United States Environmental Protection Agency

AIChE

NSF

Workshop on the Design of Sustainable Product Systems and Supply Chains

September 12–13, 2011
Arlington, Virginia







Final Report

ACKNOWLEDGEMENTS

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Workshop on the Design of Sustainable Product Systems and Supply Chains

September 12–13, 2011
National Science Foundation
Arlington, VA

ABOUT THE WORKSHOP

The Workshop on the Design of Sustainable Product Systems and Supply Chains was held September 12–13, 2011 at the U.S. National Science Foundation (NSF) offices in Arlington, Virginia. The Workshop was co-sponsored by the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD), the National Science Foundation, (NSF) and the American Institute of Chemical Engineers (AIChE) Center for Sustainable Technology Practices. The purpose of the Workshop was to foster collaboration and promote the development of a research community focused on sustainability and supply chains. This was accomplished by bringing together a diverse group of researchers and other professionals with experience relevant to sustainable supply chain design.

GOALS OF THE WORKSHOP

The goal of the workshop was to engage experts with experience in several areas. From experts with experience working within a broad, systems perspective, the goal was to elicit understanding of the key shortcomings of current practices and identify practical ways in which new or repurposed approaches could be integrated within existing frameworks. In the case of experts with experience working within a narrower focus, the goal was to work together to understand how these approaches could be integrated within existing frameworks or larger-scale models. Finally, the goal was also to explore opportunities for applying discipline-specific approaches to other problems related to the design of sustainable supply chains.

OVERVIEW

The following report provides the agenda of the meeting events, an executive summary of the reports back from the Breakout Groups, as well as additional perspectives. The report includes two Appendices: the first provides the notes from the Breakout Group sessions, as well as meeting materials, including the goals of the meeting, a list of participants, biosketches and position statements of the participants, and complete contact information on the participants; the second provides the PowerPoint presentations given at the meeting. Readers are advised to refer to these resources for more detailed information.

MONDAY, SEPTEMBER 12, 2011

WORKSHOP SESSION I: PERSPECTIVES ON THE DESIGN OF SUSTAINABLE PRODUCT SYSTEMS AND SUPPLY CHAINS

Introduction of Organizing Committee & Staff Support
Troy Hawkins, ORD, EPA

Welcome to NSF
Bruce Hamilton and Maria Burka

Introductions of Participants

Workshop Goals and Overview
Troy Hawkins

PRESENTATIONS

Design of Sustainable Products Systems and Supply Chains: Some Concepts, Cases, and Lessons from an Engineering Perspective
Bert Bras, Georgia Institute of Technology

Consumption, Sustainability, and Social Benefits
Thomas Theis, University of Illinois, Chicago

Avoiding Unintended Consequences in the Design of Sustainable Supply Chains
Sherilyn Brodersen, Kraft Foods

LCA from an Industry Perspective
Bill Flanagan, GE Global Research

EPA Sustainability and the Design of Sustainable Product Networks and Supply Chains
Joseph Fiksel, U.S. EPA, The Ohio State University

SUPPORTING SUSTAINABLE ENGINEERING RESEARCH THROUGH NSF AND EPA

Funding Opportunities at NSF for Proposals on Sustainable Product Systems and Supply Chains
Bruce Hamilton, NSF

P3 (People, Prosperity, and the Planet) Award Program: A National Student Design Competition for Sustainability
Cynthia Nolt-Helms, National Center for Environmental Research (NCER), EPA

Session II: Disciplinary Definition of the Problems and Opportunities

Discussion of Session II Breakout Questions

Ignacio Grossman, Carnegie Mellon University

Participants were provided with the following series of questions to discuss in their Breakout Groups:

1. What are the challenging industry and societal problems to be solved? What are the future drivers for design of sustainable products, manufacturing systems and supply chains? What are the next generation sustainable design-enabled strength areas in the U.S.?
2. Where are the gaps in knowledge? What are the problems faced by existing sustainable design capabilities?
3. What are the opportunities for design of sustainable products, manufacturing systems, and supply chains?

Session III: What are the common problems, common areas of need, complementary areas to be interfaced, and opportunities for cross-disciplinary fertilization facilitated by design of sustainable product systems and supply chains?

Orientation for Session III

Eric Williams, Rochester Institute of Technology

The Breakout Groups were asked to discuss the following specific questions within their groups:

- Group 1: How does sustainable design affect or impact economic drivers?
- Group 2: What technologies/tools and their integration are needed, where is the expertise, and what is the state of technical capability?
- Group 3: What are the respective roles of industry, government, and academia and how should they interrelate? What partnerships/coalitions are needed?
- Group 4: How will new and emerging technologies and capabilities need to affect organization roles and responsibilities (academia/industry, researcher/research teams)?
- Group 5: Where education and training are needed?

Breakout Groups Report Back

TUESDAY, SEPTEMBER 13, 2011

SESSION IV – WORKSHOP DELIVERABLES

On the second day of the workshop, the participants were asked to work within their groups to discuss the following issues and develop recommendations in the context of near-term and long-term, priority, and reality:

1. Identify and exemplify major application impacts, directions, and the potential for design of sustainable product systems and supply chains
2. Identify and recommend research areas that aim toward the fulfillment of this potential
3. Identify associated areas of needed emphasis with sustainable design education and training, interdisciplinary development, and support and approaches to collaboration.

The Breakout Groups were also asked to answer the following questions:

1. What investments are needed by whom, financial and other?
2. What are the key learnings and take-aways from the workshop?

SESSION IV BREAKOUT GROUPS REPORT BACK

WRAP UP AND NEXT STEPS

SUMMARY

By Troy R. Hawkins and Raymond L. Smith

Who participated in the workshop?

The workshop brought together 50 participants selected to represent a range of expertise related to sustainable product systems and supply chains. Participants were selected based on their ability to contribute to discussions based on their experience, accomplishments, and current positions. The most represented discipline was engineering, including in particular chemical, environmental, civil, and mechanical. Participation by country included Brazil, Germany, the Netherlands, Singapore, and the U.S. U.S. participants represented a wide range of regional perspectives with a bias toward the east coast, Ohio, and Washington D.C. Participation by sector could be broken down roughly as one-tenth non-profit, one-fifth industry, one-third academic, and one-third government. The government portion included representatives of the Army Corps of Engineers, Department of Energy, Environmental Protection Agency, and National Science Foundation.

Why Design Sustainable Products and Supply Chains? Framing the Issues.

Sustainability is a unifying concept underlying a wide range of efforts to improve the performance of human-influenced systems in terms of their effects on natural resources, ecosystems, human health, and long-term viability. Decision-makers in both industry and government are under increasing pressure to incorporate sustainability considerations into their activities. At the same time, industry must respond to globalization and constantly evolving resource challenges through improved economic efficiency, and policy-makers are under intense pressure to promote domestic job creation and retention and reduce budget deficits through decreasing spending and improving efficiency. A key sustainability-related concern is that the pace of this economic development has set up a situation where traditional market forces may not respond quickly enough to the constraints of natural systems to prevent undesirable and potentially severe consequences. This situation is exacerbated by the fact that competing economic and regulatory drivers often create barriers to effective collaboration between industry and policy-makers around the topics of sustainability or environmental conservation.

Sustainable development has been famously defined by the World Commission on the Environment as: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[1]” Discussion around the industrial and societal problems that must be addressed in order to meet this mandate focused on ensuring long-term and uninterrupted resource availability, maintaining human and ecosystem health, and minimizing disruption of natural cycles. The primary resource availability concerns expressed at the workshop included hydrocarbon sources for fuels and chemical feedstocks including petroleum, natural gas, and coal; water; phosphate; minerals and organic matter relevant for soil fertility; rare earth and other elements used in high tech applications; and other scarce minerals. Human health concerns related primarily to airborne emissions and other releases associated with

[1] WCED (1987). Our Common Future: Report of the World Commission on Environment and Development. Paris, France, United Nations.

acute and chronic exposure issues as well as long-lived and bioaccumulative pollutants. Ecosystem health concerns related primarily to the maintenance of ecosystem services and concerns regarding complexity and unanticipated consequences. The minimization of disruption of natural cycles is closely related to ecosystem health and refers to concerns regarding the unprecedented scale of the effect of human activities on natural systems including the cycling of carbon, nitrogen, water, phosphorus, and biomass resources. An overarching theme throughout discussions was the imperatives of responding to climate change, shifting toward energy pathways that can be maintained over the long-term, reducing and improving the efficiency of water use, avoiding dissipative uses of materials, minimizing the *footprint* of human production and consumption activities, and improving human health and worker safety.

An exponentially increasing population, the global imperative of economic growth, and increasing consumption in fast growing economies result in strong pressures counteracting efforts to achieve sustainability and establish a situation where a slow or delayed response means that even greater actions could be required in the future to mitigate human-induced disruptions and restore balance. Key dynamics include the rising middle class in emerging economies such as the BRIC countries of Brazil, Russia, India, and China and the failure of wealthy nations to mount a sufficient response to sustainability concerns. From the perspective of businesses, appropriately responding to sustainability is hampered by short-term decision horizons and the failure of markets to value externalities. From the perspective of regulatory agencies, effective decision-making is made particularly challenging by the complex interplay of social, economic, and environmental factors. At the intersection of industry and government, the failure of government to provide predictable policy actions or even to clearly express priorities hampers investment in sustainable technologies and product pathways. Relatedly, the need for policy leading to the creative destruction of industries in response to sustainable development is counteracted by the vested interests of well-established industries and their ability to influence policy-making through lobbying efforts. To date, scientific communities have been unable to provide a clear consensus regarding priorities and how to effectively regulate for sustainable development while sufficiently accounting for the framework and constraints under which they operate. The research community is facing a challenge unlike any it has previously dealt with owing to the urgency of sustainability concerns together with the irreducible complexity and the high-degree of interaction between areas of study traditionally addressed by distinct fields. Unwillingness to make sacrifices in analyzing tradeoffs, perverse outcomes of well-intentioned policy, the proliferation of partially informed findings, and apparent scientific *flip-flops* lead to contentious public discourse and confound decision-making.

Recent U.S. experience with biofuels policy provides an oft discussed example. The desire to promote domestically sourced energy and to reduce greenhouse gas emissions lead to the enactment of the Energy Independence and Security Act of 2007 in the U.S. Initial modeling efforts lead to the decision that renewable fuels would be classified as those capable of providing at least a 20% improvement in life cycle greenhouse gas emissions when compared with conventional gasoline. First considerations included primarily combustion-related emissions along the supply chain. Desire for a prompt regulatory response meant that these analyses were acted on in the final rulemaking. Subsequent studies raised a host of concerns and have lead to significant debate regarding the wisdom of initial rulemaking. Meanwhile, litigation, legal mandates, and other pressures stand in the way of immediately revisiting the regulatory framework. The grand challenge is to collectively learn from this and other similar experiences and to move forward through preemptively engaging the scientific community to ensure that the necessary data and models are available for decision-makers in the government and industrial sectors and their supporting partners in NGOs, research institutes, and academia to draw upon early in future decision processes.

Drivers for the Design of Sustainable Product Systems and Supply Chains

Discussion around the question, “what are the future drivers for design of sustainable products, manufacturing systems, and supply chains?” could be organized into the high-level categories *policy drivers* and *market drivers*. Under these headings, *policy* drivers could be placed along a spectrum between *government-initiated* and industry or *externally-initiated*. *Market* drivers could be cleanly divided into *supply-driven* and *demand-driven*.

To place the *policy drivers* of sustainability in context, it should be noted that the policies themselves are responses to pressure from the public or special interest groups. *Government-initiated* policy refers to policies first promulgated through legislative or regulatory mechanisms while *externally-initiated* policy refers in this case to voluntary standards first developed by industries or non-governmental organizations. The Energy Independence and Security Act and the associated Renewable Fuels Standards are an example of *government-initiated* policy intended, in some respects, to serve as a driver of sustainability while the Leadership in Energy and Environmental Design (LEED) Standards promulgated by the US Green Building Council, the Greenhouse Gas Protocol Initiative promulgated jointly by the World Resources Institute and the World Business Council for Sustainable Development, and the Forest Stewardship Council Certification Program all provide examples of *externally-initiated* drivers of sustainability.

The government clearly plays an important role in creating rules for markets that correct for externality distortions or preemptive adjustments to prevent sudden and undesirable crashes. Nonetheless, there are a number of ways in which even well-intentioned policy can hinder sustainability. In many cases, meeting sustainability goals requires dramatic changes to existing systems. This fact coupled with the irreducible complexity of the systems involved and legislative and regulatory constraints raises significant challenges to basing decisions on a comprehensive understanding of the implications. Thus, while policy can drive the creation of value from sustainable solutions, mechanisms such as subsidies often result in less than optimal outcomes and undesirable distortions. Stakeholder engagement, early involvement of industry in framing policy, and being open to mid-course correction can help avoid or correct unintended consequences. However, the uncertainty associated with impending policy changes hinders investment and delays adoption of sustainability measures. Even policies intended to provide benefits in an area seemingly isolated from sustainability outcomes may work against sustainability when actions are taken in isolation of broader system implications. In this vein, economic growth policies are often cited as drivers of unsustainable consumption patterns. In a more targeted example, efforts to promote environmentally-preferable purchasing within the government sector have to date been stymied by the vast array of other regulatory requirements for and restrictions on government contracts. In summary, there is general agreement that policy is an important driver of sustainability, yet there are a number of considerations which must be taken to ensure that the pressures applied have an overall positive effect.

Economic markets also serve as drivers of sustainability. In the best case, supply constraints are internalized in market pricing and markets adjust appropriately. Within industry, the perception of risk associated with resource availability drives current efforts to minimize the use of energy, water, and selected materials. Proactive efforts related to sustainability on the supply side include the scenario considerations behind investment decisions involving fixed, long-lasting infrastructure and efforts to increase the resilience of supply chains to supply shocks. These decisions are made directly through management decisions but also indirectly through the pricing models applied on the behalf of private investors. Insurance can also serve as a driver to the extent that sustainability-relevant risks are incorporated in premium pricing. For example, insurance has already begun to consider connections between global climate change, the frequency and severity of weather events, and effects on coastal communities.

A second type of market driver is on the demand-side. From a company perspective, these drivers take the form of product differentiation, long-term branding, and sustainability in terms of corporate longevity. Educating consumers about sustainability serves to strengthen demand for sustainable products and services. As markets evolve, so do the ways in which they drive movement toward or away from sustainable outcomes. Key dynamics include providing for a rapidly growing global population, bottom of the pyramid design, and providing for a growing consumer class.

Sustainable design in itself affects economic drivers. Sustainable design represents a change to an existing market. Organizations will fall somewhere along the development profile for an industry: innovator, early adopter, early minority, late majority, and laggard. For innovative organizations in a leadership position, sustainable design could potentially be a competitive advantage reducing liabilities, allowing for early influence with political organizations, and improvements in brand performance with consumers. For organizations responding to changes, their position is to minimize the cost of catch up, discredit *green* claims, take a legal defensive position, and obfuscate policy-making.

Competitive pressures can act to delay advancement. Modifying existing business practices introduces risks which may not be sufficiently rewarded through competitive advantage alone. The existence of externalities and incentives to benefit individually from collectively destructive behaviors leads to the *tragedy of the commons*. By nature, professional organizations are slow to adopt new designs or modify existing standards or establish criteria that could be perceived as advantaging a particular firm or that are associated with a foreign company.

Policy actions, economic drivers, and sustainable design cannot be separated. Differences between environmental regulations and true costs can skew markets. Subsidies can jump start new technologies, but may not be efficient in achieving long-term goals. Externality markets such as those for sulphur or carbon dioxide can level the playing field, but they must first address import concerns. In the case of certain externality markets, such as carbon, the legislative mandate is yet to be determined. When promoting technologies, decision-makers need to be aware of scarce materials, scalability, and unintended consequences. There are marked differences between optimal outcomes from individual versus collective perspectives, as is demonstrated by controversy surrounding the long-term consequences of destroying habitat. From a company perspective, there are economic advantages to sustainable product lines.

Litigation, insurance, and infrastructure are all important considerations which must be incorporated in sustainable design efforts.

Opportunities for the Design of Sustainable Product Systems and Supply Chains

Moving forward, the viability of an economy within the increasingly flat Earth[2] requires continual adjustments and creative destruction. In the case of certain industries, sustainable design requires significant shifts. In these cases, there is a distinct opportunity to redirect expertise within marginal industries toward their next-generation corollaries within a sustainable system. Affecting this shift proactively places companies in a leadership role and offers growth opportunities not available under the status quo. Examples of such shifts include redirecting expertise in pulp and paper toward bio-refineries, in fossil-based supply chains toward bio-based analogs, off-shore oil platforms toward floating wind turbines, waste management toward material recovery, primary material beneficiation toward secondary materials recovery, and logistics management to materials tracking.

There are a number of key challenges to sustainability that offer distinct opportunities for sustainable design in conjunction with research and development. New technologies can be game changing in terms of our understanding of sustainable systems. These include innovative designs for renewable energy sources, material recovery, material and energy efficient technologies, and material substitution. Sustainable design is essential to ensuring the safety and viability of high tech solutions developed via the fields of nanotechnology, nano-manufacturing, cyber-infrastructure, advanced information technologies, and biotechnology.

Beyond targeted improvements, the development of highly efficient networks and industrial symbiosis offers an opportunity for applying sustainable design capabilities and transforming regional economies. A framework and tools are needed for optimizing and assessing highly interconnected material and energy networks in terms of their benefits and implications for regional economies, ecosystems, health, and social conditions. This would allow for harnessing the greater global effectiveness of a well designed system that would not be accomplished through the status quo of optimization from an individual perspective.

Informing government sustainability policy offers a distinct opportunity for sustainable design. The Environmental Protection Agency is in the process of adopting sustainability as the paradigm for protection of human health and the environment. Sustainability offers a means of promoting coordination and efficiency across agencies. Tools capable of providing quantitative results actionable for regulatory impact assessment incorporating sustainability concerns represent a vision for the next generation of cost benefit analysis and risk assessment studies.

Sustainability is inherent in corporate efforts to promote their brand in over the long term. In this sense, brand sustainability and sustainability in the broader sense can progress hand in hand. This realization is driving many corporate sustainability efforts and private sustainability consortia which allow corporations a better means of engaging their suppliers around a broad range of sustainability-relevant concerns. New efforts related to conservation coupled with the

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[2] Friedman, T. (2005). The World Is Flat: A Brief History of the Twenty-First Century. New York, New York, Farrar, Straus & Giroux.

rapid exchange of information through social networking have placed a new burden on companies to be cognizant of a broad array of issues across their supply chains. This fact has led to a new market for tools that address these concerns in a comprehensive and concrete way.

The opportunities for designing sustainable products, manufacturing systems, and supply chains involve organizations, methods, impacts, technologies, and policies. Organizational opportunities center on collaboration. Solutions are needed at multiple scales (local to global), so prospects for crossover efforts between small scale interests (e.g., small businesses or communities) and larger ones (such as corporations, cities, or regional and national organizations) with academic and NGO input can work toward designing more sustainable systems. As businesses focus on sustainability issues it might be possible (assuming it's legal) for pre-competitive collaboration networks to develop, where these noncompetitive groups work on a sector approach to specific issues. In research, collaborations need to focus on long term sustainability or at least bridge the gap from short term solutions to the longer term. Researchers could develop design consortia that compete to be the most sustainable. Another research opportunity would involve cross-industry symbiosis to both work together and to focus on sustainable material management, a term geared toward valuing every material rather than labeling some output streams as waste.

Methods and tools for sustainable design are needed. In particular, it would be beneficial to have tools that allow for rapid screening and assessment of supply chain and product systems. Another perspective would be meta-modeling (i.e., models of models) for assessing systems and/or for creating a single integrated system model. Specific methods could include industry standards, crowd sourcing, and resilience of systems to pressures or impacts.

Various impacts are of interest in the design of these systems. Climate change is at the forefront of many lists of concerns (although perhaps in part because other impacts have been studied extensively and releases controlled for a much longer time). Another topical area is reusing, remanufacturing, and recycling, where these methods are used to (potentially) conserve material and energy feedstocks. Knowing when to apply these methods to conserve materials would be valuable information. In addition, the availability of specific materials over time is a natural area for sustainability analysis. Determining whether a specific material can be substituted for is not necessary a straight forward problem since the use of materials is always done in context, which defines the opportunity for replacement.

The replacement of rare earth elements is an example of a technology of current interest. Others of interest range from efficient shale extraction and clean coal to carbon sequestration. A renewable source of materials worth studying is algae, although currently it appears breakthroughs are needed to make it a cost effective source. On the product side, RFID systems could be exploited to improve systems and develop information.

A discussion of these systems would not be complete without considering policy. Some believe that the connection of technology and policy is the analysis of systems, so that an informed policy can guide system development. The idea is that policy will affect funding and finance, which will determine development. A question of interest is whether this end can be achieved through efficiency improvements rather than increased consumption. For instance, is the answer (i.e., means) an eco-design standard? In most cases one finds trade-offs between policy desires and also between the means of achieving desires. Can schemes be developed to deal with various trade-offs that are inherent to sustainable systems? The answers may be relatively simple, but may not necessary be easy to implement as policies. Perhaps one could hope that misinformation can be avoided, and if not, then education appears as a clear need.

Knowledge Gaps and Barriers

In the design of sustainable supply chains and product systems knowledge gaps and barriers can limit the development of systems. The costs in filling gaps and overcoming barriers offer resistance towards achieving a holistic and complete analysis, and the risks associated with gaps and barriers preclude strong moves to develop sustainable systems in the short term. Proponents of a these sustainable systems are often unaware of the historic development that has led to the current system. At the same time, detractors have not been educated or are unable to envision a system that differs significantly from the current system.

As people work on supply chain and product network problems, they face a number of issues. For instance, is research on these systems to be industrially focused, or take into account aspects that many would consider more academic (e.g., ecological economics)? Can these be brought together so that actual values replace current costs, which do not represent certain externalities, like permitted pollution? If research needs to meet incremental goals, especially always improving profitability, can one expect it to also meet long term sustainability goals? One should also realize that when research is focused in this way, it’s likely that education is as well.

Supply chain and product system designers are striving to optimize aspects of the system, meeting criteria for costs, resources, feed or product quality, robustness, timeliness, etc. As one considers various vulnerabilities and uncertainties the opportunities for simultaneously approaching a sustainable solution are limited. In fact, a process that is flexible enough to handle large fluctuations is inherently far from optimized.

In addition, the results of analyses are most often performed in silos of a particular sector, media, risk, or impact category. When analyses are attempted holistically they are often time consuming and confusing without offering a quantifiable overall goal, and answers like “it depends” are very difficult to work with. Instead of working holistically some will focus on material scarcity (for both energy and material feedstocks), while others focus on an impact, like greenhouse gases. And even if a complete analysis is done, one has to question whether one really knows all of the possible impacts. Further, methods which purport to encompass all effects (e.g., full cost accounting) normally fall short. Other methods, like standards or score cards, only address a necessarily limited field.

The analyses which attempt to meet long term sustainability goals face barriers themselves. These large analysis problems always deal with data inventory issues. Data sets lack a consensus of researchers who agree to their appropriateness (sometimes logically so, since a different use can require a different inventory data focus). In step with this lack of consensus is the lack of standards for openly shared data. Even when inventory data are developed to be transparent and complete it is still very difficult to verify results. Beyond the inventory data, impact assessment results add another layer of complexity which is difficult to verify and interpret. The interpretation is especially difficult across disparate goals like money, risks, and various impact categories.

Educational Needs

The educational needs for the design of more sustainable supply chains and product systems can be implemented through educating youth, college, and graduate students, funding and implementing research projects, and preparing professors. Much of this education is simply about sustainability or the environment, rather than any concentrated focus on supply chains or product systems.

For young people education opportunities usually come through topics that allow subject matter to overlap with meeting other curricula demands. Youth are often receptive to ideas about sustainability, but may not be exposed to the ideas. Some can get experience through extracurricular activities. For those who will obtain their information through K-12 classes, a promotion of science teachers with knowledge of sustainability would help. Education of those teachers presents another gap.

Science teachers and other college students / graduates can be provided with courses or class modules that focus on sustainability issues. For those whose future work could relate to supply chains and/or product systems, there is an opportunity to receive information that is directly relevant during college. Professors need to develop classes and have modules (or whole books) available to them to educate their students. In some college settings there may be an opportunity to encourage cross disciplinary teams of students to work on various aspects of a sustainability (supply chain or product system) problem. This holistic approach which integrates system thinking breaks from the silo-based method of learning, and can address problems of significance like the sustainability of energy, water, and improving / maintaining quality of life.

The diverse team that can approach issues from across disciplines is perhaps uniquely qualified for research funding. Funding that focuses on sustainability (for supply chains and product systems) can guide development that leads to daily activities (both in everyday living and business) that are sustainable. To move in that direction, organizations can continue or adopt similar funding of research like NSF's Innovation Corps (I-Corps) Program that promotes technologies, products, and processes for the benefit of society. Also, funding can develop PhD scientists and engineers through programs such as the Integrative Graduate Education and Research Traineeship (IGERT). The implementation of associated research projects can develop ideas for sustainable systems and well-rounded able researchers.

One place where the academic model does not do well is in developing industrially oriented professors. If the path to becoming a professor remains (most commonly) to progress from a PhD program to a postdoctoral position followed by becoming a professor, then professors will not obtain much industrial experience. This experience is important in educating people about real-world sustainability (for supply chains and product systems).

Technical Needs

During Session III of the workshop, certain breakout groups were tasked with responding to the questions: *What technologies/tools and their integration are needed, where is the expertise, and what is the state of technical capability?* This section is based on the notes from these groups, the larger group discussion that took place in connection with their report out, and some additional points pulled from other discussions that took place during the course of the sessions.

There was general consensus that system-level analyses are needed to synthesize a broad range of considerations into information relevant for decision-making. A transition is needed to move beyond one-off analyses with a singular focus to more inclusive, systems-level studies to provide actionable information related to technology transitions addressing dynamic relationships between different aspects of the system. In the case of biofuels, this might involve pulling together dynamic relationships between market effects, government initiatives such as the Conservation Reserve Program, physical and biological effects such as carbon and nutrient flows to and from soils, and behavioral analysis of key actors in supply chains such as farmers, commodity traders, fuel retailers, and consumers. And in fact, a system dynamics modeling approach is being applied to biofuel systems by the Department of Energy. In addition to the systems dynamic approach, the integration of life cycle assessment and risk assessment with incorporation of behavioral aspects was also specifically proposed as a pathway toward a well-organized and more inclusive system analysis approach.

In order to provide the necessary systems analysis capability, data and tools for seamless, consistent analyses at multiple scales need to be developed. A key tradeoff is between the accuracy associated with the narrow scale analysis versus the uncertainty/variability of the more comprehensive scale analysis. A challenge for research and development moving forward is to continue to develop models capable of maintaining the rigor associated with narrow analyses while extending the scope to include all of the system aspects at play.

A number of specific research needs were identified which contribute to the overarching goal of supporting systems level analyses including. A primary need is for well organized datasets that could be leveraged in systems analyses, in particular life cycle inventory data which are updated and maintained and provided at a low cost. Another research need is for the development of models incorporating non-linear, dynamic relationships to provide predictive capability in connection with life cycle assessment.

Another category of technical needs address gaps in the practical tools and approaches available to practitioners. These include the practical need for an agreed upon approach for producing streamlined or qualitative life cycle assessment studies. Because of the large amount of data and detailed analysis associated with a full LCA study, it often becomes impractical to apply LCA in certain areas where the available time and resources cannot support it or where the number of potential options is large. Related to this need is the need for product-specific models that could be incorporated in the design workflow to allow for parametric studies of design alternatives. When more complete systems analysis studies are performed, there is also a need for linking with benchmarking tools to allow for comparison to standard or consensus-based results or to allow for data envelope analysis.

Alongside the need for more inclusive analyses lies the need for integration of uncertainty in assessments. This need must be addressed at various levels. First, data and models must be developed in a way which captures uncertainty. For data this will involve recording not only static values, but ranges or distributions describing the variation of values under a specified set of conditions. Second, decisions must be made on the basis of likelihoods rather than definitive results and arrangements must be put in place for adjusting directions based on new information. This is especially true in connection with policies and decisions made in support of sustainability considering the wide range of considerations and the evolving nature of the science. This is not to say actions should not be taken, rather that policies should be developed following a no regrets approach taking into account a range of alternative outcomes for uncertain aspects and choosing a path that would yield benefits regardless of the way uncertain aspects turn out. Such an approach is taken by insurance companies to set policy rates and has been used in connection with infrastructure investments such as the development of harbors under consideration of the potential for sea level rise.

A clearly identified set of attributes that should be measured in connection with the design of sustainable product systems and supply chains is another requirement for moving forward. While definitions for sustainability exist and are to a large extent agreed upon within the context of product systems and supply chains, there are a wide variety of characteristics which are tracked in connection with this definition, for example:

> *fuel efficiency, weight, resource use, scarcity, conflict materials, emissions, material and use intensity, life cycle water use, labor practices, local employment, durability/longevity/upgradability/recyclable, local sourcing, avoidance of hazardous, scarce, or conflict materials, use of recycled content where possible, incorporation of remanufacturing opportunities, use of renewable materials and energy, minimization of water and energy requirements, closed loop recycling of resources where possible, conversion of residual wastes to byproducts, appropriate utilization of ecosystem services, avoidance of airborne emissions, noise and dust, minimization of transport and packaging requirements, customer-supplier collaboration on sustainable design solutions, emphasis on occupational and public safety, encouragement of supplier diversity and social responsibility, responsible and ethical treatment of workers, support for local capacity development*

This list is not comprehensive in any sense, but rather provides insight into the broad range of considerations which could fall under the umbrella of sustainability. In practice, this long list of concerns presents a distinct challenge for businesses seeking to address sustainability in their operations. There is clearly a need for a consensus-based set of attributes and/or sustainability metrics which could be used to inform the design of sustainable supply chains. Together with this set of attributes, there is a need for straightforward and streamlined approaches for assessing each attribute to avoid placing an overly burdensome responsibility on individual businesses and to provide certainty in connection with addressing sustainability concerns.

One approach to addressing *everything must be included* barrier to integrating sustainability with operational activities is to narrow the field of considerations associated with specific products through the use of product category rules. Product category rules provide consensus-based information regarding the *hotspots* associated with a particular product system and/or supply chain thereby providing a more focused framework within which decisions regarding that product could be made. However, the needs for development of product category rules in many ways relate back to the needs that must be met in order to support the design of sustainable product systems and supply chains. The process of developing product category rules should include a broad range of sustainability considerations. The advantage is that when a product category affects a number of businesses, there is the potential for pooling resources or at least leveraging a single effort to inform a broad range of companies involved in activities related to that product category. Product category rules must be developed such that they are flexible enough to incorporate new findings that arise over time and that they appropriately acknowledge uncertainty so as to avoid the *shifting sands* associated with making definitive statements based on inconclusive data.

There is also a need for new expertise in the workplace in connection with the move toward designing product systems and supply chains for sustainability. In terms of domain-specific expertise, there is no shortage. The U.S. maintains a well-educated workforce. However, there is currently an expertise gap in the area of integrating the wide variety of models and data necessary for gauging sustainability with the workflow used in the development of products. One approach to filling this gap is through engaging enterprise resource planning and product lifecycle management providers to provide new software tools and to further develop existing tools to address sustainability within the context of existing operational protocols. In fact, some such tools already exist and others are under development. However, these tools will still require users capable of running them and appropriately interpreting results.

An area of expertise that will be required to a greater extent as efforts to design sustainable products systems and supply chains move forward is for individuals capable of validating the models and accounting developed in support of these efforts. The market is already beginning to respond to this demand as can be seen in the growth of the consulting industry related to environmental sustainability and life cycle assessment. While transparent models and data are needed to provide a consensus-basis for sustainability assessments, it is also clear that confidential business information will dictate an increase in demand for third party validation should data-intensive supply chain sustainability assessments become an industry standard. Continuing to support education initiatives designed to develop a pool of well-educated practitioners in this area would help meet this need. Also, processes will need to adapt to the need for greater scrutiny associated with sustainability concerns. For product design, this may involve additional steps in the process and additional iterations as a broader range of considerations are addressed. Changes may also be required in the policy-making process as understanding the implications of policy initiatives for product systems and supply chains may require more extensive regulatory impact assessment than has been done previously. Approaches to validation and a pool of qualified independent validators may be needed in both cases.

While designing sustainable product systems and supply chains will require new expertise, it is important to keep in mind that this expertise cannot supplant the conventional domain expertise which has traditionally been applied to product and supply chain design. Rather, domain expertise must be integrated with sustainability concerns in the decision-making process. To address this need, already many education institutions are integrating sustainability with traditional engineering and business programs. This approach is useful for preparing the future workforce to understand the premise behind sustainability and to have an appreciation for the approaches used to design sustainable systems. As these complex considerations can only be addressed through interaction with cross disciplinary teams and coordination of efforts to achieve synergies, it is increasingly important that the interpersonal and teamwork expertise relevant to these interactions also be cultivated and rewarded. Incorporating a range of considerations in decision-making also requires expertise in understanding the variety of metrics tracked, processing these into a condensed set of information, and dealing with tradeoffs and multi-criteria decisions. Integrating sustainability with traditional fields such as risk assessment, operations management, mathematics, optimization, economics, public health, and behavioral sciences could serve as a means of developing the required expertise.

A number of other specific needs for technical development in association with the design of sustainable product systems and supply chains were expressed. Key needs are formulated in the following list.

- Screening level risk assessment approaches starting with general principles such as irreversibility and accumulation in environment, before moving on to complex endpoints
- Sustainability metrics and means of communicating risks, understanding the limitations of existing metrics and improving our ability to communicate the potential risks associated with current and emerging technologies
- Approaches for accounting for differences in the timing of outcomes. How do you discount future problems or benefits to inform today's decisions?
- Approaches for incorporating uncertainty regarding future scenarios and adapt them for application to design decision-making, perhaps incorporating techniques used by the insurance industry.
- Organizational structures capable of promoting data availability and transparency while maintaining confidentiality
- Impact assessment methods focused on specific issues associated with emerging technologies (our ability to make a new technology vastly outstrips our ability to answer questions about its impact)

Roles Moving Forward

Building the capacity for designing and maintaining sustainable product systems and supply chains requires the involvement of a number of stakeholders. Government, academia, industry, and non-governmental organizations each play a role. These groups must interrelate with one another effectively. In some cases partnerships and coalitions are necessary while in others a certain amount of adversarial debate and even litigation is needed.

During the Session III of the workshop, the following questions were posed. *What are the respective roles of industry, government, and academia and how should they interrelate? What partnerships/coalitions are needed? How will new and emerging technologies and capabilities need to affect organization roles and responsibilities, academia, industry, researchers, and research teams?* This section is informed by the discussion around these questions.

The Role of Industry

Industry is the key player in the design of sustainable product systems and supply chains. While other groups play roles in providing means and creating the right conditions, in the long term, success requires incorporate sustainable design in all aspects of business. In our capitalist society, industry includes the ownership of production systems and is comprised of the direct decision-makers regarding products and supply chains. Industry is the supply chain and the structure of industry is a key component of sustainability.

Industry's primary focus is, and will always be to deliver value to consumers. It is unreasonable to expect industry to play a strong role in a move toward sustainable product systems and supply chains without providing the right conditions within which to operate. That said, in many cases industry plays an important role in determining conditions through branding and advertising to influence consumer choice on one hand and lobbying activities to affect policy on the other. A role for industry in the move toward sustainability is to view these activities through the lens of sustainability. Promoting sustainability and providing a more sustainable product are good for branding and advertising and can contribute to the long-term success of a brand. Similarly, influencing regulation and market conditions to provide advantage associated with sustainability can lead to stable economic growth and a competitive advantage on the world market in the long-term. Accomplishing this requires adopting an honest assessment of the sustainability implications of an industry and using this to gauge long-term profitability. The move toward sustainable product systems and supply chains will involve growth in many areas, but also decreased activity and strategic shifts in others.

In the midst of the shift toward sustainable design, leveraging industry expertise is crucial. Given the right opportunities, industry will provide expert input to research and development as well as policy-setting activities. The attitude of individuals in industry and their organizations should be one of respect and receptiveness regarding input from other industry experts, academics, non-governmental organizations, and government. This input should be used to formulate appropriate responses and incorporated into decision-making while industry experts also serve as key voices in the public conversation ensuring that the knowledge and perspectives gained through business experience are well represented and incorporated.

The Role of Government

A primary role of government related to supply chain sustainability is to protect. In the case of the Environmental Protection Agency this role is made explicit, to protect human health and the environment. Other government agencies have missions involving other aspects of protection relevant for sustainability, for example the Food and Drug Administration (FDA), the Centers for Disease Control and Prevention (CDC), the Occupational Safety and Health Administration (OSHA), National Highway Traffic Safety Administration (NHTSA), Department of Agriculture (USDA) National Resources Conservation Service (NRCS), Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), the DOE Federal Energy Regulatory Commission (FERC), and the Nuclear Regulatory Commission (NRC). Government protection can take the form of rules and initiatives which restrict hazardous activities, but can also involve partnering with other organizations to develop and implement means of minimizing risks and reducing compliance costs.

Another role played by government is to remedy market failures. The benefit of a free market is that it is self-regulating in many ways, this is the idea of the *invisible hand*. Nonetheless, there are cases in which certain *externalities* are not well-represented in the considerations governing behavior within a free market or in which society is unwilling to accept the scale of consequences required to evoke a market reaction. In other cases, society is unwilling to impose an unequal burden on individuals or groups negatively impacted by market forces. In these cases, government has played a role in setting boundaries or creating incentives to minimize negative externalities and provide justice. Although it is sometimes the object of contention, the government also plays a role in providing a level playing field and overseeing that welfare is created through the application of fair rules.

These two roles, protection and remedying market failures, could potentially lead to a number of government actions that would promote the design of sustainable product systems and supply chains. At present, government clearly plays a role in markets through providing incentives through taxes and subsidies. Thus, the government role in designing sustainable product systems and supply chains requires the capability to determine which actions will be most effective in achieving sustainability-related goals. On the other hand, there is a need for a mechanism to identify instances when actions taken for other reasons also have sustainability-related implications. The economics literature is full of examples of how well-intentioned measures have yielded unintended consequences.

Government is also plays a key role in research and development. In the U.S., through allocation of research funding, the National Science Foundation and other government agencies play a key role in setting the course for technological development pathways and economic development. A number of government agencies are also involved in research and development directly. Of particular relevance to the design of sustainable product systems and supply chains are the EPA, DOE, USDA, Department of Defense (DOD), National Institutes of Health (NIH), and National Institutes of Standards and Technology (NIST), although there are certainly others with relevant activities as well. In fact, these agencies are already involved in a variety of research and development activities which contribute to providing the capacity required for design of sustainable product systems and supply chains. In the report *Sustainability and the U.S. Environmental Protection Agency,* the National Academy of Science provides recommendations for how the EPA should respond to the challenge presented by sustainability. The authors foresee *EPA moving into a leadership role in using a sustainability framework to deliver better results*. While the report focuses on application to the EPA, the findings and recommendations have relevance for other agencies as well. The committee recommend (1) fostering *a culture of sustainability to implement better solutions*, (2) leveraging sustainability-relevant expertise developed through regulatory activities in *nonregulatory environmental programs for businesses of all sizes, creating synergy for the sustainability, public health, and competitiveness of American businesses*, and (3) targeting activities to reduce risks toward disadvantaged communities and seeking their engagement and cooperation.

The Role of Academia

A primary role of academia is to understand the system and educate. When it comes to the design of sustainable product systems and supply chains, understanding the system is a big task involving a wide range of disciplines, as has been previously described. Academia has been a key driver of innovation in the area of sustainable design. Academics and their institutions own a significant number of ideas and serve as significant creators of new knowledge. Academic institutions often also partner with industry and/or government, playing an exploratory function within the work of those groups, paving the way in testing new approaches, and providing initial capacity as these groups move into new areas. All of these roles have relevance in moving toward a system where product systems and supply chains are designed for sustainability. Preparing a workforce with skills relevant for the design of sustainable product systems and supply chains is an essential role played by academia. Specific education needs are described separately within this report.

Working Together Effectively

There is a general consensus that in order to effectively embrace sustainability as an organizing principle for the design of product systems and supply chains, collaboration both within and between industry, government, academia, and non-governmental organizations is required. This section describes some of the key aspects of this collaboration which deserve attention.

There has been a recent shift in universities toward increased collaboration between disciplines and a blurring of the lines between traditional programs of study. This has occurred in response to a changing society and marketplace which demand graduates with new skills and a broader range of skills than has been taught in the past. In contrast to previous generations, technology is now pervasive in all aspects of life and information moves much more quickly. Globalization has led to a new era of competitiveness. Responding to these changes presents opportunities for innovative ideas and new approaches. There is also a changing view of how innovation happens. Rather than spontaneous jumps in progress, many of the new ideas shaping our world today are the result of bringing together ideas developed incrementally over time within different disciplines and applying them to new situations. Designing sustainable product systems and supply chains requires bringing together approaches developed across a broad range of disciplines and bringing them to bear on old problems in new ways. A defining feature of sustainability is that it incorporates a broad range of system considerations, including economic, social, and environmental aspects. Yet often conventional, disciplinary-based evaluation criteria are still imposed on faculty seeking to reach out across disciplines and innovate. In some cases this is related to a reluctance to leave behind the mechanisms that have brought a university to its current status, and with good reason. In other cases, the barrier is colleagues who are comfortable with existing structures and for whom new approaches present a threat to one's own status. Promoting cross disciplinary collaboration and innovation within universities requires a balanced approach that provides incentives and recognition for those working in new ways while continuing to affirm disciplinary accomplishments and dignity. One way to do this is to view the university itself as an incubator of innovative ideas and to provide mechanisms for selecting innovative activities and shielding them from counterproductive pressures. Another mechanism, and in fact one that is already being applied by NSF, is to provide special funding mechanisms for cross-disciplinary teams and activities.

Within the marketplace, collaboration and teamwork are required along supply chains. While competitiveness concerns often drive secrecy and separation, improving supply chains requires the flow of information and expertise across businesses. This exchange allows a clear assessment of sustainability outcomes along supply chains and an understanding of the potential for problem shifting associated with proposed improvements. While the initial set of considerations involved in defining sustainable supply chains is daunting, once established, operating within a well-understood supply chain provides benefits for businesses in terms of focusing efforts on a core set of well-defined issues rather than having to scan and prepare to respond to a broad range of issues. From the perspective of consumer behavior and public policy associated with promoting sustainable supply chains, supply chain communication and collaboration allows for the clear communication of benefits and potential pitfalls (ie electric vehicles and electricity sources, fluorescent lightbulbs and mercury disposal, or biofuels and effects on markets and upstream impacts).

A number of suggestions were put forward regarding how to best select, promote, and incentivize research and investment to obtain the tools and approaches that are necessary to implementing sustainable design. Case studies with engaged clients offer a means of ensuring that research activities address practical concerns. Another suggestion was to solicit proposals where the core objective is in coupling disciplinary or reductionist approaches with systems-based approaches. Caution would need to be taken to avoid proposals where the coupling is weak or ill-defined to avoid the study devolving into two separate activities. Similarly, annual reports or other research-tracking mechanisms could be used to evaluate the integration of the research, tracking, for example, the diversity of journals associated with co-authored publications. Another category of suggestion involved leveraging government funding to stimulate industry and/or NGO funding or involvement in research. While NSF currently funds programs focused on industry-academic collaboration, there is a need to evaluate this portfolio and look for ways to better connect industry clients and expertise with systems-analysis, industrial ecology, and other integrative cross-disciplinary university research activities. Doing this has the potential to provide industry with valuable approaches to the incorporation of new aspects into the design process while providing university researchers with concrete feedback based on the market realities facing businesses. Similarly, coupling university research with non-governmental organization provides a means of bringing the stakeholder/client perspective into university research and a direct mechanism for ground-truthing new ideas against ongoing efforts to engage key actors. For NGOs, coupling with universities can serve to build the scientific basis for otherwise poorly structured issues and to provide a means for evaluating the effectiveness of intervention activities. Such funding has been provided in the European Union under their Seventh Framework Programme.

While collaboration brings with it many benefits, there are also instances when divergence and adversarial exchanges can be beneficial. In the words of one workshop participant, *it is better to be honest than nice.* Conflict is often a prerequisite for stakeholder engagement. While the stakeholder engagement process can lead to collaboration, this is not always the case. Charged issues can lead to a purposeful and action-oriented stakeholder engagement process. In some cases it may even make sense to exclude a stakeholder from an engagement process when that stakeholder has a conflict of interest related to the goals of the process. The exclusion of the recycling industry from the Swedish stakeholder engagement process related to end-of-life vehicle management is a good example. From another angle, departure from collaboration to diverge onto different and original paths is necessary for innovation. Some degree of separation is needed to develop new ideas and to provide the right incentives for pioneering new approaches and technologies.

Despite the advantages of maintaining distance in certain cases, collaboration and consensus-building remain the ideal. Litigation issues rarely lead to productive collaborations and this could be a key difference between the perspectives driving LCA and risk assessment that could facilitate more efficient progress under the more inclusive, systems-based paradigm of LCA than was achieved in earlier efforts related to more focused risk assessment. The most effective stakeholder engagement groups are those that are collaborative, committed, and accountable. Partnership is stimulating in ways stakeholder consultation is not. Long engagement processes have the potential to delay innovation. Formulating the problem together, rather than in individual camps, often leads to useful directions where an adversarial process would encounter gridlock. There is a need to promote activities that bring together academia, government, industry, NGO, and the general public to weigh societal costs and benefits based on a long-term perspective. One useful approach suggested by workshop participants representing industry was to task government agencies with running a stakeholder dialog process to engage industry and other stakeholders around sustainable design issues. This approach intends to avoid potential conflicts of interest while promoting the exchange of information between industry and other stakeholders and into the policy process.

APPENDIX A

Goals of the Workshop on the Design of Sustainable Product Systems and Supply Chains

The Workshop will explore the following questions, which all participants are expected to address in their presentations and discussions:

1. What tools and methods are currently available for design of sustainable product systems and supply chains?
2. How can these tools and methods be combined in new ways to improve our ability to design sustainable product systems and supply chains?
3. Where do the most promising opportunities exist for modifying product systems and supply chains?
4. What are the implications of new methods for design of sustainable product systems and supply chains for:

    - Reducing the life cycle environmental impacts of existing products and processes?
    - The process of developing and implementing new technologies?
    - The evaluation of new technologies?
    - The design of policies and technologies that reduce pollution and/or increase recycling?

5. What indicators and metrics of sustainability are appropriate and necessary for design of sustainable product systems and supply chains?

While the Workshop will include experts from all sectors, we are particularly interested in attracting expertise in sectors of strategic importance, including biofuels, petroleum, chemicals, energy, agriculture, and consumer products. Participants with experience related to the development of new methods, supply chain design, or process design in these sectors are also being invited to attend. Participants with a wide range of experience relevant to the design of sustainable supply chains are also being invited, including those with experience in supply chain management, optimization, agent-based modeling, logistics, capital investment, industrial operations engineering, industrial symbiosis, and stakeholder engagement.

For questions regarding the workshop please contact:
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List of Participants

Meadow Anderson, U.S. Environmental Protection Agency

Bhavik Bakshi, The Ohio State University

Russell Barton, National Science Foundation

Beth Beloff, Bridges to Sustainability

Bert Bras, Georgia Institute of Technology

Sherilyn Brodersen, Kraft Foods

Maria Burka, National Science Foundation

Herb Cabezas, U.S. Environmental Protection Agency

Vincent Camobreco, U.S. Environmental Protection Agency

John Carberry, DuPont (retired)

Erin Chan, American Institute of Chemical Engineers (AIChE)

Andreas Ciroth, Green DeltaTC

Andres Clarens, University of Virginia

H. Gregg Claycamp, U.S. Food and Drug Administration*

Joseph Fiksel, The Ohio State University

William Flanagan, General Electric Company

John Glaser, U.S. Environmental Protection Agency

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Igor Linkov, U.S. Army Corps of Engineers

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Tom Seager, Arizona State University

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Rachuri Sudarsan, National Institute of Standards and Technology*

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Thomas Theis, University of Illinois

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Mark Tulay, Sustainability Risk Advisors*

Don Versteeg, Proctor & Gamble Company

Eric Williams, Arizona State University

Phil Williams, Webcor Builders, USA

B. Erik Ydstie, Carnegie Mellon University

Fengqi You, Northwestern University

**Indicates planned participants who were unable to attend the Workshop due to unforeseen circumstances.*

BIOSKETCHES

Note: Participants who were unable to attend the Workshop are denoted with an asterisk (*).

Meadow Anderson

Meadow Anderson is an American Association for the Advancement of Science (AAAS) Science and Technology Policy Fellow hosted by the Sustainability Program in EPA's Office of Research and Development. As a fellow, her main areas of focus have been life cycle assessment (LCA) and sustainable products policy. Dr. Anderson received her Ph.D.in Chemistry from the University of California, Berkeley and her B.S. in Chemistry from Oregon State University. Her research background includes physical chemistry and molecular biology.

Bhavik R. Bakshi

Bhavik R. Bakshi is a Professor of Chemical and Biomolecular Engineering and Research Director of the Center for Resilience at The Ohio State University. He recently joined TERI University in New Delhi, India as its Vice Chancellor and Professor of Energy and Environment. He holds a dual appointment at TERI University and The Ohio State University. Prof. Bakshi has active research programs in the U.S. and in India, which are developing systematic and scientifically rigorous methods for improving the sustainability and efficiency of engineering activities. This includes new methods for analyzing the life cycle of existing and emerging technologies and for designing self-reliant networks of technological and ecological systems. A major focus of his research has been on understanding and including the role of ecosystem services in industrial activities. This multidisciplinary research overlaps with areas such as thermodynamics, applied statistics, ecology, economics, and complexity theory. Applications include nanotechnology, green chemistry, alternate fuels, and waste utilization. Among his publications is a recent book on "Thermodynamics and the Destruction of Resources." His awards include the Ted Peterson award from the Computing and Systems Technology division of the American Institute of Chemical Engineers, and the Faculty Early Career Enhancement Award (CAREER) from the U.S. National Science Foundation, and several best paper awards at various conferences. Prof. Bakshi received his B. Chem. Eng. from the University of Bombay, Department of Chemical Technology and MSCEP and Ph.D. from the Massachusetts Institute of Technology, all in chemical engineering. While in graduate school, he also completed a minor in Technology and Environmental Policy and conducted research at Harvard's Kennedy School of Government.

