

Project: Information and Communication Technologies to Enable Energy Access
SPS Project Lead: Professor Daniel Kammen
Energy and Resources Group

Today more than 1.4 billion people lack access to electricity, and close to another billion have severely intermittent service. International agencies, private sector actors, philanthropic foundations, and academia have joined together with the United Nations to support Sustainable Energy for All (SE4ALL), an initiative that hopes to bridge this gap by 2030. Many are focusing on the role that Information and Communication Technologies (ICTs) can play in supporting rural energy development, by bridging common barriers such as maintenance and operation, payment, market spoiling, and risk aversion. However, little analysis has been done on the advances in this sector, and there have been no efforts to comprehensively outline the current state of the field, the successes and failures to date, or the opportunities that remain for the research community or the private sector to drive innovation.

Innovative new approaches are needed to simultaneously address the needs of those people lacking electricity while also transitioning to a decarbonized energy system. With particular focus on the energy needs of the underserved, this project presents an analytic and conceptual framework that clarifies the heterogeneous continuum of centralized on-grid electricity, autonomous mini- or community grids, and distributed, individual energy services. The present day is a unique moment in the history of electrification where decentralized energy networks are rapidly spreading based on super-efficient end-use technology and low-cost photovoltaics. This project documents how this evolution is supported by critical and now-ubiquitous information technologies, particularly mobile phones, and it demonstrate how these disruptive technology systems can rapidly increase access to basic electricity services and directly inform the emerging sustainable development goals for quality of life, while simultaneously driving action towards low-carbon, earth-sustaining energy systems.

Full project report