Russell Barton

Russell Barton is Program Director for Manufacturing Enterprise Systems and Service Enterprise Systems research in the Civil, Mechanical and Manufacturing Innovation division of the National Science Foundation. These areas have a combined annual research budget of over $9 million. Russell is on assignment at NSF from the Smeal College of Business at Pennsylvania State University, where he is a professor in the Department of Supply Chain and Information Systems. He previously served as co-director for the Penn State Master of Manufacturing Management degree program, and as associate dean for research and Ph.D./M.S. programs for

Smeal College. He holds a B.S. in electrical engineering from Princeton University and M.S. and Ph.D. degrees in operations research from Cornell University.

Beth Beloff

Beth Beloff has been a thought leader in formulating the concepts and practice of sustainable development since the early 90s. She consults through Beth Beloff & Associates on how to integrate sustainability into strategy, operations and supply chains, and develops new approaches and methodologies through BRIDGES to Sustainability Institute, which she founded in 1997. Among BRIDGES' many projects, it developed a software system to help companies understand their sustainability impacts, BRIDGESworks Metrics™, and also developed methodologies to understand full costs associated with environmental and social impacts. A significant part of her work is devoted to assessing and reporting sustainability performance, and she is a recognized leader in the area of sustainability performance measurement. She has led the Sustainable Supply Chain Roundtable for the Center for Sustainable Technology Practices of AIChE and chaired numerous conference panels on sustainable supply chains and sustainability metrics. She developed a sustainable supply chain assessment methodology and used it as a basis for discussion regarding the development of collaborative efforts between companies to improve their supply chains. She was one of the primary developers of the AIChE Sustainability Index and chairs the ICOSSE International Certificate on Sustainable Standards for Engineering effort which will result in a certification of chemical products, processes and services on the basis on their sustainability attributes, to be applied by AIChE and CECHEMA at ACHEMA and other conferences run by AIChE and DECHEMA.

Ms. Beloff has published numerous articles on sustainability education, strategy, performance measurement, and decision-support approaches and tools. She led the development of the *GEMI Metrics Navigator*™, produced in collaboration with the GEMI organization (Global Environmental Management Initiative). It has become a well-respected planning process for developing strategic plans and sustainability metrics. She also was principal editor and author of the book *"Transforming Sustainability Strategy into Action: the Chemical Industry,"* published by Wiley Inter-Science in 2005, which features many approaches to addressing the pragmatic aspects of integrating sustainability into organizations. She has just completed chapters for two sustainability books, to be published in 2011.

Prior to BRIDGES in 1991, Ms. Beloff founded and directed the Institute for Corporate Environmental Management (ICEM) in the business school at the University of Houston. Additionally, she directed the Global Commons project through the Houston Advanced Research Center (HARC) and the National Academy of Science (NAS). This was the first project of the NAS to formally address the science and business of sustainable development.
Ms. Beloff has a B.A. in psychology from University of California at Berkeley, a Master of Architecture degree from UCLA, and an M.B.A. from the University of Houston.

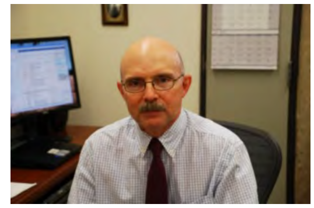
Bert Bras

Bert Bras has been a Professor at the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology (Georgia Tech) since September 1992. His research focus is on sustainable design and manufacturing; including design for recycling and remanufacture, bio-inspired design, and life cycle analysis. His primary research question is how to reduce companies' environmental impact while increasing their competitiveness (i.e., how to promote sustainable development). He has authored and co-authored more than 140 publications. His work is funded by the National Science Foundation, Ford Motor Company, and Boeing, among others. Dr. Bras was named the 1996 Engineer of the Year in Education by the Georgia Society of Professional Engineers, he received a Society of Automotive Engineers' Ralph R. Teetor Award in 1999, and the Georgia Tech Outstanding Interdisciplinary Activities Award in 2007. In 1999–2000, through the World Technology Evaluation Center (WETC), he was part of a group of experts charged by the National Science Foundation and Department of Energy with evaluating the state-of-the-art in environmentally benign manufacturing. He visited companies, universities, and governmental institutions in Europe, Japan, and the United States. From 2001–2004, he served as the Director of Georgia Tech's Institute for Sustainable Technology and Development. Dr. Bras has a Ph.D. in Operations Research from the University of Houston and an M.S. ("Ingenieur") degree in Mechanical Engineering from the University of Twente (The Netherlands). Prior to receiving his Ph.D., he worked at the Maritime Research Institute Netherlands (MARIN).

Maria K. Burka

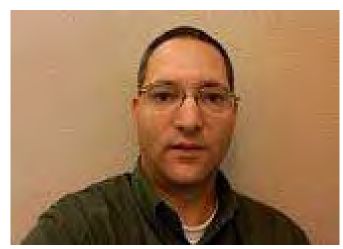
Maria K. Burka is the program director of the Process and Reaction Engineering (PRE) program in the Chemical, Bioengineering, Environmental and Transport Systems (CBET) Division of the National Science Foundation. Her responsibilities include evaluation and management of research and educational grants to academic institutions in the areas of chemical and biochemical reaction engineering, process control and process design as well as reactive polymer processing. Past employment positions have included Senior Scientist with the U.S. Environmental Protection Agency (EPA), a member of the faculty of the Chemical Engineering Department of the University of Maryland-College Park, and process design engineer with Scientific Design Company in New York City. She received B.S. and M.S. degrees from the Massachusetts Institute of Technology and M.A. and Ph.D. degrees from Princeton University, all in chemical engineering. Her research interests are in chemical process design and control. She has been active in a number of professional organizations, including the American Institute of Chemical Engineers (AIChE), the American Chemical Society (ACS), the Society of Women Engineers (SWE) and the American Association of University Women (AAUW). She is the President of AIChE for 2011.

Heriberto Cabezas



Heriberto Cabezas is the Senior Science Advisor to the Sustainable Technology Division in EPA's Office of Research and Development. Dr. Cabezas is also a former Acting Director of the Division, consisting of approximately 58 scientists, engineers, and support staff; of which approximately 40 are at the doctoral level. He also served as Chief of the Sustainable Environments Branch, a multidisciplinary research group of approximately 58 scientists and engineers, 13 at the doctoral level. Dr. Cabezas served as Chair of the Environmental Division of the American Institute of Chemical Engineers (AIChE) in 2006. He was a recipient of the 1998 EPA Science Achievement Award in Engineering, the 2007 Distinguished Alumni Achievement Award from the New Jersey Institute of Technology, and has been selected for the 2011 Research Excellence Award in Sustainable Engineering by the AIChE, among other honors. Dr. Cabezas received his Ph.D. in Chemical Engineering from the University of Florida (1985) in thermodynamics and statistical mechanics. He also holds an M.S. from the University of Florida (1981) and a B.S. (magna cum laude) from the New Jersey Institute of Technology (1980), both in Chemical Engineering. His publications include more than 60 peer-reviewed articles. He is a Fellow of the AIChE, a member of the American Association for the Advancement of Science, and a Board-Certified Member of the American Academy of Environmental Engineers. His principal area of research is the sustainable management of complex environmental systems. Dr. Cabezas is a U.S. Navy veteran of the Vietnam Conflict.

Vincent Camobreco



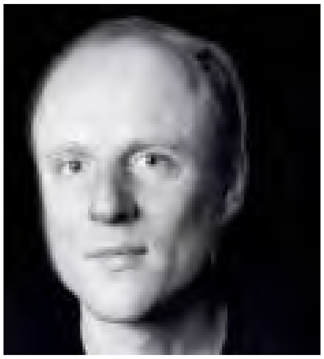
Since 2006 Mr. Camobreco has worked in the U.S. EPA's Transportation and Climate Division, his main focus being on the life cycle GHG impacts of renewable and alternative fuels. Prior to that he worked on EPA's Climate Leaders program, helping develop protocols to calculate and report corporate greenhouse gas inventories to the EPA. Mr. Camobreco's previous work experience includes over five years as an environmental consultant with Ecobalance, Inc. doing life cycle analysis for numerous industry and government clients, and several years working for an automotive parts supplier producing steering columns. His education includes a B.S. in Mechanical Engineering from Clarkson University and an M.Eng. in Agricultural and Biological Engineering from Cornell University.

John Carberry

John Carberry retired from DuPont as Director of Environmental Technology. There, he was responsible for analysis of environmental issues and recommendations for technical programs and product development. Since 1989, he led that function to provide excellence in treatment and remediation while in transition to waste prevention and product for sustainability. Mr. Carberry presently consults strategies for dealing with the environmental issues of energy, renewable energy, and nanomaterials. He chaired the AIChE Project on Metrics for Liquid Bio-fuels, has given over 135 presentations at universities and public conferences, is an adjunct professor of

Chemical Engineering at the University of Delaware, and served on the National Academy of Engineering's Roundtable on Science and Technology for Sustainability. Mr. Carberry is a founding member of the Green Power Market Development Group. He recently was Chair of the National Academy Committee on the Destruction of the Non-Stockpile Chemical Weapons, and served on nine previous National Academy Committees. He holds a B.ChE. and an M.E. in Chemical Engineering from Cornell University, an M.B.A. from the University of Delaware, is a Fellow of the AIChE, and is a Registered Professional Engineer.

Andreas Ciroth



Andreas Ciroth is founder and director of GreenDeltaTC, a consulting and software development company with a focus on sustainability assessment and life cycle analyses. Dr. Ciroth is an environmental engineer by training. He completed his Ph.D. on Error Calculation in LCA in 2001 at TU Berlin. Since then, Dr. Ciroth has been working in sustainability consulting in research, industry, and policy contexts. He is Chair of the Methodology and Data work area in the UNEP/SETAC Life Cycle initiative, and is a member of the advisory councils of Ecoinvent and the US LCI database. He was the first subject editor of the *International Journal of Life Cycle Assessment* (for the field of uncertainties). Nominated in 2004, Dr. Ciroth still holds this position and is member of the Editorial Board of the *Journal*. He is leading the open LCA project to create a free, open-source sustainability assessment software. Dr. Ciroth teaches at the Technical University of Darmstadt, Germany.

Andres Clarens

Andres Clarens is an Assistant Professor of Civil and Environmental Engineering at the University of Virginia and the Director of the Virginia Environmentally Sustainable Technologies Laboratory. His research is focused broadly on anthropogenic carbon flows and the ways that carbon dioxide is manipulated, reused, and sequestered in engineered systems. The results of his work are important for developing efficient strategies for mitigating the emissions driving climate change. At the largest scales, his system-level modeling work has explored the life cycle of systems in the manufacturing, transportation, and energy sectors. In the laboratory, he is pursuing complementary research in the phase behavior and surface chemistry of carbon dioxide mixtures at high pressure. The results of this work can be used to provide better lubricants for wind turbines and more accurate assessment of geologic carbon sequestration sites. In the classroom, Dr. Clarens engages in peer-to-peer learning at both the undergraduate and graduate levels, with an emphasis on developing innovative tools for teaching the fundamentals of climate change. He holds a Ph.D. and an M.S.E in Environmental Engineering from the University of Michigan, and a B.S. in Chemical Engineering from the University of Virginia.

Joseph Fiksel

Joseph Fiksel is Executive Director of the Center for Resilience at The Ohio State University, and Principal and Co-Founder of the consulting firm Eco-Nomics LLC. He is an internationally recognized authority on sustainability and resilience, with more than 25 years of research and consulting experience for multinational companies, Government agencies, and consortia such as the World Business Council for Sustainable Development. He is currently serving on a special appointment at EPA, helping to incorporate systems thinking into the Agency's research and development programs. A native of Montreal, Dr. Fiksel began his career at DuPont of Canada, and later served as Director of Decision and Risk Management at Arthur D. Little, Inc., and as Vice President for Life Cycle Management at Battelle. He has published more than 70 refereed articles and several books, and is a frequent keynote speaker at conferences. He holds a Ph.D. and M.Sc. in Operations Research from Stanford University, a B.Sc. from M.I.T., and an advanced degree from La Sorbonne. His latest book, *Design for Environment: A Guide to Sustainable Product Development*, was published by McGraw-Hill in 2009.

William P. Flanagan

Bill Flanagan leads the Ecoassessment Center of Excellence for the General Electric Company and is based at GE Global Research in upstate New York. Dr. Flanagan's team offers comprehensive technical expertise in life cycle assessment, carbon footprinting, human health and environmental risk assessment. He also works closely with GE's Corporate Environmental Programs team on the development of programs and policy in these areas. Dr. Flanagan graduated from Virginia Tech in 1985 and received a Ph.D. in Chemical Engineering from the University of Connecticut in 1991. He spent the first 10 years of his career focused on various aspects of environmental technology including site remediation, air and water treatment, and pollution prevention. He spent the next six or so years managing GE's combinatorial chemistry lab, a team responsible for developing and applying high throughput screening for materials development. In 2007 he returned to his roots to lead the Ecoassessment Center of Excellence. Dr. Flanagan serves on GE's extended corporate ecomagination team and is a member of the Advisory Council for the American Center for Life Cycle Assessment.

Mark Goedkoop

Mark Goedkoop is Managing Director and Senior Consultant at PRé Consultants in the Netherlands and PRé North America. He worked as an independent design consultant until 1990, when he established PRé consultants and pioneered the field of life cycle assessment (LCA). PRé has become a well-established LCA consultancy, with partners in more than 20 countries. Mr. Goedkoop's focus is on the development of practical, scientifically sound tools to improve the environmental performance of products and services. The best-known tools are the Eco-indicator and ReCiPe methodology, and SimaPro, the world's most widely used LCA software (see www.pre.nl). Mr. Goedkoop holds a M.Sc. in Industrial Design Engineering from Delft University of Technology (the Netherlands).

Ignacio E. Grossmann

Ignacio E. Grossmann is the Dean University Professor of Chemical Engineering at Carnegie Mellon University. He is Director of the Center for Advanced Process Decision-Making, an industrial consortium that involves 20 petroleum, chemical, engineering, and software companies. Dr. Grossman is a member of the National Academy of Engineering and his major awards include AIChE's Computing in Chemical Engineering Award, William H. Walker Award, Warren Lewis Award, and "One of the Hundred Chemical Engineers of the Modern Era." He is a fellow of AIChE and Institute for Operations Research and the Management Sciences (INFORMS). His research interests lie in the areas of process synthesis, energy integration, planning and scheduling of batch and continuous processes, supply chain optimization, stochastic programming, and mixed-integer and logic-based optimization. Dr. Grossman has made a number of significant research contributions in the area of sustainability; particularly in the areas of optimal synthesis heat exchanger and process water networks, simultaneous optimization and heat integration, energy and water optimization for the design of biofuel plants, and bi-criterion optimization models of supply chains with both economic and life cycle assessment measures. He obtained his M.S. and Ph.D. from Imperial College and his B.S. degree at the Universidad Iberoamericana, Mexico City.

Bruce Hamilton

Bruce Hamilton is Director of the Environmental Sustainability program in the Engineering Directorate at the National Science Foundation (NSF); a Managing Program Director in the new cross-NSF investment area, Science, Engineering, and Education for Sustainability (SEES); and in the Office of Emerging Frontiers in Research and Innovation (EFRI) in the NSF Engineering Directorate. Dr. Hamilton has been at NSF for 15 years. Before joining NSF, he worked as an engineer and manager in the chemical and biotechnology industries for 20 years. He holds a Ph.D. in Biochemical Engineering and a B.S. in Chemical Engineering, both from M.I.T.

Troy R. Hawkins

My research focuses on the application and development of environmental life cycle assessment (LCA) and input output models for decision-focused environmental analysis. At EPA I lead a project focused on environmental systems analysis of biofuel options and the development of models for designing sustainable biofuel supply chains. I earned a B.S. in Physics from the University of Michigan in Ann Arbor, Michigan in 1999 and a Ph.D. in Civil and Environmental Engineering and Engineering and Public Policy from Carnegie Mellon University in Pittsburgh, Pennsylvania in May 2007. I have taken some risks in my career and have been rewarded by the opportunities I have had to work collaboratively as a part of some very dynamic, high functioning teams. During my Ph.D. studies I developed a Mixed-Unit Input-Output (MUIO) Model for life cycle assessment and material flow analysis focusing on flows of cadmium, lead, nickel, and zinc. For the next 3 years I worked as a Researcher at the Norwegian University of Science and Technology (NTNU) where I contributed to the EXIOPOL Project, ‘A New Environmental Accounting Framework Using Externality Data and Input-Output Tools for Policy Analysis’, an EU-Funded effort to create a global, environmentally-extended, multiregional input-output (EE-MRIO) model for analysis of environmental impacts and external costs of production and consumption. Following this work, I worked on the development of an EE-MRIO model for the harmonized calculation of carbon, ecological, and water footprints across international supply chains under the EU funded OPEN EU Project. I also had had the opportunity to perform an environmental assessment of an electric versus conventional vehicle, funded by the Norwegian Research Council, and to participate in a several other research efforts. In November I began work as a Research Environmental Engineer with the U.S. Environmental Protection Agency, National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio where I co-lead the Environmental Assessment of Biofuel Options Project Team. This work has connections to other activities including the development of a life cycle inventory database within the NRMRL Sustainable Technology Division, analysis of product systems and supply chains using sustainability indicators, and the development of life cycle impact assessment methods for water and land use. Currently our efforts have focused on analyzing a suite of impacts associated with ethanol blends. Moving forward this work will incorporate additional pathways and delve deeper into the effects of changes within the biofuel life cycle and supply chain stages.

Alan D. Hecht*

Dr. Hecht a recipient of the Presidential Rank Award for Meritorious Service is Director for Sustainable Development in the Office of Research and Development (ORD) at the U.S. Environmental Protection Agency (EPA). Since 2003 he has led ORD’s planning on sustainability research. Currently he is senior advisor on sustainability to Assistant Administrator for ORD. On detail to the White House, from 2001 to 2003 he was Associate Director for Sustainable Development at the Council on Environmental Quality (2002-2003) and Director of International Environmental Affairs for the National Security Council (2001-2002) where he served as White House coordinator for preparations for the World Summit on Sustainable Development. At EPA From 1989 to 2001, he served as the Deputy Assistant Administrator for International Activities and Acting Assistant Administrator for International Activities from 1992 to 1994. During this period he led EPA’s negotiations for the side agreement to the NAFTA, launched the US-Mexico Border Program, initiated new EPA efforts on environmental security and served as senior advisor to the Administrator for the Earth Summit in Rio in 1992. Before joining EPA, Dr. Hecht was Director of the National Climate Program at the National Oceanic and Atmospheric Administration (1981-1989) and Director of the Climate Dynamics Program at the National Science Foundation (1976-1981). Dr. Hecht was instrumental in helping to create the Intergovernmental Panel on Climate Change (IPCC.) Dr. Hecht has a Ph.D. in geology and geochemistry from Case Western Reserve University. He has written extensively on climate change and sustainability. One of his most recent publications is “EPA at 40: Bringing Environmental Protection into the 21st Century” *ES&T*, 209, 43, 8716-8720.

Michael Hilliard

Michael R. Hilliard is a research staff member in the Center for Transportation Analysis at Oak Ridge National Laboratory. Dr. Hilliard’s research efforts focus on developing analysis tools and decision support systems that leverage optimization techniques and emerging computational technologies. Recently, he led a team that developed the Biofuel Infrastructure and Logistics Tool (BILT), a regional optimization-based model of the cellulosic biofuel supply chain to analyze the limitations and impact of the evolving biofuel supply chain on U.S. infrastructure. He also developed a model to optimize the planting of switchgrass in a watershed based on a multi-objective sustainability measure and helped show that the best options could improve water quality with minimal loss of profitability. Dr. Hilliard is currently collaborating with a team of environmental scientists and economists to develop a set of socio-economic indicators for bioenergy supply chain sustainability. He has also developed planning systems for infrastructure investment and agent-based simulations of job markets. Dr. Hilliard received a Ph.D. in Operations Research from Cornell University, with an emphasis in optimization and game theory, and a B.S. in Mathematics from Furman University.

Yinlun Huang

Dr. Yinlun Huang is Professor of Chemical Engineering and Materials Science and Charles H. Gershenson Distinguished Faculty Fellow at Wayne State University, where he has been directing the Laboratory for Multiscale Complex Systems Science and Engineering. His research has been mainly focused on the fundamental study of multiscale complex systems science and the applied study on engineering sustainability, encompassing the development of sustainable (nano)materials, integrated design of sustainable product and process systems, integration of process design and control, and large-scale industrial system sustainability assessment and decision making under severe uncertainty. He has published widely in these areas. In the past few years, he has co-organized/co-chaired four international conferences on sustainability science and engineering, and sustainable chemical product and process engineering. Dr. Huang was Chair of AIChE Sustainable Engineering Forum (SEF) in 2008-09 and ACS Green Chemistry and Green Engineering Subdivision in 2010. Currently, he chairs the International Committee of the AIChE-SEF. At Wayne State University, he is leading the Industrial and Urban Sustainability (I&US) Group and co-directing the Sustainable Engineering Graduate Certificate Program. Among many honors, Dr. Huang was the recipient of the first Michigan Green Chemistry Governor’s Award in 2009 and the AIChE Sustainable Engineering Forum’s Research Excellence in Sustainable Engineering Award in 2010. He was a Fulbright Scholar in 2008-09. Dr. Huang holds a B.S. degree from Zhejiang University, China, in 1982, and a M.S. and a Ph.D. degree from Kansas State University, in 1988 and 1992, respectively, all in chemical engineering. He was a postdoctoral fellow at the University of Texas at Austin before joining Wayne State University in 1993.

Marianthi G. Ierapetritou

Marianthi Ierapetritou is a Professor in the Department of Chemical and Biochemical Engineering at Rutgers University, New Jersey. She obtained her B.S. from the National Technical University in Athens, Greece; her Ph.D. from Imperial College; and subsequently completed post-doctoral research at Princeton University before joining Rutgers University in 1998. Among her accomplishments is the Rutgers Board of Trustees Research Fellowship for Scholarly Excellence and the prestigious NSF CAREER award. Dr. Ierapetritou is also serving as an elected Trustee of CACHE, and as a director of CAST division at the AIChE. Dr. Ierapetritou's research focuses on the following areas: 1) process operations; 2) design and synthesis of flexible manufacturing systems; 3) modeling of reactive flow processes; and 4) metabolic engineering. She has published 117 papers and given 125 presentations at national and international conferences. She has also been invited to present her work at a number of universities and conferences around the world (44 invitations). She is a member of INFORMS and SIAM, and she actively participates in the scientific advisory committees of ESCAPE 16, 17, 21 and PSE 2006, 2009, and FOCAPD 2009. In 2008, she organized the fifth International FOCAPO Conference. Dr. Ierapetritou is an active educator, both in the classroom teaching graduate and undergraduate classes in the Chemical Engineering department, and as an advisor currently supervising the Ph.D. of seven students and one postdoctoral fellow.

Wesley Ingwersen

Dr. Wesley Ingwersen works in the program areas of Sustainable Supply Chain of biofuels and consumer products within the Systems Analysis Branch of the Sustainable Technology Division at the U.S. EPA's National Risk Management Research Laboratory. His research experience is primarily in life cycle assessment (LCA) and emergy analysis in the food, mining, and transportation sectors but works broadly in the environmental science and policy arena. Prior to his work with the U.S. EPA, he advised research with the UF Costa Rica Conservation Clinic in payment for ecosystems services for wetlands (2010) and led an investigation into the development of an EPD labeling program in Costa Rica (2009). With the UF Center for Environmental Policy, he helped lead a study of life cycle greenhouse gases from future transportation scenarios for the state of Florida and conducted LCAs for pineapple and gold mining (2007-2009). As a Transatlantic Fellow at the Ecologic Institute in Berlin, Germany (2006) he worked in the areas of international trade and the environment, sustainability metric evaluation, and climate change management and policy. His Master's research (2003-2005) focused on ecological restoration and modeling.

Wes is particularly interested in LCA-based product claims. He actively participates on committees through the American Center for Life Cycle Assessment and PCF World Forum on alignment of product category rules and contributes to the literature in this field.

Wes is a member of the standards committee of the International Society of Emergy Research. Wes has M.S. and Ph.D. degrees in Environmental Engineering from the University of Florida (2006, 2010), where he was mentored by Dr. Mark T. Brown, and a B.A. from Georgetown University (1999). He has been a Life Cycle Assessment Certified Professional since 2008.

Olivier Jolliet

Dr. Olivier Jolliet is Professor of Impact and Risk Modeling at the School of Public Health of the University of Michigan. His research and teaching programs aim a) to assess the life cycle risks and benefits of products and emerging technologies and b) to model population-based exposure, intake fractions and pharmacokinetics for outdoor and indoor emissions. Dr. Jolliet has a large experience in impact modeling and in the Life Cycle Assessment of a large range of products. He co-initiated the UNEP (United Nation Environment Programme)/SETAC Life Cycle Initiative and is one of the developer of the USEtox model for the comparative assessment of chemicals. He founding member of the University of Michigan Risk Science Center. Dr. Jolliet obtained a Master's degree and Ph.D. in Physics in 1988 at the Swiss Federal Institute of Technology Lausanne (EPFL). He worked as a postdoc at the Silsoe Research Institute (GB) and as a visiting scholar at MIT and Berkeley (USA). Between 1999 and 2005, he was assistant professor at the EPFL (Switzerland).

Vikas Khanna

Dr. Khanna received his B.ChE. from Panjab University in India. He received his Ph.D. in Chemical Engineering with a dual Masters in Applied Statistics from The Ohio State University. His doctoral work focused on the environmental evaluation of emerging nanotechnologies and multiscale modeling for environmentally conscious design of chemical processes. While in graduate school, he also finished a science and technology policy fellowship at the National Academy of Sciences in Washington DC. After spending a year in the biofuels R&D group at ConocoPhillips, he joined the University of Pittsburgh in 2010 where he is an assistant professor in the Department of Civil and Environmental Engineering. His research and teaching interests are in the general areas of sustainability science and engineering, industrial ecology, applied statistics, and role of environmental policy in engineering decision-making. Current focus is on studying the life cycle environmental impacts of infrastructure-compatible hydrocarbon biofuels, ecosystem services, and integrated economic-environmental modeling.

Christoph Koffler

Chris Koffler is the Technical Director of PE INTERNATIONAL, Inc. In this role, he is responsible for the underlying quality of all North-American Life Cycle Assessment consulting projects and GaBi and SoFi software solutions, technical development, project oversight, and in key selected areas, such as Automotive, as primary lead. Before joining PE, Chris was an associate researcher at the Volkswagen Group research department, working in the environmental design of new vehicles and the underlying LCA based tools development. He had performed numerous LCA studies with different branches of the Volkswagen Group and key suppliers, automotive light weighting in all its forms (steel, aluminum, magnesium, carbon fiber, (bio)polymers, natural fibers), hybrid and electric vehicle propulsions systems as well as various manufacturing processes. During his first three years at Volkswagen, Chris was also a postgraduate student at the Darmstadt University of Technology, where he received a Ph.D. in Engineering.

Angie Leith

Ms. Leith is a Senior Policy Analyst at the U.S. Environmental Protection Agency. She has been with the Agency since 1988, specializing in materials management policy, life cycle policy approaches and environmental innovation issues. She was the lead in managing the *Beyond RCRA 2020 Vision* which suggests that we redefine the concept of waste and move towards an integrated materials management approach designed to conserve resource. She was part of the federal-state workgroup tasked with developing a roadmap for implementing the *Vision* which was endorsed by the Agency. She is an active participant in several international activities focusing on materials and life cycle assessment, including the 3Rs Initiative, the UNEP effort to develop global guidance for life cycle databases, the OECD project on Sustainable Materials Management and Resource Productivity, and EPA Green Economy workgroup's papers for Rio+20 on product life cycle and sustainable products and services. Prior to joining the Agency, Ms. Leith was a project manager with an economic consulting firm, working primarily on issues related to energy conservation and local government finance issues. She was a National Urban Fellow and worked on Capitol Hill for a U.S. Representative. She earned an M.A. in Urban Affairs from Occidental College, Pasadena, California, and a B.A. in Political Science from Marymount College, Tarrytown, New York.

Reid J. Lifset

Reid J. Lifset is the Associate Director of the Industrial Environmental Management Program and Resident Fellow in industrial ecology at the School of Forestry and Environmental Studies at Yale University. Industrial ecology is an emerging field that examines the flow of materials and energy at various scales as part of the study and pursuit of sustainable production and consumption. He is the editor-in-chief and founder of the Journal of Industrial Ecology, an international, peer-reviewed bimonthly on industry and the environment, headquartered at and owned by Yale University and published by Wiley-Blackwell. He serves on the Science Advisory Board of the U.S. Environmental Protection Agency, and is a member of the governing council of the International Society for Industrial Ecology (ISIE), and the editorial advisory board for the Springer book series on Eco-efficiency in Industry and Science. His research focuses on the application of industrial ecology to novel problems and research areas, and the evolution of extended producer responsibility (EPR). He did his graduate work in political science at the Massachusetts Institute of Technology and in management at Yale University.

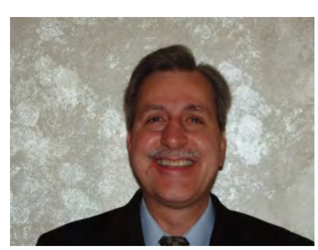
Clare Lindsay

Clare Lindsay is Project Director for Product Stewardship in the Office of Resource Conservation and Recovery at EPA in Washington, D.C. Ms. Lindsay has been with EPA for 20 years, specializing in municipal waste recycling policy and product stewardship. She led EPA's efforts to initiate the first-ever national dialogue on electronics product stewardship in the U.S. This initiative catalyzed and informed action by the numerous states that now have electronics takeback laws. Ms. Lindsay has participated in many various product stewardship initiatives addressing products as diverse as packaging, carpet, office furniture, and paint. She founded and currently helps lead a cross-office network of EPA professionals interested in promoting more sustainable product standards. This team is preparing recommendations for Agency senior management on how EPA can increase its engagement in this growing movement. Ms. Lindsay was part of an EPA/State team that developed and is implementing a roadmap for EPA and states to move beyond waste management towards sustainable materials management. Before coming to EPA, Ms. Lindsay practiced environmental and energy law in the private sector. She has an undergraduate degree from Smith College and a J.D. from George Washington University.

Eric Masanet

Eric Masanet is Deputy Leader of the International Energy Studies Group at Lawrence Berkeley National Laboratory, where he leads research in industrial energy systems analysis and life cycle systems modeling. A key activity is technology assessment and modeling for the EPA's ENERGY STAR for Industry program, which works directly with numerous energy-intensive industries, Fortune 500 companies, and supply chains to minimize energy use and emissions through technology adoption and improved energy management. Recently, he developed a hybrid supply chain modeling approach, which couples input-output LCA methods with sector- and process-level techno-economic energy analysis data and methods. The approach allows for both environmental and economic assessment of discrete technology and process improvement opportunities across the many energy and emissions sources, end- use technologies, and sectors that comprise a product's supply chain footprint.

Dennis E. McGavis*



Over 25 years experience in Sustainability and environmental product stewardship. Most recent role is as Shaw Industries' Product Stewardship and Regulatory Affairs Director. Focus at Shaw is around Life Cycle Assessments (LCAs), product Eco-label certifications, Design for Environment (DfE) program management, and product regulatory affairs. Prior to Shaw, helped HP and the electronics industry develop product stewardship solutions around product energy efficiency (co-developed the EnergyStar program for office equipment), product chemical and material content, product recyclability, product recycled content (plastics and packaging), end of life (EOL) product classification, supply chain management, and take back and recycling. Married to the smartest woman on the planet and blessed with six grown children and thirteen grandchildren.

Dima Nazzal

Dima Nazzal is an Assistant Professor of Industrial Engineering at the University of Central Florida since 2006. She received her Ph.D. from Georgia Institute of Technology. At the start of her academic career, she focused primarily on stochastic modeling and analysis of facility logistics systems. Motivated by the urgency of the topic, she expanded her research interests to cover sustainable production systems and sustainability education. Such ventures into the nascent and multidisciplinary field of environmental sustainability are motivated by a passion to undertake research that is applicable to the engineering grand challenges and societal concerns that can be addressed through industrial engineering research methodologies. In 2010, she received the competitive NSF-CCLI award to integrate environmental sustainability into the Industrial Engineering curriculum to develop future engineers that are knowledgeable and prepared to work on solving these challenges.

Cynthia Nolt-Helms

Ms. Nolt-Helms is the project manager for EPA's P3 (People, Prosperity and the Planet) Program. For the past five years, she has overseen this innovative program to fund sustainability research from over 200 teams composed of university students. These teams have developed sustainable approaches to everything from a green-tea based cancer treatment to the world’s first floating wetlands classroom, with many of these projects designed to support sustainability efforts in developing nations. The P3 Program has given over 2000 participants the opportunity to come to Washington, DC, meet their peers and compete for additional funding to develop their innovative technologies. Some of the P3 teams have even gone on to create small businesses or found NGOs.In her previous years at EPA, Ms. Nolt-Helms managed EPA grants for drinking water research and contributed to the development of drinking water research plans. While working for EPA’s Office of Water, she also led agency efforts to develop national wildlife criteria for toxic chemicals and contributed to the Great Lakes Water Quality Initiative Final Rule which included the nation’s first aquatic criteria for the protection of higher-trophic level wildlife species. Ms. Nolt-Helms has a Bachelor’s degree in Chemistry and Biology from Lebanon Valley College and a M.S. in Environmental Toxicology from Cornell University.

Sergio Pacca

Sergio Pacca is an Associate Professor at the University of São Paulo in Brazil. He teaches in the undergraduate Environmental Management Program, and is affiliated with graduate programs in Energy and Environmental Engineering Sciences. He also has experience teaching Industrial Ecology courses abroad (in the United States, Japan, and Iceland). He has worked as a consultant for the World Bank, UNEP, and Brazilian NGOs. His research is focused on life cycle assessment (LCA) of energy technologies and extended input-output (I-O) models. He has worked with LCA of renewable energy sources, such as hydroelectric plants, PV, and biofuels. He has built national and regional I-O models to understand the effects of the supply chains on the final consumption of households. His goal is supporting the adoption of low carbon technologies, thereby contributing to carbon emissions mitigation.

Omar Romero-Hernandez

Omar Romero-Hernandez is a Chemical Engineer with graduate studies in Economic Policy and Government and a Ph.D. in Process Economics and Environmental Impact from Imperial College, London, England. Prof. Romero-Hernandez has worked for a diverse range of public and private organizations with large and complex supply chains, such as Procter & Gamble and PEMEX (Oil & Gas). He served as a consultant for Accenture and the Ministry for the Environment. In 2001, he was appointed as Professor at ITAM, and Fulbright Professor in 2009. Prof. Romero-Hernandez is Faculty and a Professional Researcher at the Haas School of Business. He is author of three books: *Renewable Energy Technologies and Policies*, *Industry and the Environment*, and *Introduction to Engineering—An Industry Perspective;* as well as several international publications on engineering, business, and sustainable development. Dr. Romero-Hernandez has led various internationally recognized projects in the field of renewable energy, sustainable business strategies, and business processes. Projects include Life Cycle Implications of Value Chains; Economic, Environmental, and Social Implications of Biofuels; and Business Intelligence in Energy Value Chains. Prof. Romero-Hernandez was the recipient of the 2010 Franz Edelman Award, the world's most prestigious award on Operations Research and Management Science.

Thomas Seager

Thomas P. Seager, Ph.D. is Associate Professor of Sustainable Engineering and the Built Environment at Arizona State University. Dr. Seager is the author over 50 publications related to sustainability, with particular emphasis on the environmental implications of alternative energy technologies. Most recently, Dr. Seager has been working in collaboration with researchers at the U.S. Army Corps of Engineers and Purdue University to establish quantitative measures of resilience applicable to complex systems. Dr. Seager's approach emphasizes the importance of understanding resilience management as an ongoing process, rather than a variable of state. Most importantly, resilience approaches must be differentiated from (and understood as complementary to) traditional risk-based approaches to be most effective.

Raymond L. Smith

Ray Smith is a Chemical Engineer within the Systems Analysis Branch in the Office of Research and Development at the U.S. EPA. He obtained his Ph.D. in Chemical Engineering in the area of process design from the University of Massachusetts Amherst. Ray has worked for the EPA for over 10 years with focus areas including the evaluation of green chemistries and technologies, chemical process design and optimization, life cycle assessment, and recycle process design for industrial ecology. He has also worked on biofuel analysis projects and is currently a lead for the Sustainable Supply Chain Design for Biofuels team. This project is analyzing various environmental impacts, indicators and sustainability metrics for biofuel supply chains from feedstock production through end use. In addition, the project considers the expansion of biofuel supply chains, different ways the infrastructure could develop, and how the form of the supply chain could influence impacts, indicators and sustainability metrics.

Rajagopalan Srinivasan

Dr. Rajagopalan Srinivasan is an Associate Professor in the Department of Chemical and Biomolecular Engineering at the National University of Singapore. He is concurrently a Principal Scientist at the Institute of Chemical and Engineering Sciences, where he leads the Process Systems and Control Team. Dr. Srinivasan received his B.Tech. from IIT Madras in 1993 and his Ph.D. from Purdue University in 1998, both in Chemical Engineering. He worked as a research associate in Honeywell Technology Center, before joining NUS. Dr. Srinivasan's research program is targeted toward developing artificial intelligence and systems engineering approaches for benign process design, agile process supervision and supply chain management.

Martha Stevenson

Martha is Senior Program Officer of Research and Development, Markets at World Wildlife Fund. She has specific content expertise in life cycle assessment (LCA), corporate sustainability, packaging materials and end-of-life technologies. For the past year and a half, Martha ran her own consultancy advising organizations on LCA, including the U.S. Environmental Protection Agency, General Services Administration, PepsiCo and Environmental Defense Fund. Previous to that, she was a project manager for GreenBlue's Sustainable Packaging Coalition (SPC), where she led development of the Design Guidelines for Sustainable Packaging, the COMPASS® software, and Closing the Loop: an international study conducted for the California Department of Conservation to document approaches encouraging the coordination of package design with end of life recovery technologies. This work has led to strong relationships with NGOs, government agencies and companies focused on materials recovery in North America, Europe and Australia. Before joining GreenBlue, Martha worked in the private sector at an environmental engineering firm managing site investigation and brownfield redevelopment projects. Prior to that, Martha worked as a research assistant with Dr. Deborah McGrath on a National Science Foundation-funded project in Manaus, Brazil, studying phosphorus availability in Amazonian soils. Martha earned a Bachelor of Science degree in Forestry from the University of the South, Sewanee, Tennessee in 2000.

Thomas L. Theis

Thomas Theis is Director of the Institute for Environmental Science and Policy (IESP) at the University of Illinois at Chicago. IESP focuses on the development of new cross-disciplinary research initiatives in the environmental area. From 1985 to 2002, he was at Clarkson University, where he was the Bayard D. Clarkson Professor and Director of the Center for Environmental Management. Dr. Theis received his Ph.D. in Environmental Engineering, with a specialization in environmental chemistry, from the University of Notre Dame. His areas of expertise include life cycle assessment, industrial ecology, environmental policy, the mathematical modeling and systems analysis of environmental processes, the environmental chemistry of trace organic and inorganic substances, interfacial reactions, subsurface contaminant transport, and hazardous waste management. Dr. Theis has been principal or co-principal investigator on more than 50 funded research projects; authored or co-authored more than 100 papers in peer-reviewed research journals, books, and reports; and has delivered in excess of 300 presentations at professional meetings, conferences, and panels. He served as a member of the EPA Chartered Science Advisory Board (2003-2009), and is past editor of the *Journal of Environmental Engineering*. He has published widely on the problem of reactive nitrogen in the environment and is the co-chair of the EPA Science Advisory Board committee on Integrated Nitrogen Management. From 1980 to 1985, he was the co-director of the Industrial Waste Elimination Research Center (a collaboration of Illinois Institute of Technology and University of Notre Dame), one of the first Centers of Excellence established by EPA. In 1989, he was an invited participant on the United Nations' Scientific Committee on Problems in the Environment (SCOPE) Workshop on Groundwater Contamination. In 1998, he was invited by the World Bank to assist in the development of the first environmental engineering program in Argentina. In January 2009, he delivered the keynote address at the NitroEurope Conference in Gothenburg, Sweden, and in October 2009 he was a member of the U.S. delegation to the U.S.-Japan Workshop on Life Cycle Assessment and Infrastructure Materials in Sapporo, Japan. Dr. Theis is the founding Principal Investigator of the Environmental Manufacturing Management Program, funded in the first cohort of NSF IGERT awards. He is a member of the International Society for Industrial Ecology, the American Society of Civil Engineers, the American Chemical Society, and the Association of Environmental Engineering and Science Professors.

Arnold Tukker

Arnold Tukker has more than 20 years of experience in sustainability research and policy making. He is currently Business Line Manager for Societal Innovation and Economy at the Netherlands Organisation for Applied Scientific Research TNO, one of the largest not-for-profit research institutes in Europe, with 5,000 staff. He set up the Sustainable Consumption Research Exchanges (SCORE!), a network of several hundred researchers under the EU's Sixth Framework Program, which developed knowledge for various international policy agendas, such as the United Nations' 10-Year Framework of Programs Sustainable Consumption and Production (SCP). Recently, with the main umbrella of European NGOs, the European Environmental Bureau; he wrote the "Blueprint for European SCP" (www.eeb.org). He also leads a multimillion project for the EU on the construction of a global economic and environmental input output database (EXIOPOL). He was engaged in the UNEP's Green Economy Initiative and supported UNEP's Resource Panel in editing the report on environmental impacts of products and resources. He also managed the EU Sustainable Product Development Network (SusProNet) on Sustainable Product Services, leading to various scientific papers on sustainable product system development, and a book—edited with Ursula Tischner—*New Business for Old Europe*, published by Greenleaf Publishing, Sheffield, U.K., 2006. He is a board member of various scientific journals, including the *Journal of Industrial Ecology*. Since April 2010, he has been a part-time professor of sustainable innovation at the Industrial Ecology Program at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway.

Donald Versteeg

Donald J. Versteeg is an environmental risk assessor and sustainability expert with The Procter & Gamble Company. A Principal Research Scientist in the Environmental Stewardship Organization, Dr. Versteeg leads an environmental risk assessment team working to improve risk assessment approaches. His research has ranged from the use of ecotoxicogenomics to understand the mode of toxic action in fish to the generation of quantitative structure activity relationships to reduce animal use in toxicology. He has more than 25 years of industry experience, and has more than 40 publications in refereed journals on the fate, effects, and environmental risk assessment of pharmaceuticals, personal care products, and emerging contaminants. He earned his Ph.D. from Michigan State University, is a member of the Society of Environmental Toxicology and Chemistry (SETAC), and serves as an editor of aquatic toxicology for the journal, *Environmental Toxicology and Chemistry*.

Eric Williams

Eric Williams is Associate Professor at the Golisano Institute of Sustainability at Rochester Institute of Technology (RIT). After undergraduate, graduate and postdoctoral work in physics, Eric has worked on industrial ecology and life cycle assessment at United Nations University in Tokyo, Carnegie Mellon University, Arizona State University, and most recently, RIT. Much of his research has dealt with environmental assessment and management of information technology, including materials flow analysis and LCA of semiconductors and computers. He has also examined the sustainability of global reverse supply for end-of-life electronics, including consideration of informal recycling in the developing world. Recent research focuses on systems assessments of renewable energy technologies, urban form, and energy-water issues. Methodological interests include hybrid life cycle assessment, uncertainty analysis, technological progress modeling and thermodynamics.

Phillip Williams

Phil Williams is the Vice President of Sustainability and Technical Systems for Webcor Builders. As the Sustainability Vice President, Phil is responsible for all sustainability efforts related to building construction, internal business processes, institutional as well as private sector research and development. He directs all work relating to reducing environmental footprint and collaboratively promoting, innovative, sustainable processes, systems and materials. Under his guidance Webcor has recently been selected as the only construction firm to "Road Test" the World Resource Institute (WRI) carbon accounting/greenhouse-gas (GHG) scope 3 protocol. In 2009 Webcor was the first and only California business to report and independently verified complete Scope 1, 2 and 3 emissions to the California Climate Action Registry. To support construction industry research regarding supply chain carbon accounting, Webcor, along with six other West Coast firms and through the University of Washington, established the “Carbon Leadership Forum”.

Mr. Williams is Chair of the Industry Advisory Board for the Center for the Built Environment (CBE) through the University of California at Berkeley, serves on the Advisory for the Business Council on Climate Change (BC3 in affiliation with the United Nations Global Compact and serves on several cleantech/greentech venture capital advisory boards based in Silicon Valley. In addition, he serves as the Chairman of the San Francisco Mayor's Task Force on Green Buildings, which developed legislative recommendations that were adopted in 2008 for private sector green building requirements. Mr. Williams also was a key member of the Green Building Code working groups established for the Cities of San Jose and Oakland. He is a professional engineer, serves as the American Society of Concrete Contractors (ASCC) Sustainability Committee Chair, is a member of the Strategic Development Council BIM committee (SDC under ACI), and American Concrete Institute (ACI) Committee 130 on Sustainability. Projects of note include the California Academy of Science (LEED Platinum), Park Mercer (LEED Platinum), San Francisco Public Utilities Commission (SFPUC) Head Quarters (LEED Platinum) and over 40 other LEED projects, of which 53% are LEED certified as Platinum or Gold, with project totals exceedingly 28 million square feet and $16 billion of revenue.

B. Erik Ydstie

B. Erik Ydstie is a Professor of Chemical and Electrical Engineering at Carnegie Mellon University and Professor II of Electrical Engineering at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. He earned his B.S. and M.S. degrees in Chemistry from NTNU and a Ph.D. in Chemical Engineering from Imperial College in London, UK. From 1982 till 1992 he was professor of Chemical Engineering at the University of Massachusetts. From 1999 and 2000 he was Director of R&D for Elkem Metals in Norway. His responsibilities included technical IT, corporate and business unit R&D, and day-to-day management of the research center. He initiated corporate research programs in the areas of carbothermic aluminum production and high purity silicon for solar cells. In 2005 he founded iLS Inc. to commercialize nonlinear adaptive control and real time optimization systems. ILS is also been working on commercialization of a new process for making silicon wafer for solar cells. Prof. Ydstie has held consulting agreements with PPG, Elkem and ALCOA. He is on the advisory boards of the American Chemical Society, Petroleum Research Fund, and the Worcester Polytechnic Institute; he also has held visiting positions at Imperial College, Ecole des Mines in Paris, France, and the University of New South Wales in Australia. He has authored over 200 articles on process control, optimization and modeling of chemical processes. His current areas of research are process control, modeling, design and scale-up. He works on supply chain management and solar cells, aluminum production processes and oil and gas field control and optimization systems. He won the Kun Li award for excellence in teaching at CMU (2007, 2010), the CAST division award of the AIChE (2007) and he was the Sargent Lecturer at Imperial College in 2006.

Fengqi You

Fengqi You is an Assistant Professor of Chemical and Biological Engineering at Northwestern University. He received a Ph.D. from Carnegie Mellon University in 2009 and a B.S. from Tsinghua University in 2005, both in Chemical Engineering. His graduate research is concerned with the development of mixed-integer nonlinear programming models and algorithms for the design of chemical supply chains under uncertainty. From 2009 to 2011, Dr. You was an Argonne Scholar at Argonne National Laboratory, where his efforts were concentrated on the analysis, design, and optimization of sustainable energy supply chains. He started as an Assistant Professor at Northwestern University in 2011. His group's research focuses on the development of novel computational models, optimization techniques, and systems analysis methods for problems in process-energy-environmental systems engineering. Dr. You has published more than 25 journal articles and book chapters. His recent honors include the W. David Smith, Jr. Award from the CAST Division of AIChE (2011), Director's Postdoctoral Fellowship from Argonne National Laboratory (2009-2011), and the Ken Meyer Award for best doctoral thesis at Carnegie Mellon University (2010).

Position Statements

Note: Participants who were unable to attend the Workshop are denoted with an asterisk (*).

Bhavik Bakshi

Sustainable Supply Chains as Techno-Ecological Networks

My group's research is motivated by the need to understand, learn from, and emulate ecological systems to develop human-designed systems that are likely to be sustainable. Over the last decade, our work has developed ways of accounting for the contributions from nature for supporting human activities. The main motivation for this work is that such accounting is essential for understanding and appreciating the role of the systems essential for sustainability of all planetary activities.

This has resulted in many directions of research, including the use of thermodynamic methods for resource accounting and for integrated analysis of industrial and ecological systems. This work has culminated in the development of a framework for Ecologically-Based Life Cycle Assessment (Eco-LCA). Application of this framework and related data to products (e.g., transportation fuels) has resulted in unique insight, such as the apparent trade-off between renewability and physical return on investment. This insight implies the importance of relying on the "free" work done by nature and conserving these ecosystem services for maximizing renewability and return on investment. Recently, we have also shed light on the carbon-nitrogen nexus for these fuels by showing that many biofuels may save the carbon cycle, but worsen the nitrogen cycle. This involves the use of new data about both cycles and a definition of the nitrogen footprint.

This work is relevant to supply chain management because it helps to identify the contribution of various processes in the supply chain to the overall environmental impact. This information could be used to determine where improvement efforts should be directed to enhance supply chain sustainability. In addition, our work is also relevant for understanding the risks to industry and economic activities due to depletion of ecosystem services. The input-output framework also can be used to connect the latest advances in life cycle assessment with the latest methods in operations research and supply chain management.

I expect to learn more at this Workshop about sustainability and supply chains from various perspectives, including various academic disciplines and industries. This should help in motivating further research and collaborations that can address many practical challenges of achieving sustainability in supply chains.

Russell Barton

My primary purpose for attending the workshop is to gain a better understanding of sustainable production and supply chains, particularly for the chemical and batch process industries. I am seeking cross-fertilization opportunities with the research community that I support as an NSF program director. This community focuses primarily on discrete part manufacturing and operations management and associated supply chains. The following titles of recently funded research in the programs I manage indicate the opportunity for our communities to learn from each other:

- Real-Time Control of Production Systems for Energy-Efficient Manufacturing: Theory and Applications;
- Cost-Effective Energy Efficiency Management of Sustainable Manufacturing Systems;
- Closed Loop Supply Chain Design for Uncertain Carbon Regulations and Random Product Flows;
- Optimizing the Supply Chain for Cost and Carbon Footprint; and
- Analytical Approaches for Assessing the Revenue Aspects and Environmental Impacts of Demanufacturing.

My own supply chain research (in collaboration with Jun Shu at Penn State) focuses on the monitoring of timeliness and correctness of the movement of entities through a supply chain. A class of data we call individualized trace data identifies the real-time status of individual entities as they move through execution processes, such as an individual product passing through a supply chain. A state-identity-time Framework represents individualized trace data at multiple levels of aggregation for different managerial purposes. Using this framework, we formally define two supply chain quality measures—timeliness and correctness—for the progress of entities through a supply chain. The timeliness and correctness metrics provide behavioral visibility that can help managers to grasp the dynamics of supply chain behavior that is distinct from asset visibility such as inventory. We develop special quality control methods using this framework to reduce overreaction of supply chain managers faced with large volumes of real-time data (e.g. RFID or GPS data).

Beth Beloff

From my work in seeking collaboration between companies on qualifying the sustainability of supplies and suppliers in their joint supply chains, I have several positions to share. They are as follows:

1. The purchasing decisions of companies and other kinds of organizations contribute significantly to the "sustainability" or the environmental footprint that they create; creating sustainable supply chains will push better decisions regarding sustainability through the whole value chain of commerce.
2. Only through better information regarding sustainability aspects of products, processes and services in the supply chain can decision makers make better decisions.
3. Requesting sustainability-related information and verification of that information regarding attributes of products and practices of suppliers is costly to both the supplier and the purchaser, particularly if each purchaser is asking a different set of questions.
4. Getting reasonable lifecycle data about materials in products is both costly and time consuming. The methodologies are complex and expensive.
5. There is no standardization or consensus regarding the definition of a sustainable product system, although there are numerous certifications that cover certain aspects of sustainability regarding products.

6. Working collaboratively with organizations with similar supply chains to 1) request information of suppliers, 2) verify that information, 3) share the information with others, and 4) mentor suppliers as to how to improve will help improve the sustainability of the whole supply chain.

Bert Bras

The design of sustainable product networks and supply chains is a complex issue. It is very easy to focus on a particular subset of problems and lose sight of the larger picture needed to achieve sustainable development, (i.e., "development that meets the needs of the present generation without compromising the needs of future generations").

While performing this workshop, we should not ignore prior work and results from other workshops in the area. For example, in 2001, the National Science Foundation and Department of Energy sponsored a comprehensive global study on Environmentally Benign Manufacturing. The study found that there was no evidence that the environmental problems from our production systems are solvable by a "silver bullet" technology [1]. Rather, the need for systems-based solutions was noted, requiring a comprehensive systems approach in which, for example, the product's design is performed in conjunction with its logistical and recycling systems, integrating key disciplines such as environmental science and policy, engineering, economics, and management. Several key elements are needed to move from our current "take-make-waste" production system to a sustainable system. Clearly, this raises the level of design complexity and a need exists for a framework for such a systems-based approach that is both efficient and effective in reducing environmental impact while maintaining or increasing a supply chain's technical and financial performance.

While many researchers are working to address important needs in sustainable manufacturing, the cumulative impact of the work is often limited by its fragmented nature, lack of a systems view, and lack of connectivity to industry. Critical elements needed to achieve a systems view and move to sustainability are life cycle and closed loop thinking, multi-scale/multi-level modeling and assessment, inclusion of geospatial locality, and understanding societal and user behavior.

Closed loop thinking that includes material recycling, product and part remanufacture as part of an extended supply chain is gaining ground, but is still an exception rather than a rule. Especially remanufacture can result in significant material and energy savings, if done appropriately with proper warranties and pricing.

More and more people are realizing that local conditions can affect supply chain performance enormously. For example, moving an entire facility or supplier from a region with coal-fired electricity generation to an area where hydropower is prevalent may offer more benefits than incremental process improvements.

Emerging concerns around local water consumption and use also force rethinking of production and process locations and technologies. Whereas greenhouse gases are a global issue, water scarcity and quality is typically a local issue subject to a variety of local policies and regulations.

The importance of understanding consumer and human behavior is widely recognized in business and also gaining traction in engineering. For example, good truck driver behavior can improve fuel efficiency significantly—outperforming many bolt-on technologies. Similarly, any efficiency gains can be negated by rebound effects, if one is not careful.

Last, but not least, we also should not ignore the importance of good basic engineering. Reducing material intensity, increasing energy efficiency, etc. are all based on good engineering practices. Nevertheless, just improving efficiency will not be enough. Resources should be channeled to innovation and adoption of potentially game-changing technologies and products. Proper up-front modeling and assessments are crucial in order to avoid unintended consequences from wide-spread adoption.

1. Gutowski, T.G., C.F. Murphy, D.T. Allen, D.J. Bauer, B. Bras, T.S. Piwonka, P.S. Sheng, J.W. Sutherland, D.L. Thurston, and E.E. Wolff, *Environmentally Benign Manufacturing*, 2001, International Technology Research Institute, World Technology (WTEC) Division: Baltimore, MD. (www.wtec.org/pdf/ebm.pdf)

Maria K. Burka

Sustainable product systems and supply chains cover areas of great interest to NSF. Numerous core programs fund research in various aspects that will be discussed at the workshop. In addition, there are many cross-cutting, NSF-wide programs that these topics would fit directly. Some examples include Cyber-enabled Discovery and Innovation (CDI), Software Infrastructure for Sustained Innovation (SI2), etc. These solicitations as well as core program descriptions can all be found at http://www.nsf.gov.

Heriberto Cabezas

Sustainability is widely associated with the statement from the World Commission on Environment and Development, 1987: "… development that meets the needs of the present without compromising the ability of future generations to meet their own needs…" Hence, sustainability is about the world supporting human society for the indefinite future. Because a major feature of human society is the production and use of goods and services using a supply chain, it is important for sustainability that these supply chains spanning the entire life cycle be as sustainable as possible. To do this in any practical way, however, one needs at least semi-quantitative means of measuring progress towards or away from sustainability. There is, therefore, a need for scientifically sound indicators and metrics to at least provide quantitative measures of progress. Note, though, that there is a distinct difference between pollution prevention and sustainability. Pollution prevention is when the environmental impact is reduced along the supply chain for the activities of raw material acquisition and transportation, goods and services production, goods and services distribution, and goods disposal. Pollution prevention is based on indicators that may include indexes of environmental impact, energy efficiency, raw material to product ratios, etc., and these can greatly reduce environmental impacts when used judiciously. Sustainability, however, goes beyond reducing environmental impacts and considers whether the underlying processes in the ecosystem, energy flow and cycling system, the economy, and society are functioning well and are being preserved. This requires a wider look, not so much at the components of the supply chain, but at the supply chain in its entirety. This requires the use of sustainability metrics, which may be based on footprint analysis (e.g., ecological foot print), energy systems analysis (e.g., emergy), thermodynamic analysis (e.g., exergy), economics (e.g., green accounting), and information theory (e.g., Fisher information); and it also requires criteria that relate these metrics to sustainability. These sustainability indicators and metrics are necessary for the design and retrofit for sustainability of supply chains spanning the product or service life cycle in its entirety.

Vincent Camobreco

As part of revisions to the National Renewable Fuel Standard program (commonly known as the RFS program) as mandated in the Energy Independence and Security Act of 2007 (EISA), EPA analyzed lifecycle greenhouse gas (GHG) emissions from increased renewable fuels use. EISA established eligibility requirements for renewable fuels, including the first U.S. mandatory lifecycle GHG reduction thresholds, which determine compliance with four renewable fuel categories. The regulatory purpose of EPA's lifecycle GHG emissions analysis is therefore to determine whether renewable fuels produced under varying conditions meet the GHG thresholds for the different categories of renewable fuel. Determining compliance with the thresholds requires a comprehensive evaluation of renewable fuels, as well as of gasoline and diesel, on the basis of their lifecycle emissions.

In order to calculate the lifecycle GHG emissions of various fuels, I led the team at EPA that utilized models that take into account energy and emissions inputs for fuel and feedstock production, distribution, and use, as well as economic models that predict changes in agricultural markets. In developing this analysis, the Agency employed a collaborative, transparent, and science-based approach. Through technical outreach, the peer review process, and the public comment period, EPA received and reviewed a significant amount of data, studies, and information on our proposed lifecycle analysis approach. We incorporated a number of new, updated, and peer-reviewed data sources in our final rulemaking analysis, including better satellite data for tracking land use changes and improved assessments of N2O impacts from agriculture.

The lifecycle methodology that we developed for the RFS rulemaking analysis included the use of economic models to perform a consequential type of lifecycle analysis. This has implications for the design of sustainable product systems and supply chains. The lifecycle approach is itself a way to measure impacts across product systems and supply chains. Furthermore, the type of lifecycle analysis that was conducted as part of the RFS analysis for renewable fuels has implications on the type of information that could be included in examining other product systems or supply chains.

John B. Carberry

Supply Chain Sustainability

Moving a supply chain toward a more sustainable position requires analyzing that particular business versus the specific sustainability issues that are most impacted by that business. The sustainability of suppliers, customers, and one's own manufacturing must be assessed and that must balance the environmental, societal, and business issues in combination. At least for chemical companies, the summary developed by the Center for Waste Reduction Technologies of the AIChE is an excellent list of "environmental issues" to start from. From that, an industry can develop a plan for more sustainable manufacturing of more sustainable products in a more sustainable business area.

Andreas Ciroth

Sustainability Assessment

I have worked in sustainability research and consultancy since about 1998 on projects for industry, governments, organizations, consultancies, and universities. I am working in method development and implementation for LCA, social LCA, and Life Cycle Costing. I also work in software and data development and have been involved in several smaller and larger projects. I like to use advanced statistical and analytical methods "where fit," and I especially like the statement, "*vom Primitiven über das Komplizierte zum Einfachen*" (from primitive, to complex, to simple) as guidance for developing anything. This statement is attributed, somewhat unfortunately, to both Wernher von Braun and Antoine de Saint Exupéry.

I see the following needs for sustainability assessment and its application, and would like the workshop to discuss these, and ideally, decide on next steps:

1. Finding the right scope for sustainability analyses: Carbon footprint/(environmental) LCA/social LCA/economic impacts over the life cycle, LCC—all provide some aspects of sustainability assessment. When applying one of these, there are different nuances and modeling decisions that usually influence both the scope of the analysis and the effort. One example is the impact categories addressed in an LCA (e.g., toxicity and land use or more the classic categories as GWP, AP, EP, etc.). There is not really guidance for this scoping today, besides a review panel that might question these modeling decisions by expert judgment. Consequently, many studies might investigate spots that are not really relevant for their own research/study interest and bypass others that would be required.
2. Finding ways to deal with diverse information: This is linked to the statement above. One benefit of choosing a single score method is the simplicity of the result; so it might have been selected not because it fits the problem of interest but because the result is more easily understood. Sustainability is always a diverse issue; therefore, knowledge and tools on how to deal with diverse information—especially ways to aggregate/interpret/process information in results of analyses so that it can be understood by the addressees—are important. Currently, there are some approaches discussed, but rarely applied.
3. Availability of transparent data and transparent tools: LCA often claims to be science-based, but many of the tools and data are not transparent. This is well accepted in practice, and yet

contradicts science and prevents a more in-depth quality assurance process. While there are sensitivity issues, of course, that need to be respected, there are currently few incentives to provide transparent data (and tools), which makes data and tools more often nontransparent than necessary.

4. Interoperability of tools and data: Currently, many LCA tools work in isolation; exchange from one tool to another is not usually possible without information loss and (even if the loss is accepted) in an automated way. The LCA data exchange formats are interpreted somewhat differently by many tools, which always makes data exchange a surprising, non-routine effort. This needs to be changed. Tools should work together.
5. Making better analyses and validating data and studies: The modeling and quality assurance process for LCA studies seems to be somewhat old-fashioned and simple. There are usually many processes to be connected in a study, but each process is modeled as a linear combination of inputs and outputs that is generated once and expert judgment is usually employed to evaluate its quality. Uncertainty information is usually not added or added with expert judgment only, although flows for processes are uncertain. There are more refined quality assurance tools available "outside" of the LCA domain that should be investigated. For the models, generic data are used for (usually) a large part of the data. Methods of collecting real data and integrating it into cases and studies should be investigated.
6. Sustainability Life Cycle Assessment: These assessments should be made much more available for day-to-day decisions. Historically, LCA has been quite an academic and research field. LCA needs to be more available in the everyday life of businesses and consumers in a way that is "easy to consume and use." I believe this includes my points 1–5, but adds communication and maybe other things, such as intrinsic incentives to use LCA information.

Andres Clarens

My research groups' interests lie broadly in the areas of anthropogenic carbon flows, reuse, and sequestration. Specifically, we carry out work in: 1) high-pressure fluid-phase behavior of CO_2 mixtures and 2) carbon accounting of systems-level processes. These complementary areas are important as policymakers and engineers grapple with better ways to manage the emissions that are driving climate change. There is currently a great deal of uncertainty and lack of understanding of how and where carbon moves through the technosphere. Our work aims to try and fill some of these gaps, so we can make more meaningful progress on the climate change problem. In preparation for this workshop, I will focus my discussion on the second area, larger systems-level research, since it is the most closely related to supply chain modeling.

Over the past several years, we have been exploring the large-scale systems-level environmental impacts of engineered processes. This work is of vital importance as government-mandated CO_2 emissions reporting rules are developed. Fundamental advances in the science of life cycle assessment are needed to provide the necessary tools in carbon accounting. To this end, we are developing a model for transportation departments, allowing them to incorporate CO_2 emissions into pavement management decisionmaking. This project aims to go "beyond" the traditional life cycle assessment scope to try and embed the knowledge into the engineering design process. There is a good deal of overlap between this work and supply chain design. In particular, we are looking at the ways in which decisions about maintenance set off a cascade of processes from contractors and state agencies to move huge amounts of material and create significant environmental burdens. This work has also highlighted some of the ways in which existing life-cycle methodologies, which are typically used to study manufacturing products or processes, are inadequate for modeling large-scale infrastructure projects with use phases on the order of many decades.

Another project is using life cycle modeling techniques to characterize algae-based biofuels and assess how large-scale deployment of algae for bioenergy will impact the environment. This is a particularly challenging problem because there are few operating examples upon which to develop systems-level models, and yet the scale at which some would deploy the technology is quite large. The results of the algae work are being used to inform future research; our team is working to explore one promising area that would leverage synergies with wastewater treatment and carbon sequestration. This work has revealed how little is known about the ways that CO_2 would be sourced in the marketplace for use in sequestration or reuse projects. This is not a trivial problem, since the scale of CO_2 that is used industrially today is considerably smaller than the amount of CO_2 that is emitted in combustion gases and other waste streams. Many trained professionals believe that using flue gas from fossil plants is a trivial obstacle with few collateral impacts. The reality is likely to be quite different, and this work is trying to identify the tools that will be needed to make better management decisions. Understanding CO_2 supply chains is likely to be an important topic of research in the short term until we can move toward more carbon-neutral fuel sources.

This workshop will be a valuable opportunity to learn about new analytical tools being applied by the supply chain community. The area of carbon management is nascent and could benefit from the lessons learned by the supply chain community. While some characteristics of carbon management (e.g., scale, stocks and flows, and volume) are likely to be unlike most others, the academic literature contains a number of examples of how to investigate co-products and their burden allocation. I expect this workshop will provide a useful venue to explore potential collaborations and to learn about the state-of-the-art in fields closely related to our own interests.

Joseph Fiksel

Supply Chain Resilience and Sustainability

Leading global companies are expanding the scope of their sustainability initiatives to encompass the full product life cycle, ranging from the conduct of upstream suppliers to the disposition of obsolete products. For example, HP and Wal-Mart have implemented green purchasing policies to ensure that their suppliers adopt sustainable business practices. As multinational firms extend into emerging markets, globalization and outsourcing have only accentuated the importance of environmental and social responsibility in supply chain management. At the same time, supply chain disruptions such as natural disasters and contamination incidents have heightened concerns about business continuity and product integrity.

Life cycle assessment (LCA) tools are increasingly used to support business decisions regarding new product introduction, supplier selection, capital investment, supply chain operations, and product take-back processes. LCA methods can be challenging to apply, and may be inappropriate if adequate data are not readily available. However, life cycle *thinking* is essential for a modern enterprise to understand risks and opportunities throughout its supply chain. In some cases, the use of streamlined LCA or footprint indicators may be sufficient to support strategic priority-setting and decisionmaking. For example, Coca-Cola has adopted a water stewardship strategy based on a water efficiency ratio (i.e., liters of water per liter of product) that they estimated to be about 2.5 in 2007. The company's ultimate goal is to achieve "water neutrality" by returning water to nature equivalent to what it uses in its operations.

Recently, much attention has been focused on the "energy-water-nexus"— water is essential to the supply of energy and vice versa. In fact, the global water cycle is closely linked to the global carbon cycle, with vegetation playing a vital role through photosynthesis. Extension of this integrative thinking suggests the "material-energy-water nexus"—materials are essential to the supply of both energy and water, and vice versa. In fact, the root cause of the enormous carbon footprint of the U.S.—over 7 billion metrics tons per year—is *material throughput*, which drives the consumption of energy throughout the economy.

Current efforts at supply chain sustainability improvement are focused on incremental efficiency gains, such as shorter transport distances and pooled urban distribution via common carriers. However, the real sustainability challenge is to reduce the growth of material requirements—to decouple economic wellbeing from resource consumption. What is needed is a paradigm shift from a *material-based* economy based on throughput, product delivery, and material wealth; to a *value-based* economy based on knowledge, service delivery, and quality of life.

Finally, the journey to sustainability must be accomplished in an increasingly complex and unpredictable business environment. Technological innovation, resource scarcity, regulatory pressures, and climate change—as well as political and economic volatility—are creating new challenges for global supply chain management. In order to remain competitive, enterprises are beginning to emphasize resilience—the capacity to survive, adapt, and flourish in the face of turbulent change. For example, Dow Chemical is working with Ohio State to measure and improve supply chain resilience in its worldwide businesses.

Resilience is sustainability in real-time. Put another way, resilience in the current environment is a prerequisite for achieving long-term sustainability. Human societies can learn from the resilience characteristics of living systems—a balance between autonomy and control, and a keen ability to sense and respond to threats. It is important for government, industry, and communities to work together in order to ensure both the sustainability and resilience of the natural resources, economic assets, and infrastructure that represent the foundation of future economic prosperity.

William P. Flanagan

William Flanagan leads GE's Ecoassessment Center of Excellence (COE) and works closely with GE Corporate Environmental Programs, GE Ecomagination, and many of the GE business units on a variety of product-focused environmental issues and strategies. The ecoassessment COE focuses primarily on life cycle assessment and carbon footprinting and is also working to implement life cycle management approaches to guide internal product development teams. We are participating in this workshop specifically to share ideas and learn more about what others are doing in this space. We hope to come away from this workshop with fresh new insights that can potentially be reflected in our ongoing program development.

Our experience driving sustainability-related projects within a business context has led to insight around five enabling principles that we feel are important to consider when formulating product ecodesign strategies:

(1) Be strategic and selective. Application of LCA, and more specifically the collection of inventory data to support LCA or supply chain initiatives, can be resource intensive. While LCA is a very powerful tool that can provide deep and valuable insight, it must be applied strategically and selectively to ensure maximum benefit.
(2) Leverage qualitative screening approaches. Insights can be gained by applying qualitative approaches early in product development. The reduced time, effort, and expertise required for qualitative screening approaches offers the potential for cost-effective application to a wider spectrum of product development activities. Screening approaches should serve as a funnel to identify those opportunities requiring further analysis using more sophisticated quantitative approaches, such as structured DfE methodologies or detailed LCA.
(3) Focus on value creation. For any initiative to thrive within industry, it must create value. There are many opportunities to create value from sustainability-based initiatives, particularly those focused on energy and resource efficiency.
(4) Be flexible and customize programs for relevance to individual business context.
(5) Leverage the power of innovation. Great ideas can come from anywhere within a company. Invite active engagement, particularly in customization of tools and approaches.

Mark Goedkoop

Towards an LCA 2.0: Our Rethinking of the Position of LCA as an Important Basis for Decision Support

<u>Motivation</u>
After being one of the key companies in the LCA scene for more than 20 years, with achievements in developing and marketing the most widely used LCA software; developing leading methodologies such as Eco-indicator and ReCiPe; and serving as an active contributor in many organizations, promoting transparency and open access to data and methods; we realized the LCA world is rapidly changing as companies are starting to understand sustainable products have become a competitive advantage. Sustainable products are an important growth- and value-driver.

<u>Method</u>

We gathered information from clients and opinion leaders, studied several trend reports, and analyzed articles (e.g., *Harvard Business Magazine* and the SLOAN/MIT publications). We engaged in the development and road-testing of the WBCSD/WRI GHG protocol and in the Sustainability Consortium as a Tier1 member. We also experimented with changing the way we make offers to gauge responses from clients.

Results (What we see happening in the market)

LCA has always been done in an ad hoc mode and a key focus was writing the report. Such ad hoc studies have the reputation of being expensive, and this is not completely untrue. Ad hoc studies are relatively inefficient to conduct, and by the time the results are in, the issue may already have lost its priority.

Many companies are now changing this, and are developing internal competence centers that can take a much more structural and efficient approach. The internal competence center works with one database that gradually grows to cover all major activities in which the company is engaged. This internal knowledge base makes it much more efficient and effective to answer questions, screen issues, and set priorities. The shift is from report-writing to actively engaging in design and management decisions.

Relevance of These Results

The new trend has major implications for the actors in the LCA community. LCA moves from fringe activity in a niche market to a strategic tool for companies that want to use sustainability as a growth-driver, and a value-creator.

Implications

This means:
- Education on a massive scale is needed to train the people in the competence centers.
- New tools are needed to support such decisionmaking.
- Instead of focusing on reports, EPDs, and green marketing; LCA practitioners need to get engaged in the way companies want to create a decision support system in design processes and management decision support.
- Data and methodologies need further standardization and transparency. It is unthinkable that in the long run, companies and clients or consumers will put trust in privately held, confidential data.

Ignacio E. Grossmann

Optimal Design of Sustainable Chemical Processes and Supply Chains

My general research interests lie in the application of mathematical programming to the design and operation of chemical plants and process supply chains. More specifically, my research interests are in process synthesis, energy and water integration, process flexibility, design under uncertainty, planning and scheduling of batch and continuous processes, supply chain optimization, and algorithms for mixed-integer and logic-based optimization. Within these areas we have worked on a number of problems related to the optimal design of sustainable chemical processes and supply chains.

We have developed in our group a number of mathematical optimization models for heat integration that include the linear programming transshipment model for predicting the minimum energy consumption and/or cost for a set of hot and cold streams (Papoulias and Grossmann, 1983), and a mixed-integer nonlinear programming model for automatically synthesizing network structures in which energy consumption, number of units, and area cost are simultaneously optimized (Yee and Grossmann, 1990). In addition, we have developed a nonlinear programming model for simultaneous optimization and heat integration (Duran and Grossmann, 1986) that has the interesting effect of reducing the consumption of feedstock through efficient energy integration. We have also addressed the synthesis of integrated process water networks for minimizing the consumption of freshwater. The optimization problem involves bilinearities that give rise to multiple local solutions (Galan and Grossmann, 1998). We have developed a spatial branch and method to rigorously obtain the global optimum in these networks (Karuppiah and Grossmann (2006). We have recently extended this work to more general superstructures (Ahmetovic and Grossmann, 2011).

We have also directed our efforts toward the energy and water optimization of biofuel plants; for example, the design of corn based ethanol plants (Karuppiah, Peschel, Martín, Grossmann, Martinson, and Zullo, 2008) in which the steam consumption was reduced by 66 percent through the use of multi-effect distillation columns. In a subsequent series of papers we addressed the design of second generation biofuels plants using a superstructure optimization approach to optimize energy use in these processes (e.g., bioethanol plants from switchgrass via gasification and hydrolysis [Grossmann and Martin, 2011]). We have also addressed the minimization of freshwater consumption in some of these plants. For corn based ethanol plants we showed that a consumption as low as 1.5 gallons of freshwater per gallon of ethanol can be achieved (Ahmetovic, Martin, and Grossmann, 2010).

We have also considered environmental issues in design and operation of process systems and supply chains through a multi-objective optimization framework. For instance, in Grossmann, Drabbant, and Jain (1982) we incorporated toxicology measures to be minimized versus the maximization of net present value in the design of chemical complexes. More recently we addressed the bi-criterion optimal design and planning of sustainable chemical supply chains under uncertainty (Guillen-Gonzalez and Grossmann, 2009) in which uncertainties in the emissions of the Eco-indicator-99 are considered. We have also addressed the problem when there are uncertainties in the damage assessment model (Guillen-Gonzalez and Grossmann, 2010). Finally, we also performed research on an interesting case study related to a hydrogen supply chain in the UK where reforming, biomass and coal gasification technologies were considered (Guillen-Gonzalez, Mele, and Grossmann, 2010).

Bruce Hamilton

NSF has established a major new cross-NSF investment area, Science, Engineering, and Education for Sustainability (SEES). SEES is offering a number of new funding opportunities that are very relevant to the topic of this workshop. The workshop itself provides an opportunity for teams to nucleate and go on to submit winning proposals for SEES funding. For example, one such opportunity is the RCN-SEES track of the already posted RCN solicitation. RCN stands for Research Coordination Networks. RCN grants support research coordination, not research itself, and they provide funding for new interdisciplinary research networks to assemble. RCN-SEES grants can be for up to $750K, with a duration of 4–5 years. New RCN-SEES grants I am managing that are relevant to this workshop are one on biofuels sustainability and another on sustainable manufacturing.

Workshop participants should not let this funding opportunity pass them by. The next deadline for RCN-SEES track proposals is February 3, 2012. The solicitation is posted at http://www.nsf.gov/pubs/2011/nsf11531/nsf11531.htm. Another major new SEES solicitation is being posted that supports sustainability network research, not just research coordination— the Sustainability Research Networks (SRN) solicitation. SRN awards can be for up to $12 million for up to 5 years. Additionally, another SEES solicitation that is being posted is the Sustainable Energy Pathways (SEP) solicitation, with research grants for up to $3 million over 3 years. For international research, the PIRE solicitation, focused entirely on SEES, is already posted at http://www.nsf.gov/pubs/2011/nsf11564/nsf11564.htm, with a deadline of October 19, 2011, and so is the G8 Dear Colleague Letter on material efficiency, with a deadline of September 30, 2011 (see http://www.nsf.gov/pubs/2011/nsf11068/nsf11068.jsp). Also being posted is the SEES Fellows solicitation for support of post-docs in the sustainability area. These are all wonderful and immediate funding opportunities of relevance to this workshop.

Troy R. Hawkins

This workshop has grown out of efforts underway within the Sustainable Technology Division of the National Risk Management Research Laboratory on the design of sustainable supply chains for biofuels and consumer products. One approach to this problem is to focus on a particular supply chain or perhaps a particular process within a supply chain over which one has control and to modify aspects of the process or processes to improve the environmental profile. It soon becomes clear, however, that although each actor’s sphere of control within a supply chain may be small, the ultimate goal is to optimize the environmental performance across the supply chains providing inputs to the final product as well as the remainder of the product life cycle. This is the reason “product systems” was included in the workshop title. To a great extent, the workshop participants also reflect two primary areas: focused design and broader systems analysis. Both of these skills are required for the design of sustainable product systems and supply chains. The challenge from the focused design perspective is that while optimization may only be tenable for a narrow system boundary, this approach risks missing effects occurring outside the boundary. The challenge from the perspective of a broader systems analysis is that moving between detailed, high resolution processes and their interactions with the global system requires so much information that models generally address a simplified representation of reality arrived at through crude assumptions.

Through my involvement in planning this workshop, I have had the opportunity to interact with an incredible group of individuals involved in the Organizing and Advisory Committees. The final format of the workshop is stronger for each of their contributions. If you were to ask each of these individuals what goals and key outcomes of the workshop are, you might think we were planning 14 distinct workshops. Yet, there are many common points and in the end I hope the workshop does some small justice to this diversity of perspectives. In the end, I believe we have managed to bring together experts on different aspects of this topic from academia, government, and industry in a forum where they can discuss the current state of research and practice in this area, explore opportunities for cross-fertilization of research efforts across disciplines, and prioritize and make recommendations regarding research directions. For the most part, the workshop participants approach this topic from an engineering perspective, some coming out of chemical engineering and others from a broader systems analysis or decision-support perspective. While most participants are from the U.S., the final group represents a range of geography with Europe being the second best represented region.

In moving the design of sustainable product systems and supply chains forward as a research area, there are a few practical challenges I see that need to be overcome. None of these are insurmountable. However, addressing them may require shifts in our approach.

The first challenge is to focus on collaboration and coordination rather than competition. There is a lot of work to be done; the limitations are resources and time. Research support should be designed to promote openness and sharing of information and to push back against individuals' tendencies to restrict access to their work in order to maintain competitive advantage. Comprehensive environmental systems analysis requires a large amount of data and highly complex models. Performing analysis across levels of resolution makes it necessary to link models together. This requires harmonization, where appropriate, and coordination across research efforts. This, however, should be done without compromising the healthy competition needed to allow for creative destruction and replacement of models and creative freedom in research efforts.

The second challenge is the need to agree on everything before we move forward on anything. One example of this is the amount of attention that has been placed on how to define or frame sustainability. The ideological or philosophical goals of sustainability are more or less understood. The problem is operationalizing these goals in the face of considerable data gaps, model/system complexity, and drivers working against dramatic changes in existing systems of production and consumption. Another example is the ongoing efforts to agree on a single method for calculation of metrics or impacts. This exercise is useful for research coordination and facilitating information transfer across efforts, but it should not delay progress on the development of the new methods needed. A better approach would be to demonstrate best practice through carrying out high-quality analyses that can be used as examples for the next generation of work.

A third challenge is the large amount of data required for comprehensive environmental systems analysis. This presents a particular challenge for research efforts because these data are costly and time consuming to develop and, yet, there is not a lot of research credit to be gained solely through data collection. My experience lies primarily in the area of life cycle assessment (LCA). There are many unexploited opportunities for application of LCA and we have many of the pieces needed for sustainable product systems and supply chain design in terms of models. The problem is the lack of data—and especially high-quality datasets—that can be applied in a consistent way across different models. One way to move forward in this area is to require disclosure of datasets together with publication of results in such a way that they can be easily integrated into consecutive modeling efforts by others.

A fourth challenge is that the network tying together modeling efforts relevant to the design of sustainable product systems and supply chains is not sufficiently interconnected or efficient. Only a small group of experts often know how to run the appropriately complex models of economic and environmental systems. These individuals may be connected with their counterparts working with other models, but few have an overview from the perspective of the complete system. One option would be to develop user-friendly interfaces, but this is difficult work that is currently not well rewarded. User interfaces must allow access to the richness of the model while providing appropriate feedback and access to underlying information to prevent misuse or misinterpretation of results. This challenge could be addressed by designing research support that promotes interaction across levels of detail and recognizes the contribution of interfaces that simplify access to complex models and streamline interaction between models.

There are three key outcomes I hope to see from this workshop:

(1) A strong report detailing research needs and priorities and proposing some paths for accomplishing these things.
(2) Continued interaction between the attendees and the development and growth of a network around the design of sustainable product systems and supply chains.
(3) The development of proposals leading to funded, well coordinated, and collaborative projects focused on the design of sustainable product systems and supply chains.

My intention is that the report from this workshop will be picked up and used to influence decision-making regarding research supported by government, industry, and non-governmental organizations. I also hope that the opportunities provided by existing approaches and their use in combination will be picked up by those involved in the practicalities of product system and supply chain decision-making and used to shift the paradigms of their organizations. The National Science Foundation is already committed to funding projects in this area and this workshop will serve as a starting point for discussions leading to research coordination and collaboration projects addressing the design of sustainable product systems and supply chains. Finally, this workshop contributes to building the connections between individuals involved in different aspects of this problem who are required to move forward on appropriate complex efforts addressing this problem with a solid grounding in social and economic realities.

Michael R. Hilliard

Three recent research efforts provide a view into my interests in sustainable supply chains. The intersection of the three efforts is in the production of biofuels, particularly the potential for developing a sustainable cellulosic ethanol supply. The corn-based ethanol industry has been able to leverage the existing corn processing infrastructure, but the cellulosic industry will require almost all new infrastructures. I am particularly interested in the question of what type of system will evolve when viewed from a macro level. Will biomass production be focused in a few high density locations (a “biomass belt”) or will biomass be grown in smaller quantities spread across a wider collection of locations using marginal lands? Will pre-processing facilities become economical, producing a more transportable biomass format? What will be the preferred size for refineries, balancing economies of scale with costs of transportation and distribution? How will our demand for biofuels be distributed relative to population—uniformly or clustered?

We began studying these questions by developing a supply chain model focusing on the economics of the infrastructure and the linkages between the actors in the supply chain. We developed a prototype optimization model, the Biofuel Infrastructure, Logistics and Transportation (BILT) model capable of simultaneously specifying infrastructure for the entire supply chain, including selection of biomass, transport, location, and capacity for preprocessing and refinery facilities and distribution. The supply chain is modeled through a mixed integer linear program, a technique ideally suited for problems with multiple complex and contradictory objectives and constraints including the economic collaboration between entities. The MILP approach can be effectively parallelized for high performance computing, allowing the global optimization model to solve difficult problems and scale up for nationwide analyses. We are working to provide a limited version of the BILT on-line while the full model is being integrated into a national economic model of biofuel sustainability.

In an initial effort to consider the interplay of environmental effects and economic demands, we developed a model for locating plantings of switchgrass in a watershed. Using an environmental model to estimate the local and downstream effects of plantings in various types of soil in various locations, I developed an optimization approach to maximize profit and water quality measures (potassium, nitrogen, and sediment) while limiting the conversion of agricultural land to switchgrass. The model is called the Biomass Location for Optimal Sustainability Model (BLOSM). We were able to demonstrate a win-win situation where plantings increased profits and improved water quality. BLOSM also allows us to estimate the cost of water quality as the loss in profit with increased targets for water quality.

Currently, I am participating in the development of a set of socio-economic sustainability indicators for the biofuel supply chain. This is an attempt to identify quantifiable values that could capture the social and economic impacts of a developing biofuel supply chain from biomass production and logistics to refinery operations and distribution. The challenge is to identify a limited set of indicators that have a viable source for data. The results will become a partner study to an effort published earlier this year on environmental indicators for biofuel supply chain sustainability.

Yinlun Huang

Engineering sustainability is a science of applying the principles of engineering and design in a manner that fosters positive economic and social development while minimizing environmental impact. The mission can be largely accomplished through designing new systems and/or retrofitting existing systems of various length/time scales that meet sustainability goals. Among these, design sustainability of product systems and supply chains is of upmost importance, but it faces tremendous challenges, mainly due to the complexity in multiscale design and the existence of uncertainties contained in the accessible data and information. At Wayne State University, the Huang research group has been developing multiscale systems modeling, analysis, and decision-making methodologies and tools for the design of sustainable physical systems, such as nanomaterials at the microscale, products with needed properties at the mesoscale, and process systems as well as large-scale industrial system (e.g., industrial zones) at the macroscale. At the supply chain design level, our group has extended an ecological input-output analysis (EIOA) modeling approach through separating the system output into functionally different groups so that sustainability assessment can be more meaningfully conducted and design modification opportunities can be relatively easily identified. The methodology can be used to systematically characterize material and energy flows among industrial systems of any complexity.

In addition, our group has introduced the Collaborative Profitable Pollution Prevention (CP3) design methodology, which can advise synergistic efforts among industrial entities to maximize economic gains while minimizing industrial pollutions. The collaboration can be at either the management or the technical levels. It is recognized that one of the most challenging issues in sustainability research is how to deal with uncertainties. This is especially true when future sustainability performance needs to be predicted and/or a short-to-long-term sustainable development plan is to be developed. The Huang group has classified the sustainability-related uncertainties into two categories (i.e., aleatory and epistemic uncertainties), analyzed the applicability of three types of approaches to handling severe uncertainty (i.e., the information gap approach, the probability bounds analysis approach, and the fuzzy logic approach), and developed a general guideline for handling uncertainties in modeling, analysis, and decision making. A fuzzy-logic-based decision-making methodology has been introduced to develop short-to-long-term sustainability improvement strategies for industrial zonal development problems. Recently funded by the NSF, Huang is leading a team of 21 domestic and foreign universities and 10 national organizations/university centers to initiate a 5-year project, RCN-SEES: Sustainable Manufacturing Advances in Research and Technology (SMART) Coordination Network. In this project, design of sustainable product systems and supply chains are among the focused areas for research coordination. The experiences and connections to be gained through attending this workshop should help greatly the implementation of the RCN-SEES project and others.

Marianthi Ierapetritou

Integration of Decision Making Stages for Sustainable Supply Chain Management

Modern process industries operate as a large integrated complex that involve multiproduct, multipurpose, and multisite production facilities serving a global market. The process industries' supply chain is composed of production facilities and distribution centers, where final products are transported to satisfy the customer demand. The multisite plants produce a number of products driven by market demand under operating conditions such as sequence-dependent switchovers and resource constraints. Each plant within the enterprise may have different production capacity and costs, different product recipes, and different transportation costs, according to the location of the plants. To maintain economic competitiveness in a global market, interdependences between the different plants, including intermediate products and shared resources, need to be taken into consideration when making planning decisions. Furthermore, the planning model should consider not only individual production facilities constraints, but also transportation constraints. In addition to minimizing the production cost, it is important to minimize the costs of transportation from production facilities to the distribution centers.

Thus, simultaneous planning of all activities from production to distribution stage is important in a multisite process industry supply chain [1]. To achieve enterprise-wide optimization (EWO) in spatially distributed production facilities and distribution centers, interactions between different complexes should be taken into consideration and their optimization should be tackled simultaneously. In recent years, multisite production and distribution planning problems have received a good deal of attention in the literature [2-4].

The planning problem covers a time horizon of a few months to a year and is concerned with decisions such as production, inventory, and distribution; whereas the scheduling problem deals with issues such as assignment of tasks to units and sequencing of tasks in each unit that covers a time horizon of a few days to a few weeks. Since there is a significant overlap between different decisions levels, it is necessary to integrate planning and scheduling problems to achieve global optimal solutions for the entire supply chain [5]. For multisite facilities, the size and level of interdependences between these sites present unique challenges to the integrated tactical production planning and day-to-day scheduling problem. These challenges are highlighted by Kallrath, 2002 [6].

In this work, we focus on the integration of planning (medium-term) and scheduling (short-term) problems for the multiproduct plants that are located in different sites and supply different markets. In recent years, the area of integrated planning and scheduling for single sites has received much attention [7-9]. Although most companies operate in a multisite production manner, very limited attention has been paid to integrating planning and scheduling decisions for multisite facilities.

We first propose an integrated planning and scheduling model for multisite production and distribution facilities that takes into consideration shared resources and intermediates between production facilities, transportation time between production facilities, between production site and distribution center, and in some rare cases, between distribution centers. To account for the situations when—due to production capacity limitations or raw material availability limitations—industry cannot satisfy the demand; we consider the option of hiring external contractors. The full-scale integrated planning and scheduling optimization model spans the entire planning horizon of interest and includes decisions regarding all production sites, distribution centers, and transportation between them. Since the production planning and scheduling levels deal with different time scales, the major challenge for the integration using mathematical programming methods lies in addressing large-scale optimization models. When a typical planning horizon is considered, the integrated problem becomes intractable and a mathematical decomposition solution approach is necessary. To effectively deal with complexity issues of the integrated problem, the block angular structure of the constraints matrix is exploited by relaxing the inventory constraints between adjoining time periods using the augmented lagrangian decomposition method. To resolve the issues of non-separable cross-product terms in the augmented lagrangian function, we apply the diagonal approximation method. This decomposition then results in separable planning and scheduling problems for each planning period and for each production site. To illustrate the effectiveness of the proposed model and decomposition approach, we apply them to different sizes case studies.

Although the work discussed in the previous paragraphs focuses on the integration of planning and scheduling (tactical and operational level in supply chain management [SCM]), the next step is to move up the SCM hierarchy and incorporate strategic-level decisions, including network optimization (including the number, location, and size of warehousing, distribution centers, and facilities). With this work we hope to convey the role of the integration and the importance of simultaneous consideration of different decisionmaking levels in SCM.

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Wesley Ingwersen

My primary interest is in improving methods to measure product environmental sustainability, which I approach with a systems perspective, and typically with a life cycle assessment framework. Through our sustainable supply chain research programs in biofuels and consumer products in the Sustainable Technology Division at EPA, we are approaching supply chains both from the national scale (for fuels) and at specific corporate supply chains (for consumer products). Within the supply chains we are looking into specific agricultural and manufacturing processes and beginning to understand how to design in changes that result in full life cycle improvements. Relying on single indicators of environmental performance can be misleading in terms of sustainability. Therefore, we are working on selecting indicators and applying more complex system-level metrics (e.g., emergy) to measure sustainability of individual processes as well as complete product systems. Supply chain sustainability assessment at all scales requires new ways to measure, exchange, and process large amounts of data and also requires working with teams with experts on various processes with a high-level of coordination. We are in the process within our group of building our capacity to perform these assessments. At the same time, we are trying to create a model for sharing life cycle data and models—using standardized, transparent, and non-proprietary models to the extent possible—that can feed into the work of others in this growing field.

While we are attempting to advance the science of supply chain assessment, it is also practically important to set standards for ways that manufacturers can make environmental product claims in the meantime so that fair comparisons can be made that will allow market mechanisms to work to favor more sustainable supply chains. For this reason, I am engaged in efforts to standardize rules for life cycle-based product claims, with the aim of making claims more rigorous and to prevent "greenwashing."

Olivier Jolliet

Having been involved in the development of Life Cycle approaches and methods during the last two decades, here are a few lessons learned related to our research experience on life cycle and supply chain management:

- KICS (Keep It Cleverly Simple) is my preferred approach to understanding complex systems, such as sustainable supply chains, identifying the key technological, environmental and economic processes and focusing analyses on these.
- We presently see several signs of maturity in Systems and Life Cycle Research applied to products. For example, the field of life cycle toxicity assessment is fully part of a collaborative effort in which scientists from multimedia modeling, risk assessment, indoor air pollution, and LCA have, for example, commonly defined the concept of intake fraction (Bennet et al., 2002). In addition, life cycle and supply chain approaches are published in the best environmental journals, such as *Environmental Science and Technology*; furthermore, journals such as *International Journal of LCA* or *Journal of Industrial Ecology* now have relatively high impact factors in science citation indices.
- In this sense, methods and databases such as those recommended by the EU for impact assessment are operational and can now be applied.
- There is still a lot to be achieved by bringing specialists and system researchers closer together. An area of special need is the understanding of sustainable consumption (i.e., linking consumption, production and its supply chain, emissions, and population impacted in a consistent framework). One of our contributions is to demonstrate, for example, that around one fourth of the impacts of particulate matter in Asia are due to OECD consumption of products outside of the region (mostly North America and Europe).
- Taking only cost-effective actions to reduce environmental impacts will not lead, in and of itself, to sustainable consumption. Money saved by the consumer with, for example, energy savings, may and will be reinvested in other activities, such as flying, which may be even more environmentally damaging than the initial activity.
- Therefore, policies for sustainable supply chain and consumption should be complemented by public and corporate sustainable consumption strategies that provide incentives to a) carry out all cost-effective actions to mitigate environmental impacts and promote social well-

being, and b) reinvest the saved money "for sustainability," (i.e., in efficient measures that are *not* individually cost effective but are close to). In the aggregate, overall costs will be similar to the initial situation, but with far better environmental or social performances.

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Vikas Khanna

Designing sustainable products and processes requires joint consideration of economic, environmental and social aspects that span multiple spatial and temporal scales. Proper understanding of the complex interactions at multiple scales is crucial for designing sustainable product supply chains. With greater appreciation of environmental challenges, methods that take a holistic life cycle view have been developed and utilized for evaluating the life cycle environmental impacts of products of processes. Some examples include life cycle assessment, material flow analysis, and thermodynamic-based methods for sustainable engineering. While life cycle approaches represent an important step in the context of sustainable process design, their utility is limited for engineering decision-making due to several formidable challenges. These include the selection of arbitrary process boundaries, the static nature of most existing methods, and combining data at multiple scales and in disparate units. This is especially challenging for emerging products and technologies at an early stage of research, such as nanoproducts. In reality, data and models are available at multiple spatial scales ranging from the narrowly focused equipment or manufacturing scale, to the supply chain and the economy scales. The outstanding challenge is the integration and utilization of available information across scales in a systematic manner for the environmentally conscious design of products and supply chains.

In my opinion, some knowledge and/or data gaps within my discipline for the sustainable design of products and supply chains are as follows:

- Inadequate understanding of dynamic modeling tools
- Lack of a better understanding of tools and techniques across scales
- Improved understanding that may lead to recognizing patterns and developing heuristics for sustainable design of product networks
- Collaboration across disciplines

- Better education in sustainable engineering

Progress in the above domains could play a crucial role in reducing the environmental impact of existing products and processes and sustainable development of emerging technologies.

Chris Koffler

Chris Koffler's Ph.D. dissertation was on *Automobile Product Life Cycle Assessment* (Koffler, 2007). His focus was on streamlining the process of conducting Life Cycle Assessments for complex technical products such as passenger cars as a prerequisite for a better integration in the product development process. In his Ph.D. thesis, he developed a procedure that included specifying and implementing software to collect and process all necessary data for full vehicle LCAs in a semi-automatic manner, reducing the overall effort required by well over 80 percent (Koffler et al., 2007). All current vehicle and technology LCAs published by Volkswagen today are based on this system (www.environmental-commendation.com). The rest of the thesis evolved around decision-making based on LCA indicator results, challenging common approaches of Multi-Attribute Decision-Making (MADM) in terms of their effectiveness in group decision making. He then proposed a combined approach of MADM and Voting Rules to arrive at a decision more likely to represent the majority of the decision makers' preferences in a panel-based decision situation (Koffler et al., 2008). Both of these publications represent relevant references in the problem field of Design for Environment.

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Reid Lifset

My experience related to the design of supply chains stems from my work as editor-in-chief of the *Journal of Industrial Ecology (JIE)*. Sustainable supply chain management is a component of the field both in terms of assessment (i.e., via life cycle assessment) and with respect to more normative efforts to improve environmental performance. The field engages these topics under the rubrics of life cycle management, a generally qualitative approach that encompasses both upstream and downstream considerations, and supply chain management, especially closed loop supply chain (CLSC) management, as studied by an allied research community within the field of operations research. My personal research does not involve the design of sustainable supply chains, but I have observations to offer from the bird's eye view provided by my role as editor.

- Most research to date is polarized between static (snapshot) environmental assessments and analytically sophisticated, but overly complex, operations research (OR) models.
- There is a strong disconnect between the research in the traditional field of supply chain/operations management (*aka* operations research—OR) as practiced in business schools and the questions that arise in environmental circles. The OR field prizes analytic rigor and often does not reward applied work. Where environmental issues are engaged—most prominently in the CLSC literature—the environmental dimensions are thin. For example, environmental performance is often proxied as the number of products returned or remanufactured, rather than environmental burdens reduced. Some work on carbon footprinting is emerging, but it is nascent.
- There is OR literature on the design of supply chains associated with names such as Hau Lee at Stanford and Corey Billingto at IMD. In my role as chair of the 2010 Gordon Research Conference on Industrial Ecology, I sought speakers who had applied their expertise in the design of supply chains to issues of sustainable supply chains, but was unsuccessful.
- The well-deserved emphasis on GHG emissions from supply chains needs to be balanced by more comprehensive environmental analyses (i.e., including conventional air and water pollutants, toxicity, ozone depletion, etc.). Carbon footprinting should complement, not displace, the multi-attribute environmental characterizations generated by LCA; otherwise, we will end up with more situations like corn ethanol, in which attention to GHGs played a role in neglecting the water quality problems posed by corn cultivation (i.e., excess nitrogen and hypoxia).

My motivation in attending this workshop is to see where current work in this domain is heading in order to encourage valuable papers in the *Journal of Industrial Ecology* and to help shape the direction of work through the workshop discussions.

Dennis McGavis*

Product innovation in the flooring business at Shaw has brought sustainability improvements in both the commercial and residential markets over the past several years, resulting in significant energy, GHG, water, and solid waste savings. Further, significant decreases in energy use, GHG generation, and solid waste production at our manufacturing plants have been accomplished. As a sustainability expert for this business, it is my role to identify opportunities for product and process improvements and to work with our Innovation and R&D teams to find appropriate chemistries that meet our Design for Environment (DfE) goals. Sustainability is central to Shaw's business and growth strategy and in our commitment to touch and improve our customer's lives now and for generations to come. Sustainability is brought to life through programs that integrate our core values with product development, understanding our customer's needs, lifecycle assessment, trade organizations, multi-stakeholder groups, safety, operations, logistics, suppliers, etc. We collaborate closely with suppliers across the entire supply chain as they are our source of materials, packaging, systems, services, and ideas for innovation. We view suppliers as critical partners in improving the environmental performance of our end-to-end supply chain. We also learn from each other's best practices as we navigate the emerging field of sustainability.

My interest in the workshop is to better understand how experts in other industry sectors are improving the sustainability of their products, processes, operations, and supply chain. If possible, I would like to bring their experiences into Shaw to share best practices with the goal of building a world class Product Stewardship and Sustainability program.

Eric Masanet

There is growing interest among manufacturers, retailers, and governments in understanding the supply chain energy and carbon "footprints" of products, as well as in ways to reduce such footprints. While much attention has been paid to life cycle assessment (LCA) methods for environmental footprint estimation, comparably little attention has been paid to robust, quantitative methods for analyzing design, process, and policy opportunities for reducing product environmental footprints. Supply chains are not static systems, and they often cannot be credibly assessed using static life cycle inventory (LCI) data. Rather, they consist of discrete processes and technologies that vary over scales of time and space, and from supplier to supplier. For robust decision making regarding low-carbon supply chain performance, modeling details on process and technology options are critical, both for understanding the underlying sources of emissions in a supply chain and for identifying realistic options for reducing such emissions. My research has developed a hybrid supply chain modeling approach, which couples input-output LCA methods with sector- and process-level techno-economic energy analysis data and methods. The approach allows for both environmental and economic assessment of discrete technology and process improvement opportunities across the many energy and emissions sources, end use technologies, and sectors that comprise a product's supply chain footprint. It also provides insights on how much carbon can be saved at what level of cost investment. Preliminary results suggest that there are key technology proxy data that correspond to low-carbon supply chain performance, which might be more easily compiled by OEMs than (often highly uncertain) carbon footprint data. Technology data can provide much-needed information to establish low-carbon supply chains while the states of data and science on quantitative metrics evolve. Furthermore, preliminary results suggest that there are many low-hanging fruits for emissions savings in the supply chains of services, which, compared to industrial and agricultural products, have received limited attention in supply chain carbon footprinting initiatives to date.

Dima Nazzal

My research in sustainability has two main thrusts:

(1) Analyzing product servicing as a mechanism for sustainable consumption and measuring its impact on a firm's production, inventory, and capacity expansion decisions.

Combining product lifespan extensions with eco-efficiency, defined as the increased resource productivity that enables simultaneous progress toward economic goals and environmental goals by reducing resource intensity and ecological impacts, is key to achieving sustainable consumption. Product servicing has been proposed as a mechanism for extending lifespans. However, including servicing can be a cause of concern, and even resistance, for a producer needing to watch its bottom line. My research focuses on understanding the structure of the integrated product servicing and production systems and the decision tradeoffs will help to support the proposition that reducing consumption via a shift to product servicing does not automatically imply a drop in producer's profit.

(2) Integrating Life Cycle Assessment (LCA) into production, pricing, and logistics decisions in supply chains to assess and minimize the environmental impacts of such decisions.

Life Cycle Assessment (LCA) studies the varying levels of damage to the environment that occur throughout the "life" of a product, from resource extraction to manufacturing, end-use, disposal, and recycling. Historically, LCA has mainly been applied to products, but recent literature is examining how LCA assists in identifying more sustainable options in process selection, design, and optimization. The research investigates the relationship between environmental impacts and supply chain planning decisions in order to characterize environmentally-conscious supply chains and understand the tradeoffs between the environmental metric and the economic metric.

Sergio Pacca

We have been working on supply chain analysis of sugarcane ethanol because of the intrinsic vocation of the Southwestern Brazil region as a biofuel producer. Several studies are found in the academic literature but most of them are based on corn feedstock. We realized that there is a lack of life cycle assessments of sugarcane ethanol.

The scientific development of this research field over the last 5 years was intense. For example: discounting carbon emissions over the life cycle of biofuels; accounting for direct and indirect land use change effects; accounting for various stocks and flows of carbon such as soil carbon, and several other issues. In our studies, we always take as granted the life cycle approach to investigate the net result of biofuels use versus fossil fuels. Therefore, we apply consequential life cycle assessment methods. In our last study, we wanted to show that besides ethanol sugarcane is a source of electricity (bioelectricity), and the joint consumption of these two secondary energy types might increase the mobility efficiency per unit of cropped land. We realized that it is possible to improve the efficiency of sugarcane based energy as a mobility source, and that such a scheme brings in environmental benefits. In this work we considered technology that is currently available and cost competitive for energy production and end-use, and showed that the land required to power our current mobility needs is less than it is usually stated.

According to our results, based on 2010 values, 2 million ha are enough to power the Brazilian fleet, 25 million ha are enough to power the US fleet and 67 million ha are enough to power the global car fleet. If minor efficiency gains are considered, 19 million ha will be enough to power the US fleet in 2030, whereas the needs for the Brazilian and the global fleet remain basically the same due to efficiency gains. Our analysis shows that sugarcane's harvested energy density equals to 306 GJ. ha per year, which is 1.7 times the value usually reported in the literature for biofuels. As a result, and based on sugarcane's primary energy potential, 4% of the world's available cropland area is enough to power the global car fleet.

In a previous study we considered the potential of carbon sequestration and storage CCS in ethanol production. We calculated the amount of CO_2 released during fermentation and we concluded that if ethanol + electricity + CCS are fully exploited the use of sugarcane derived energy implies negative carbon emissions.

We consider that these results may shape new policies that support international sugarcane ethanol trade and the increase in the worldwide sugarcane cropped area, provided that other environmental impacts are considered. We understand that there is a limit to the maximum attained area but we understand that there is still room to expand sugarcane cropped area. However, the worthiness of this endeavor depends on the full exploitation of technological potentials.

It is important to take into account both the land and the carbon footprint of biofuels in an integrated way. It is important to consider end use technologies that maximize the life cycle energy efficiency of biofuels and reduce its land footprint.

Finally, we should consider assessments that go beyond accounting based on fossil fuel emission factors and include new scientific knowledge in the balance of greenhouse gas emissions. In developing countries, we still need to provide opportunities for the poor; therefore, it is important to include social aspects in the assessment of supply chains so that we foster sustainable development.

Furthermore, in addition to the climate change conundrum, several other environmental issues are prominent on the international policy agenda, and our assessments should identify synergies among coexistent environmental goals.

Omar Romero-Hernandez

Improving the sustainability and performance of products and services lies at the core of innovation and competitive advantage. Whether motivated by societal and environmental concerns, government regulation, stakeholder pressures, or economic profits, managers and policy makers need to continue making significant changes to effectively manage their social, economic, and environmental impacts. Focusing only on on-site emissions and local improvement has been proven to be insufficient and sometimes misleading. Upstream and downstream supply chain carbon emissions (other than a firm's direct emissions) can account for about 75% of the total emissions (see Matthews et al., 2008, and Huang et al., 2009). Similar problems arise if we try to evaluate water footprint or social impacts, such as health risk and working conditions. There is a need to understand the sustainability implications of a product along its whole supply chain.

One of the motivations for improving the sustainability of a firm's supply chain is the fact that customers and other stakeholders do not usually distinguish between a company and its suppliers. Furthermore, society usually blames the brand owner if its suppliers have poor environmental performance. Tackling this problem is not trivial. Since there are many activities in a supply chain, the interaction and trade-offs are complex. Trade-offs not only appear between the different activities, (e.g., transportation emission and the emission from suppliers), but also between different environmental impacts, (e.g., carbon emission and water consumption), interested parties (suppliers, OEMs, customers, local communities), business strategies, and initial incompatibility of regulations and business objectives. Economic, environmental, and social impacts are related to each other. We expect that when one of these impacts changes, the others will also be affected, hopefully in a positive way. To date, sustainable supply chains, environmental risk assessment, industrial ecology, have remained unlinked. There is a clear need to fill this void through multidisciplinary research.

This statement is based on previous research work carried out by our research group along with discussion with other colleagues who met in Berkeley on June 2006 to discuss the implications of measuring carbon and energy footprints in supply chains.

Our work has managed to address a set of sustainability criteria used for supplier selection, facilities location, and product manufacturing. Assessment models, a Life Cycle Assessment (LCA) methodology, and a hypothetical case study on modeling the shipping of goods.

A critical challenge for researchers is still to expand current models and incorporate the role of (i) data uncertainty and data quality and, (ii) human and environmental health. Ultimately, these attributes, along with previous work will help us to develop an integrated piece of knowledge that aims to (i) provide a basis for regulators and policy makers and, (ii) provide a robust set of the best sustainable practices to be adopted by those companies who wish to be part of a sustainable supply chain.

<u>Research Questions</u>

1. How do different multidisciplinary decisions, once integrated into a single framework, affect the overall sustainability performance of a supply chain?

   A simple cost analysis to determine the most suitable location for a manufacturing plant or the best network array may not represent the most socially responsible decision. Environmental loads of the whole supply chain may be significantly different from one location to the other.

There is a need to devise and test well-defined multidisciplinary framework for green supply chain operations. The framework will be based on empirical studies, with an emphasis on the multidisciplinary steps needed to keep high levels of reliability in the supply chain while keeping a green perspective. The issue of data uncertainty and data quality will be included in the framework.

A supply chain may be considered sustainable when the operation of the supply chain and its metrics (reliability, time, availability, etc.) are kept to the required levels of quality, and the improved supply chain leads to lower environmental impact (lower carbon footprint, lower use of resources, lower toxicity values along the chain, etc.), larger social benefit and sound financial models.

Integrating different tools and concepts such as LCA, human health, multi-objective modeling, and policy analysis into a business problem is indeed a significant challenge. Empirically, this can be tackled with a set of parallel activities that include: (i) risk assessment management, based on pollutant fate and transport model along with a dose-response model that will determine health impacts and hot spots, (ii) probabilistic models that provide a better understanding of data uncertainty and parameter sensitivity, (iii) a analysis based on existing case studies, databases and a reference case study to be developed by the research group, (iv) a public policy study based on scenario analysis.

2. How can we deal with uncertainty in the design of sustainable products and supply chains?

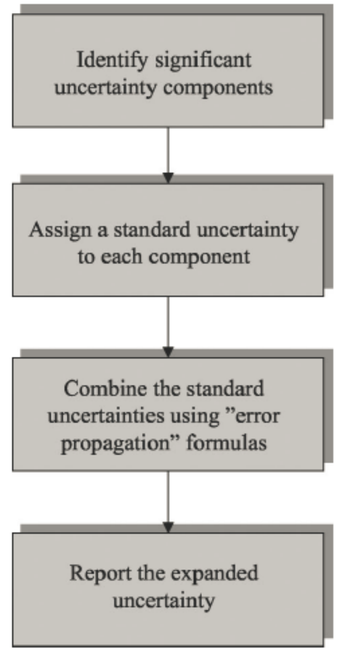
   Understanding uncertainty lies as one of firms' major challenges. Uncertainty arises from several sources, like incomplete or conflicting information, variability and errors among others. There is an increasing interest in LCA to include uncertainty. A preliminary literature review carried out to prepare this statement shows several case studies and methodological proposals, along with scientific-specialized databases. Probabilistic models will provide a better understanding on data uncertainty and parameter sensitivity. The mathematical method proposes processes and models, to combine individual probability distributions and produce a single distribution of the input data. This set of activities is presented in the following figure:

1. *Scanning uncertainties*, determining the variables and processes were the data is either not reliable or incomplete.

2. *Input uncertainties*, determination of the variability and uncertainty for each of the previous variables.

3. *Processing uncertainties*, incorporation of the uncertainties in the model, to use in statistical tests and analysis of error propagation.

4. *Output uncertainties*, report standard deviation, mean values, sensitivity analysis.



Connection to public policy. Government regulations and industry codes of conduct require that companies must increasingly address sustainability. Non compliance with regulations was (and still is) costly, as regulatory noncompliance cost to companies include: penalties and fines, legal cost, lost productivity due to additional inspections, potential closure of operations and the related effects on corporate reputation. Increased regulatory pressures would "push" companies to improve industrial performance. However, a better understanding on the suitable conditions to adopt cost effective project lies as the main driver for sustainable products and supply chain that lead to competitive advantages such as differentiation.

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Thomas Seager

Business strategy with regard to sustainability is currently dominated by an eco-efficiency approach that seeks to simultaneously reduce costs and environmental impacts using tactics such as waste minimization or reuse, pollution prevention or technological improvement. However, in practice, eco-efficiency optimization rarely results in improved diversity or adaptability and consequently may have perverse consequences to sustainability by eroding the resilience of production systems. An improved understanding of resilience is essential to sustainable supply chain management. To this end, it is important to recognize that resilience is differentiated from risk, and may be in opposition to eco-efficiency. In some cases, the system attributes that are critically important to resilience – such as spare capacity, reserve resource stocks, and redundancy, can result in increased costs and environmental impact.

Nevertheless, recent catastrophes such as the Fukushima nuclear power plant, flooding caused by Hurricane Katrina, the Deepwater Horizon oil spill, and the mortgage derivatives crisis have renewed interest in the concept of resilience, especially as it relates to complex systems vulnerable to multiple or cascading failures. As originally applied in an ecological context, resilience refers to the capacity of a system to adapt to changing conditions without catastrophic loss of form or function. However, in an engineering context, the meaning of the term resilience remains contested. It is most helpful to think of resilience a process, rather than a variable of state. An idealized model of resilience includes Sensing, Anticipating, Learning, and Adapting. These processes, summarized, are:

1. Sensing - The process by which new system stresses are efficiently and rapidly incorporated into current understanding.
2. Anticipation - The process by which newly incorporated knowledge is used to foresee possible crises and disasters.
3. Adaptation - The response taken after information from Sensing and Anticipation are carefully considered.
4. Learning - The process by which new knowledge is created by observation of past actions. After Adaptation the level of appropriateness of adaptive actions can be assessed and future iterations can incorporate this knowledge.

From this perspective, resilience analysis can be understood as differentiable and complementary to risk analysis, with important implications for the adaptive management of complex, coupled ecological-engineering systems. One case study in mobile phone manufacturing clearly illustrates how understanding this recursive process is essential for responding and adapting to unexpected shocks. (See Sheffi 2005). When a fire at a Philips' microchip plant in New Mexico interrupted production of a cell phone component critical to both Ericsson and Nokia, the two leading European manufacturers responded in different ways. Both manufacturers were notified of a disruption in supply (an example of sensing). Ericsson accepted Philips' promise that microchip deliveries would resume in a week. However, Nokia correctly anticipated the possibility of a more serious interruption. To enhance sensing, Nokia sent an investigative team from Scandinavia to New Mexico to learn more about the extent of the fire and Philips' reparation plans. As Nokia learned more about the potentially catastrophic consequences of the fire, they successfully adapted by contracting with alternative suppliers and modifying their cell phone design to work with alternative chips. By contrast, Ericsson was forced to halt production, resulting in an irrevocable loss of market share. This example illustrates how resilience is best understood as the consequence of continuous efforts, rather than as a property (such as strength) of a technological system.

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Ray Smith

In the Sustainable Technology Division of the National Risk Management Research Laboratory in the EPA's Office of Research and Development, an on-going research project is progressing in the field of Sustainable Supply Chain Design for Biofuels. As one of the leads on this project, along with Troy Hawkins, we have formed a team of researchers who are developing a methodology to assess the sustainability of supply chains with a focus on biofuel systems. Other biofuel life cycle studies have been done to analyze greenhouse gas emissions, energy use and production, and sometimes an additional aspect such as water use. Our team's work expands these categories to consider many environmental impacts in a life cycle assessment for the comparison of corn ethanol to petroleum gasoline. (Additional biofuel systems of interest will be studied in the future.) In addition to the comparative analysis, this research will provide information on environmental hot spots in the supply chains and will allow for consequential studies on improving the biofuel supply chain. Improvements could occur at the conversion facilities, in the transport of materials, in the methods used for farming feedstock's, etc. While the environmental impact results and other indicators provide meaningful information on individual aspects of the supply chain, a complete assessment of sustainability should consider broad-based sustainability metrics that integrate information from across the system. In particular, we are actively researching metrics in emergy, return on energy invested, ecological footprint, and green net value added. A breakdown in any one of these sustainability metrics would signal a breakdown of the whole system in terms of its sustainability.

Rajagopalan Srinivasan

Decision Making for Sustainable Supply Chain Management Using Agent-Based Models

As the issue of environmental sustainability is becoming an important business factor, companies are now looking for decision support tools to assess the fuller picture of the environmental impacts associated with their manufacturing operations and supply chain activities. Lifecycle assessment (LCA) is widely used to measure the environmental consequences assignable to a product. However, it is usually limited to a high-level snapshot of the environmental implications over the product value chain without consideration of the dynamics arising from the multi-tiered structure and the interactions along the supply chain. LCA results are derived from a product-centric perspective without considering the dynamics and effects of various logistics options, inventories, distribution network configurations, and ordering policies. These can be captured through a dynamic simulation model of the supply chain, incorporating LCA indicators for measuring environmental impacts.

Dynamic models of various supply chains can be developed using the agent-based modeling paradigm. The dynamics of any supply chain is governed by the behavior of intra-enterprise and external entities. Internal entities are functional departments within the enterprise that are involved in the supply chain operation: procurement, operations, sales, distributor, and logistics. Examples of external entities are suppliers, third-party logistics providers, and customers. In the agent-based modeling paradigm, these supply chain entities are modeled as individual agents whose interactions lead to system-level behavior (i.e., the overall supply chain performance). From a modeling perspective, the modularity imbued by the agent-based modeling paradigm enables easy customization of each entity. For instance, different policies can be plug-and-played and the effect of various decisions or disturbances on both the economic and environmental sustainability indicators can be evaluated. Context-specific triple bottom-line performance metrics such as economic profit and customer satisfaction and various indicators from environmental and social LCA can be incorporated into the model and evaluated through simulation. We have used such agent-based models to provide decision support in a wide range of case studies from specialty chemicals, biodiesel, and consumer products industries. These case studies involve different aspects of supply chain management—product decisions and strategic-level supply chain design decisions, as well as operational policy decisions.

In the product decision case studies, the supply chain sustainability of different product compositions is evaluated. While the trade-off between environmental impact and cost of using different raw materials is more easily observed, the case studies reveal that the recipe (specifically, amount of raw materials required) determines the transportation requirement, which could have a significant impact on the overall result.

At the strategic level, we have evaluated the impact of supply chain design decisions, such as upgrading a plant to produce a more environmentally friendly product. Another strategic-level case study evaluates the distribution network. While the single distributor channel could be more cost-efficient and easier to manage, two distribution channels would have the benefit of being at closer proximity to customers. Another advantage of the two distributor channels is that robustness increases since, in the event of disruptions, one can serve as a backup to the other, leading to higher customer satisfaction levels.

At the operational level, the effect of different supply chain policies is analyzed. In the case of ordering policy, less frequent ordering in larger batches would mean fewer transportation trips and consequently a reduction in transportation impact and cost. Another operational decision is supplier selection, where different suppliers with different reliability, cost, lead time, and environmental characteristics can be compared. The simulation model can also be coupled with optimization techniques (e.g., genetic algorithm) to optimize these decisions. Overall, these case studies serve to highlight the need for considering supply chain dynamics in any sustainability consideration and also the benefit of a multipurpose decision support approach.

Finally, even after comprehensive evaluation of the various effects, decisionmaking can be challenging since there are multiple performance indicators and numerous scenarios to consider. To ease decisionmaking, a triple-bottom line visualization scheme has been developed in the form of a ternary diagram, which consists of a collection of nodes. Each node in the diagram corresponds to a set of weights for the economic, environmental, and social indicators. For example, a node at (0.6, 0.1, 0.3) corresponds to a 60%, 10%, and 30% weightage for the economic, environmental, and social indicators, respectively. For each node, the policy (scenario) that yields the best performance is shown in the diagram. The ternary diagram thus visually brings out the robustness of policies (scenarios) across the weight space and shows regions where each policy (or scenario) yields the best overall performance.

Martha Stevenson

Through my formal background in forestry, I have cultivated the capacity to understand complex systems with complex relationships. I spent 5 years working at an environmental engineering firm cleaning up spills that had already occurred—affecting both soil and groundwater—and through this experience, I became determined to alter decision-making protocols that result in flawed systems with unintended consequences.

To this end, I read the literature of industrial ecology and went to work at GreenBlue, a non-profit focused on reducing industry's impact on the environment, to develop the Sustainable Packaging Coalition (SPC). The SPC is an industry working group consisting of 200+ companies spanning all positions on the supply chain. The premise of this project was to try and shift an entire industry toward more sustainable practice without merely shifting the problem to another point in the supply chain—instead, to evaluate the full life cycle. Our main approach was to educate critical industry participants (e.g., designers and engineers) and develop tools to improve their decision making. Through this work, I developed a deep understanding of Life Cycle Assessment and its use in the public interest, where there are strengths and weaknesses. I also have a solid understanding of Ecosystem Services, Toxicity Risk Assessment, Water Footprinting, Design for Environment, and Corporate Social Responsibility Reporting. I have participated in stakeholder venues and committees for the U.S. Department of Energy, EPA, GSA, and UNEP focused on product sustainability assessment. I have also worked with many Fortune 100 companies on these same issues.

My new role at World Wildlife Fund has enabled me a broader purview of conservation, something that was previously out of my comfort zone. Through this experience, it has become clear to me that many of the assessment methods traditionally used by companies to analyze product or supply chain sustainability do not capture some of the most important environmental impacts. They rarely take into account a fixed place in the world and all of the biophysical properties of that place, including species present, water availability, soil type, or current demands on natural resources. I am still in the learning and listening mode, but very interested in understanding the intersection of all different sustainability assessment methods and how they complement one another to analyze the broader issues by different audiences, through different views (boundaries), toward different impacts that occur at different scales. Once this larger framework is developed in an explicit way, I believe that a deeper understanding and more effective conversation will emerge toward preserving critical ecosystems and human health.

Given the current pressures on our planet, including climate change, water availability, ocean acidification, etc., sustainability assessment methods will prove to be one of two things: either a very detailed record of how we as a species destroyed our planet through the mismanagement and lack of imagination about industrial processes, or the roadmap by which, we as a species recognized our flaws and collectively designed a sustainable industrial system. My hope is for the second and I am excited to participate in these discussions at the Workshop.

Thomas L. Theis

Consumption, Sustainability, and Social Benefits

Product supply chains are usually defined in terms of the steps involved in acquiring, refining, and delivering materials and energy to manufacturers, plus the many stages of the manufacturing enterprise itself (including transport of parts, sub-components, and the final product or service) up to the point-of-sale to the consumer. Such chains can be quite complex to design and operate since they often involve hundreds of materials and suppliers, complex manufacturing processes, and quality control issues. Life cycle analysis grew out of industry's need to understand how these systems behave; and to develop workable models that could be used to control and optimize material and energy flows, ensure product quality, manage environmental impacts, and minimize costs. Complete life cycle approaches also examine consumer uses and the post-consumer disposition of the product, part of the product chain that is considered if significant regulatory or economic factors that are deemed to be the responsibility of the manufacturer are present (for example CAFE standards for automobiles; market trading schemes for SO_2 and NO_x). This has led to product conceptualization and development that incorporate "design for the environment," "green engineering," or "green chemistry" principles, and business practices built upon the concept of "eco-efficiency."

It is generally believed that if these principles and practices can become widespread enough (i.e., if the complete product chain can be "greened" enough), then better material and energy efficiencies will result, effectively "decoupling" environmental impacts from the consumptive habits of the human population. The social benefits of consumption are less clearly understood, but it is assumed that a greater variety of environmentally conscious products and services made available at lower costs will necessarily yield societal benefits, thereby moving toward at least partial fulfillment of the sustainability paradigm.

However, available evidence does not wholly support this conceptual framework. Throughout recent U.S. history (~100–200 years), increases in human consumption in fundamental sectors of the economy (energy, materials, transportation, and food) have consistently outpaced gains in manufacturing efficiency, resulting in greater, not lesser, resource consumption *on a per person basis.* In this presentation, these data will be reviewed and amplified, with a particular focus on the product-consumption-societal benefits chain associated with artificial lighting, a basic human need. The results illustrate the interplay among technological breakthroughs, efficiency gains, prices, and societal benefits; with a resulting increase, rather than decrease, in the total and per capita energy used for lighting. This is a tradeoff: higher energy consumption and accompanying energy-related contaminants versus benefits to society, the nature of which range from higher productivity, to better delivery of services, to a greater variety of products in commerce, to more aesthetic enjoyment of light-enabled activities. Whether nanotechnology-based solid-state lighting can reverse these trends while expanding benefits is yet to be demonstrated; however, long-term trends suggest that it is unlikely that efficiency gains alone will result in a more sustainable lighting sector for society.

These results point to three general directions for product-chain research:

1. The need for a much stronger interdisciplinary effort to understand the complex factors emergent across the complete product chain (including human behavior) that contribute to resource consumption, environmental degradation, and human health risk, while recognizing benefits to society;
2. The need to expand green, design for the environment, and organizational eco-design principles beyond their traditional focus on increasing efficiency and lowering pollutant loads per unit product to include economic and behavioral factors; and
3. The need to investigate more highly integrated policies, based on the sustainability paradigm, that are able to meet human needs while capturing economic excesses and decoupling environmental degradation that have their roots in over-consumption.

Arnold Tukker

Sustainable Product–Services: An Opinion

(1) Motivational statement providing the reason for conducting the study and its importance:

Product-service systems (PSS) are a specific type of value proposition that a business (network) offers to (or co-produces with) its clients. PSS consists of a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer needs. The PSS-concept rests on two pillars:

1. Inherently taking the final functionality or satisfaction that the user wants to realize as a starting point of business development (instead of the product fulfilling this functionality).
2. Elaborating the (business) system that provides this functionality with a greenfield mindset (instead of taking existing structures, routines, and the position of the own firm therein for granted).

PSS are often depicted as an opportunity to enhance resource efficiency and business performance at the same time. The EU Sustainable Product Development Network (SusProNet) aimed at analyzing the realism of this expectation and working with companies to see under which boundary conditions they would implement a PSS business model.

(2) Description of the method used:

As a Network project, SusProNet had limited opportunities for doing primary research. A thorough review of the business and sustainability research in the field was done and enriched with the practical experiences of the more than 20 companies that are part of the Network. This "practice research" ultimately was sublimated in key success and failure factures of PSS business models, policy implications, and a PSS business model development manual.

(3) Statement of the most important results:

PSS certainly have a potential to enhance competitiveness and contribute to sustainability at the same time. Compared to products, they can produce superior tangible and intangible value by delivering more customized solutions, and reduce the efforts of the customer "to make the product work." They also can lower system costs. In the case of result-oriented PSS, one actor becomes responsible for all costs of delivering a result, and hence has a great incentive to use materials and energy optimally. Finally, PSS can help a firm to improve the position in the value chain; for instance, if the PSS include elements with a higher profit margin or create unique and customized client relationships that cannot be copied by competitors.

PSS Type	Advantages	Disadvantages
1. Product-oriented services	Easy to implement Close to core business	Incremental environmental benefits (20%)
2. Use-oriented services	Medium (Factor 2) Changes consumer behavior Very successful in B2B context.	Low intangible added value => consumer acceptance difficult, because of ownership conflict, etc.
3. Result-oriented services	Radical (Factor x potential)	Risks/ Liabilities How to measure result? Customer loses power over means

However, PSS don't deliver such bonuses by definition. Particularly in a B2C context, product ownership contributes highly to esteem and hence intangible value. Access to the product is often more difficult, creating tangible consumer sacrifices. Costs can be higher if the PSS has to be produced with higher-priced labor or materials, or when the often more networked production systems generate high transaction costs. Sometimes a switch to PSS may weaken the position in the value chain. In industries where excellence in product manufacturing and design form the key to uniqueness and hence power in the value network, diverting focus to an issue such as PSS development is a recipe to lose rather than win the innovation battle.

(4) Discussion of the relevance of the results:

In sum, firms have to assess carefully if they can competitively make and consumers will buy their PSS. SusProNet helped considerably to untangle some simplistic myths that PSS always would be sustainable and always make business sense. It helped to identify factors that businesses need to take into account in their analyses if a switch to service-oriented business models makes business sense.

(5) Implications of these results for the design of sustainable product systems and supply chains:

SusProNet helped to provide a realistic development framework for PSS that makes true business sense and offers environmental benefits. It also made clear what limitations concepts like PSS and sustainable supply chain management have to realize a sustainable society. The true problem from a sustainability perspective is that society needs major system innovations. These are a form of creative destruction, in which also contextual factors and framework conditions must change. This needs a much broader system approach than the business-consumer interaction along a value chain, so central to the PSS concept. Therefore, the fostering of system innovation needs a broader analytical frame that combines insights of business developers, designers, consumer scientists, and system innovation specialists in its effort to depict credible implementation pathways for sustainable systems in the field of food, mobility, and housing/energy.

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Don Versteeg

Product innovation in the Fabric & Home Care business of P&G has brought compact liquid and powdered detergents, an ultra-compact unit dose detergent, and a coldwater detergent to the market in the past several years, resulting in significant energy, GHG, water, and solid waste savings. Further, significant decreases in energy use, GHG generation, and solid waste production at our manufacturing plants have been accomplished. As a sustainability expert for this business, it is my role to identify opportunities for product and process improvements and to work with our technology groups to find appropriate chemistries that meet our safety and sustainability goals. Sustainability is at the heart of P&G’s purpose and in our commitment to touch and improve consumer’s lives now and for generations to come. Sustainability is brought to life through programs that integrate our core values with product development, consumer understanding, appliance manufacturers, life cycle assessment, trade organizations, safety, operations, logistics, suppliers, etc. We collaborate closely with suppliers across the entire supply chain, as they are our source of materials, packaging, systems, services, and ideas for sustainable innovation products. We view suppliers as critical partners in improving the environmental sustainability of our end-to-end supply chain. We also learn from each other’s best practices as we navigate the emerging field of environmental sustainability. Our supplier interaction is governed by guidance documents, expectations, and a scorecard that we use to understand progress against sustainability goals.

My interest in the workshop is to better understand how experts in other industry sectors are improving the sustainability of their products, processes, operations, and supply chain. If possible, I would like to bring their experiences into P&G to help us meet our goals and will bring our supplier scorecard to share.

Eric Williams

My sense is that the main recent development in sustainable supply chains is increased use of Life Cycle Assessment. There are high expectations being put on LCA, in particular efforts to use LCA for consumer labeling that would distinguish between similar products from different manufacturers. There is a need to grapple with uncertainty in LCA. I see dealing with growth and rebound effects as key unsolved challenges that link with the definition of a “sustainable supply chain.” The common metrics used to measure progress focus at the product level, but it is not clear that improvements at the product level will be sufficient to manage sustainability issues of the whole production system.

Phil Williams

Supply Chain Carbon Accounting Position Statement

The following information is offered to serve as back ground information to help provide orientation on Webcor Builders and our relationship with supply chain carbon accounting.

As a General Contractor/Builder we specialize in large commercial projects in California that range from high rise multi-tenant condominiums, apartments, hotels, and offices. We also have extensive experience in owner-occupied corporate campuses, museums, and medical acute care facilities. In business terms our annual revenues average over $1 billion utilizing just 400-450 permanent employees. In addition to our General Contracting/Builder division we are the 8th largest specialty structural concrete contractor in the nation and provide international construction management consulting services.

In 2009, we were the first firm from any industry category in California to report our complete scope 1, 2, and 3 carbon emissions to the California Climate action Registry (CCAR). In that analysis we reported that 99.6 percent of the carbon we generate is from our scope 3 emissions and 0.4 percent was a result of our scope 1 and 2 activities.

(1) Critical point of information: The fact that 99 percent of our emissions are from our supply chain made it very clear to us that one of the greatest impacts we could make was squarely in our scope 3 supply chain in the form of the embodied energy/CO_2-e in building materials and activities.

As a company we strive to incorporate all aspects of sustainability in our projects. In 2010, more than 98 percent of our revenue was generated from projects that were registered or received certification under the U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED). USGBC and LEED are widely recognized as the world’s largest independent third party green building organization and most broadly accepted and respected building rating system. The LEED system measures environmental impacts from the site, water efficiency, material resources (MR), energy and atmosphere, indoor environment quality, and innovation in design. The USGBC does not create standards. They adopt accepted standards from other professional organizations (ASHRAE, BAAQMD, IEEE, EPA, etc.) and award credits based on the levels of performance per those independent standards.

The LEED system category that deals with materials is Material Resources (MR). M.R. is currently very limited in scope and the credits awarded are based upon a percent of products sourced within 500 miles from the project site, percent of material that is recycled content, sustainably harvested wood, rapidly renewable materials, and low or no VOC off gas from materials. While these measurements try to reduce the embodied energy of materials they do not have a basis in science, they do not use accepted carbon accounting methodologies and are not related to any LCA systems. It is best to say that the attempt to quantify materials in buildings was admirable when the USGBC LEED systems were first introduced in 1998, but they are immature and due for improvement.

(2) Critical point of information: The USGBC LEED system provides the building industry with a mature, widely accepted building rating system and tens of thousands of professionals who are attempting to quantify and qualify the sustainability aspects of materials as part of the rating system. Unlike any other significant industry in the U.S., the commercial building design, construction, and user/ownership community has pressing marketing and technical needs and an immediate demand for an accurate supply chain carbon accounting system that can be readily adopted by manufacturers and credibly applied to the LEED rating system.

In 2009, our proposal was accepted by the San Francisco Public Utilities Commission (SFPUC) to provide scope 3 carbon accounting services for their new 250,000 square foot headquarters project. This work was outside of any LEED credit. As a result of the collaborative effort a concrete structure was delivered with CO_2-e emissions 7 million pounds less than what would have been provided under the LEED systems as a sustainable “green concrete”. This 7 million pound reduction represented over 49% of the total embodied energy of the buildings structural system. We are now providing other major California construction projects with this same scope 3 supply chain design formulation and site verification accounting procedure.

(3) Critical point of information: The hybrid economic input-output (Hybrid EIO) method was utilized for our CCAR reporting as well as for the SFPUC project. This method was selected because it uses readily available financial information and is rapidly and accurately customizable for our wide variety of products and the large quantities of new “green” materials. This same method is actively being employed on additional projects.

To further embody energy research related to building design, materials, and construction, in 2009 Webcor and six other west Coast firms met and formed the Carbon Leadership Forum (CFL). The CFL selected the University of Washington and Kate Simonen as part of the College of Architectural and Environment Design, as the institution to host this independent non-industry specific research effort. We also work closely with Stanford University and Dr. Michael Lepech in support of their supply chain and LCA graduate student research.

Additionally, in 2010 Webcor was selected by the World Resource Institute (WRI) as a “Road Tester” for their supply chain accounting standard. Of the 70 global firms selected, only Webcor represented the commercial building industry. The WRI standard is set to be released to the public on October 4th of this year in New York City.

(4) Critical point of information: Even as research continues regarding supply chain accounting methodologies, there is enough accurate and accepted information available to allow industries, agencies, and government bodies the ability to adopt reasonable scope 3 supply chain standards. Supply chain scope 3 CO_2-e emission reductions can be immediate, substantial, and bankable. Operational CO_2-e emissions are surely needed; however, they are

accrued over long time periods, are small on an annual basis, and because they require continued operations and facilities upkeep, they are variable.

Fengqi You

Optimal Design and Operations of Sustainable Biomass-to-Liquid Hydrocarbon Fuels Supply Chains Under Uncertainty

Concerns about climate change, energy security, and the diminishing supply of fossil fuels are causing our society to search for new renewable sources of transportation fuels. Domestically available biomass has been proposed as part of the solution to our dependence on fossil fuels. Biofuels, especially liquid hydrocarbon fuels produced from cellulosic materials, have the benefits of significantly reducing greenhouse gas (GHG) emissions and leading to new jobs and greater economic vitality in rural areas. [1, 2]. The U.S. only produced less than 1 billion gallons of liquid fuels from cellulosic materials in 2010, but the Renewable Fuels Standard (RFS) establishes a target of 16 billion gallons of cellulosic biofuel annual production by 2022 [3, 4]. In observance of this mandatory production target, many new cellulosic biomass-to-liquid hydrocarbon fuels supply chains will be designed and developed in the coming decade for better economic, environmental and social performances. However, uncertainty resulting from supply and demand variations may have significant impact on the biofuel supply chain. Therefore, an efficient optimization strategy is urgently needed to for the design and operations of sustainable and robust biomass-to-biofuel supply chains.

In this work, we address the optimal design and planning of biomass-to-liquids supply chains under supply and demand uncertainty. A two-stage stochastic mixed-integer linear programming (SMILP) model combined with Monte Carlo sampling and the associated statistical analysis [4, 5] is proposed to deal with different types of uncertainty, and it is incorporated into a multi-period planning model that takes into account the main characteristics of the advanced biofuel supply chains, such as seasonality of feedstock supply, biomass deterioration with time, geographical diversity and availability of biomass resources, feedstock density, diverse conversion technologies and byproducts, infrastructure compatibility, demand distribution, regional economic structure, and government incentives. In the two-stage framework, the supply chain network design and capacity planning decisions are made “here-and-now” prior to the resolution of uncertainty, while the production, transportation and storage decisions for each time period are postponed in a “wait-and-see” mode. The SMILP model integrates decision making across multiple temporal and spatial scales and simultaneously predicts the optimal network design, facility location, technology selection, capital investment, production operations, inventory control, and logistics management decisions. In order to solve the resulting large scale SMILP problems effectively, a decomposition algorithm based on sampling average approximation [5] and multi-cut L-shaped method [6, 7] is proposed by taking advantage of the problem structure.

In addition to the economic objective of minimizing the annualized net present cost, the SMILP model is also extended to integrate with life cycle assessment (LCA) and regional economic input-output (REIO) analysis through a multiobjective optimization scheme to include two other objectives: the environmental objective measured by life cycle greenhouse gas emissions and the social objective measured by the number of accrued local jobs resulting from the construction and operation of the biofuel supply chain. The multiobjective optimization framework allows the model to establish tradeoffs among the economic, environmental, and social performances of the cellulosic biofuel supply chains in a systematic way. The multiobjective optimization problem is solved with an ε-constraint method and produces Pareto-optimal curves that reveal how the optimal annualized cost and the supply chain network structure change with different environmental and social performance of the entire supply chain [10, 11].

The proposed optimization model and solution method is illustrated through county-level case study for the state of Illinois. Three major types of biomass, including crop residues, energy crops, and wood residues, and three major conversion pathways, including biochemical conversion, gasification followed by Fischer-Tropsch synthesis and fast pyrolysis followed by hydroprocessing are considered. Uncertainty information is generated from the time series analysis [8] based on the historical data of biomass feedstock supply [9] and liquid fuel demand [1]. County-level results will be presented that provide regionally-based insight into transition pathways of biomass production and conversion. Computational results also demonstrate the effectiveness of the proposed decomposition algorithm for the solution of large-scale SMILP problems.

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Breakout Group Notes

Session II

Group 1 – Discussion Leader: Thomas Seager

PowerPoint Slides:

I. Paradox of Policy and Sustainability

- Policy can be both a impetus (driver) and an obstacle to innovation
- Policy can originate in government, but it can also originate in other places (e.g., USGBC).
- Technology and policy are complicated. The technological stability of the building industry (e.g., compared with electronics) may have facilitated other types of innovations, such as creating a market for green buildings based upon standards that are progressive, but not rapidly obsolete

II. Resource Risk Assessment

- Incremental increases in vulnerabilities
- Have LCA, LCC, but no algorithms for materials scarcity or supply chain vulnerability
- Non-linearity
- It takes a catastrophe

III. Climate change and Technological Systems

Group 2 – Discussion Leaders: Troy Hawkins and Bert Bras

PowerPoint Slides:

- System boundary issues:
  - Economic value system (the consumption society) – is it off limits?
- Policy drivers can create value for renewables or other sustainable technologies
- Subsidies can help, but also hurt (= challenge) – also need to be strategic and well informed
- Local versus global needs and solutions
- Possible workshop outcome: don't fund technologies, but fund studies/analyses that can inform the policies

- How do you get industry to participate?
- Job are a challenge
- Need for clear consensus on science is needed. "It depends" is a difficult thing to understand for policy makers
- Overcome stereotypes of "bad" industry, emotional NGOs, etc.
  - How do you convey environmental information to consumer an others
  - Studies on consumer behavior?

Future Drivers

- Industry does not like uncertainty in policy and being involved with informing would help all.
  - Level playing field is preferred
- Affect consumer behavior
  - Rule out certain products

- Give information – but difficult to condense
- Scoring system like LEED?
  - Problems exist
  - Do benefits outweigh the problems

Real Drivers – Future Lack of Resources
• Energy, water, selected materials are really the true future constraints compared to jobs right now o Studies needed for full understanding of available of material and energy stocks o Also, how do we trade-off? o Even ecological economics and value of ecosystem services have severe uncertainties

Next gen US strengths in Sustainable Design (1)
• Stewardship program around "endangered" materials o Status, conservation, recycling • Also look at material substitution and game-changing technologies o Where can US companies really take a leading role versus foreign companies • Turning expertise into an opportunity: o Bio/fuel refineries from paper factories o Floating wind farms from oil platforms o Requires some governmental leadership

Next gen US strengths in Sustainable Design (2)
• Is industrial symbiosis a new way to revitalize US manufacturing o Local inefficiencies can be allowed but overall effectiveness increases • Research opportunity: o Look at entire US industry and see opportunities for cross-industry symbiosis o Are there simple pairings possible? ▪ Wine store is always next to grocery store ▪ What are the best practices? • Pre/Non-competitive industry collaboration exists and needs to be fostered

What SHOULD we be good at
• Long term thinking o For example, lack of energy policy… o Without long term policy, competitive behavior is focused on short term • Better linking branding to sustainability and long term (economic) viability • Disconnect between funding from industry and NSF for academia o More funding for research on system level issues where collaboration between industry and academia is required

Notes:

- Bill Flanagan: Are we supposed to discuss the larger societal context for consumption? Policy drivers determine the framework in which we operate; policy drivers could provide market for renewables.
- Think about solar energy – needs subsidies.
- What is our ability to provide a clear consensus?
- Industry needs a consistent, level playing field.
- Dupont teamed with NRDC to provide guidelines for nanomaterials.

- Could this policy stay in place for the long term?
- NGOs completely ignore science in favor of emotion.
- How do we handle the NGO issue?
- Could we have credible third parties?
- Improving education:
    - Will consumers respond well to environmental labels?
- Future drivers?
- Thoughts:
    - How to reconcile?
    - Creative destruction versus collaborative regulation
    - Efficiency versus disposable income.
- How do you manage sustainable new products in the context of growth?

<u>Group 6 – Discussion Leaders: Ignacio Grossman and Ray Smith</u>

PowerPoint Slides:

Q1A: What are the challenging industry and societal problems to be solved?
• Resource Availability, Human Health and Ecosystem Health (e.g., Climate, Biodiversity, Rare Earths, Future Energy needs) • Increasing Wealth Disparity and Rising Middle Class in BRIC Countries • Short-term perspective (e.g., quarterly returns and 2-year budgets)/Ethical Challenges in Financial Institutions • Loss of Credibility in Authority and Traditional Institutions • Population Growth What are the future drivers for design of sustainable products? • Corporate – Product Differentiation, Company Survival (Source Supply), Imitation of Corporate Leaders • Climate Adaptation – (e.g., loss of available agricultural land but more mouths to feed) • Technologies that solve problems AND create resources • Bottom of pyramid product design will revolutionize design and consumption

Q2: What are the next generation sustainable design-enabled strength areas in the US?
• Rebrand US as a sustainable global leader • Sustainable Nano-tech and Nano-manufacturing, Cyber Infrastructure, Advanced IT and Systems Engineering, Biotechnology • Conservation, Social Networking, Pragmatism, Power of Philanthropic Sector, Creativity • Private Sustainability Consortia Where are the Gaps in Knowledge? • Education, Knowledge of History, Vision, Naiveté • What are the new feedstocks for materials and energy • We do analysis by sector or silo, never big picture – no overall quantifiable goal. • Do we really know all of the impacts? What about that which we cannot measure? • Lack of will • Insufficient collaboration and trust between disciplines.

Q3: What are the problems faced by existing sustainable design capabilities?
• Inexpensive energy and material resources • Lack of data (also seen as recalcitrant sector excuse) • Lack of verification of LCA results • Need undergraduate and graduate school programs • Lack of open standards for data What are the opportunities for design of sustainable products, manufacturing systems and supply chains? • Minimal standards for eco-design • Remanufacturing • Sustainable design tool kits • Design consortia that compete to be green • Pre-competitive collaboration networks • Finding environmental leverage points • Taxing bads and rewarding goods

Notes:

- Challenging Problems:
  - Replacing rare earths
  - Resources, biodiversity, climate, human health, ecosystems
  - Wealth disparity growing to extremes
  - Overall increases in consumption (from BRICs' middle class)
- Also a development goal:
  - Short-term outlook
  - Lack of awareness of sustainability
  - Population growth (shrinkage)
  - Lack of roadmap
  - How do we design something we don't know what it looks like?
  - How do we secure energy in the future?
  - Ethical challenges in finance and capitalism
  - Loss of credibility and authority in traditional institutions
- Drivers
  - Product differentiation provides value (lose big picture)
  - Self-interested focus on corporate survival by some companies is creating leadership pressure by citizens
  - Imitation of corporate leaders
  - Climate adaptation
  - Replacement of depleted natural resources with substitutes
  - Technologies that solve problems *and* create resources
- Bottom of pyramid product development will revolutionize lots of design and consumption
- Strength Areas
- Rebrand U.S. as sustainability global leader. Slogans lead to behavior, supported by national policy.
  - Sustainable nanotech and nanomanufacturing
  - Cyber Infrastructure (CI) enhanced manufacturing
  - Advanced IT systems engineering (e.g., logistics, remote sensing)

    - RFID
    - Conservation
    - Social networking—crowd sourcing
    - Biotechnology—synthetic biology—increasing yields
    - Pragmatism
    - Power of philanthropic sector
    - Creativity and “can do” attitude in industry
    - Private sustainability consortia
- Gaps:
    - Education
    - Knowledge of history
    - Vision
    - Naiveté
- How to create materials by design to replace scarce natural resources?
- How to efficiently harvest/utilize solar energy?
    - Analysis by sector or silo never gets to the big picture
    - Thus, no overall quantifiable goal
    - What is success quantitatively and how can we succeed?
- Micromeasures to large goals?
    - Knowledge in solar technology/science
    - Do we really know all the impacts?
    - Lack of will
    - Insufficient collaboration / trust
- Problems in Design:
    - Inexpensive energy / resources
    - Lack of (environmental) data – can be an excuse not to act
    - Short-cut methods make excuses “go away.”
    - Can’t verify LCA results
    - Need undergraduate and graduate school programs to get people excited
    - Needs to be chic
    - Lack of open standards for data
- Opportunities in Design:
    - Minimal standards for eco-design (see problems above)
    - Remanufacturing, design for (and on-shore)
    - Sustainable design tool kits
    - Design consortia that compete to be as green as possible
- There is a need for pre-competitive collaboration networks that agree on sustainable design, materials, and use of energy (competition for other parts).
- Finding environmental leverage points—this change makes a big difference:
    - Mining landfills
    - Taxing “bads,” rewarding “goods,” “user fees”

<u>Group 7 – Discussion Leader: Darlene Schuster</u>

PowerPoint Slides:

Big challenges

• The nexus between increases in efficiency leading to increases in economic development and consumption
  o Efficiency leads to more consumption, reduced sustainability
  o Market fails to recognize externalities*
  o Irreducible complexity
• Possible solution strategies
  o Market signals to incentivize sustainable design AND sustainable consumption
  o Designing framework conditions (level playing field concept)
  o Possible use of full cost accounting**

Gaps in Knowledge

• Make LCA Approachable and Usable in ‘thinking”
  o Cannot do full LCA on every decision
  o Wastes time and money
  o Too much information
  o Need life cycle thinking -
• Need Full cost accounting
  o To include: indirect impacts (e.g. Work force impacts, and societal costs in economic terms)
• Need Systems thinking
  o Research on systemic effects along supply chain
  o Water Tools as an example (WBCSD), ecosystem services work

Problems and Opportunities
• Need to develop rapid screening and assessment tools for supply chain systems, • Supply chain design should include resilience concepts and adaptation methods • Need for industry standards to characterize sustainable supply chain components • Misinformation – quick scientific response team to counter misinformation and educate public and policy makers

Notes:

* Beth Beloff: If externality here means the traditional environmental economics' definition of environmental costs that are not internalized, I am not sure about its direct links with rebound effects.

** Beth Beloff: Based on the reason above, I am not sure if this is a solution.

<u>Group 8 – Discussion Leader: Herb Cabezas</u>

PowerPoint Slides:

• Define and communicate priorities; for example: what are the main water and energy consumers… • Working on developing a green energy standards for chem. products • Development of a product score card. Companies tell their providers what they value most. For example: energy, water and waste. It helps a lot to come up with common scorecards… An Industry Consortium should come up with that

- Opportunities for industry symbiosis (industrial ecology) where the waste from one company / process becomes the input material of another company/process
- How to transform a whole supply chain so that we can boost reuse, remanufacturing as opposed to making more new products – would that need a different supply chain?

- Opportunities for industry symbiosis (industrial ecology) where the waste from one company / process becomes the input material of another company/process
- How to transform a whole supply chain so that we can boost reuse, remanufacturing as opposed to making more new products – would that need a different supply chain?

- Gather a better understanding on where the hotspots are…and consequently, the best opportunities – better understand two fold question: efficiency vs. consumption
- Every single product has unique opportunities which may vary substantially.
- How can we gain a better understanding on the world opportunities and hotspots (per type of material)
- Challenge: to innovate and device more alternatives to traditional supply chains. Include new products, manufacturing process, etc.
- How to better gather data, not only in terms of quantity but also in terms of uncertainty challenges.
- Better understanding of the impact of new materials, for example Algae systems

- How to engage the average citizen into sustainability initiatives?
- We need more and better methods to integrate information from different stakeholders involved in different stages of the supply chain
- Revisit how environmental law and regulations are written to promote sustainability (Herb's example on a Chem. Industry in CA)
- Provide a solution on why green consumption is still on a very early stage… what can we do to increase consumer awareness and engagement

<u>Group 9 – Discussion Leader: Bhavik Bakshi</u>

PowerPoint Slides:

Problems

- Materials, energy, water are the main challenges for future design
- Pollution is less important as long as we continue pursuing excellence in reducing emissions.
- In a way, energy consumption and CO_2 emissions are interchangeable (?)
- Energy: efficiency from industrial point of view, consumption in terms of societal point of view
- Need to de-carbonize energy supply
- Switch to renewable energy in more systemic way

Gaps

- Lack of realistic models/data away from metrics related
- No consistent methodology to look at the supply chain: no consensus among the community
- Need for better data with industry participation

- Need to be able to focus on particular products with highest impact: Product label like Energy Star (?)
- Knowledge and data management
- How society can be better informed
- Public willingness to act and maintain

Opportunities
• Developing data, models and methods for guiding policies based on life cycle impacts • Identify the top products that have the most impact (environmental footprint); have consistent data and methodology • Methodologies to analyze existing data and connected with optimization and decision making • Resource optimization opportunities, for example water • Design considering the end of life of the product into account • Consider issues beyond engineering, include economic and social factors

SESSION III NOTES

<u>Group 1 – Discussion Leader: Thomas Seager</u>

PowerPoint Slides:

As with most/all change or new design the answers depend on what group is answering the question.

If it is an organization that is innovative and in a leadership position, new is:

- Interesting and worthy of investment
- A potential competitive advantage
- An alternative to legal risk of non-compliance
- Early influence with political organizations
- Brand influence with consumers

For the organizations that are responding to the new design or idea the answers can be just the opposite, such as:

- Cost of catch-up
- A reactionary tone with a need to refute and discredit, followed by being a "fast follower"
- Legal defensive position
- Political rebuttal and obfuscation

The development profile for any industry and any thing new is:

Innovator, early adopter, early minority, late majority and laggard.

We believe that:

1) New metrics will need to be established that allow for new values to be evaluated against current metrics (i.e. miles/gallon, ppm CO_2, kg/cu. meter).
2) Revised rating system based upon new metrics for at a minimal compliance with opportunities for incremental "better than std." evaluations and differentiation.

3) Competitive pressures will delay advancements. Industry professional affiliations will not immediately adopt new designs if they are not close enough to existing standards, fall with in established criteria, if they are perceived as a competitive advantage for a particular firm or are developed in a foreign country.
4) Sustainability can be (is currently) a politically charged issue dependent on parties and regional agendas. Only business market factors independent of legislation will more than likely be able to influence adoption.

Group 2 – Discussion Leaders: Troy Hawkins and Bert Bras

PowerPoint Slides:

Group 2 – Technologies/Tools - Needs

- Different tools are needed for different audiences/users
  - Expert versus practitioner version of tools
  - Differentiation between product design and design of sustainable supply chains
  - Input-Output approaches seem to work well for large supply chain assessments
- Lack of integration of LCA databases/data with Computer-Aided Design tools
  - Both in ME as well as ChE and economics
  - Not difficult to do
- Tools are out there, but workflow integration is needed
- Subscription costs can be a barrier

Lower Level Needs

- Need for more LCA inventory data that is maintained consistently for a cheap price
- Need for non-linear, dynamic data/models for LCA predictive capability
- Designer workflow could be more product specific allowing for parametric studies
- Qualitative screening/streamlined LCA
  - Third party validated?
- Benchmarking tools linked to system analysis tools
  - Advantage: Can compare against "the standard"
  - E.g., data envelope analyses

Scales

- Data and tools for seamless consistent analyses at different/multiple scales is lacking
- Accuracy of narrow scale versus uncertainty of comprehensive scale – how do we manage?

System Level Analyses

- How do we integrate all models like risk analysis, consumer behavior, LCA, etc.
- Model Based Systems Engineering (MBSE) field may have to be engaged
- Industry/practitioners still like/prefer MS Excel
- How do we do systems level analyses versus single technology analyses, e.g., to
  - Predict effects of technology transitions
  - Capture system dynamics effects
- Examples exist (e.g., biofuel analyses), but
  - How do we do expand these system studies on a broader scale?
  - How do we integrate other metrics/impact categories?

o Who is the user/audience?

Expertise

• Plenty of technical domain specific expertise is available
• No expertise on systems level integration and workflow integration
  o Engage ERP, PLM providers
  o A few examples exist of LCA integration with product design focused industrial software tools
• Need for standardization
  o Product category allocation rules
• Need for validation
  o Policy and product decision level
• Expertise and effort needed to integrate uncertainty characterization, management, etc. in an expert manner
• Domain expert(ise) has to be integrated in decision making process
  o Be careful with automation of LCAs
  o Result of the tools have to reflect that it is not the final answer
  o Impact categorization/information typically has to be condensed/converted by humans into appropriate knowledge
  o Expertise needed on impact category valuation/trade-off

Technologies tools	Integration needed?	Where is expertise?	State of technical capability?
Define criteria	Social and economic expertise	LCA is not enough	
	Weighting factors	NIST US EPA	Flexible weighing systems exist, but not used
Integrated assessment	Multi criteria optimization	Systematic dynamic modeling	EIO use and research
Visualization tools		Aspen for CPI Cad Cam?	Not in as wide use as needed
Collaborative design	Cloud computing	ASP	

<u>Group 3 – Discussion Leader: Raj Srinivasan</u>

PowerPoint Slides:

General observations on stakeholder process
• Debate by openly publishing even provocative data and statements is sound! (the 80s) • Stakeholder and consensus process may lead to wishy-washy, and not always useful. (the 90s) • Joint venture between industry and NGO are interesting. How can we work together addressing some common issue? (the 00s) • And now?? (10s): Specific actions, sharing a common specific goal and interest.

Stakeholders role
• The government role is to overregulate and overspend, the industry role is to pollute and cut corners, the academia role is to be sufficiently obscure and the NGO role is to whine! • Government role is to protect? Also stimulate and fund research, partnerships? Remedy market failures. • Role of academia: understanding the system and educating • Role of industry is to respect? Also an expert role

Attitude and timing
• There is a time to collaborate and build consensus, there is a time to diverge and take different and original paths. • Litigation issues rarely lead to productive collaborations (difference LCA – Risk Assessment), but… • Conflict is often the prerequisite for stakeholder engagement • Be more honest than the politically correct requirement of being nice to one another • What makes a collaboration interesting… Could be a paper, funding, access to knowledge, access to data, ensure an independent point of view

Which variety of stakeholder process is useful and under which circumstances?
• Smart stakeholder management – need to understand what is each other's time frame, aware of respective interest. • Most effective stakeholder groups: collaborative, committed and accountable • Think that the problem cannot be solved on its own. • Is it legitimate to deliberately exclude some stakeholder? E.g. the recycling industry in Swedish ELV management • Stakeholder consultation is different from a roundtable. Stakeholder process is usually purposeful and action related • Partnership is stimulating, stakeholder consultation is boring, could delay innovation… unless clear purpose • Useful to formulate the problem together

<u>Group 4 – Discussion Leader: Thomas Theis</u>

PowerPoint Slides:

• Organizational structures for data availability and transparency while maintaining confidentiality • Assessments have to go beyond sciences/engineering. Need to incorporate decision analysis, social sciences, economics – but how? • Weigh benefits to society as well as costs with a long-term perspective • Need impact method development to keep up with emerging technologies

• Policies should provide incentives for sustainable technologies
• Collaboration
  o In universities across disciplines
  o Incubator mentality?

- Along supply chain to avoid displacing problems
  - E.g. Electric vehicles – no consideration of electricity source
  - E.g. Fluorescent bulbs – no consideration of disposal
- How do you provide incentives?
- How do you made it work? - Publish case studies – use examples, models of success, good stories
- NSF/EPA funding?!

- Screening level risk assessment
  - Use general principles to evaluate a chemical before understanding complex endpoints (e.g. irreversibility, accumulation in environment)
- Improve communication about emerging technologies and potential risk
- Understanding the limitations of our existing sustainability metrics
  - E.g. Japanese nuclear accident – would we have predicted that?
- How do you discount problems of future for today?

Group 5 – Discussion Leaders: Maria Burka and Eric Williams

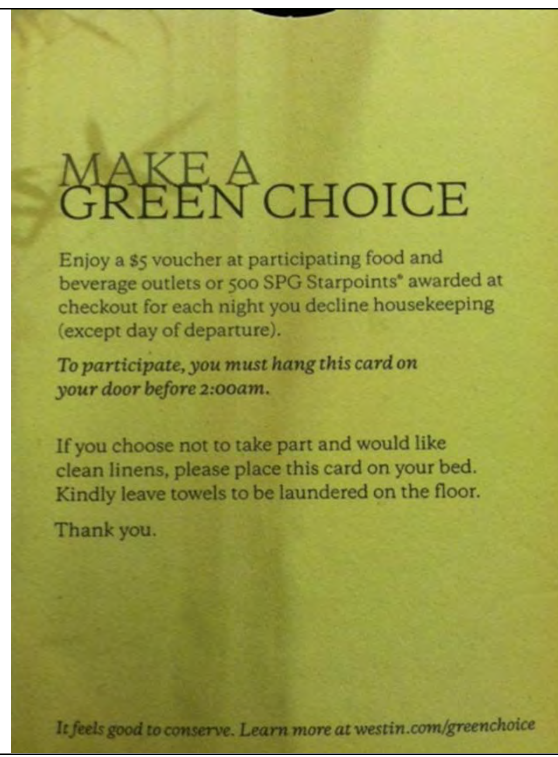
PowerPoint Slides:

Education and Sustainability

What is education?
Make audience understand what we are trying to do

Sustainability often viewed negative:
"It's expensive"

Well…The alternative may be more expensive!!



Sustainability education is important

• Stewardship of resources (parents):
  o Children/grandchildren
• Big problem (challenge, need buy-in from society)
  o Water
  o Energy
  o Quality of life
• Difficult to evaluate impact – very long time scales
  o scare tactics: Downside is huge in future and even now
  o positive thinking: What is the upside (clean water, health, abundance, new economy (branding!)…)

Who is the Audience? *(Where is education needed)*

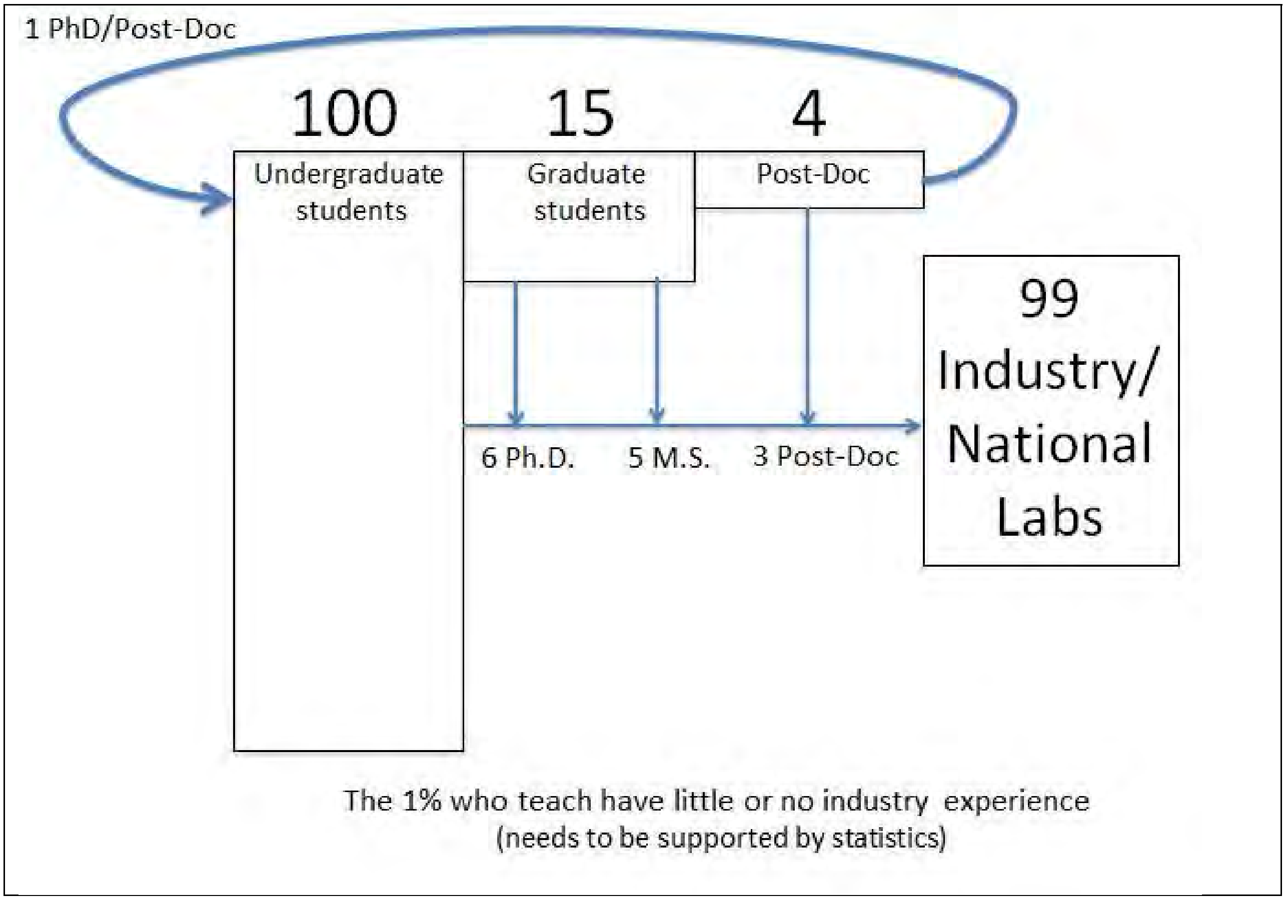
• *K-12 very receptive - but teaching resources lacking, bad teaching*
• Undergraduate/Graduate School students - curriculum has not been developed yet.
• Encourage cross disciplinary teams
  o (business, law, engineering...)
• Work against traditional silo thinking
• *Population at large is confused and too narrowly focused*
  o *Politicians (polarized)*
  o *Industry (unpredictable business environment, CO_2 tax?)*
  o *Electorate (polarized and lacking information*
  o …..
 	
Need to raise awareness and change attitude, go global….

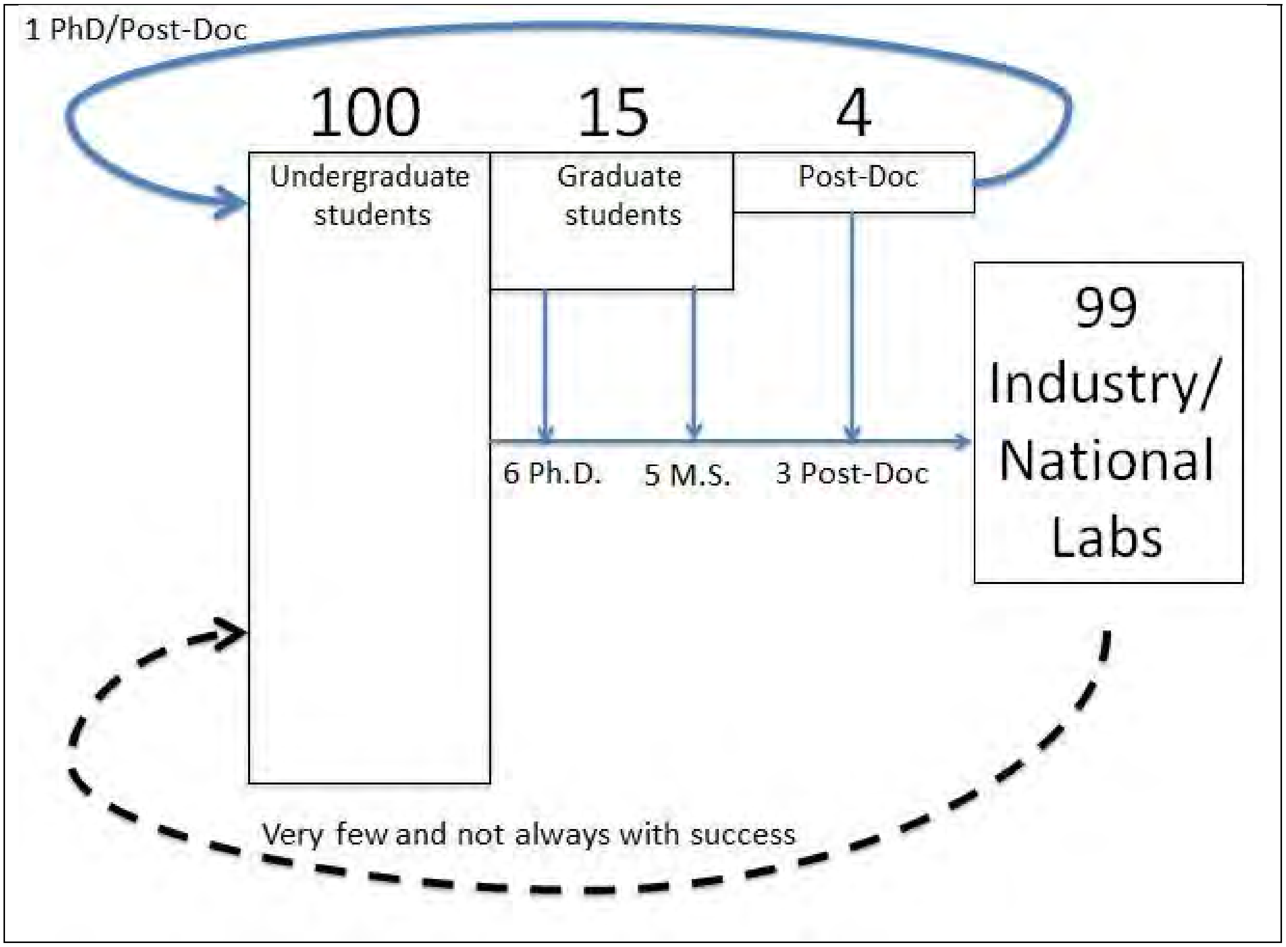
What and how to teach

• Need language and sensitivity to develop basis for communication along the supply chain (every discipline has their own language and jargon)
  o Terminology, taxonomy of sustainability
  o Metrics to measure if a process/product is sustainable
• Make sure that "systems thinking" is integrated throughout and across the curriculum
• A holistic approach (multi-dimensional analysis)
  o Example: photosynthesis to capture CO_2, all aspects
  o Is this contrary to basic research?
  o Is it fundable when it is so broad?

Integration Academia with Industry

• How to change big business attitude
• How to change university
• How to start a small business
  o What is innovation
  o What is the impact of an idea (health, environment, economic...)
• Many resources
  o NSF ICORE
  o SBIRs
  o State funding
  o ……


1 PhD/Post-Doc
100
15
4
Undergraduate students
Graduate students
Post-Doc
99 Industry/ National Labs
6 Ph.D.
5 M.S.
3 Post-Doc
The 1% who teach have little or no industry experience
(needs to be supported by statistics)



Funding and Infrastructure for Educational

• K-12 need very good teachers (Statistics in US are dismal)
  o Teach for America
  o Teaching as a viable profession for engineers and scientists
• Undergraduate level
  o Develop course material for supply chain and sustainability
  o Business/industry develop examples of sustainable supply chain
  o More?….
• EPA/NSF workshop on sustainability and supply chain
• *(At ASU some years back – report is upbeat)*
• IGERT, Regular proposals
• Propose NEW programs
  o ERC with focus of sustainability and supply chain issues
  o Sustainability in education

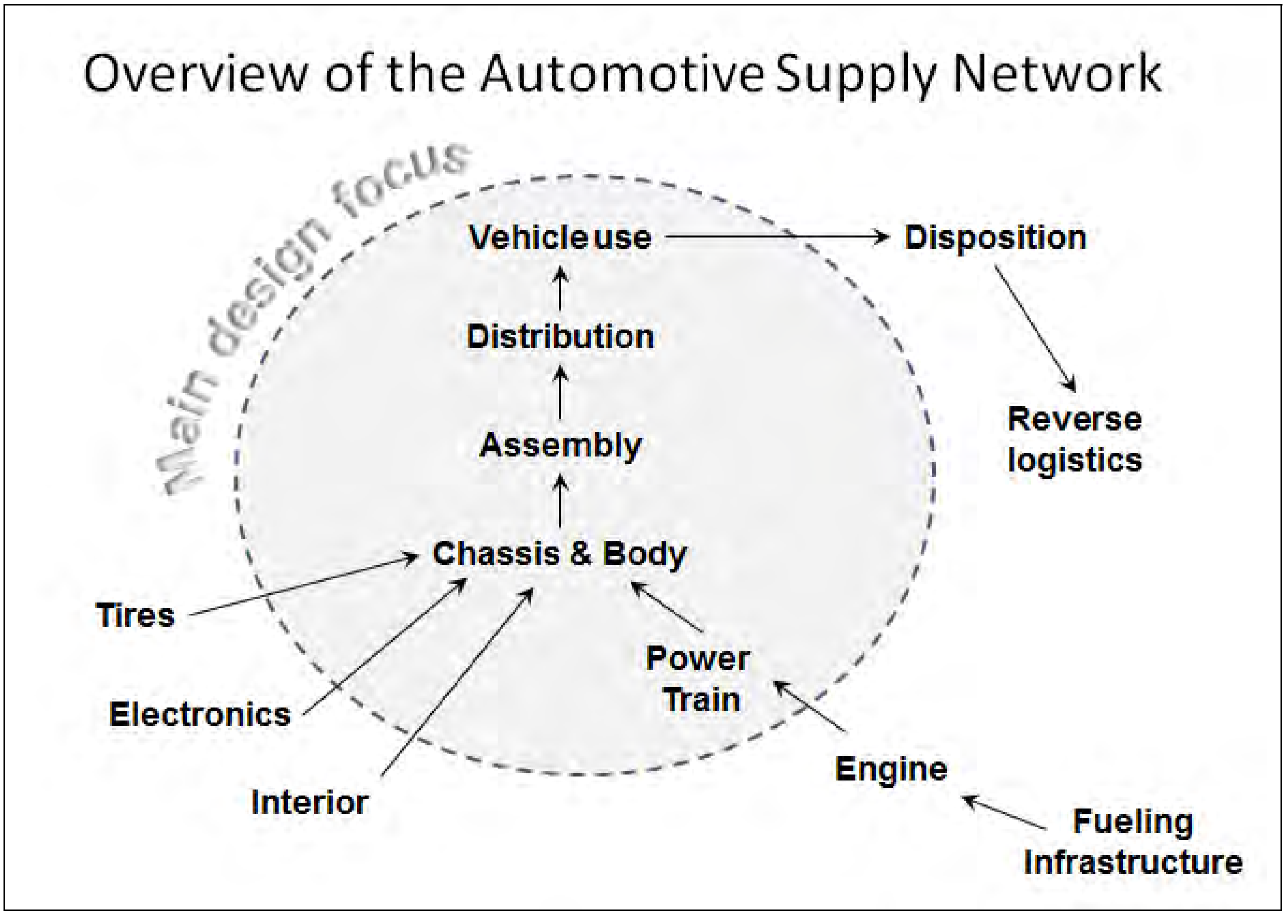
Group 6 – Discussion Leaders: Ignacio Grossman and Ray Smith

PowerPoint Slides:

How do economic drivers affect sustainable design?
• The two are inherently inter-linked and difficult to consider independently – policy is important to consider as well • Operating under different environmental regulations without embedding "true costs" can skew markets • Subsidies can help to jump start new technologies, but can also create an unsustainable environment • Carbon markets and other instruments that embed externalized costs could help to level the playing field – if applied on imports and domestic production • New technologies ("sustainable") that depend on scarce materials (e.g., lithium) can inflate prices and limit overall development of technology • Companies still gain economic advantage on their sustainable product lines (e.g., milk). Still have trade value. • There are examples of where "sustainable" design incentivizing unintended consequences. (e.g., Africa producing biofuels for Europe). • No agreed upon "value of nature" – lack of vision understanding long term consequences of destroying habitat • Litigation, Insurance Sector and Infrastructure Building are also critical elements to consider

Group 7 – Discussion Leader: Darlene Schuster

PowerPoint Slides:



Define Sustainability Indicators
• Fuel Efficiency in use • Weight • Resource use and integrity   o scarcity of rare earths, conflict minerals • Emissions • Material and use intensity • Life cycle water use • Labor practices • Local employment • Durability/longevity/upgradability/recyclable

Desirable sustainability characteristics of the vehicle supply chain/product system.
• Local sourcing where possible • Avoidance of hazardous, scarce, or conflict materials • Use of recycled content where possible • Incorporation of remanufacturing opportunities

- Use of renewable materials and energy where possible
  - Minimization of energy and water requirements
  - Closed loop recycling of resources where possible
  - Conversion of residual wastes to byproducts
  - Appropriate utilization of ecosystem services
  - Avoidance of airborne emissions, noise, dust, etc.
  - Minimization of transport and packaging requirements
  - Customer-supplier collaboration on sustainable design solutions
  - Emphasis on occupational and public safety
  - Encouragement of supplier diversity and social responsibility
  - Responsible and ethical treatment of workers
  - Support for local capacity development

<u>Group 8 – Discussion Leader: Herb Cabezas</u>

PowerPoint Slides:

Role of Industry, Academia and Government…
• Industry owns most of production systems, identifies opportunities for new products and services that deliver value to consumers • Academia owns a significant number of ideas, represents a sources of knowledge creation • Government sets the playing field, oversees that welfare is created along fair rules, and right incentives • Examples on materials, processes and metrics

Incentives are not always the same so we all (academia, government, industry, NGO, general public) need to get together and identify the main decisions to be made in term of sustainable chains…

We need to find the best way to get together and define, collect and decide on the most adequate sustainability metrics and indicators that represent the best impacts For example: energy options, material options, human health, ecosystems… to work with…

We need to find venues to incorporate NGOs into the decision making process

Group 9 – Discussion Leader: Bhavik Bakshi

PowerPoint Slides:

Examples of Emerging Technologies
• Nanotechnology • Biofuels and biomaterials • Genetically engineered technologies, etc. • Our ability to make a new technology vastly outstrips our ability to answer questions about its impact

Challenges
• Tools may not be available to evaluate new technologies • How do we build computing infrastructure that can help meet these challenges • Can there be standard methods to assess new technologies? • Insurance approach to deal with uncertainty • Get industry to fund assessment research – has not worked in the past. Role for government and academia interaction with industry

• Industry-academic-government collaboration to avoid corn ethanol type of fiascos; Also need to consider political aspects • Develop focus on a metric and a target; that is what worked for CFC substitutes; however may be impossible to define such fixed targets; use adaptive management and resilience • Have industry participate in the stakeholder dialog run by the government • Researcher teams should combine reductionist with systems research • Need to develop longer-term focus

SESSION IV BREAKOUT GROUP NOTES

Group 2 – Discussion Leader: Darlene Schuster

Notes:

Sustainable Automotive Powertrain Supply Chain

- Overarching question: Who is the client of the research?
- Measuring and reporting is not the end goal. Raising awareness is.
- Research Areas
- Material availability and resiliency
  - Scarcity/supply, Stock depletion, local impact, diversity of supply
  - Scenarios around material recovery
- What is the indirect impact of a new powertrain/part/material (e.g. lithium)
  - Does it impact current supply chains and demand?
  - Risk/scenario analyses
- What are the supply chain options
  - Existing or new?
- Value chain economics related to status quo
- Hazardous handling and social issues (human rights, child labor)

- Does dissemination of DFE principles really lead to sustainable supply chains?
- What do consumers really need?
  - Efficiency, range, other
  - Access versus mobility
- Tradeoff of accuracy of information versus information gathering effort
- Needs:
  - Scenario capability
  - Breadth
  - Depth
  - Connection to “regular” research on supply chains e.g., Just in Time manufacturing economics, etc.
  - Better connection to “practice” and their decisionmaking needs
- Observations:
  - Pilot approach works best to start with industry
  - Many consortia already exist—value proposition is needed
  - “Tool” ownership is an issue

Sustainable automotive powertrain?

- Understanding of the supply chain
- Tools to understand look broadly across the supply chain:
- What attributes of the supply chain are important?
- Sourcing – materials availability and constraints
- Scarcity issues, conflict issues…
- Scenario – what does the market look like when this product might come back into the system?
- Materials that involve hazardous handling or EHS issues?
- Child labor?
- Social, value chain economics relative to status quo? Are we developing a different supply chain that would redistribute wealth? Are we creating jobs? Are we reducing jobs?
- Can we use the same sites we had before? Compatibility with existing facilities? Who is bigger Ford or Bosch?

Client?

- Final product manufacturer, intermediate product manufacturer, consumer, regulator?
- How to manage information flow?

Scenario Capability

- Resource constraints
- Regulatory environment
- Does it impact existing technologies / production lines that I have?
- How does it affect demand? How will introducing this product affect demand for my other products?
- Rebound effect?

Breadth Issues

- Are we being flexible?
- Regional rail versus regional air

Depth Issues

- Social issues
- Worker exposure/safety issues
- How will this play into user behavior?
- Risk analysis
- Within the technological system
- Interaction with the environment
- What is the indirect impact of an automotive part using lithium?
- Heuristics that work for supply chains rather than individual processes within those supply chains.
- Do heuristics for processes apply for supply chains? Or are we at risk of perverse impacts?
- What are the environmental/sustainability implications of my operational decisions?
- Weibull modeling – could easily do an LCA on the output
- Costing software – could link to LCA software
- New turbine designs – different operating modes – different startup modes,
- How to structure the research?
- Come from the risk perspective.
- Start with a small pilot project.
- Do we work on this internally or do we engage partners?
- If we build a tool, who maintains it, who owns it? Who puts in the hours of labor?
- Many consortia already exist, value proposition needed.
- Ideas for OTAQ meeting—what tools are needed? Are there modeling capabilities that we could help you develop, i.e. having you as a client? What involvement might we develop between OTAQ and STD?
- Intelligent Manufacturing Systems (IMS)—funding source for collaborative projects.
- NSF partnership with USAID to fund international, collaborative research efforts.
- If you want to do economic, social-decision, and behavioral science, include experts on your proposal
- IDEA: Where do we have good ideas that were considered good ideas by sustainability professionals, and why did they fail? What are the lessons learned from previous failures?
- Invest in education
- Invest in workforce development
- Jobs in sustainable industries are sustainable jobs

- Create an online wiki-based tool for environmental charette
- NSF will sponsor decision-support tool
- Could we build an NSF project on the Federal Interagency LCA Data Commons
- We have the functional unit wrong.
- We need applied, technical social and decision scientists.
- Organize a follow up workshop to bring together equal numbers of social and decision scientists and engineers/technically capable individuals
- There is nothing that integrates the blizzard of assessment tools across this issue of sustainability.
- IDEA – For this we need computer/technical individuals
- Poster – "Research project needs decision-scientist"

Group 5 – Discussion Leaders – Maria Burka and Eric Williams

Notes:

What supply chain to pick? food/nutrition

- cellulosic ethanol / algae biofuels
- food/nutrition
- pharmaceuticals
- sandstone natural gas/fracking
- pulp and paper

Biofuels – all biofuels cellulosic and algal

Issues

- Land or ocean
- Variability in climate
- Resources: carbon, nutrients, water
- Farmer's behavioral issues, getting people to change, incentives
- How to deal with waste
- Co-product substitution, effects on other markets
- GMOs
- Hope to reduce CO_2, improve energy security, rural development/employment
- Land use:
    - Food versus fuel (conversion)
    - Agricultural practices – especially crop
    - Ecosystems services from different land use options
    - Containment of GMOs microbes, algae
    - Pumping energy
    - Role of LCA in development: can LCA identify inefficiencies to do better LCC.

Don't understand:

- Land use change

- Nutrient flows for some options
- Energy flows for new options
- Ecosystem effects, ecosystem services
- New crops such as miscanthus, that can compost
- Organism characterization
- How to get farmers to do harvesting and biorefinery
- Substitution effects
- Use phase – demand, different operational emissions from different
- Combinatorial approach to supply chains
- Transportation, logistics

APPENDIX B

PRESENTATION: WELCOME TO THE DESIGN OF SUSTAINABLE PRODUCT SYSTEMS AND SUPPLY CHAINS WORKSHOP

Welcome to the Design of Sustainable Product Systems and Supply Chains Scientific Workshop

National Science Foundation
Arlington, Virginia
September 12, 2011

Workshop Co-Sponsors:
U.S. Environmental Protection Agency,
National Science Foundation, and
American Institute of Chemical Engineers

Workshop Goals

1. What tools and methods are currently available for design of sustainable product systems and supply chains?
2. How can these tools and methods be combined in new ways to improve our ability to design sustainable product systems and supply chains?
3. Where do the most promising opportunities exist for modifying product systems and supply chains?
4. What are the implications of new methods for design of sustainable product systems and supply chains for:
   - Reducing the life cycle environmental impacts of existing products and processes?
   - The process of developing and implementing new technologies?
   - The evaluation of new technologies?
   - The design of policies and technologies that reduce pollution and/or increase recycling?
5. What indicators and metrics of sustainability are appropriate and necessary for design of sustainable product systems and supply chains?

Monday Morning Agenda

8:30 – 9:00	**Session I – Perspectives on the Design of Sustainable Product Systems & Supply Chains** • Welcome to NSF, Bruce Hamilton and Maria Burka • Workshop Goals and Overview, Troy Hawkins • Introduction of Organizing Committee and Staff Support, Troy Hawkins • Introductions of Participants – name, affiliation, and expertise/background relevant for this workshop
9:00 – 10:30	**Design of Sustainable Product Networks and Supply Chains: The Need for a Systems View at All Levels**, *Bert Bras, Georgia Institute of Technology* **Consumption, Sustainability, and Social Benefits**, *Thomas Theis, University of Illinois, Chicago* **Avoiding Unintended Consequences in the Design of Sustainable Supply Chains**, *Sherilyn Brodersen, Kraft* **LCA from an Industry Perspective**, *Bill Flanagan, GE*
10:30 – 10:45	Break
10:45 – 11:30	**EPA Sustainability and the Design of Sustainable Product Networks and Supply Chains**, Joseph Fiksel, US EPA
11:30 – 12:00	Supporting Sustainable Engineering Research through NSF and EPA • **NSF Funding Opportunities** - Bruce Hamilton • **EPA NCER Activities** - Cynthia Nolt-Helms

Monday Afternoon/Evening Agenda

12:40 – 1:00	**Session II – Disciplinary Definition of the Problems and Opportunities** **Lead by Ignacio Grossmann**
1:00 – 2:20	Work in breakout groups
2:20 – 3:15	Breakout Groups Report Back – Group Discussion
3:15 – 3:30	Break
3:30 – 3:50	**Session III – What are the common problems, common areas of need, complementary areas to be interfaced, and opportunities for cross-disciplinary fertilization facilitated by design of sustainable product systems and supply chains?** **Lead by Eric Williams**
3:50 – 5:00	Work in breakout groups
5:00 – 5:30	Breakout Groups Report Back – Group Discussion
5:30 – 6:45	Break/Gather in bar area of Westin Hotel for drinks and discussion (optional)
6:45	Meet group in hotel lobby to walk to dinner (optional) - Westin Hotel
7:15	Group dinner (optional) – Ted's Montana Grill

Questions for Session II – Definition of the Problem and Opportunities

1. What are the challenging industry and societal problems to be solved? What are the future drivers for design of sustainable products, manufacturing systems and supply chains? What are the next generation sustainable-design enabled strength areas in the US?
2. Where are the gaps in knowledge? What are the problems faced by existing sustainable design capabilities?
3. What are the opportunities for design of sustainable products. manufacturing systems and supply chains?

Questions for Session III

Group 1 – How does sustainable design affect or impact economic drivers?

Group 2 – What technologies/tools and their integration are needed, where is the expertise, and what is the state of technical capability?

Group 3 – What are the respective roles of industry, government, and academia and how should they interrelate? What partnerships/coalitions are needed?

Group 4 – How will new and emerging technologies and capabilities need to affect organization roles and responsibilities – academia/industry, researcher/research teams, etc.

Group 5 – Where are education and training needed?

Tuesday Morning Agenda

8:00– 8:20	Check-in - NSF, 1st floor Visitors Desk Greeting and refreshments, provided by AIChE
8:30 – 9:45	**Continue Session III Breakout Group Reporting, Lead by Eric Williams** Summary of Monday Progress Continue Questions and Group Discussion
9:45 – 10:00	Break
9:45-10:15	**Workshop Session IV – Workshop Deliverables** **Lead by Darlene Schuster** Introduction to Day 2
10:15 – 11:15	Work in breakout groups, facilitated by Darlene Schuster • Develop recommendations in the context of near- and long-term, priority, and reality.
11:15 – 11:45	Session IVa Breakout Groups Report Back – Group Discussion, moderated by Darlene Schuster

Questions for Session IV – Workshop Deliverables

1. Identify and exemplify major application impacts, directions, and the potential for design of sustainable product systems and supply chains?
2. Identify and recommend research areas that aim toward the fulfillment of this potential
3. Identify associated areas of needed emphasis with sustainable design education and training, interdisciplinary development, and support and approaches to collaboration.

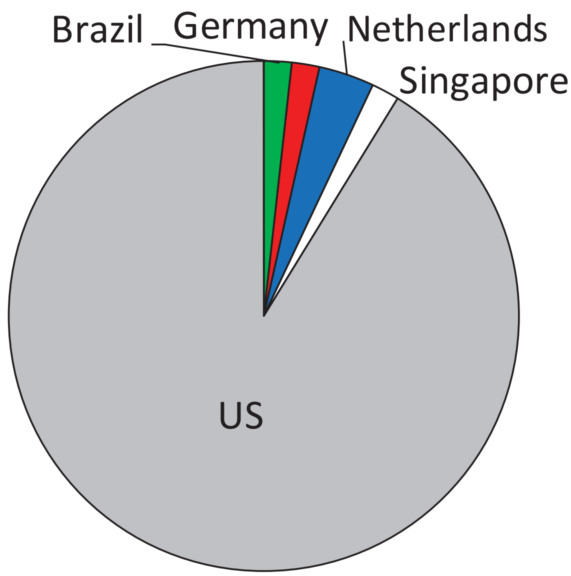
Tuesday Afternoon Agenda

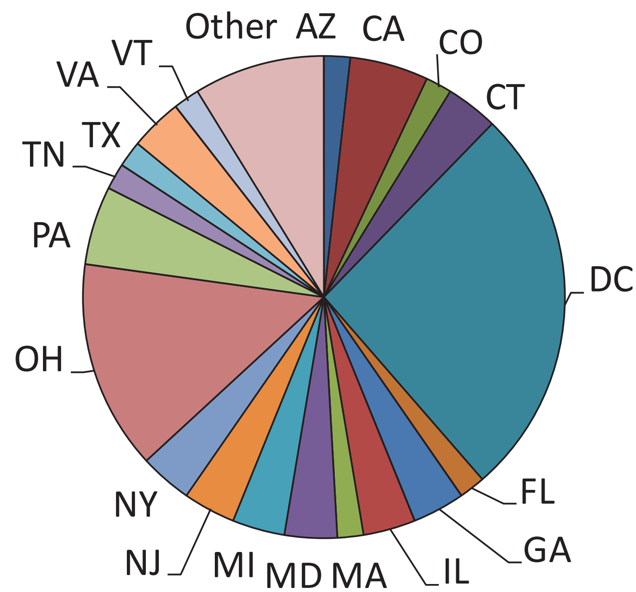
12:30 – 1:15	Continue Session IVa - Breakout Group Reporting, moderated by Darlene Schuster
1:15 – 1:30	Collective vote on priorities, lead by Darlene Schuster
1:30 – 2:00	Summarize priorities
2:00 – 2:45	Work in breakout groups, facilitated by Darlene Schuster (1) What investments are needed by whom, financial and other? (2) What are the key learnings and take-aways from the workshop?
2:45 – 3:00	Break / Load breakout session presentations
3:00 – 4:00	Session IVb Breakout Groups Report Back, Group Discussion, moderated by Darlene Schuster
4:00 – 4:30	Wrap up, next steps, Troy Hawkins

Opportunities Following the Workshop

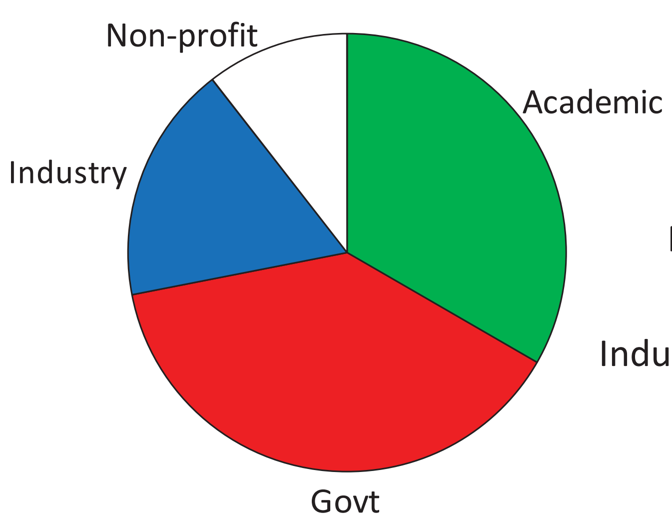
- Contribute to workshop report
- Assist in dissemination of workshop findings
- Participate in workshop email distribution list
- Pursue research collaboration funding opportunities

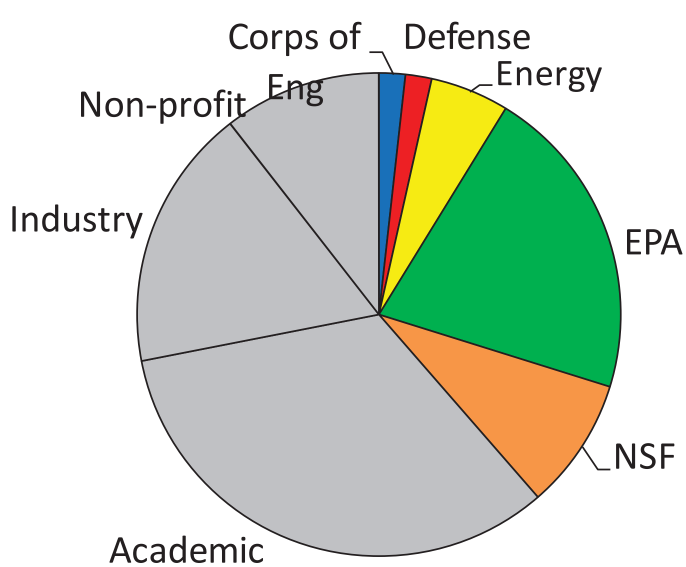
Who are we?





Who are we?





Special thanks to...

Organizing Committee	Advisory Committee	Staff
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Heriberto Cabezas	Saif Benjafaar	Michelle Nguyen
Bruce Hamilton	Bert Bras	Eric Chan
Troy Hawkins	Ignacio Grossmann	Dan Tisch
Darlene Schuster	Alan Hecht	Donna Jackson
Raymond Smith	Raj Srinivasan	Sonia Williams
	Thomas Theis	
	Eric Williams	

Brief introductions…

Name, affiliation, and expertise/background relevant for this workshop

Workshop Co-Sponsors

U.S. Environmental Protection Agency
U.S. National Science Foundation
American Institute of Chemical Engineers

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Rachuri Sudarsan, NIST
Dennis McGavis, Shaw Inc

Presentation: Design of Sustainable Products Systems and Supply Chains: Some Concepts, Cases, and Lessons from an Engineering Perspective, by Bert Bras

Design of Sustainable Products Systems and Supply Chains – Some Concepts, Cases, and Lessons from an Engineering Perspective

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Sustainability: Common Definition

"development that meets the needs of the present generation without compromising the needs of future generations."

United Nations' World Commission on Environment and Development in their report "Our Common Future", 1987

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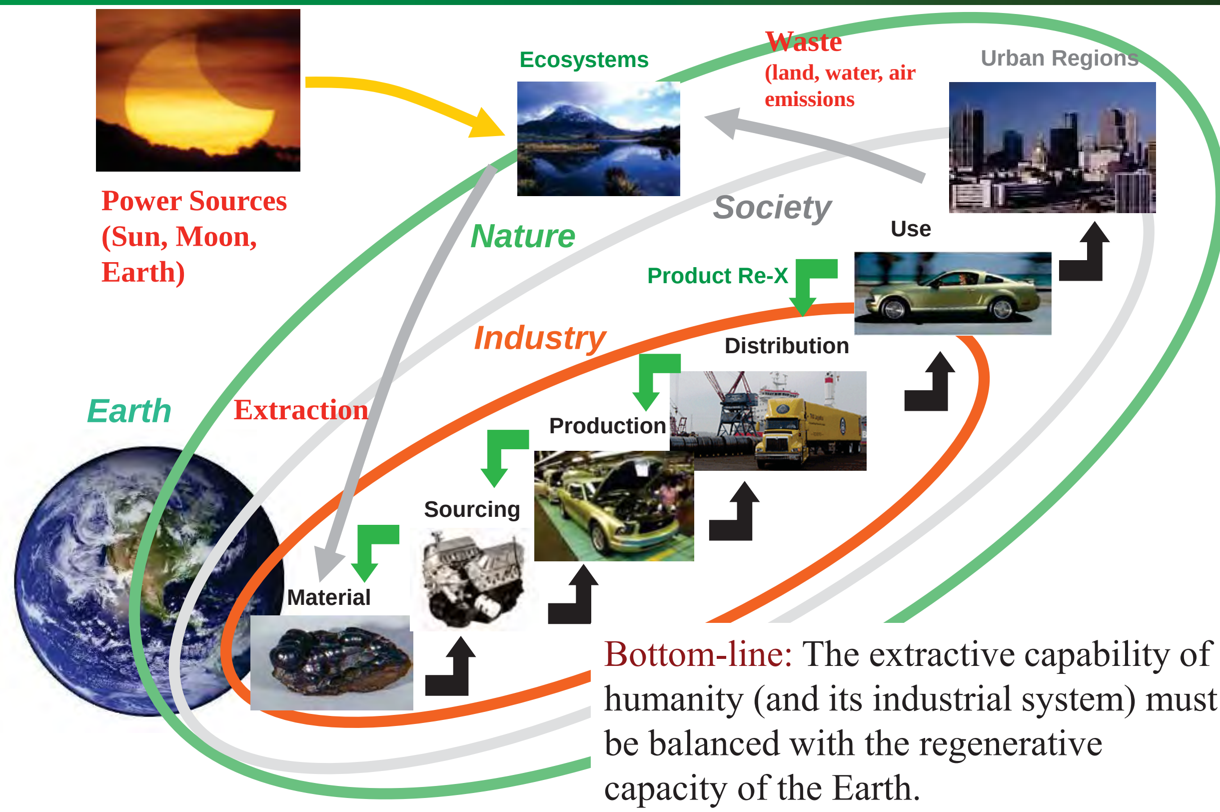
Sustainability: Physical and Biological Limits



Bottom-line: The extractive capability of humanity (and its industrial system) must be balanced with the regenerative capacity of the Earth.

Key variables: Time & Location

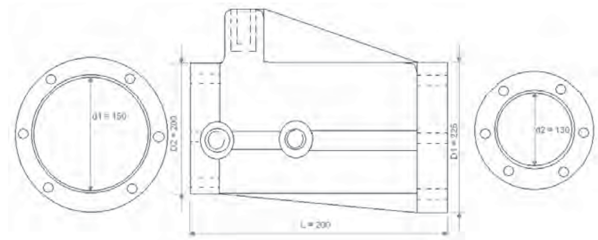
Need for a Systems Approach

Observations from 2001 National Science Foundation sponsored global study on Environmentally Benign Manufacturing:

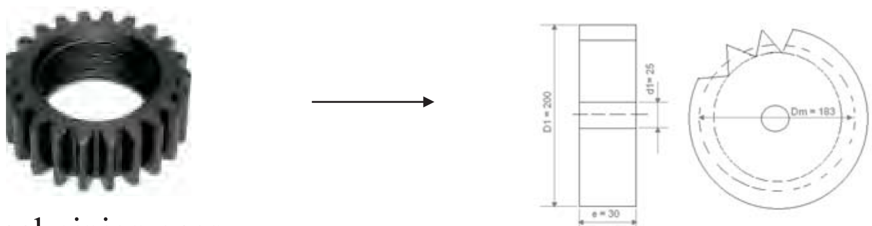
- There was no evidence that the environmental problems from our production systems are solvable by a “silver bullet” technology.
- There is a need for **systems-based solutions**
  - which requires a comprehensive systems approach
  - where scientists, engineers, managers, economists, entrepreneurs, policy-makers, and other stakeholders all work together to
    - address environmental issues in product realization and
    - achieve economic growth while protecting the environment.

- **Final Report**: *Environmentally Benign Manufacturing*. WTEC Panel Report, Baltimore, MD, Loyola College, 2001.
- **Online**: http://itri.loyola.edu/ebm/ebm.pdf

Example - Two Automotive Parts



Aluminum transfer case



Steel pinion gear

- Simple question: What is better?
  - Virgin manufacturing & disposal
  - Recycling
  - Remanufacturing

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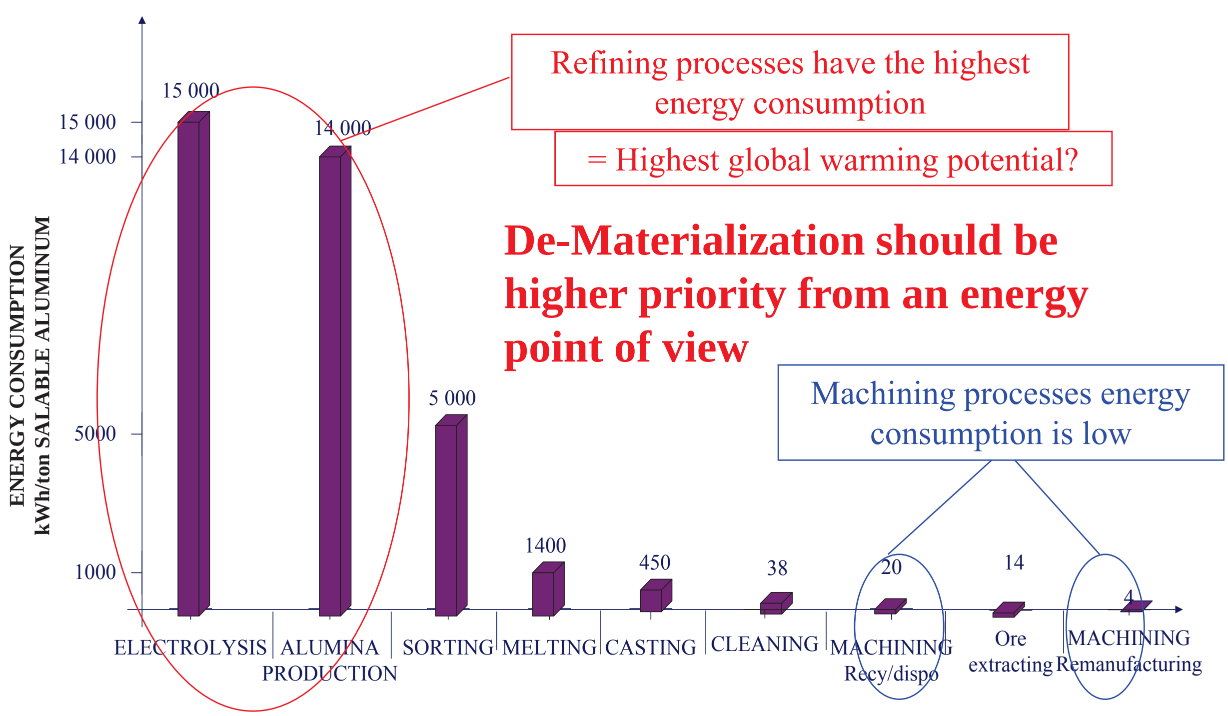
Life-Cycle Perspective is Crucial

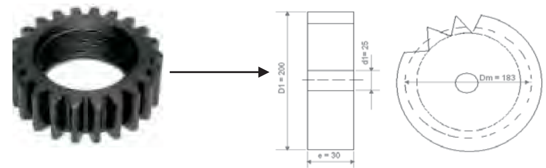


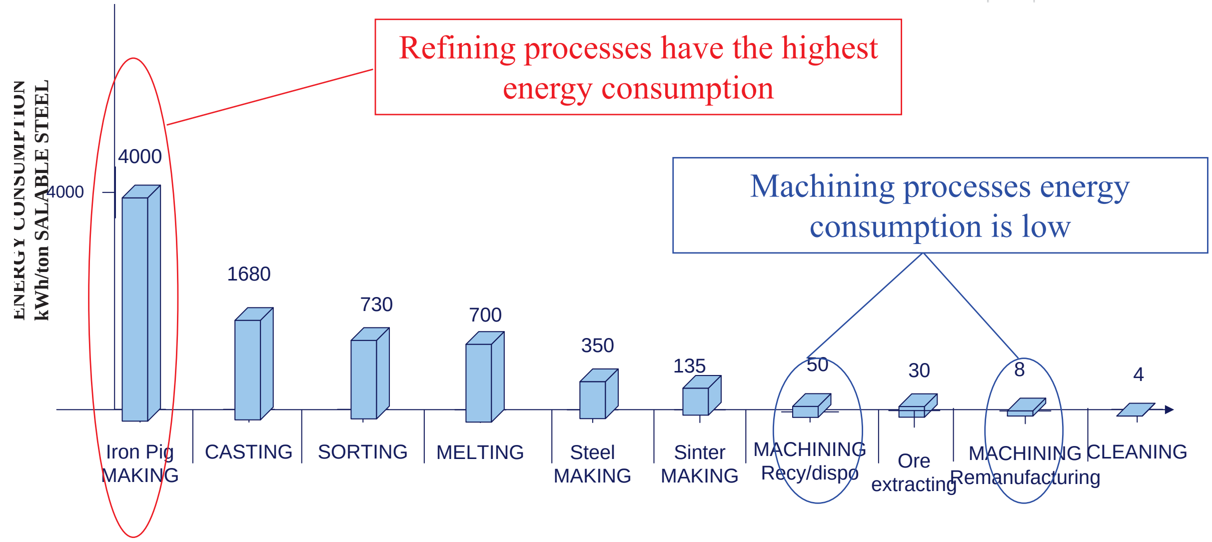
Bras, B., "Sustainability and Product Life Cycle Management – Issues and Challenges", International Journal of Product Life-Cycle Management, Vol. 4, No 1-3, pp. 23-48, 2010

NSF Grant # 0522116

Steel Processing Energy Consumption

De-Materialization again will result in higher gains from an energy pint of view





STEEL PRODUCTION PROCESSES

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Energy Consumption in Manufacturing Sectors

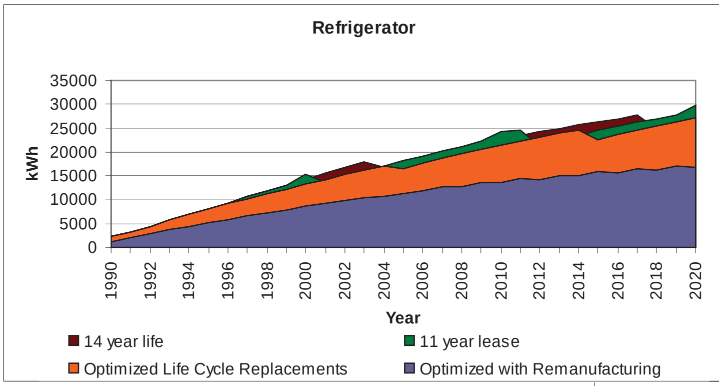
- **Manufacturing process energy savings are small when majority is embodied in upfront material production/refining**
- **Closed loop supply chains that save material through recovery, reprocessing, recycling, remanufacturing, etc. (re-X) is an important aspect to be pursued**

		MECS Survey Years	
NAICS	**Subsector and Industry**	**1998**	**2002**
311	**Food**	**1,044**	**1,123**
312	Beverage and Tobacco Products	108	105
313	Textile Mills	256	207
314	Textile Product Mills	50	60
315	Apparel	48	30
316	Leather and Allied Products	8	7
321	Wood Products	509	377
322	**Paper**	**2,747**	**2,363**
323	Printing and Related Support	98	98
324	**Petroleum and Coal Products**	**7,320**	**6,799**
325	**Chemicals**	**6,064**	**6,465**
326	Plastics and Rubber Products	328	351
327	Nonmetallic Mineral Products	979	1,059
331	**Primary Metals**	**2,560**	**2,120**
332	Fabricated Metal Products	445	388
333	Machinery	217	177
334	Computer and Electronic Products	205	201
335	Electrical Equip., Appliances, and Components	143	172
336	Transportation Equipment	492	429
337	Furniture and Related Products	88	64
339	Miscellaneous	89	71
	Manufacturing	23,796	22,666

Consumption of Energy (Site Energy) for All Purposes (First Use) for Selected Industries, 1998 and 2002 (Trillion Btu)

Source: Energy Information Administration, Form EIA-846, Manufacturing Energy Consumption Surveys, 1998 and 2002, http://www.eia.doe.gov/emeu/efficiency/mecs_trend_9802/mecs9802_table1a.html

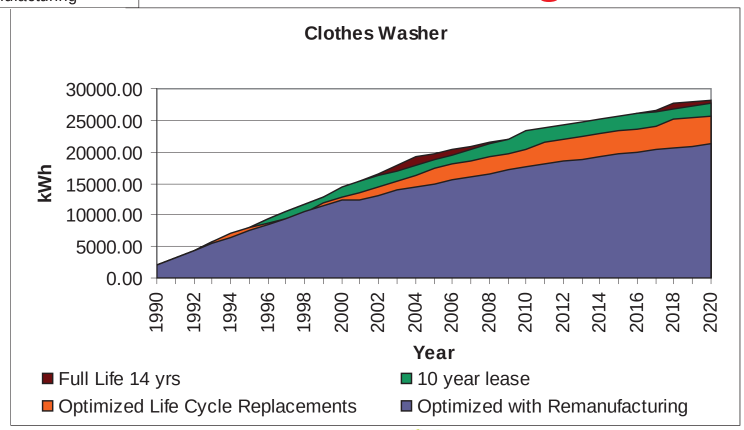
Re-X: Energy Savings through Remanufacturing



- Replacing products more frequently with more energy efficient technology helps
- But bigger gains can be made by including **remanufacturing**

Need:

- **Understanding of user behavior**
- **Understanding and modeling of impact of different options**
- **New enabling technologies**
  - Additive Manufacturing
  - Non-destructive testing



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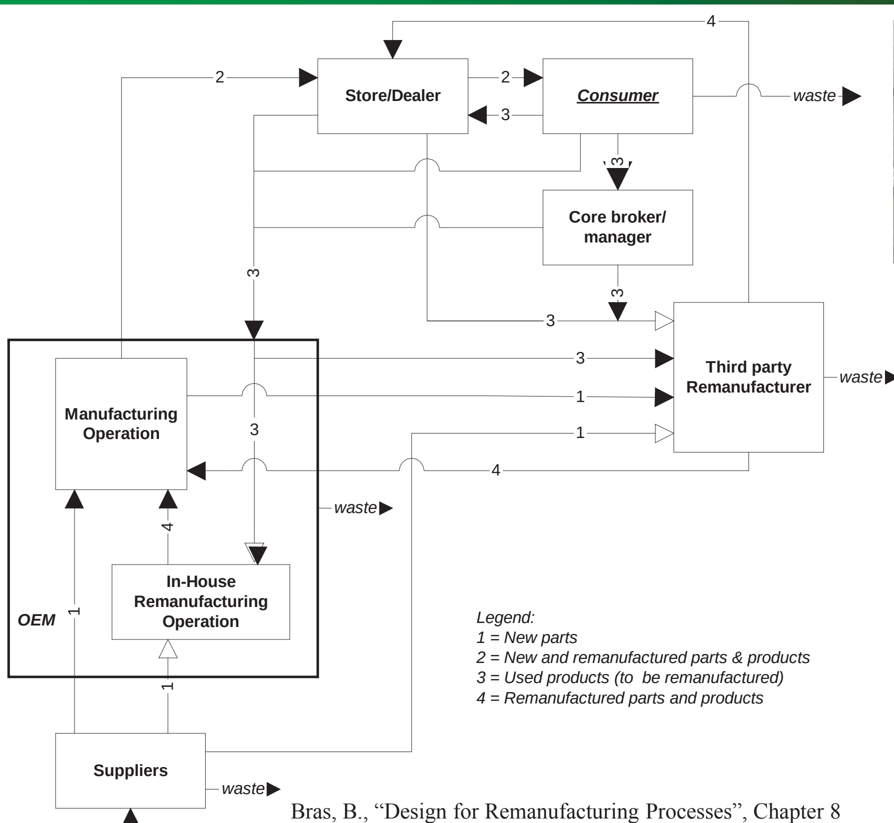
Intlekofer, K., Bras, B., and Ferguson, M., "Energy Implications of Product Leasing", Environmental Science and Technology, Vol. 44, No. 12, pp. 4409-4415, 2010

NSF Grant # 0620763

Remanufacturing Supply Chain -- Messy



Social consequences – Re-X in China

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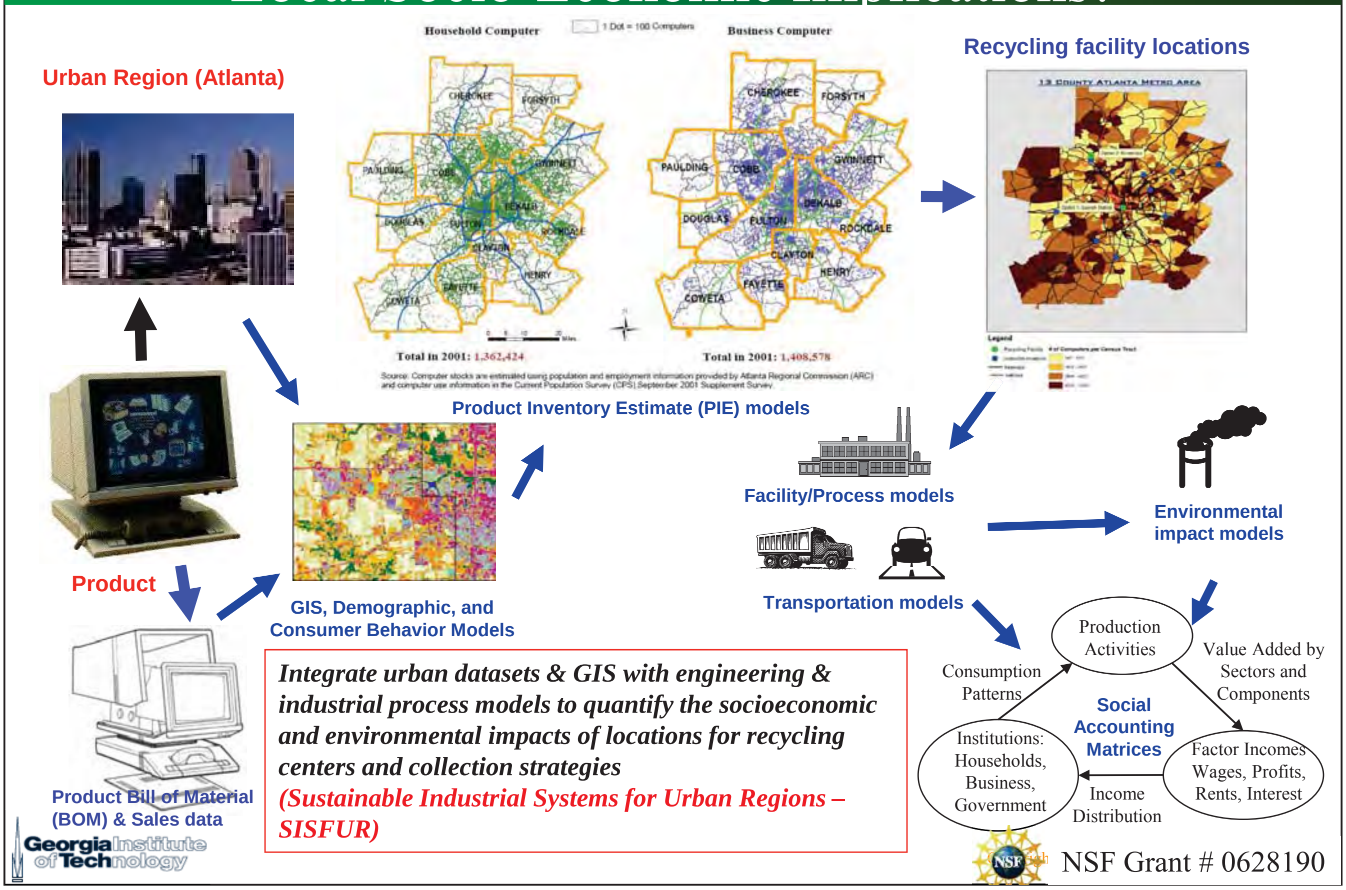
Bras, B., "Design for Remanufacturing Processes", Chapter 8 in Handbook for Environmentally Conscious Mechanical Design, (Myer Kutz ed.), Wiley, pp. 283-318, 2007

Mining Material from Cities (Urban Mining) – Local Socio-Economic Implications?



Another "Simple" Question…

- *What is better for the environment*: Digital pictures or conventional pictures?
  - Digital camera avoids chemicals in film developing.
  - However, digital cameras require electronics and computers that need energy and contribute to greenhouse gasses.

- Typical (correct) answer: *"It depends…"*
- In truth, the question has become irrelevant because the market has already spoken…

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Again, it gets more complicated…

- **Consumer has many different options**
- **What is the environmental performance of product systems?**

Imaging Scenarios	ABBR	Capture	Processing	Output
Film Capture to Retail Print	FC/R	Film	Retail	Retail
Film Capture to Wholesale Print	FC/W	Film	Wholesale	Wholesale
Digital Capture to CRT Retail Print	DC/CR	Digital	PC/CRT	Retail
Digital Capture to LCD Retail Print	DC/LR	Digital	PC/LCD	Retail
Digital Capture to CRT Wholesale Print	DC/CW	Digital	PC/CRT	Wholesale
Digital Capture to LCD Wholesale Print	DC/LW	Digital	PC/LCD	Wholesale
Digital Capture to CRT Inkjet Print	DC/CI	Digital	PC/CRT	PC / CRT Inkjet
Digital Capture to LCD Inkjet Print	DC/LI	Digital	PC/LCD	PC / LCD Inkjet
Digital Capture to Display CRT	DC/CD	Digital	PC/CRT	PC / CRT Display
Digital Capture to Display LCD	DC/LD	Digital	PC/LCD	PC / LCD Display

Companies make strategic product and processes technology decisions and need to know the environmental issues associated with *different product systems, strategies, and use scenarios.*

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LCA Results

Scenario	ABBR	Greenhouse Emission	Water Use	Waste Generation	Energy Use
		kg CO_2 eq. / kg CO_2 eq.	m^3 / m^3	kg / kg	MJ / MJ
Film Capture to Retail Print	FC/R	**1**	0.0075	0.0992	0.9801
Film Capture to Wholesale Print	FC/W	0.6127	**0.0064**	**0.0714**	0.6508
Digital Capture to CRT Retail Print	DC/CR	0.6770	0.2053	0.2512	0.7945
Digital Capture to LCD Retail Print	DC/LR	0.6409	0.0595	0.2281	0.6786
Digital Capture to CRT Wholesale Print	DC/CW	0.4673	0.2053	0.2494	0.6193
Digital Capture to LCD Wholesale Print	DC/LW	**0.2085**	0.0547	0.2034	**0.2235**
Digital Capture to CRT Inkjet Print	DC/CI	0.3122	0.1976	**1**	0.4606
Digital Capture to LCD Inkjet Print	DC/LI	0.2798	0.0670	0.9794	0.3567
Digital Capture to Display CRT	DC/CD	0.5145	**1**	0.3388	**1**
Digital Capture to Display LCD	DC/LD	0.3337	0.2709	0.1724	0.4203

Best and worst are indicated in each column

Outcome/Impact:

- No clear winning or high risk scenario
- Supported business decision to go "digital"
- Digital technologies offer more choice and flexibility, resulting in a much wider range of potential impact
- Influence of consumer during use phase can significantly influence environmental burden
- ***Providing services (wholesale printing, Ofoto) instead of products (PC printers) is better (in this case)***

Muir, M., Bras, B., and Matthewson, J., "Life Cycle Assessment of Film and Digital Imaging Product System Scenarios", Journal of Sustainable Manufacturing, Vol. 1, No. 3, pp. 286-301, 2009

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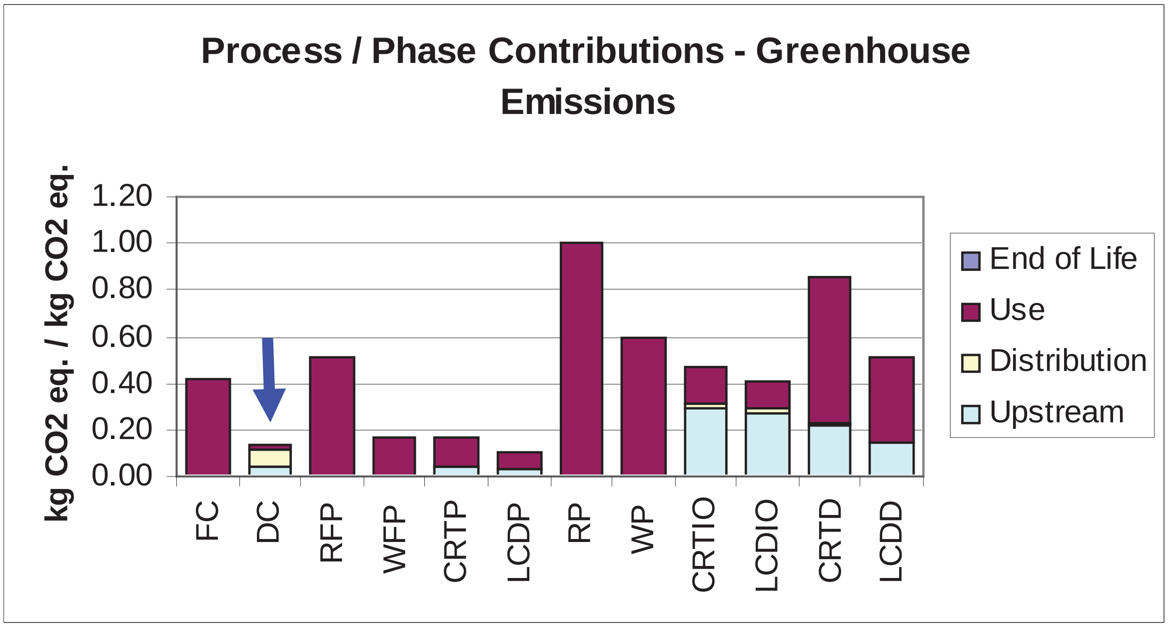
GHG Emissions – Logistics are irrelevant



- GHG emissions for various options by process
- Distribution has only real impact in DC (Digital Camera). ***Any ideas why?***

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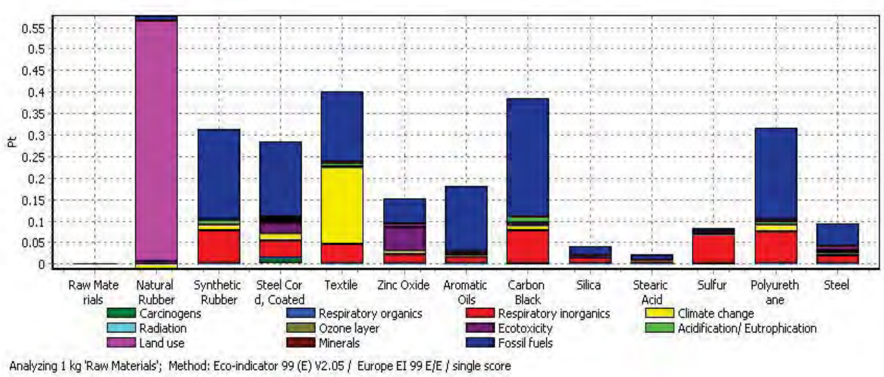
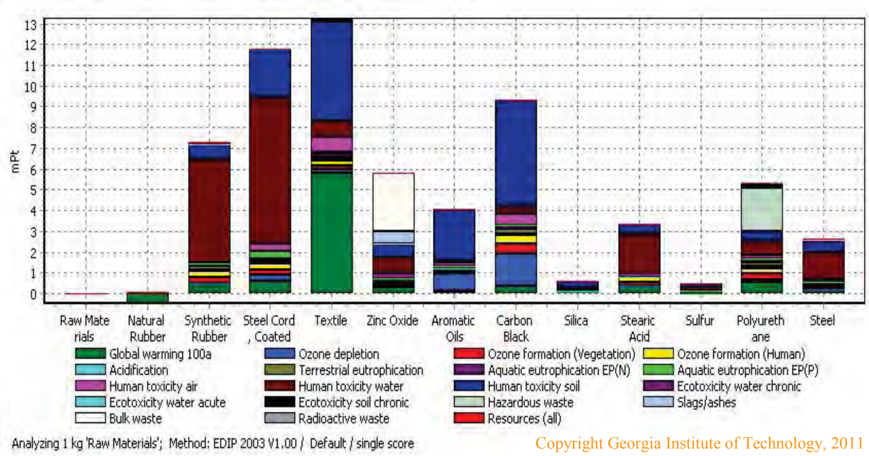
Natural vs Synthetic Rubber – Typical Dilemma

- Impact of production of 1 kg of raw material – EcoIndicator 99 versus EDIP 2003
- ***What now?***
- ***One solution: check whether it even matters…***





Bras, B. and Cobert, A., "Life-Cycle Environmental Impact of Michelin Tweel® Tire for Passenger Vehicle", SAE International Journal of Passenger Cars– Mechanical Systems, June, Vol. 4, No.1, pp. 32-43, 2011

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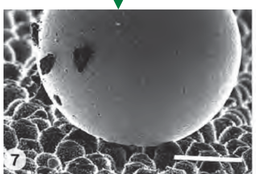
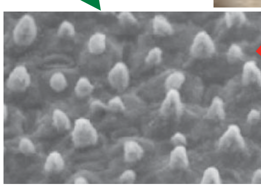
MICHELIN

Direct Modeling and Simulation of Effects on Ecosystems – Great in theory, but hard in practice

Lotus effect (self-cleaning)

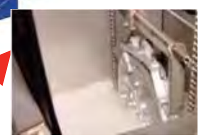




Surface nano-bumps

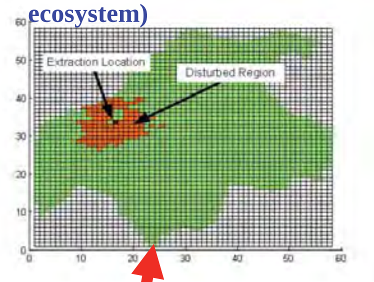
Process: aqueous cleaning machine

Part: transmission casing

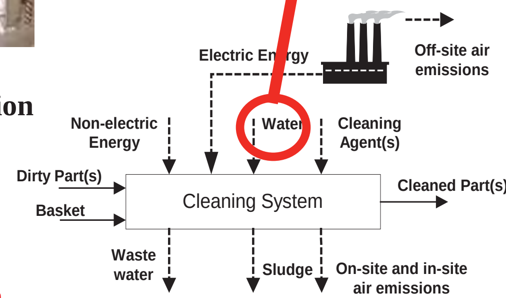


Ecosystem

Spatial ecosystem landscape model (predicting effect on ecosystem)



Idea: Reduce water consumption in remanufacturing through self-cleaning surface



Process model (predicting water use)

Reap, J., Roman, F., Guldberg, T., and Bras, B., "Integrated Ecosystem Landscape and Industrial Modeling for Strategic Environmentally Conscious Process Technology Selection", 13th CIRP International Conference on Life-Cycle Engineering Conference, Leuven, Belgium, May 31-June 2, 2006

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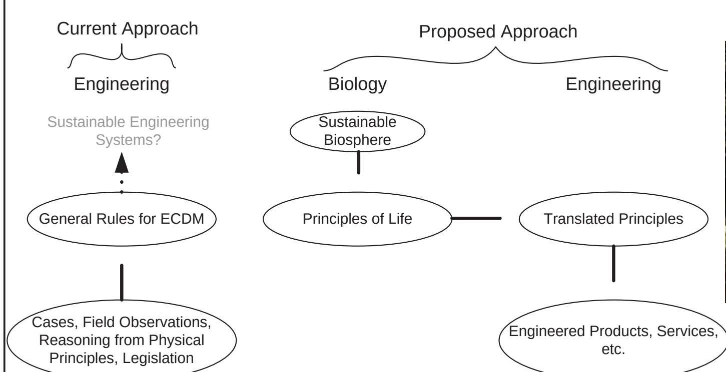
Bio-Inspired Metrics and Guidelines

Going beyond the metric conundrum:

- Nature has been sustainable for a long time.
- What can we learn from past & present biological systems?
  - Including extinct systems…
- Can we derive design guidelines from Nature that will result in inherently sustainable engineered systems?



NSF Grant # 0600243

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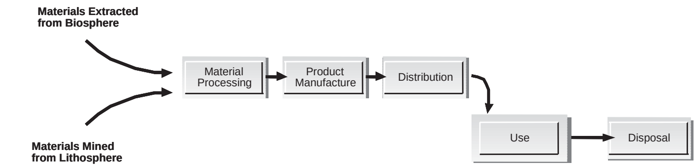
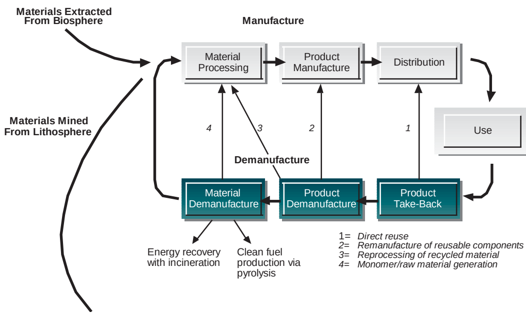
Different Production Systems



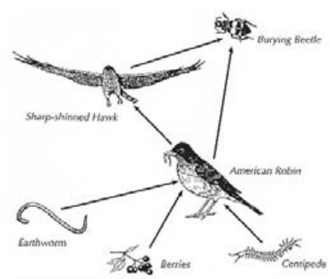
Linear Production:
"Take, make, waste"
(our current system)



Vs.

Closed Loop, Industrial Symbiosis, etc., as promoted by Industrial Ecologists

Vs.

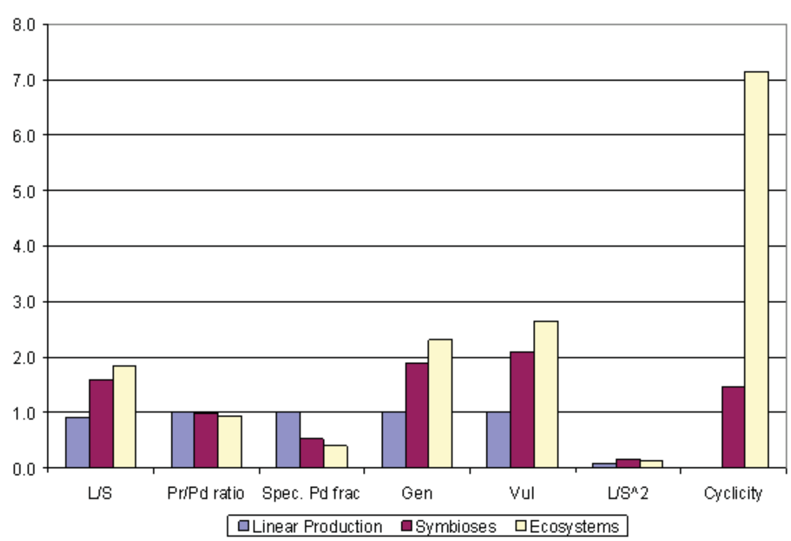


An example of a food web.

Ecological Networks
(as in Nature)

How do they compare?

How industrial ecosystems rank



Average ecological structural metrics for a linear production chain, industrial symbioses (n=29) and ecosystems (n=40)

- Industrial symbioses have greater resource efficiency and less waste compared with linear counterparts
- Statistically, industrial symbiosis and food web structures cannot plausibly be grouped with food webs.
- Symbioses represent middle ground
- Worth exploring result of patterning closed industrial material flows after those found in nature

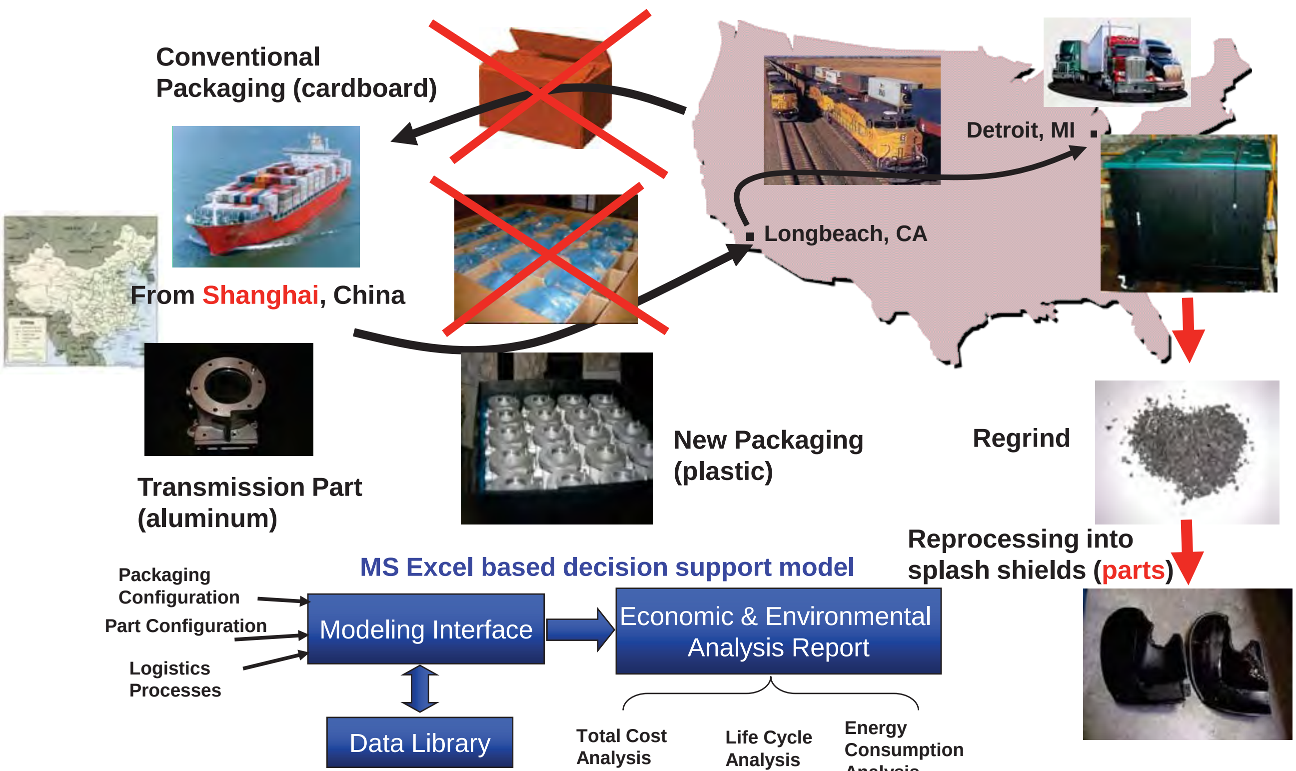
Work in progress…

NSF Grant # 0967536

Importance of "Triple Bottom Line"

- Environmental assessments are not enough
- Financial is also needed
  - Total Cost Analysis
  - Life-Cycle Costing
  - Activity-Based Costing
- Social "quality of life" assessments also desirable
  - but harder for engineers
  - Example metrics: job creation, ergonomics, etc.
- Metrics are often not independent, but causally related

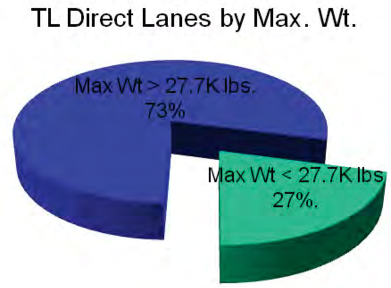
Triple Win Example – It can be done! B2B Packaging



A key to success: Standard internal six sigma process format was used

Rethinking Delivery – Engaging External Parties with Sound Engineering

- Many systems are over-engineered
- Appropriate technology and sound engineering can go a long way towards sustainability
- Switching from Class 8 High Duty Diesel trucks to Ford F750 can provide significant savings.
- Ideas were triggered by quest for fuel savings.



	Ford F-450/550	Class 6 Ford F-650	Class 7 Ford F-750	Class 8 (Freightliner Day Cab)
MSRP (New)	$42,295/$45,240	$54,167	$55,448	$140,000
Price w/ Incentives	$33,750/$36,463	$43,334	$44,358	$87,000
Curb Wt.	17,950 – 19,000 lbs. (GVWR)	9,300 lbs.	9,300 lbs.	16,000 lbs.
Gross Combined Wt. Rating	24,000 – 33,000 lbs.	50,000 lbs.	50,000 lbs.	80,000+
Towing Wt.	24,800 lbs.	40,700 lbs.	40,700 lbs.	57,000 lbs.
Max Payload	16,800 lbs.	27,700 lbs.	27,700 lbs.	44,000 lbs.
Output	325-362 hp	325 hp	325 hp	410-550 hp

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Limits of Engineering

- **Be aware of "systems solutions" beyond engineering as well as "unintended consequences"**

For example:

- Localities matter in sustainability
  - Relocating a manufacturing facility to a locality with renewable power often has a larger carbon footprint effect than any process efficiency improvement

  GA Power Plant Bowen (Cartersville):
  - **CO_2 emission: 0.9 kg/kWh**
  - **H_2O evaporation: 0.4 gallons/kWh**

  South-East average (incl. Georgia):
  - **CO_2 emission: 0.6 kg/kWh**
- Social behavior may have larger influence than engineering
  - Car pooling creates more fuel savings than all technologies combined
  - Rebound effect can kill any efficiency gains

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Some Lessons Learned (over the years)…

- Assessment approach (top down, bottom up, accuracy level, etc.) and data requirements depend on the question to be answered
- Data is everywhere and nowhere, and never reconciled
- Legacy systems are a fact of life
- Location and time matter (where and when)
- System boundaries changes can fudge the numbers
- Expect the unexpected
- Verify! (prediction ≠ reality)
- Transparent modeling is crucial (for cont. improvement/use)
- Need for model base instead of database
- Start simple with best and/or worst case scenarios
- Best solutions invariably require change of system boundary
- The wheel is reinvented all the time – also in academia

In Summary…

- Key concepts:
  - Life Cycle Thinking
  - Closed Loop Thinking (Re-X)
  - Systems Thinking, Modeling & Simulation
  - Good science and engineering
- Some tools are available, but …
  - Not mainstream
  - Validity can be weak
  - Integration severely lacking
- Success is enhanced by using/extending/adapting known methods, techniques and tools
  - Six Sigma, Activity-Based Costing, etc.
- Evolution of thinking typically occurs - pushing the system boundaries
- Achieving sustainability solutions is a very complex, multi-scale problem requiring multi-disciplinary teams and approaches
  - which equates to slow going with high learning curves
  - Good Teams: Engineering + City/Regional Planning + Sciences (Earth & Atmospheric Science + Biology) + (Industrial) Practitioners + Management/Economics
- Need more dissemination, communication, and education

PRESENTATION: CONSUMPTION, SUSTAINABILITY, AND SOCIAL BENEFITS, BY THOMAS THEIS

Consumption, Sustainability, and Social Benefits

Thomas L. Theis
Institute for Environmental Science and Policy
University of Illinois at Chicago

Workshop on Design of Sustainable Product Systems and Supply Chains
12-13 September, 2011

Life Cycle Assessment

- A systems methodology for compiling information on the flow of materials and energy throughout a product chain
- LCA evolved from industry needs to understand manufacturing, and market behavior, and make choices among competing designs, processes, and products
- Defines four general sections of the product chain:
  - materials acquisition
  - manufacturing/fabrication
  - product use
  - downstream disposition of the product

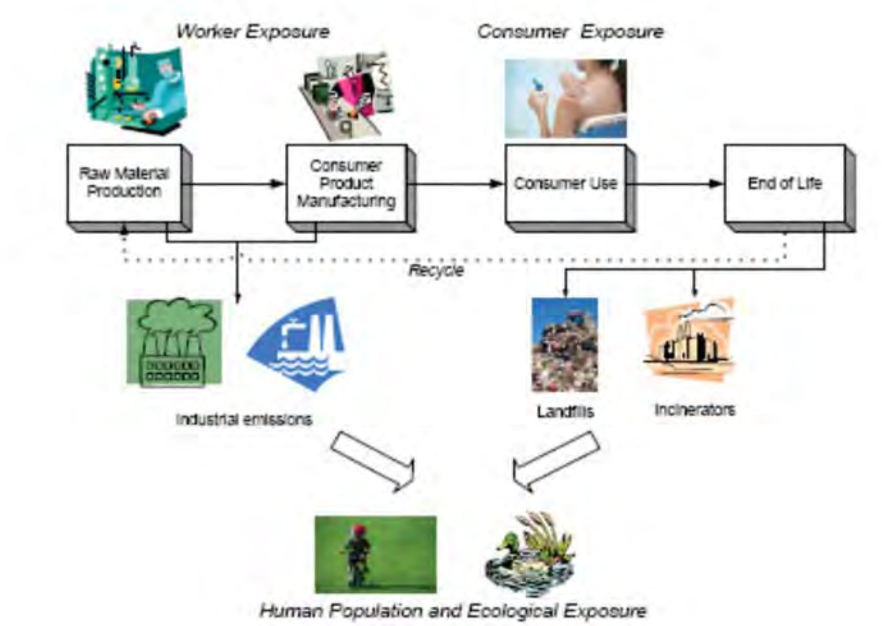
What is Life Cycle Good For?

- ID energy/material/waste hot spots
- Compare options
- Improve product/service chain
- Avoid displacing pollution
- Very good at framing policy issues

What is it not especially good for?

- Detailed risk assessments

Life Cycle Assessment Stages (USEPA)



"Greening" product chains

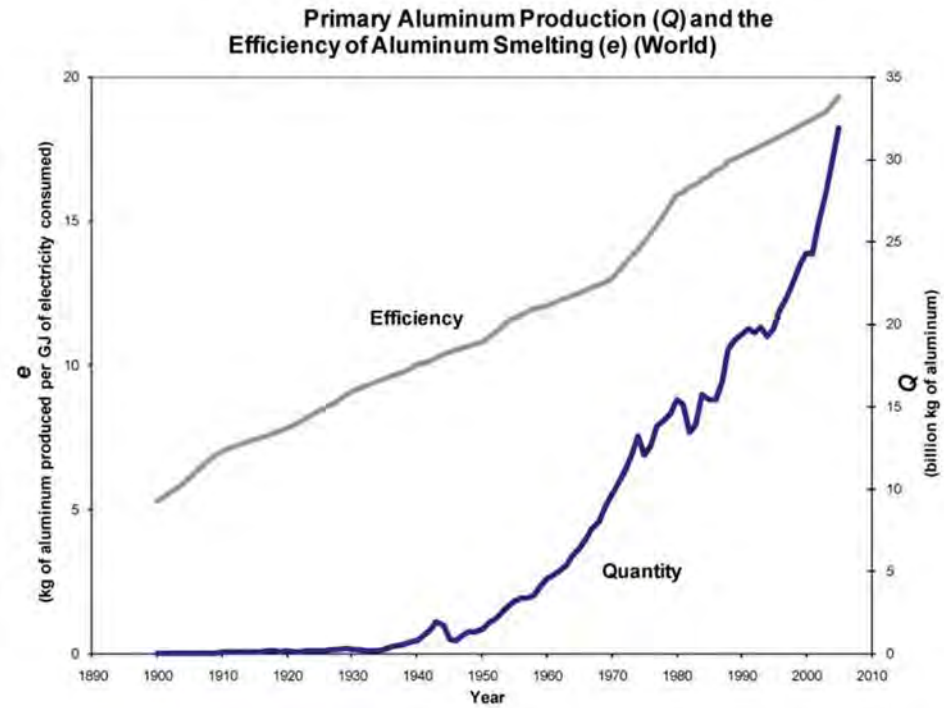
Product conceptualization, development, manufacturing, distribution, marketing, use, and post-use disposition that incorporate

- Design for the environment principles
- Green engineering
- Green chemistry
- Business practices built upon the concepts of systems thinking and "eco-efficiency"

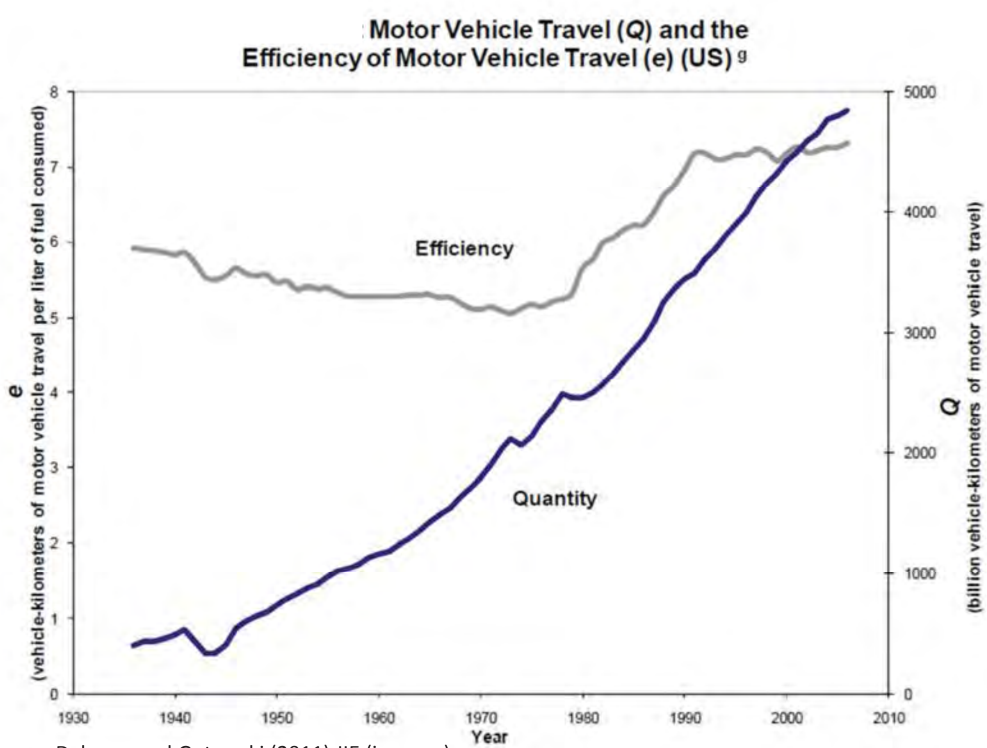
Underlying assumptions…

It is generally believed that if these principles and practices can become widespread (i.e. if the complete product chain can be "greened" enough), then better material and energy efficiencies will result, effectively "decoupling" environmental impacts from the consumptive habits of the human population

The social benefits of consumption are less clearly understood, but it is assumed that a greater variety of more efficient and environmentally-conscious products and services, sometimes made available at lower costs, will necessarily yield societal benefits, thereby moving toward at least partial fulfillment of the sustainability paradigm



From: Dahmus and Gutowski, (2011) JIE (in press)



Source: Dahmus and Gutowski (2011) JIE (in press)

Historical Efficiency and Consumption Trends

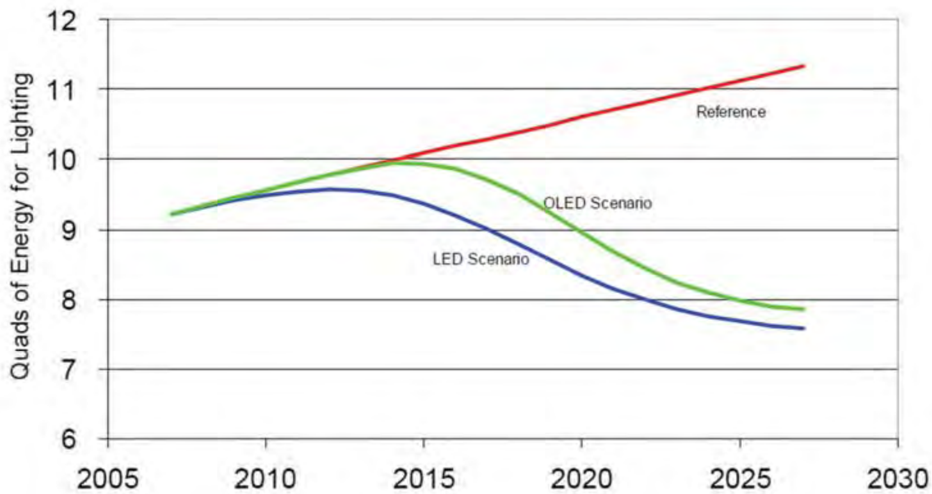
(Dahmus and Gutowski, JIE 2011)

Activity	Sector	Time Period	Avg Annual Efficiency Improvement (%)	Avg Annual Increase in Consumption (%)	Ratio: Consumption/ Efficiency
Pig Iron	Materials	1800-1990	1.4	4.1	3.0
Aluminum	Materials	1900-2005	1.2	9.8	7.9
N-Fertilizer	Food	1920-2000	1.0	8.8	8.9
Elec-Coal	Energy	1920-2007	1.3	5.7	4.5
Elec-Oil	Energy	1920-2007	1.5	6.2	4.2
Elec-Nat Gas	Energy	1920-2007	1.8	9.6	5.5
Freight Rail Travel	Transportation	1960-2006	2.0	2.5	1.2
Air Passenger Travel	Transportation	1960-2007	1.3	6.3	4.9
Motor Vehicle Travel	Transportation	1940-2006	0.3	3.8	11.0

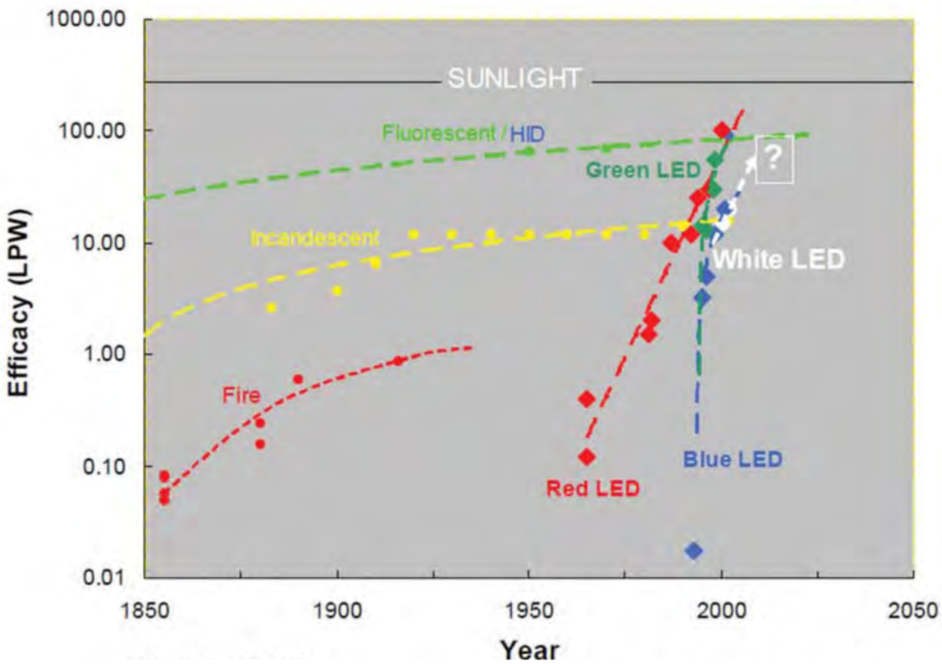
Example: Artificial Lighting

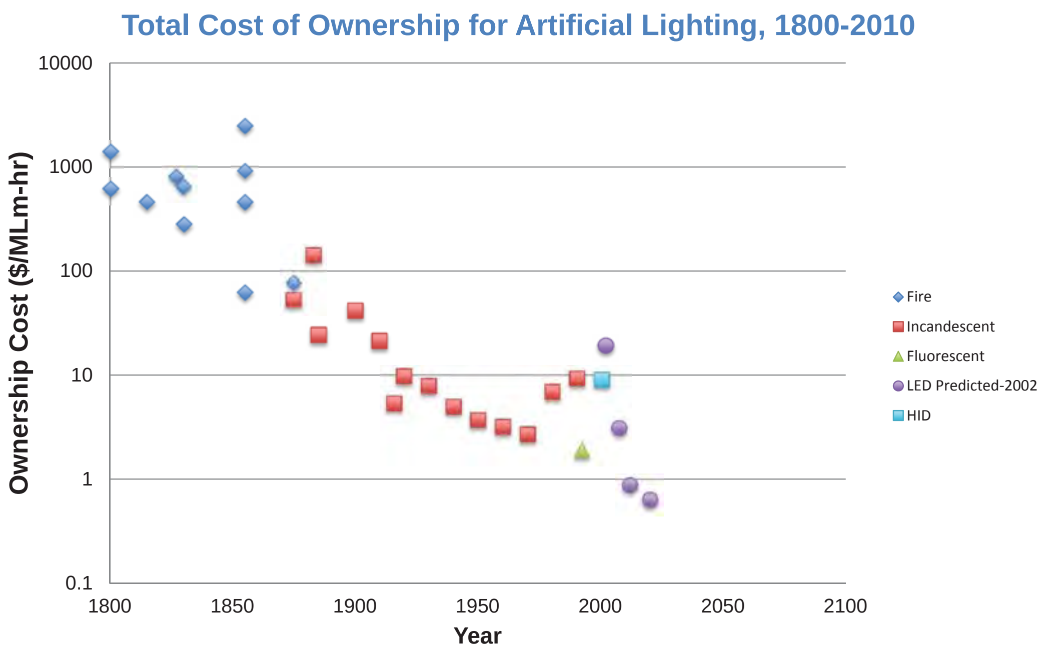
- No realistic substitutions
- Lighting is undergoing a “nano-enabled” evolution to SSL
- SSL: About 10 times as efficient as incandescent, 2 times fluorescent
- Last 30 times as long as incandescent, 3 times as long as CFLs
- So, we’ll use less energy and generate fewer energy-related emissions, right?

Projections for Energy Consumption for Lighting Through 2027 (US)



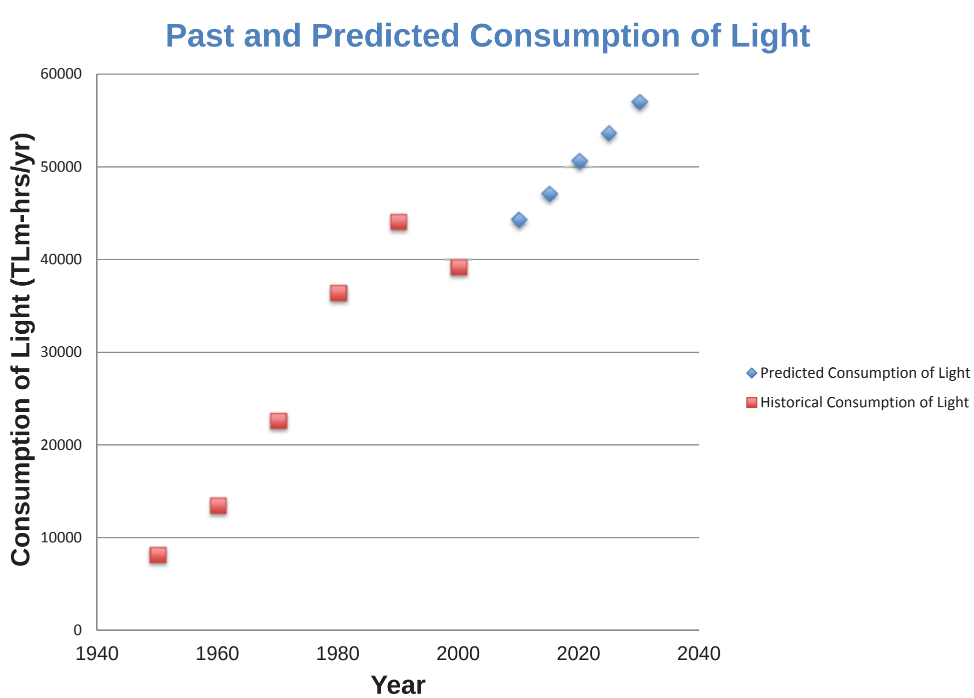
"Energy Savings Potential of Solid State Lighting in General Illumination Applications", Navigant Consulting, Washington DC (2006)





Data for Fire and Incandescence modified from W.D. Nordhaus, In T.F. Breshnahan and R.J. Gordon, Eds., The Economics of New Goods (U of Chicago Press, 1997) pp. 29-70.
Data for SSL-LEDS taken from 2002 U.S. SSL Roadmap.

Expressed in 2010 dollar amounts



Source for predicted consumption: Energy Savings Potential of Solid-State Lighting in General Illumination Applications 2010 to 2030 Navigant Consulting, 2010

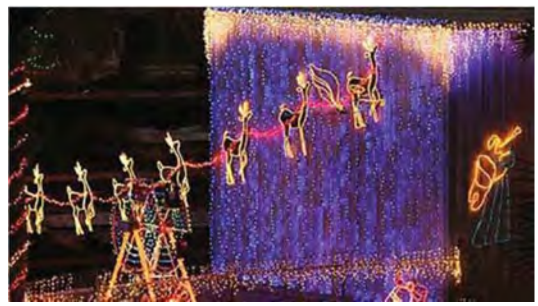
Summary trends

YEAR	Real Price of Fuel	Efficiency of Lighting	Real Price of Light	Consump-tion of Light	Energy for Light	Energy/ Person for Light	% of Total Energy Devoted to Light
1800	1	1	1	1	1	1	1
1900	0.27	14.5	.024	220	8.97	2.45	~1
2000	0.18	700	0.0003	34,000	72.92	11.63	10










Costs and Benefits

(1) Each of these applications, viewed by itself, is more efficient than what it replaced.

(2) Many, maybe all, of these applications help us to be safer, healthier, happier, more productive, and “greener”

(3) But viewed collectively our energy and material consumption continues to increase.

We’re “greener”, but are we more sustainable?

Combining physical and social science…

J Y Tsao, H D Saunders, J R Creighton, M E Coltrin and J A Simmons (2010) “Solid-state lighting: an energy-economics Perspective”, *J. Phys. D: Appl. Phys*. 43 (2010) 354001

There is a massive potential for growth in the consumption of light if new lighting technologies are developed with higher luminous efficacies and lower cost.

This increased consumption may increase both human productivity and the consumption of energy associated with that productivity.

Is the increase in human productivity and quality of life due to an increase in consumption of light worth the increased energy burden?

Three general directions for sustainable product-chain research:

(1) Stronger interdisciplinary effort to understand the complex factors emergent across the complete product chain that contribute to resource consumption, environmental degradation, and human health risk, while recognizing benefits to society,

(2) Expansion of “green”, design for the environment, and organizational eco-design principles beyond their traditional focus on increasing efficiency and lowering pollutant loads per unit product to include economic and behavioral factors, and

(3) Investigation of the impacts of more highly integrated policies, based on the sustainability paradigm, that are able to meet human needs while capturing economic excesses and decoupling environmental degradation that have their roots in over-consumption.

PRESENTATION: LCA FROM AN INDUSTRY PERSPECTIVE, BY BILL FLANAGAN

LCA from an Industry Perspective

William P. Flanagan, PhD
Ecoassessment Leader
GE Global Research

US EPA-NSF Scientific Workshop:
Design of Sustainable Product Systems
and Supply Chains

Arlington, Virginia
September 12-13, 2011

imagination at work

Ecoassessment

Center of Excellence

A systematic way to assess environmental footprint of selected GE products

- Strategy and vision
- Expertise and guidance
- Tools and processes
- Education and awareness
- Policy and advocacy

Ecoassessment COE

External networks are important

- External LCA experts
- Academics
- 3rd-party critical review
- Software providers
- NGOs
- Industry LCA contacts

imagination at work

Business-driven application of LCA

direct and indirect value

eco Product Innovation
LCA a key element of environmentally conscious product design
(but not the only element)

Commercial
(1) Ability to deliver complex environmental messaging;
(2) Ability to compete for bids requiring LCA / carbon footprint

Business Strategy
Identify strategic business opportunities

Due Diligence / Risk Management
Identifying and addressing potential perceptual and business risks

Reputation
(1) Enhancing corporate reputation and eco brand value;
(2) Ensuring seat at environmental policy table

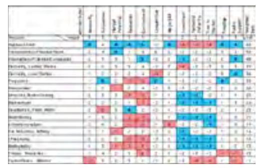
imagination at work

LCA application space within GE

R&D /
Business strategy

Product design

Product evaluation

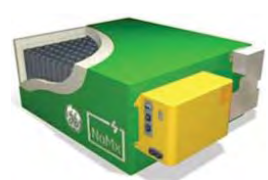


Commercial support

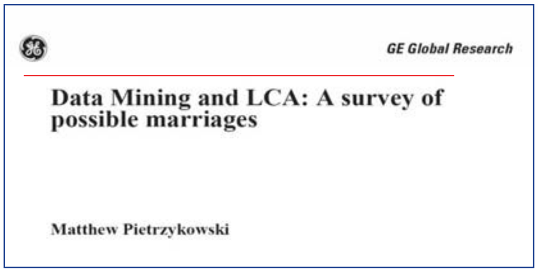
Understanding benefits, risks, opportunities

Selected project examples

- Biomass/coal gasification
- 2.5MW wind turbine
- CdTe thin film solar
- Durathon™ sodium metal halide battery
- Smart Meter
- Single-use process equipment for biopharmaceutical manufacturing



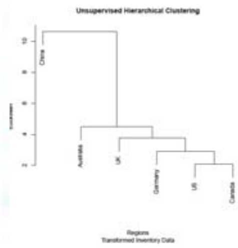
Advanced statistics and numerical analysis
Sensitivity and uncertainty analyses

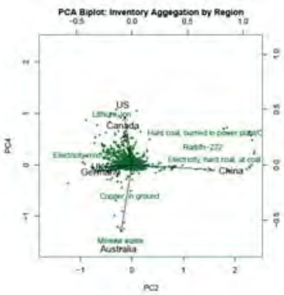

GE Global Research

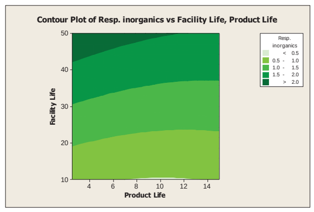
Data Mining and LCA: A survey of possible marriages

Matthew Pietrzykowski

LCA IX, Boston, MA, Oct 2009








Matt Pietrzykowski


Ron Wroczynski

<u>Short courses</u>:

- Statistical Methods in LCA
- Advanced Statistics and Data Analysis

Offered at LCA XI, October 3, 2011, Chicago

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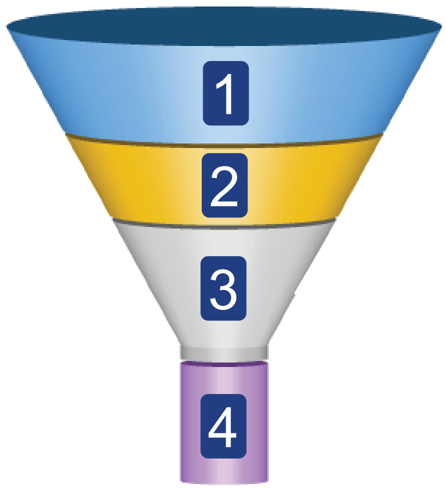
Five enabling principles

Be strategic and selective



Little or no expertise required

1 Qualitative Evaluation
- Qualitative
- Substances of concern
- Product regulatory compliance
- Material sustainability

2 Screening LCA
- High-level, data "lite"
- Hot spot identification

Deep expertise required

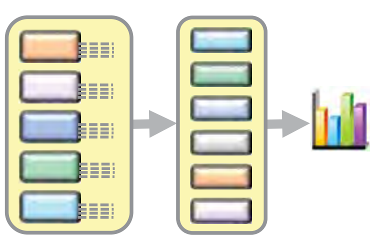
3 Streamlined LCA
- Reduced system boundaries
- Suitable for internal use

4 Extensive LCA
- Required for support of external claims
- ISO 14040-44
- 3rd-party panel review required for external claims involving comparative assertions

Strategic down-select → business efficiency

imagination at work

Leverage qualitative screening



- Insight and awareness
- Reduced time and effort
- Quickly identify areas that may require further analysis

Efficient | Effective | Can be used by non-experts

imagination at work

Focus on value creation

- For any idea to thrive within industry, it must create value
- Many opportunities to create value from sustainability-based initiatives

imagination at work

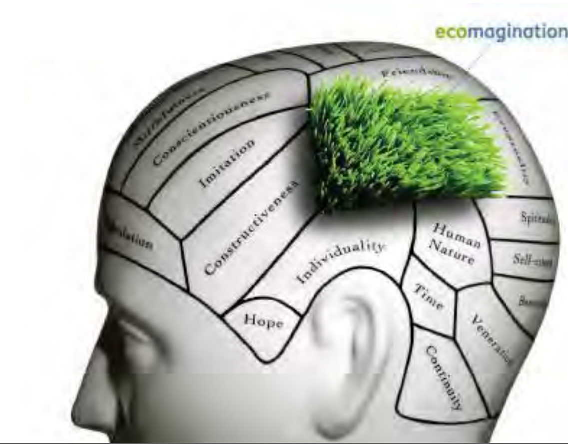
Customize to business context

- No "one size fits all" tool or strategy
- Be prepared to customize content
  - ✓ Invites ownership
  - ✓ Enhances relevance and value

imagination at work

Leverage power of innovative thinking

- Great ideas can come from anywhere
- Invite active engagement



Final thoughts

1. Be strategic and selective
2. Leverage qualitative screening
3. Focus on value creation
4. Customize to business context
5. Leverage power of innovative thinking

ecoassessment
center of excellence

Bill Flanagan
Ecoassessment Leader
GE Global Research
1 Research Circle
Niskayuna, NY 12309
flanagan@ge.com
(518) 387-5070

PRESENTATION: EPA SUSTAINABILITY AND THE DESIGN OF SUSTAINABLE PRODUCT NETWORKS AND SUPPLY CHAINS, BY JOSEPH FIKSEL

Design of Sustainable Product Systems & Supply Chains

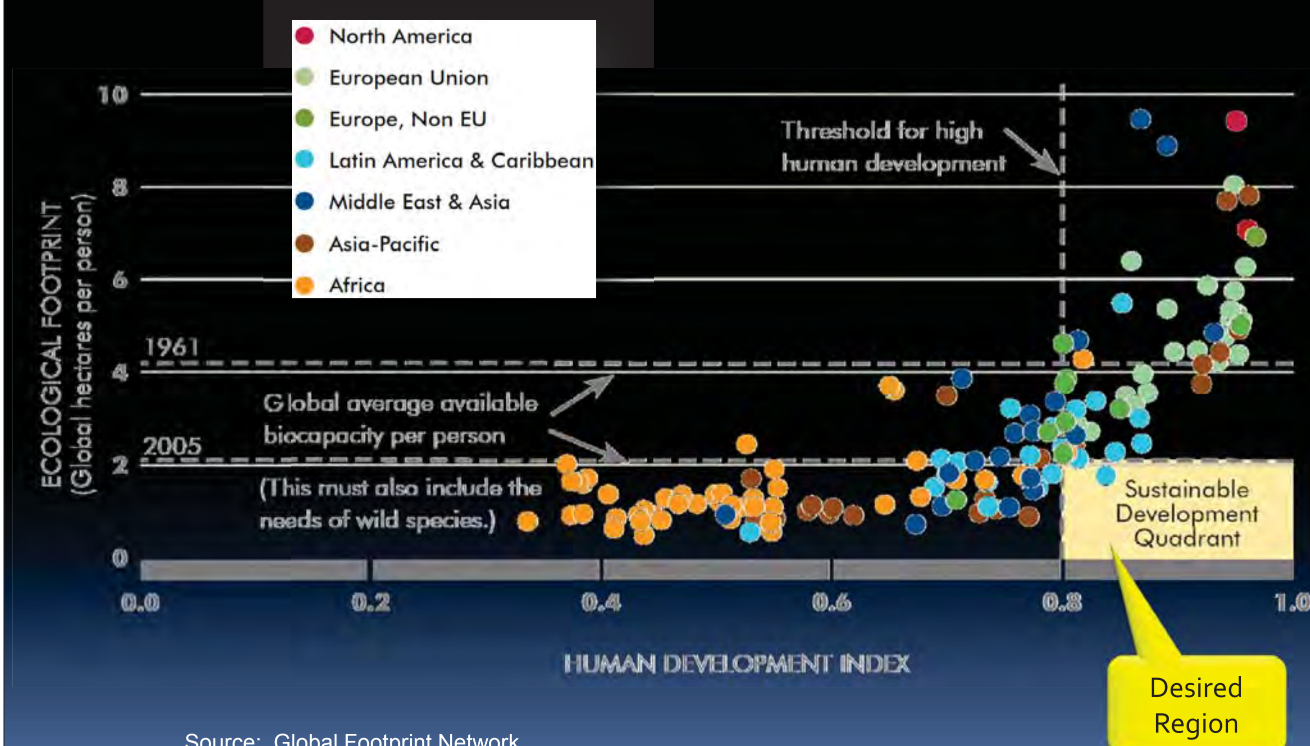
Joseph Fiksel

Sustainability Advisor, U.S. EPA
Office of Research & Development*

Executive Director, Center for Resilience
The Ohio State University, USA

*The content of this presentation reflects the views of the author and does not represent the policies or position of the U.S. EPA.

Trajectory of Human Progress

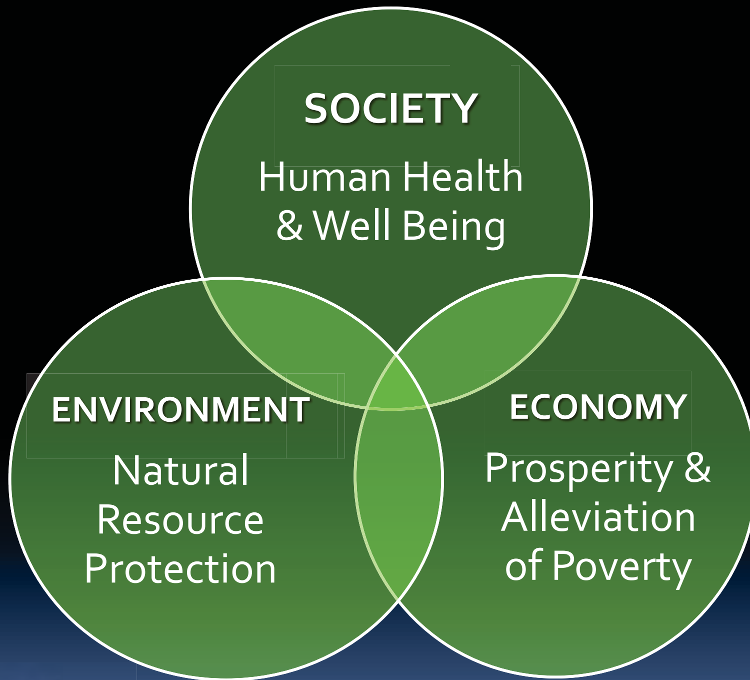


Source: Global Footprint Network

Sustainability Paradigm

"It is important for EPA to optimize all three pillars of sustainability... decisions that further one of the three pillars should, to the extent possible, further the other two."

—NRC Green Book, 2011



Changing the Game at U.S. EPA

- "The major challenges to sustainability, human health, and the environment...are not incremental problems, and they do not lend themselves to incremental solutions....Only by implementing **systems thinking and integrative approaches** to complement our traditional single-discipline approaches, will we be better able to solve these challenging problems."

  Paul Anastas, ORD Assistant Administrator

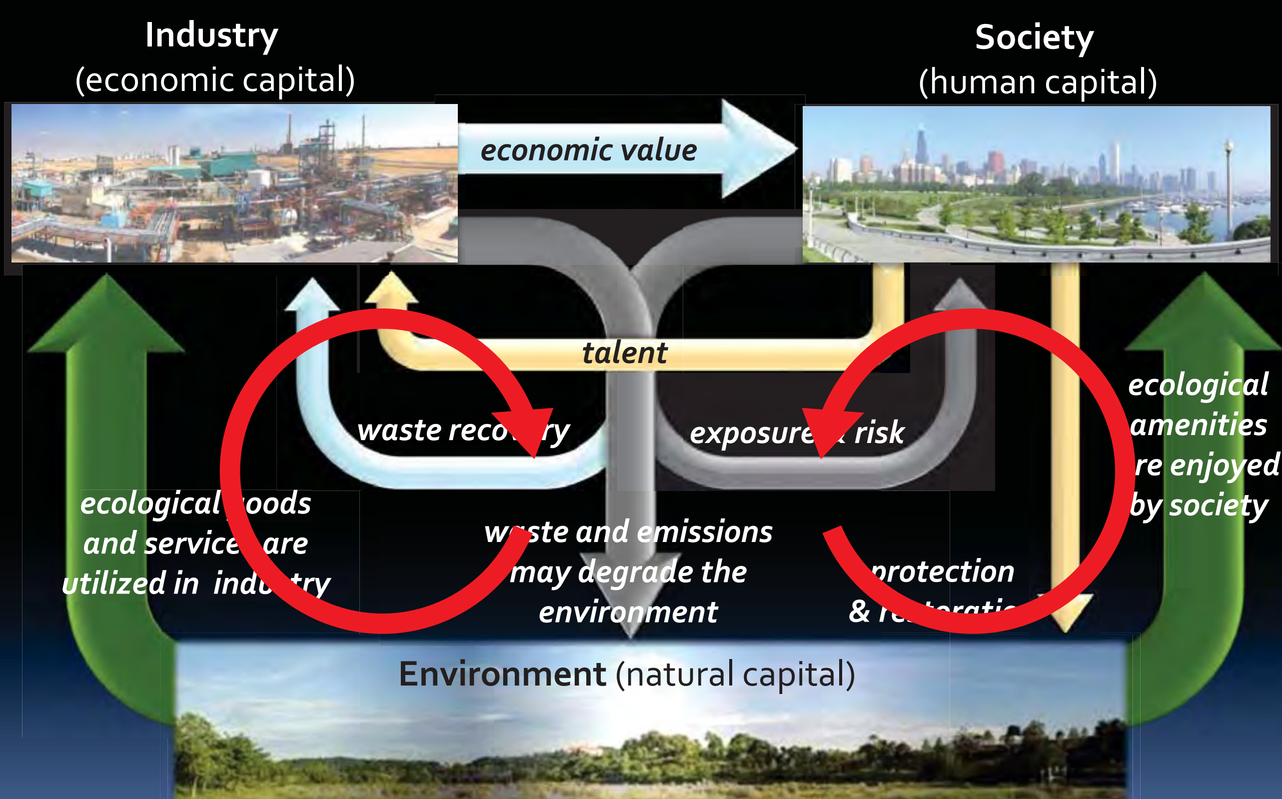
- "Well-conceived, effectively implemented environmental protection is good for economic growth."

  Lisa Jackson, EPA Administrator

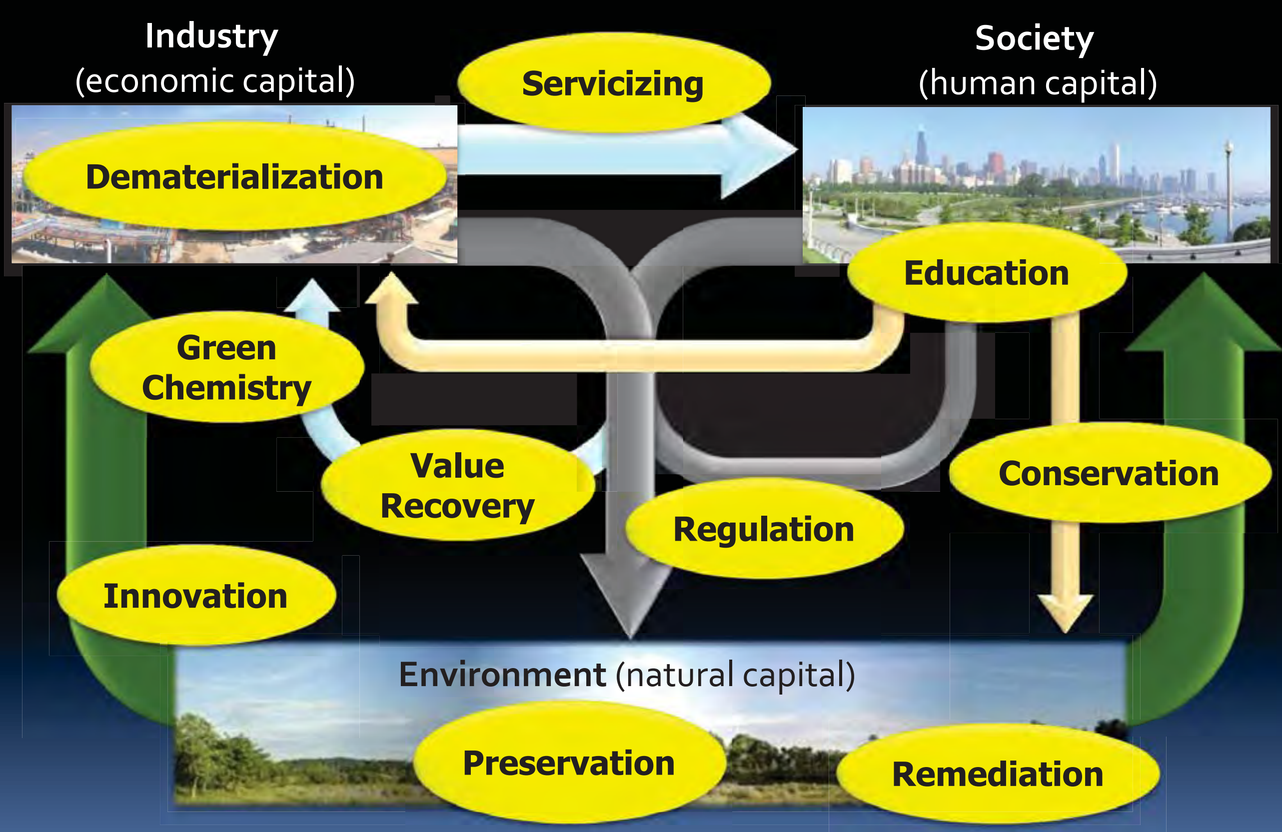
What is systems thinking?

- A holistic approach for understanding the interactions and feedback loops among
  - Economic systems—companies, supply chains....
  - Ecological systems—forests, watersheds....
  - Societal systems—communities, networks....
- Helps to consider the potential benefits and unintended consequences of human interventions, such as new policies, new technologies, and new business practices

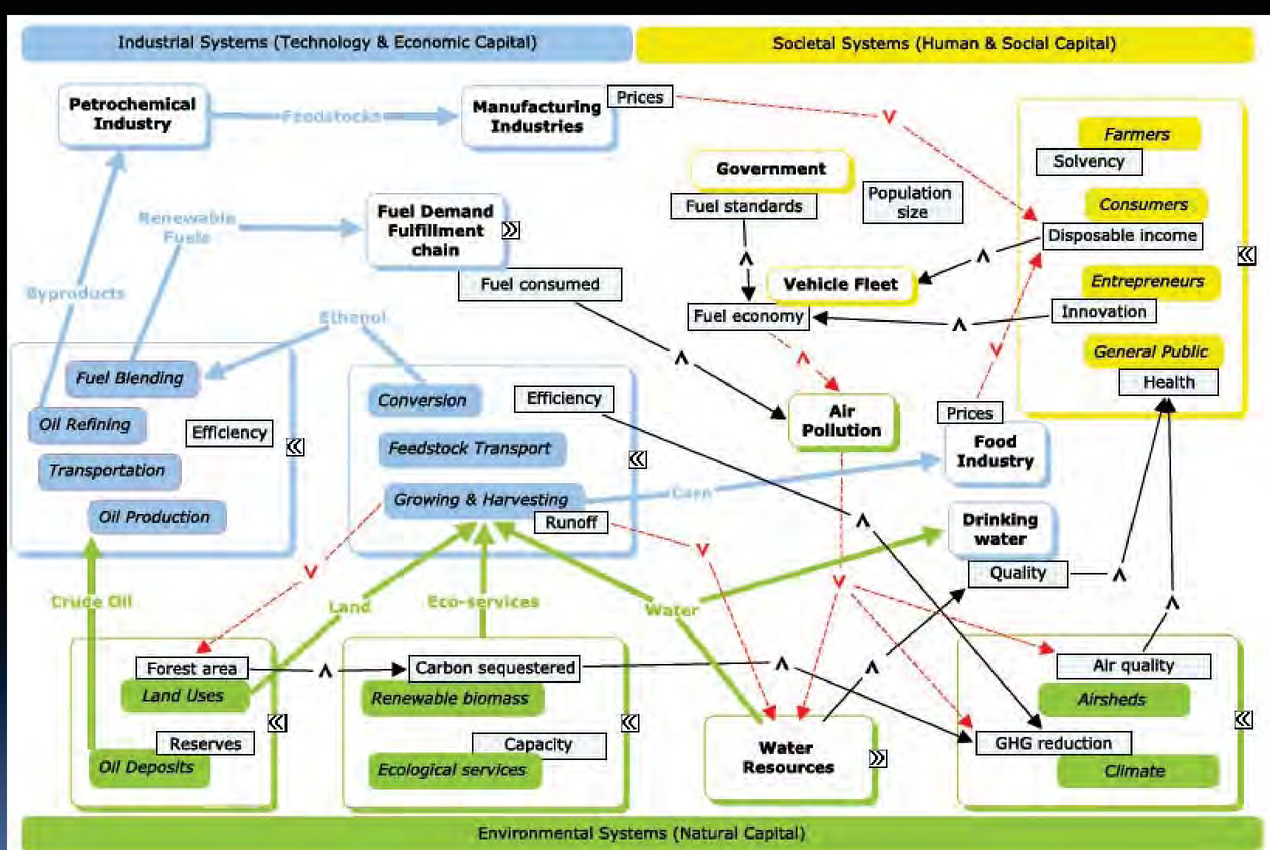
Systems Thinking: Triple Value Model

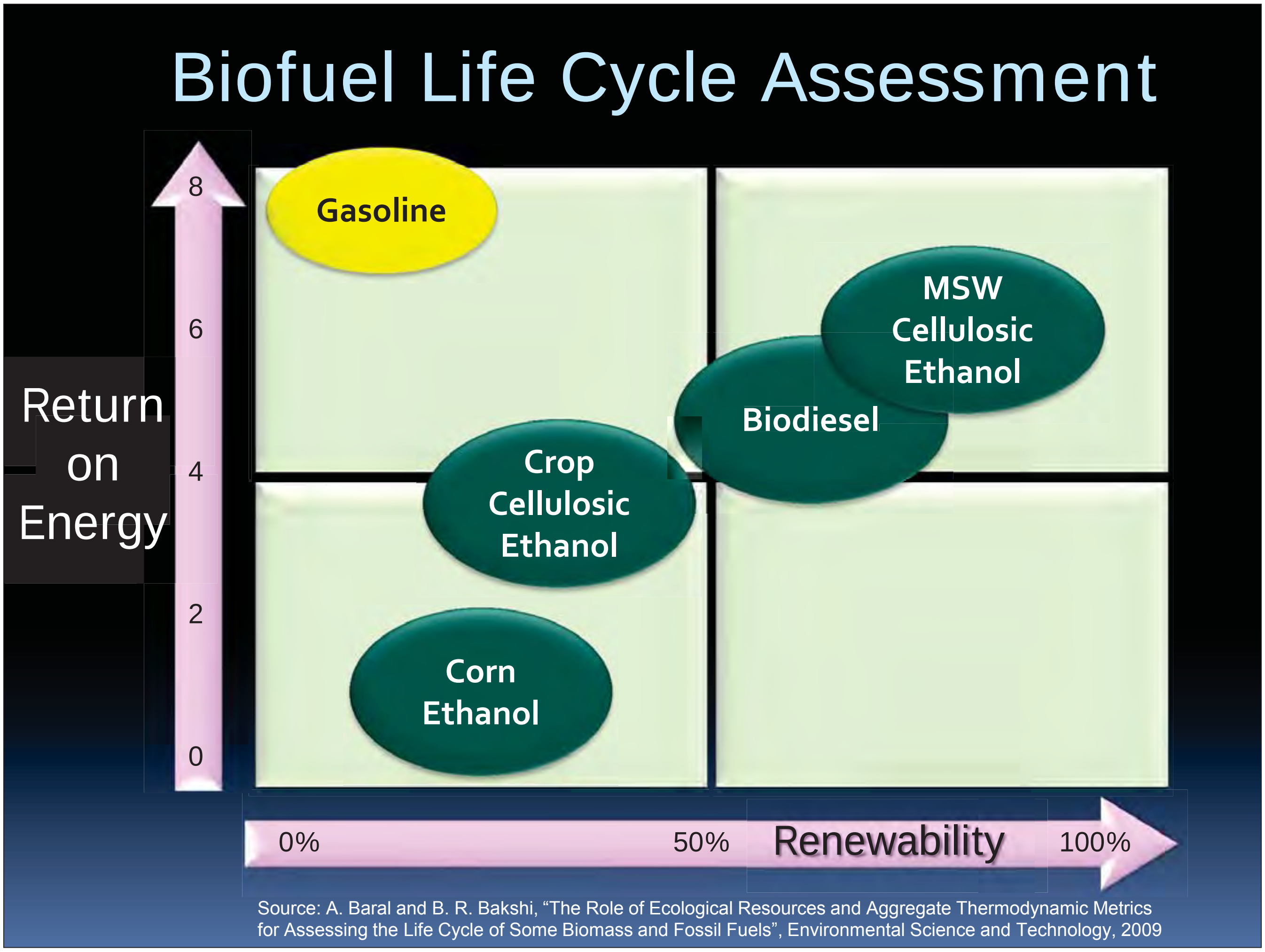


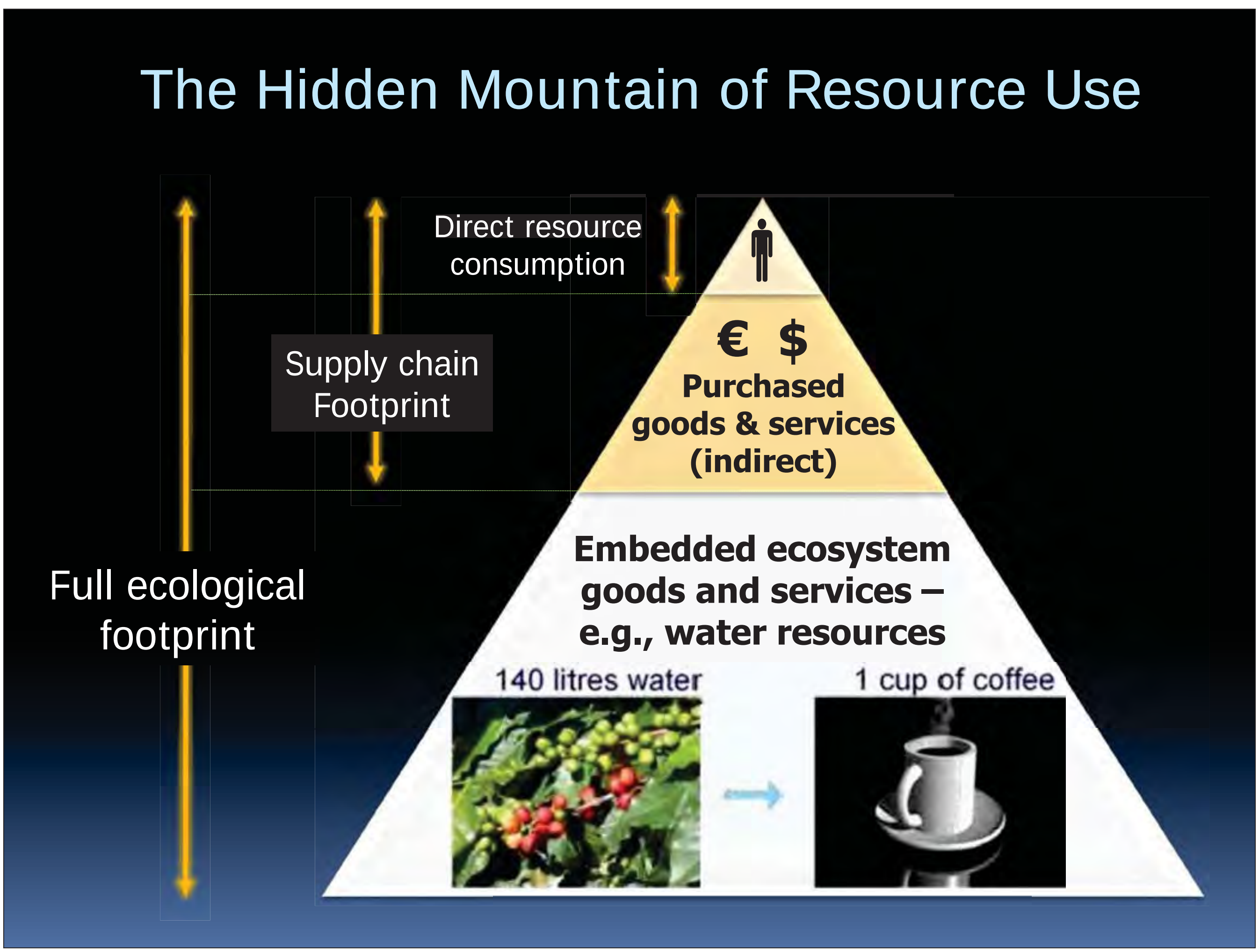
Opportunities for Intervention



Example: Corn Ethanol Product System

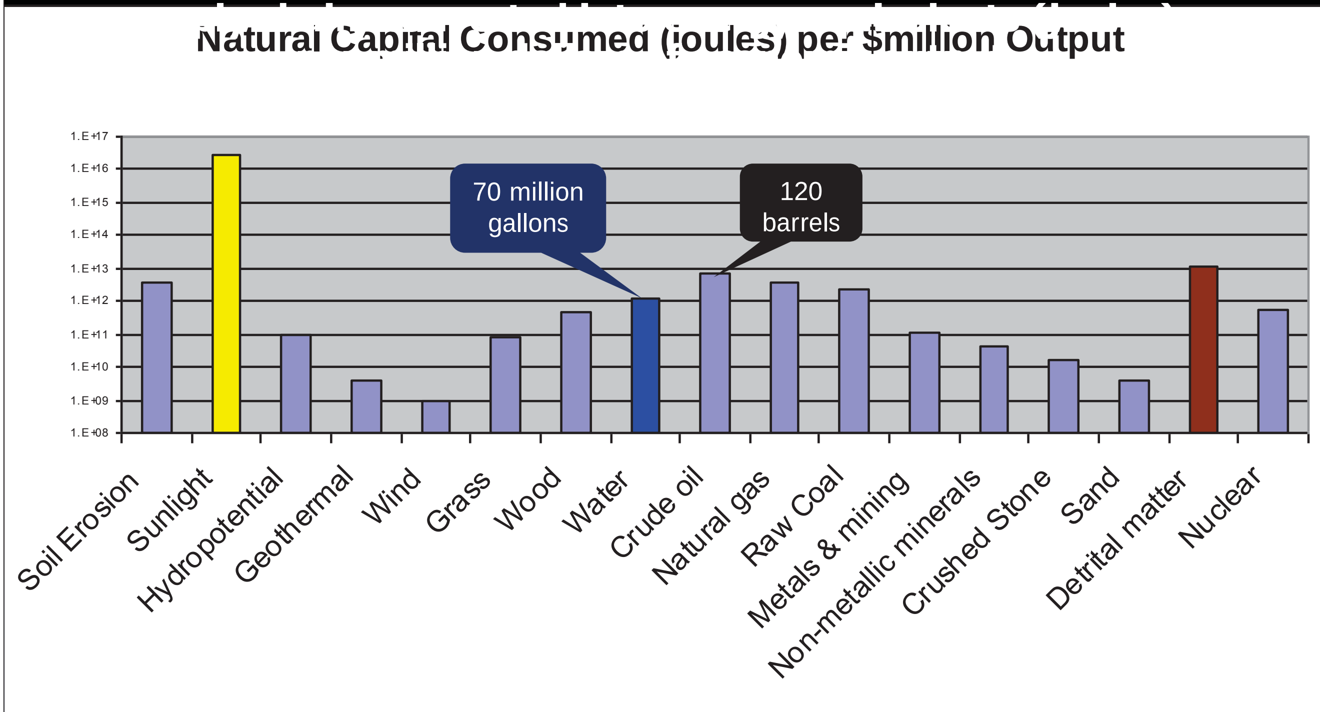



Biofuel Life Cycle Assessment
Return on Energy
8
6
4
2
0
Gasoline
MSW Cellulosic Ethanol
Biodiesel
Crop Cellulosic Ethanol
Corn Ethanol
0%
50%
Renewability
100%
Source: A. Baral and B. R. Bakshi, “The Role of Ecological Resources and Aggregate Thermodynamic Metrics for Assessing the Life Cycle of Some Biomass and Fossil Fuels”, Environmental Science and Technology, 2009


The Hidden Mountain of Resource Use
Direct resource consumption
Supply chain Footprint
Full ecological footprint
€ $
Purchased goods & services (indirect)
Embedded ecosystem goods and services – e.g., water resources
140 litres water
1 cup of coffee

Example: Snack Food Industry

“Embedded” natural capital for a typical U.S. snack food



Source: OSU Center for Resilience **Eco-LCA**™

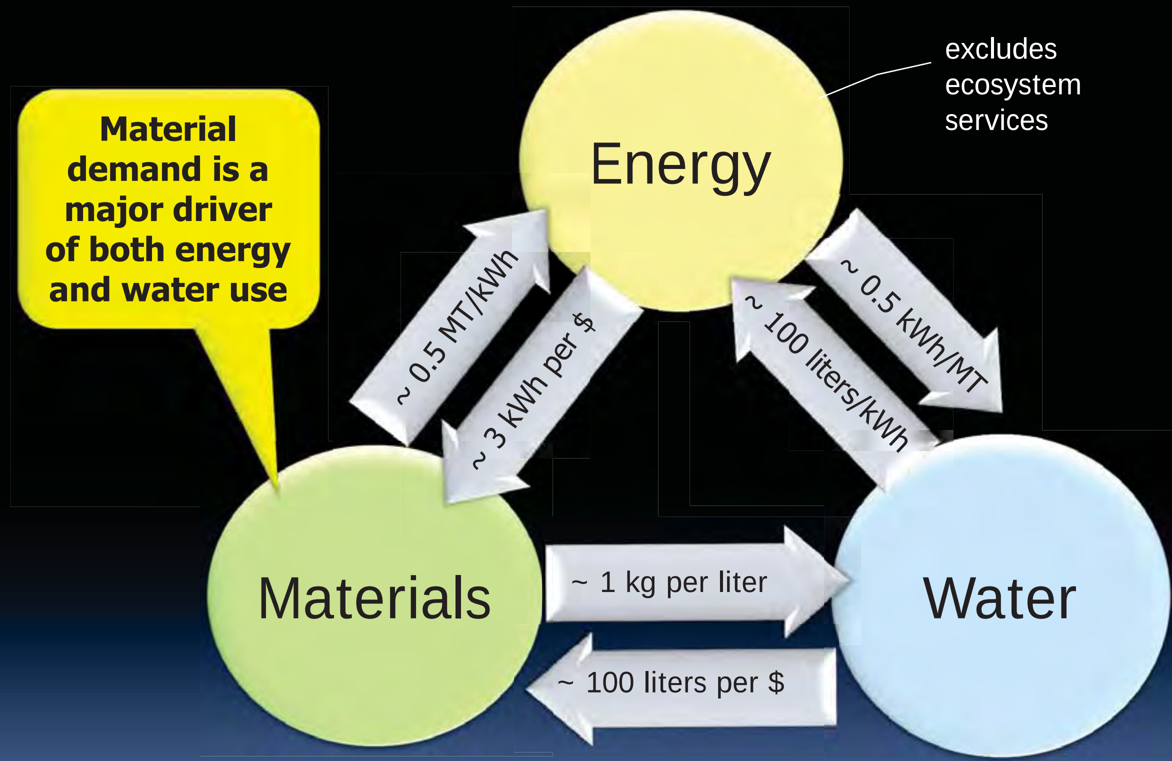
Sustainable Materials Management

“...an approach to promote sustainable materials use, integrating actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life-cycle of materials, taking into account economic efficiency and social equity.”

OECD

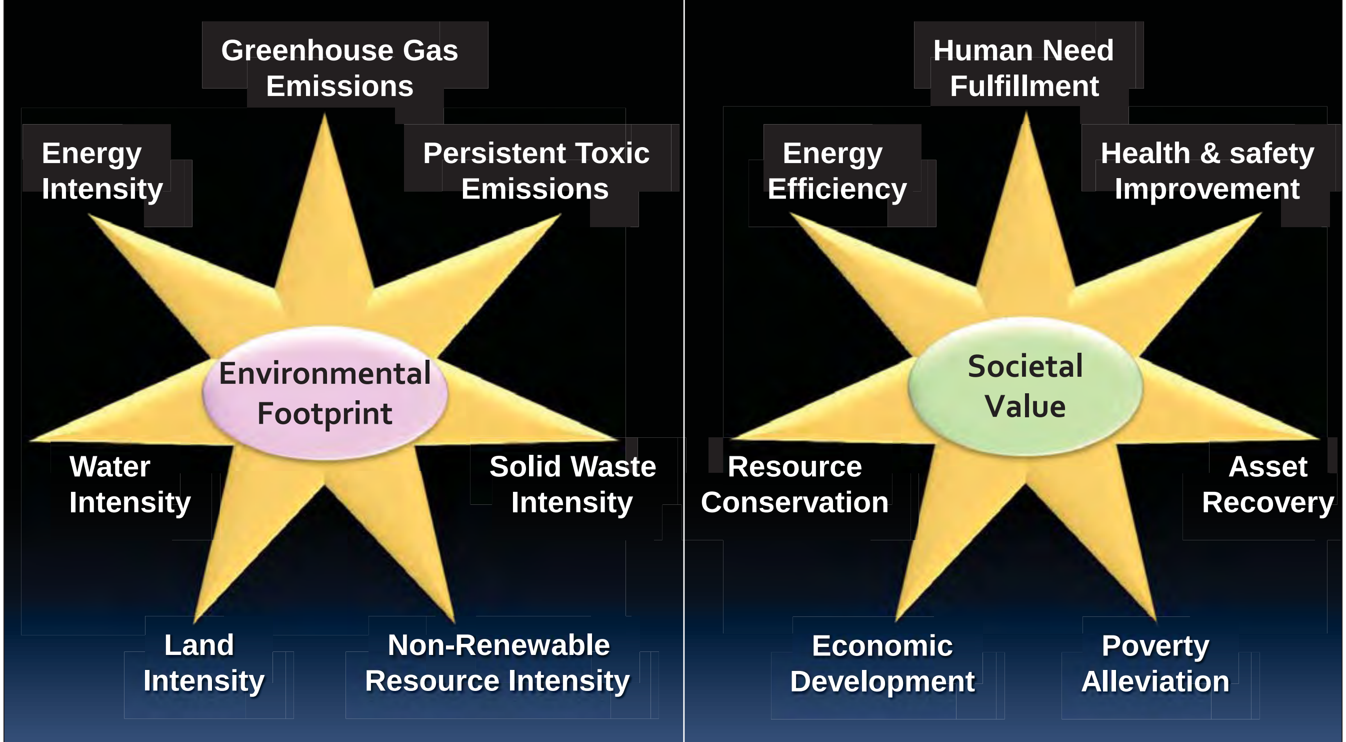
Working Group on Waste Prevention and Recycling

Material-Energy-Water Nexus



Source: J. Fiksel, "Evaluating Supply Chain Sustainability," *Chemical Engineering Progress*, May 2010.

Sustainability Progress Indicators



The Need for Collaboration

- **Incremental** improvements in supply chain efficiency will not be sufficient to offset global economic growth
- Transformational change in production and consumption patterns will require broad **collaboration** between government, industry, and civil society
- Companies are already collaborating with suppliers, customers, competitors, and environmental advocacy groups

Supply Networks: Robust and Fragile

Source: New Economic Foundation

Sustainability and Resilience

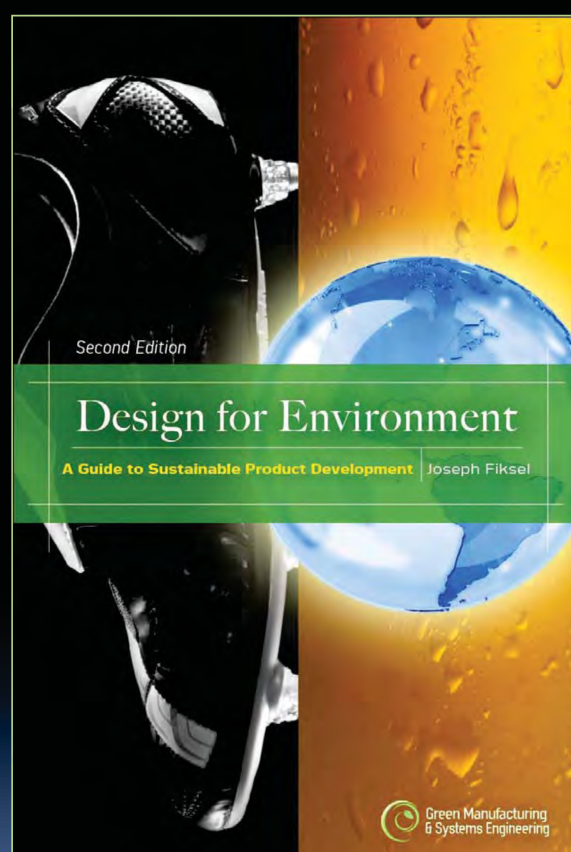
- **Sustainability** is the capacity for long-term realization of human health and well being, economic prosperity, & environmental protection
- However, unforeseen conditions can lead to unintended and/or undesired consequences
- **Resilience** is the capacity to survive, adapt, and flourish in the face of changing conditions and potential disruptions
- In a complex and turbulent world, resilience is a **prerequisite** for realization of sustainability goals

Design for Environment

Joseph Fiksel

McGraw-Hill, July 2009

(Paperback edition 2011)

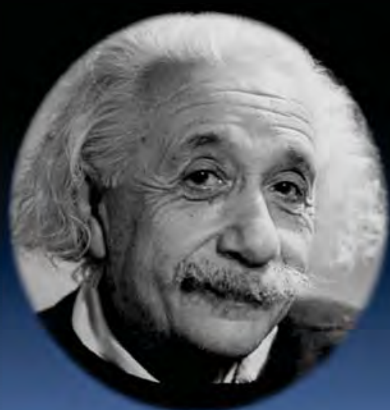


- Disruptive Innovation
- Product Development
- Process Eco-Efficiency
- Life Cycle Management
- Business Value Creation
- Supply Chain Sustainability

"We shall require a substantially new manner of thinking if mankind is to survive."

Albert Einstein

1879-1955



PRESENTATION: FUNDING OPPORTUNITIES AT NSF FOR PROPOSALS ON SUSTAINABLE PRODUCT SYSTEMS AND SUPPLY CHAINS, BY BRUCE HAMILTON

Funding Opportunities at NSF

for Proposals on Sustainable Product Systems and Supply Chains

Bruce Hamilton
NSF/ENG Program Director
Environmental Sustainability

Selected Menu of NSF Funding Opportunities for Sustainable Product Systems and Supply Chains

- New SEES Opportunities Relevant to Workshop
  - RCN
  - SRN
  - SEP
  - PIRE (all SEES)
  - SEES Post-docs
- G8 Material Efficiency DCL
- CBET/ENG Environmental Sustainability Program
- CBET/ENG Process and Reaction Eng'g Program
- CMMI/ENG SES and MES Programs
- ENG IDR Opportunity
- IGERT Solicitation

Web Info on All the Listed NSF Funding Opportunities

www.nsf.gov

New SEES Funding Opportunities

- SEES = Science, Engineering and Education for Sustainability
- SEES is a new NSF-wide investment area
- A number of new SEES calls-for-proposals are being posted (new “solicitations”)
- Workshop-relevant SEES solicitations include RCN, SRN, SEP, PIRE, and SEES Post-docs

National Science Foundation

New SEES Solicitations

- RCN = Research Coordination Networks (~$750K each for RCN-SEES track)
- SRN = Sustainability Research Networks (~$12 million each)
- SEP = Sustainable Energy Pathways (~$2 million each)
- PIRE = Partnerships for International Research and Education (typically ~$4 million each)
- SEES Post-docs (~$450K each)

RCN-SEES Track

- Program Scope: supports coordination of sustainability research, not research itself
- Next Deadline: Feb. 3, 2012
- Grant Size: up to a total $750K for 4 to 5 years
- Contact: Bruce Hamilton bhamilto@nsf.gov

RCN-SEES EXAMPLE #1

1140000

“RCN-SEES: Sustainable Manufacturing”

PI: Yinlun Huang (Wayne State U.)

- $722K over 5 years
- Numerous university and industry partners

National Science Foundation

RCN-SEES EXAMPLE #1 (continued):

Sustainable Manufacturing

Grant Activities

- Conduct a comprehensive review of frontier research and technological development for sustainable manufacturing; identify research gaps and needs
- Formulate a research roadmap for sustainable manufacturing
- Coordinate partner research through sharing knowledge, resources, software, and results
- Establish additional partnerships with universities and industry
- Conduct stakeholder education and outreach

National Science Foundation

RCN-SEES EXAMPLE #2

1140190

"RCN SEES: Sustainable Energy Systems"

PI: Tom Seager (ASU)

- $750K over 5 years
- Partners: other universities, EPA, USACE

RCN-SEES EXAMPLE #2 (continued):

Sustainable Energy Systems

Coordinate Activities Through Groups Focused on:

- Innovations in energy technologies
- Sustainability implications of alternative energy technologies at full scale
- Energy and human development

RCN-SEES EXAMPLE #3

1140152

"RCN SEES: Pan American Biofuels Sustainability"

PI: David Shonnard (Michigan Technol. U.)

- ~$750K over 4 years
- Numerous partners in North America, Central America, and South America

SRN:
Sustainability Research Networks

- Program Scope: supports research (while RCN does not support research)
- Deadline: December 1, 2011
- Award Size: up to a total $12 million over 4 to 5 years
- Contact: Bruce Hamilton
  bhamilto@nsf.gov

National Science Foundation

SEP:
Sustainable Energy Pathways

- Program Scope: supports research on sustainable energy pathways (think LCA)
- Deadline: to be posted by the end of September 2011
- Grant Size: up to $2 million over 4 years
- Contact: Ram Gupta

ragupta@nsf.gov

PIRE:
Partnerships for International Research and Education

- Program Scope: now 100% sustainability (this is a change from earlier PIRE rounds
- Must have overseas partners
- Next Deadline: October 19, 2011
- Award Size: typically $4 million (but can be more) over 5 years
- Contact: Carleen Maitland

cmaitlan@nsf.gov

SEES Post-docs

- <u>Program Scope</u>: special post-doc solicitation, 100% SEES
- <u>Deadline</u>: December 5, 2011
- <u>Award Size</u>: up to a total of ~$450K each for up to 4 years
- <u>Contact</u>: Sue Kemnitzer

  skemnitz@nsf.gov

G8 Material Efficiency DCL

- DCL = Dear Colleague Letter
- G8 = Eight developed nations (US, UK, Canada…)
- <u>Program Scope</u>: Call for research proposals involving at least one US institution partnered with institutions in at least two other G8 nations
- <u>Deadline</u>: September 30, 2011
- <u>Award Size</u>: up to a total of ~$450K for US partner for up to 3 years for each grant
- <u>Contact</u>: Bruce Hamilton

  bhamilto@nsf.gov

CBET/ENG

Environmental Sustainability Program

- Program Scope: takes sustainability proposals that are driven by engineering principles
- Proposal Types: unsolicited and CAREER
- Next Deadline (unsolicited): Feb. 17, 2012
- Grant Size (unsolicited): up to a total $300K for up to 3 years
- Program Director: Bruce Hamilton
  bhamilto@nsf.gov

CBET/ENG

Process & Reaction Eng'g Program

- Program Scope: takes sustainability proposals that are driven by process and reaction engineering principles
- Proposal Types: unsolicited and CAREER
- Next Deadline (unsolicited): Sept. 15, 2011
- Grant Size (unsolicited): up to a total $300K for up to 3 years
- Program Director: Maria Burka
  mburka@nsf.gov

National Science Foundation

CMMI/ENG

Service Enterprise Systems (SES) & Manufacturing Enterprise Systems (MES) Programs

- **Program Scopes**: accept proposals on sustainable supply chains, among others
- **Proposal Types**: unsolicited and CAREER
- **Next Deadline** (unsolicited): February 15
- **Grant Size** (unsolicited): up to a total of about $300K for up to 3 years
- **Program Director**: Russell Barton

rbarton@nsf.gov

ENG Interdisciplinary Research (IDR) Opportunity

- **Program Scope**: all engineering and beyond
- **Proposal Type**: unsolicited
- **Next Deadline**: Feb. 15 (CMMI); Feb. 17 (CBET)
- **Grant Size**: typically $600K, perhaps as large as $1 million over 3 years
- **Special Requirements**: involvement of two divisions (e.g., CMMI & CBET); PI must be in an engineering department
- **Program Director**: Bruce Hamilton or others

bhamilto@nsf.gov

Integrative Graduate Education and Research Traineeship Program (IGERT)

- Program Scope: NSF wide, focused on graduate student education and research in any STEM area
- Proposal Type: solicited
- Next Deadline: May 1, 2012
- Grant Size: typically $3 million over 5 years
- Special Feature: almost all funds are for support of graduate students
- Program Director: Carol Stoel
  cstoel@nsf.gov

Funding Opportunities at NSF

QUESTIONS???

Bruce Hamilton
bhamilto@nsf.gov

National Science Foundation

Selected Menu of NSF Funding Opportunities for Sustainable Product Systems and Supply Chains

- **New SEES Opportunities Relevant to Workshop**
  - RCN
  - SRN
  - SEP
  - PIRE (all SEES)
  - SEES Post-docs
- **G8 Material Efficiency DCL**
- **CBET/ENG Environmental Sustainability Program**
- **CBET/ENG Process and Reaction Eng’g Program**
- **CMMI/ENG SES and MES Programs**
- **ENG IDR Opportunity**
- **IGERT Solicitation**

National Science Foundation

PRESENTATION: P3 (PEOPLE, PROSPERITY AND THE PLANET) AWARD PROGRAM: A NATIONAL STUDENT DESIGN COMPETITION FOR SUSTAINABILITY, BY CYNTHIA NOLT-HELMS

EPA
United States
Environmental Protection
Agency

P3-*People, Prosperity and the Planet-* Award Program: A National Student Design Competition for Sustainability

Cynthia Nolt-Helms

Office of Research and Development
National Center for Environmental Research

September 9, 2011

EPA
United States
Environmental Protection
Agency

Mission of EPA

…to protect human health and the environment

- **Establish and enforce** environmental protection standards consistent with national environmental goals
- **Conduct research**
  - on adverse effects of pollution
  - on methods and equipment for controlling it
  - to gather information on pollution and use it to strengthen environmental protection programs and recommend policy
- **Assist others**, through grants, technical assistance and other means, in arresting pollution of the environment

EPA
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Environmental Protection
Agency

EPA's P3 Award Program

- Launched in 2004 as two-phase grant competition
- Harness the energy, creativity and enthusiasm of college students
- Infuse students with an awareness of their impact on the economy, society, and the planet
- Contribute to the integration of sustainability principles into curricula

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Environmental Protection
Agency

P3 Project Areas

Open to research proposals addressing sustainability challenges anywhere in the world in the following areas:

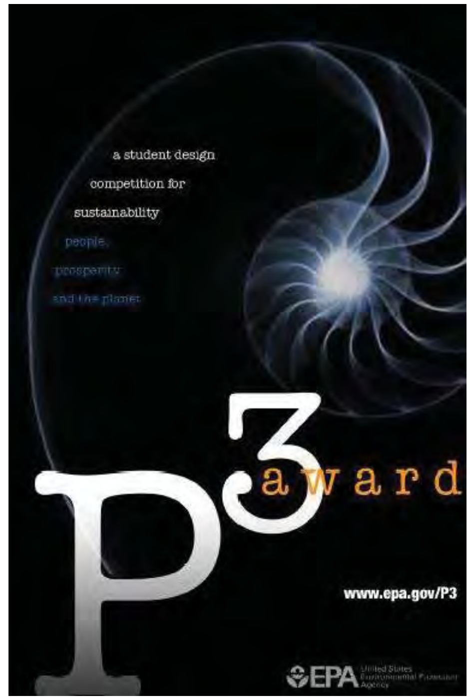
- Water
- Energy
- Agriculture
- Built Environment
- Materials and Chemicals

3

United States Environmental Protection Agency

P3 Program Process- Phase I

- Solicitation open Sept-Dec
- Student teams submit proposals for proof-of-concept innovative technology or design
- Proposals are peer reviewed
- Phase I grants awarded - fall following year
- P3 teams submit *Project Report*
  - Phase I accomplishments
  - Phase II proposal
- Students participate in the National Sustainable Design Expo



United States Environmental Protection Agency

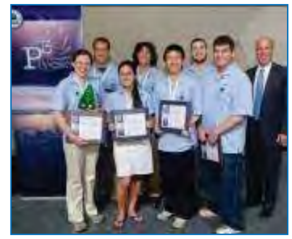
National Sustainable Design Expo

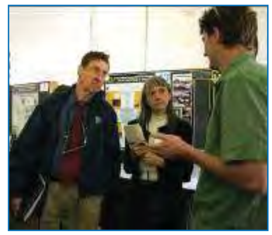
- –Co-sponsored public event at base of the Capitol on the National Mall
- –Opportunity for P3 team members to interact
- –Opportunity to expand conversation on sustainability

EPA United States Environmental Protection Agency

P3 Program Process- Phase II

- Phase I winners compete for P3 Award and $90,000 grant to develop technology
- Panel of judges convened by AAAS (American Association for the Advancement of Science)
- P3 Awards presented at P3 Award Ceremony





EPA United States Environmental Protection Agency

Aspects of P3 Projects

- P3 teams encouraged to be student-led and interdisciplinary
  - –Included representation from engineering departments, chemistry, biology, architecture, industrial design, business, economics, policy, social science, and others
  - –Partnerships with industry, non-governmental organizations (NGOs), government, and the scientific community.
- Require integration of sustainability concepts as an educational tool
- Encourage development of small businesses

United States Environmental Protection Agency

P3 Projects: Developed World

- Green Buildings including living roofs, smart windows, improved energy efficiency, solar power
- Real-time feedback of environmental performance
- "Biosphere" cities
- Recycling logistics, infrastructure, and strategies
- Policy analyses
- Sustainability indicators
- Fuel cell advances
- Sustainable energy technologies: wind, solar, bio-methane, biodiesel, biohydrogen
- Bioremediation of agricultural chemicals
- Educational programs on sustainability or energy

United States Environmental Protection Agency

P3 Projects: Developing World

- Water treatment: point-of-use or small, centralized facilities
- Water conservation, extraction or delivery
- Strategies for improved sanitation
- Alternative pest management strategies
- Appropriate construction materials
- Sustainable housing
- Renewable energy: wind, solar
- Planning for growth

United States Environmental Protection Agency

Educational Benefits

- Collaboration among students
- Valuable "life" experiences to students
  - Apply themselves to "real-world" issues
  - Multidisciplinary team experience
  - International travel
  - Cross-cultural work experience
- Raise awareness of sustainability and the environment on college campuses/local communities
- Publication of research results
- Provides "seed" money for further research and additional funding

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United States Environmental Protection Agency

P3 Update

- Nearly 400 Phase I grants
  - 49 states & Puerto Rico
  - 166 schools
  - Over 2000 students
- 49 Phase II grants
  - ~25% of Phase II winners started new companies or NGOs
  - Leveraged P3 funds to gain venture capital & additional grant funds
  - Commercialized new products

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EPA United States Environmental Protection Agency

UC Davis - 2008 P3 Award Winner - Micromidas Biodegradable Plastic Production From Municipal Wastewater

– **Project**
  - Use municipal sewage to create a biodegradable plastic
– **Return on Investment**:
  - Micromidas Company founded 1year after P3 award
  - now employs 26
  - Negotiated contracts with Waste Water Treatment Plants
  - Several companies interested in the plastic (ie,Nestles, Pepsi)
  - Successfully leveraged $3.6M venture capital funding
  - Selected as one of the ***Top 50 Water Innovation Leaders*** by the Artemis Project
– **Process & Advantages:**
  - Waste is raw material carbon source
  - Natural pond bacteria culled for PHA producing types to digest sludge
  - Sludge converted to fatty acids by microbes which produce intra-cellular PHA
  - PHA is extracted & pelletized

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EPA United States Environmental Protection Agency

Oberlin – 2005 P3 Award Winner Lucid Design Group: Building Dashboard

– **Project:**
  - Develop real-time feedback system to see if can motivate people to conserve energy and water
  - Competitions motivated people to conserve: 1 dorm saved $5.1K in 2 weeks
– **Return on Investment**:
  - Developed Building Dashboard
  - Started: the Lucid Design Group
  - Now employs 18
  - Developed a resellers program
  - Leveraged $6M venture capital
  - Dashboard now installed at >100 large institutions
  - Selected as a Category Finalist for the 2010 Adobe MAX Awards
– **Process & Advantages:**
  - Real-time feedback prompts big energy and water savings
  - Turns passive consumers into active managers

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United States Environmental Protection Agency

University of Virginia - 2007 P3 Award - The Learning Barge Elizabeth River Project

- **Project:**
  - Design & build a floating classroom to teach people about river ecology and sustainable technologies
  - Partnered with Elizabeth River Project and local schools
- **Return on Investment**:
  - P3 Award leveraged industry, institution and private contributions
  - More than 6500 visitors in first season
  - Created 7 jobs
- **Process & Advantages:**
  - >34 UVA students were involved in the construction of the barge
  - World's 1st floating wetlands classroom
  - Lead science coordinators and teachers designed the curricula

United States Environmental Protection Agency

Western Washington University – 2007 P3 Award Biomethane for Transportation

- **Project:**
  - Develop a biogas refining process using dairy cow manure and anaerobic digesters to produce biomethane for vehicular use.
  - Biomethane produces about 95 percent less carbon than a traditional fuel
- **Return on Investment:**
  - Technology demonstrated at pilot scale. P3 Award helped leverage additional awards.
    - Including $.5M DOE Clean Cities Recovery Act Award
    - Start up company being considered.
- **Process & Advantages:**
  - Pilot plant collects manure at local dairy farm which is broken down in an anaerobic digester.
  - Methane and other gases are generated. Contaminants removed by a scrubber.
  - Clean biomethane is collected, compressed and ready to burn in a combustion engine
  - WWU estimates that there is enough farm waste to fuel all vehicles in the region.

United States Environmental Protection Agency

MIT – 2008 P3 Award - Solar Thermal Micro-generators

- **Project:**
  - Provide a renewable energy source to Lesotho using novel solar thermal micro-generators, solar collectors, and “ORC” (Organic Rankine Cycle) engines.
- **Return on Investment:**
  - NGO established to train local town members to operate and maintain the system
  - Additional Awards leveraged
  - Power and hot water system installed for a medical clinic in Lesotho
- **Process & Advantages:**
  - ORC engine converts heat to electricity using solar panels to provide the energy to drive the engine.
  - Generates more than 3 kilowatts of electricity and hundreds of gallons of hot water daily.

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United States Environmental Protection Agency

8th Annual Expo
April 20-22, 2012

www.epa.gov/P3

nolt-helms.cynthia@epa.gov

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EPA United States Environmental Protection Agency

Feedback from Participants

"We appreciate the support of the EPA P3 Program, and we believe it has made a tangible difference in how these issues are seen at M.I.T."

- Prof. Jeffrey I. Steinfield, Massachusetts Institute of Technology

"Awarding many small grants for undergraduate research is a great idea. My students learned much working on this project and continue to do so."

- Prof. Kathleen Bower, Eastern Illinois University

"It is exciting and sometimes frustrating to work on a ‚real life' project, but always rewarding."

- Phoebe Richbourg, Student on Univ. VA's P3 Award-winning Team, 2007

"… Through these speaking engagements and interactions, the students have also educated and enriched the lives of the practicing engineers in New Hampshire."

- Prof. Jenna Jambeck, University of New Hampshire

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PRESENTATION: DISCUSSION OF SESSION II BREAKOUT QUESTIONS, BY IGNACIO GROSSMAN

Session II – Disciplinary Definition of the Problems and Opportunities

Discussion of Session II Breakout Questions

Ignacio Grossmann, Carnegie Mellon University, Pittsburgh

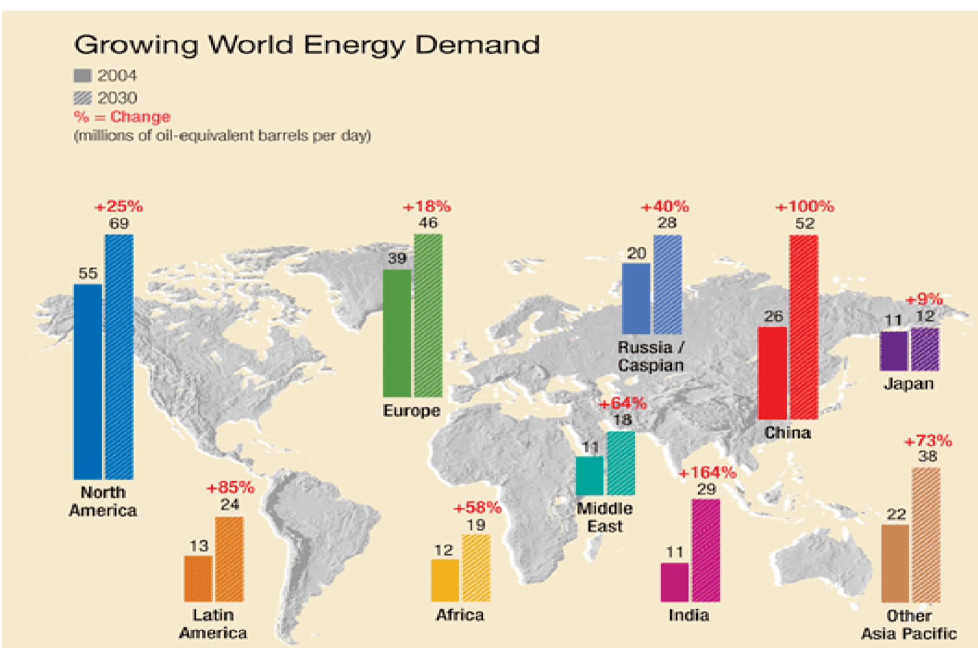
1. What are the challenging industry and societal problems to be solved? What are the future drivers for design of sustainable products, manufacturing systems and supply chains?

2. What are the next generation sustainable-design enabled strength areas in the U.S.? Where are the gaps in knowledge?

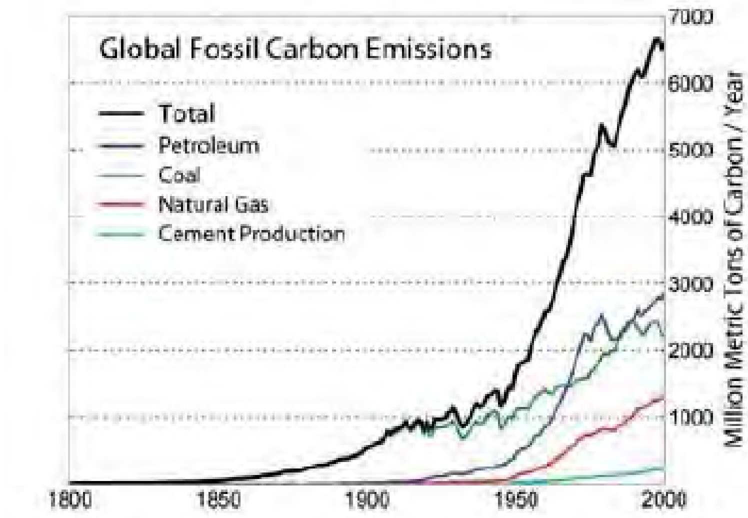
3. What are the problems faced by existing sustainable design capabilities? What are the opportunities for design of sustainable products, manufacturing systems, and supply chains?

1. What are the challenging industry and societal problems to be solved?

- Industry: Raw materials, energy, water, pollution
- Societal: Food, health (water), energy, pollution, climate change, social justice

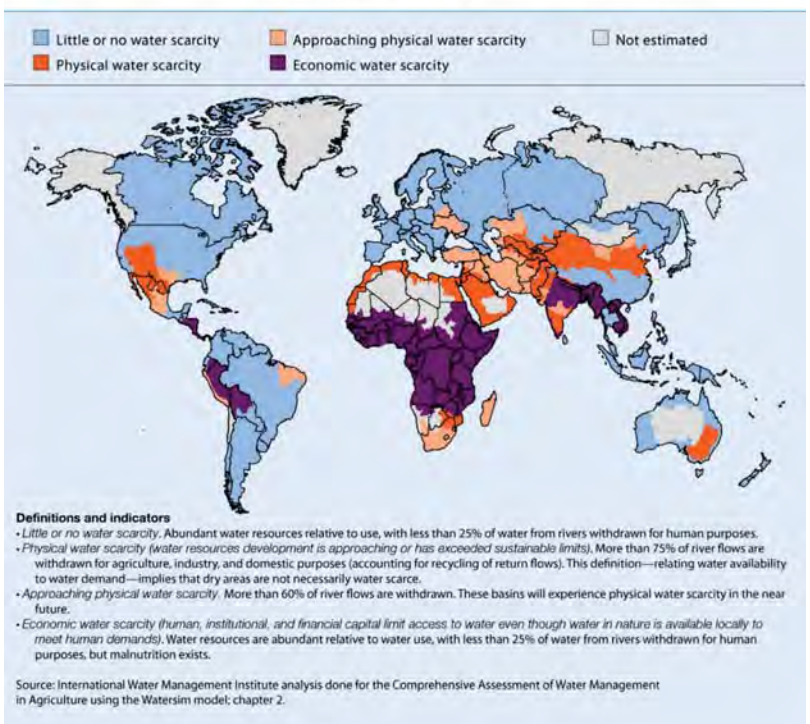


Growing emissions of CO_2



Sheppard, Socolow (2007)

Water scarcity

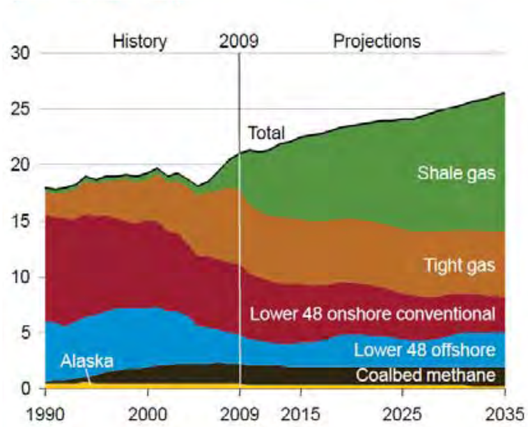


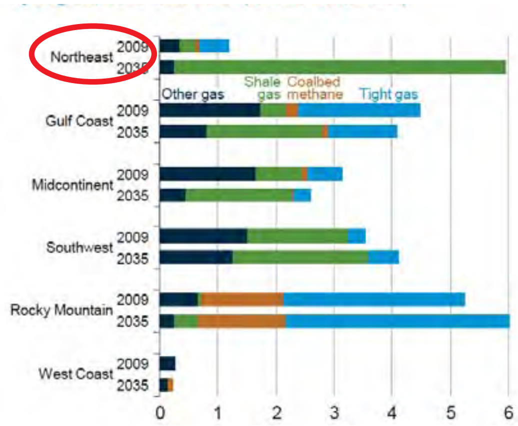
Two-thirds of the world population will face water stress by year 2025

What are the future drivers for design of sustainable products, manufacturing systems and supply chains?

- Depletion of fossil fuels?

Growth in Shale Gas





In 2035 close to 50% from Shale Gas

Northeast: from 0.3 trillion scft 2009 to 5.8 trillion scft 2035

What are the future drivers for design of sustainable products, manufacturing systems and supply chains?

- Handling of waste/landfills (recycle policies)

- Threat of climate change

- Greater pressure from citizens (Millennial generation)

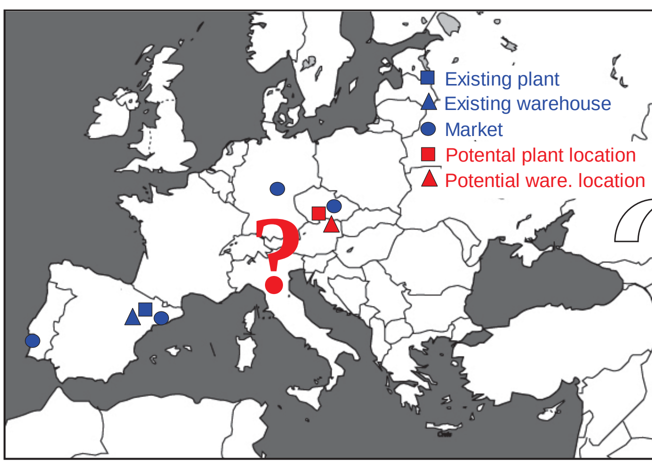
- Greater social/environmental responsibility by politicians (e.g. CO_2 tax)

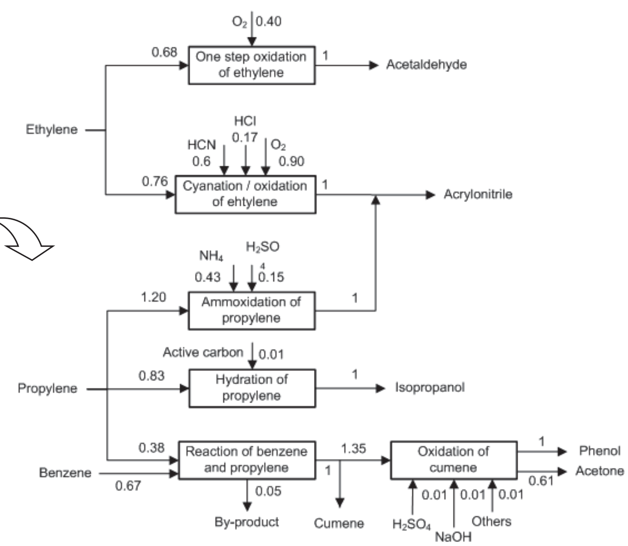
2. What are the next generation sustainable-design enabled strength areas in the U.S.?

Optimal Design of Chemical Supply Chains

Guillén-Gosálbez, Grossmann (2009)

Design of chemical SCs





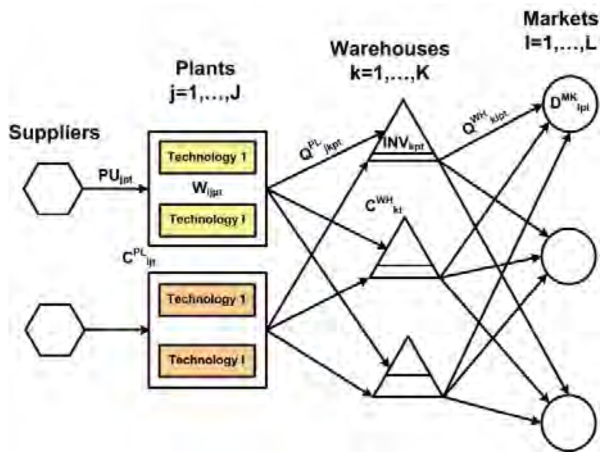
- **<u>Given are</u>:**
  - ✓ **Demand of final products**
  - ✓ **Investment and operating costs**
  - ✓ **Available technologies and potential locations**
  - ✓ **Life cycle inventory of emissions associated with the SC operation**
- **The task is to determine the <u>optimal SC configuration</u>**
- **In order to <u>maximize NPV and minimize environmental impact</u>**

Uncertainty in emissions

Carnegie Mellon

Universitat Rovira i Virgili

MILP Model



1. Postulate a superstructure with all possible alternatives
2. Build an MILP model:
   - Mass balance equations
   - Capacity constraints
   - Objective function calculations

Net Present Value

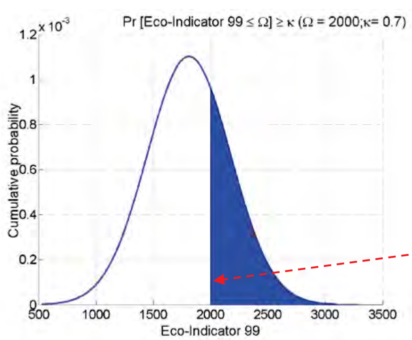
Eco-indicator 99: 11 environmental impacts aggregated into 3 damage categories

- **Human health:** DALYs (Disability Adjusted Life Years)
- **Ecosystem quality:** PDF·m^2·yr (Potentially Disappear Fraction of Species)
- **Resources:** MJ surplus energy · kg^{-1}

Life cycle inventory must account for a large number of chemicals: high degree of uncertainty!

Uncertainty in the emissions

Assumption: emissions follow normal distributions



Probabilistic objective:

Minimize the environmental impact for a given probability level

$$\Pr[ECO_{99} \leq \Omega] \geq \kappa$$

Ω **Target level omega**

Chance constraint programming

- Probabilistic constraint is converted into its deterministic equivalent *(Kataoka, 1963)*

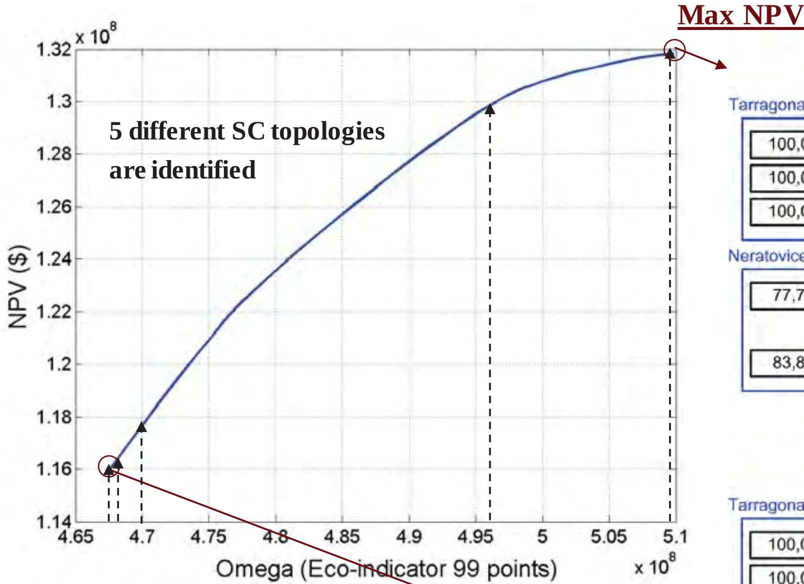
$$\Pr[\frac{ECO_{99}-\hat{ECO}_{99}}{ECO_{99}^{SD}} \leq \frac{\Omega-\hat{ECO}_{99}}{ECO_{99}^{SD}}] \geq \kappa \dashrightarrow ECO_{99}^{SD}\Phi^{-1}(\kappa)+\hat{ECO}_{99} \leq \Omega$$

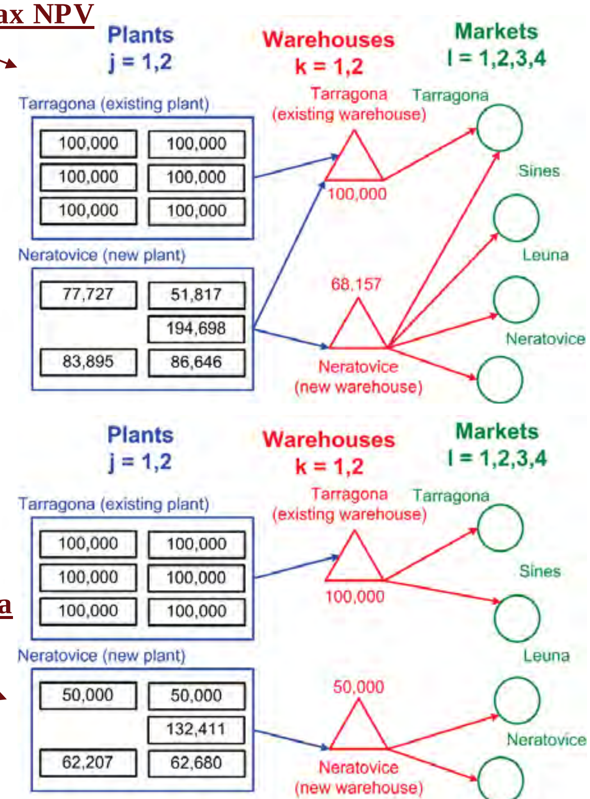
$$\max_{x,y}(NPV(x,y), -\Omega(x,y))$$ **Bi-criterion robust optimization MINLP problem**

Can be reformulated as a parametric convex MINLP *(Dua and Pistikopoluos, 2003)*

Pareto set and extreme solutions

Environmental improvements are achieved through changes in the network





The environmental impact is reduced by adjusting the structure of the network:

- **Reduce the capacities of plants and warehouses**
- **Reduce the flows of materials**

Carnegie Mellon

Universitat Rovira i Virgili

Where are the gaps in knowledge?

Examples:

How to build cheap photovoltaic solar cells?

How to build cost effective/safe fuel cells (hydrogen)?

How to effectively manage power distribution systems with renewables?

How to design bacteria that increase the yields in biomass processes or tolerate higher concentration of alcohols?

How to effectively design integrated supply chain for transportation fuels?

3. What are the problems faced by existing sustainable design capabilities?

Lack of knowledge of advanced engineering tools

Energy consumption corn-based process

Author (year)	Energy consumption (Btu/gal)
Pimentel (2001)	75,118
Keeney and DeLuca (1992)	48,470
Wang et al. (1999)	40,850
Shapouri et al. (2002)	51,779
Wang et al (2007)	38,323

Water consumption corn based - process:

Author (year)	Water consumption (gal/gal ethanol)
Gallager (2005) First plants	11
Philips (1998)	5.8
MATP (2008) Old plants in 2006	4.6
MATP (2008) New plants	3.4

From Karrupiah et al (2007)
24,918 Btu/gal vs 38,323 Btu/gal
Why? ***Multieffect distillation and het integration***

From Martin and Grossmann (2007)
1.5 gal water/gal ethanol vs 3.4
Why? ***Integrated process network with reuse and recycle***

3. What are the opportunities for design of sustainable products, manufacturing systems, and supply chains?

Some more or less obvious
but important

-Energy conservation

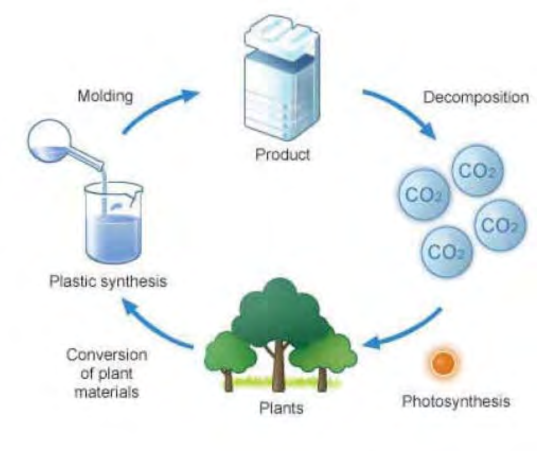
-Green buildings

-Fuel efficient cars

3. What are the opportunities for design of sustainable products, manufacturing systems, and supply chains?

Need to think out of the box

Biodegradable plastics



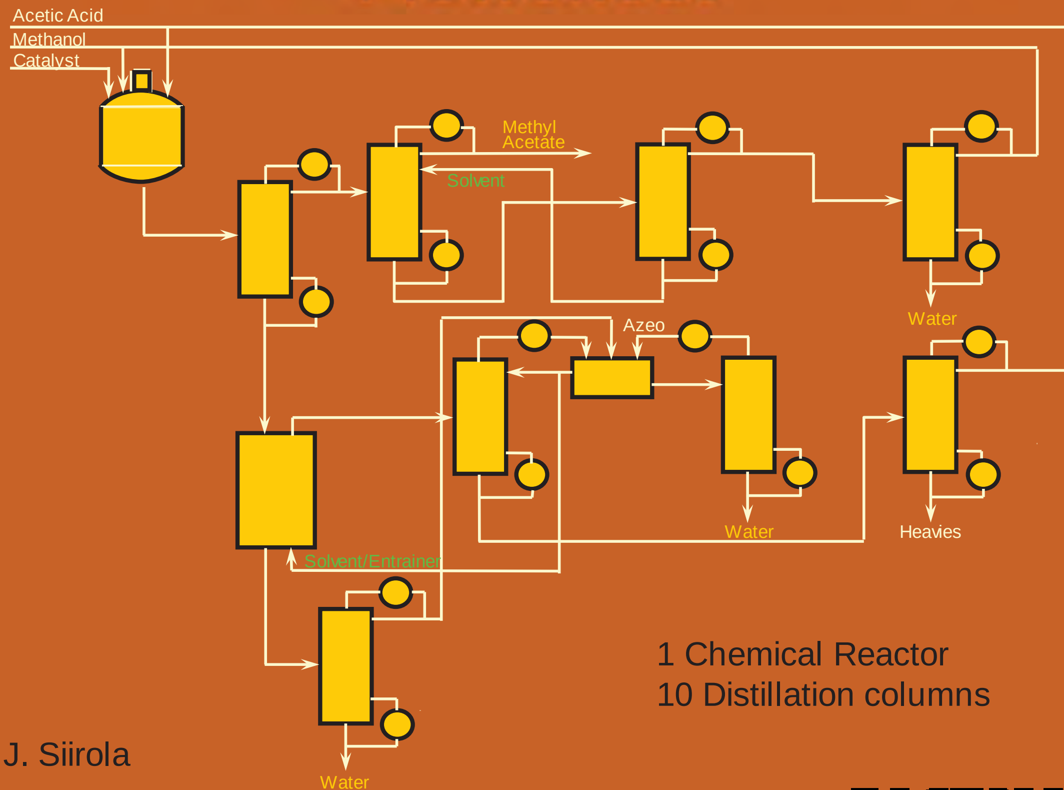
Polyhydroxyalkanoates (PHAs) vs. Polylactic acid (PLA)

Improving mechanical propertites

Process Intensification

Making changes that render a manufacturing or processing design substantially improved in terms of energy efficiency, cost-effectiveness or enhancement of other qualities.

Original Methyl Acetate Flowsheet



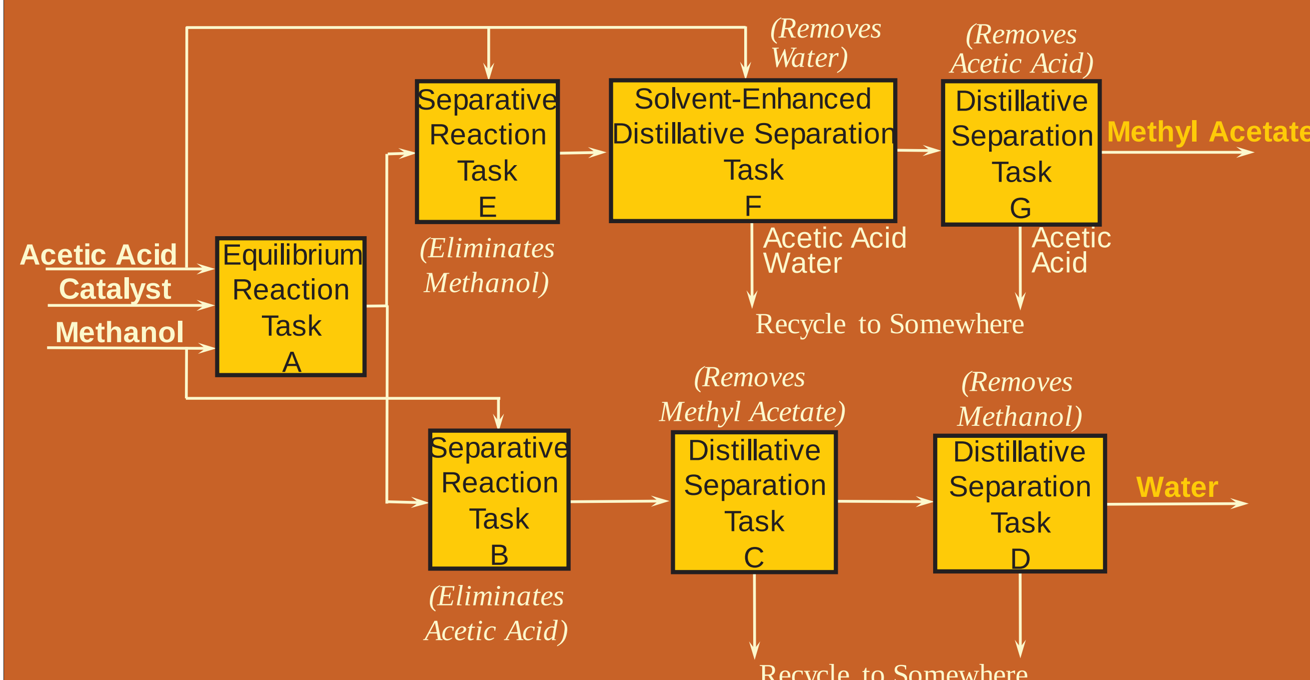
1 Chemical Reactor
10 Distillation columns

J.J. Siirola

EASTMAN

Synergistic Task Integration

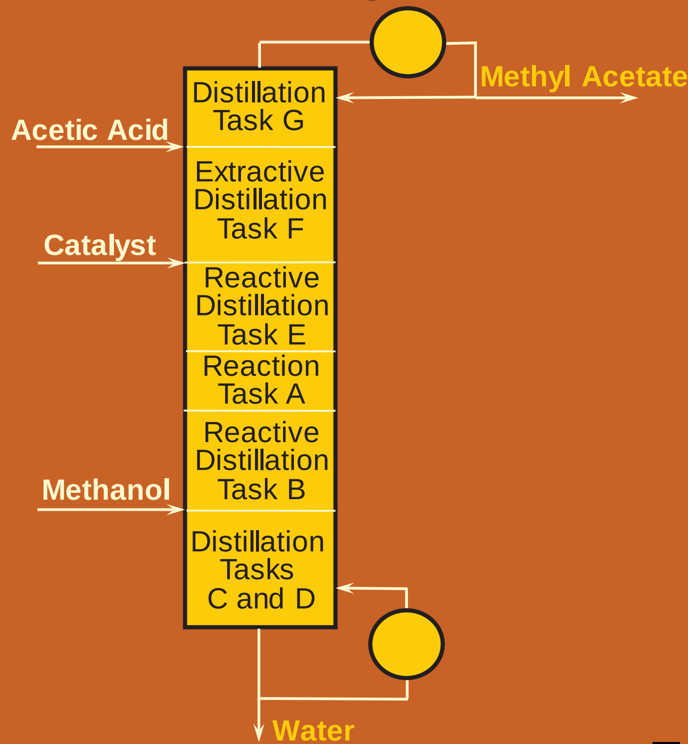
Reaction to Alter Separation Problems



EASTMAN

Consecutive Task Integration for Process Intensification

Single Column Methyl Acetate Process



EASTMAN

Session II – Disciplinary Definition of the Problems and Opportunities

Discussion of Session II Breakout Questions

1. What are the challenging industry and societal problems to be solved? What are the future drivers for design of sustainable products, manufacturing systems and supply chains?

2. What are the next generation sustainable-design enabled strength areas in the U.S.? Where are the gaps in knowledge?

3. What are the problems faced by existing sustainable design capabilities? What are the opportunities for design of sustainable products, manufacturing systems, and supply chains?

Breakout Groups

Breakout Group 1
Tom Seager*, Ariz State U
Andres Clarens, UVA
Yinlun Huang, Wayne State U
Christoph Koffler, PE International
Phil Williams, Webcor Builders, USA
Michelle Nguyen, AIChE

Breakout Group 2
Bert Bras*, GA Tech
Vikas Khanna, U Pittsburgh
Troy Hawkins*, EPA
Vincent Camobreco, EPA
William Flanagan, GE, USA
Margaret Mann, NREL

Breakout Group 3
Raj Srinivasan*, U Singapore
Olivier Jolliet, U of MI
Reid Lifset, Yale
Sherilyn Brodersen, Kraft Foods
Michael Hilliard, ORNL

Breakout Group 4
Thomas Theis*, U Illinois
Sergio Pacca, U Sao Paulo
Alan Hecht, EPA
Wes Ingwersen, EPA
Andreas Ciroth, Green Delta
Arnold Tukker, TNO

Breakout Group 5
Eric Williams*, RIT
B. Erik Ydstie, CMU
Meadow Anderson, EPA
Maria Burka*, NSF
John Glaser, EPA
Eric Masanet, LBNL

Breakout Group 6
Ignacio Grossmann*, CMU
Fengqi You, Northwestern
Ray Smith*, EPA
Mark Goedkoop, Pre Consultants
Martha Stevenson, WWF US

Breakout Group 7
Darlene Schuster*, AIChE
Joseph Fiksel, EPA/OSU
Cynthia Nolt-Helms, EPA NCER
Sangwon Suh, UCSB
Mark Tulay, Sustainability Risk
Beth Beloff, Bridges to Sustainability

Breakout Group 8
Omar Romero-Hernandez, UC B
Herb Cabezas*, EPA
Igor Linkov, Army Corps of Eng
Don Versteeg, P&G
Russell Barton, NSF
Erin Chan, AIChE

Breakout Group 9
Jay Golden, Duke
Marianthi Ierapetritou, Rutgers
Angie Leith, EPA
Carole LeBlanc, Dept of Defense
John Carberry, DuPont
Bhavik Bakshi*, Ohio State

Breakout Group 10
Bruce Hamilton*, NSF
H. Gregg Claycamp, FDA
Clare Lindsay, EPA
Dima Nazzal, U Central Florida
Rachuri Sudarsan, NIST
Dennis McGavis, Shaw Inc

PRESENTATION: ORIENTATION FOR SESSION III, BY ERIC WILLIAMS

Orientation for Session III

Eric Williams

Rochester Institute of Technology

R·I·T Golisano Institute for Sustainability ROCHESTER INSTITUTE OF TECHNOLOGY

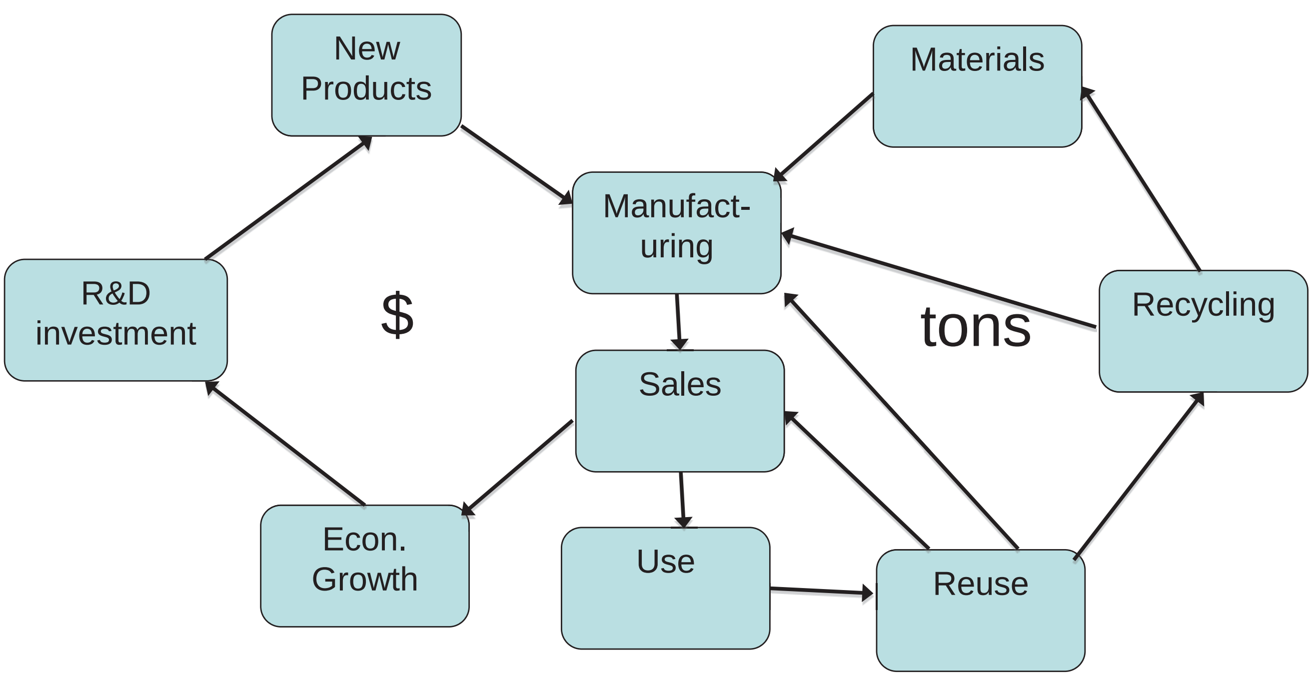
The Golisano Institute of Sustainability

- **Academic Programs**
  - Sustainability Ph.D.
  - Sustainable Systems M.S.
  - M. Sustainable Architecture
- **Four Main Research Thrusts:**
  - Sustainable Production Systems
  - Eco-IT
  - Sustainable Mobility
  - Energy Systems
- **Industrial Applications & Technology Transfer**
- **Promote Innovative Campus Wide Sustainability Initiatives**
- **3 admin faculty, 7 academic faculty, 4 research faculty**

R·I·T Golisano Institute for Sustainability ROCHESTER INSTITUTE OF TECHNOLOGY

New Institute of Sustainability Building

- $14 million grant from NIST
- Integrated fuel cell, solar and wind power systems
- Can run independently from electrical grid
- Construction completion: 9/2012



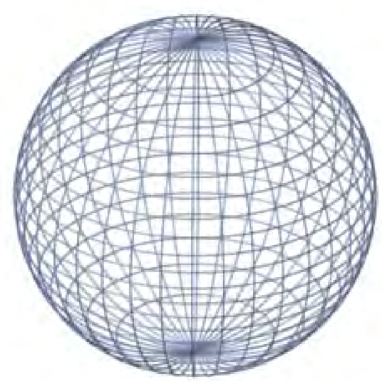
R·I·T
Golisano Institute for Sustainability
ROCHESTER INSTITUTE OF TECHNOLOGY

Session III Overview

Theme: Cross-disciplinary needs and challenges

Overarching question: What are the common problems, common areas of need, complementary areas to be interfaced, and opportunities for cross-disciplinary fertilization facilitated by design of sustainable product systems and supply chains?

= ?



R·I·T Golisano Institute for Sustainability ROCHESTER INSTITUTE OF TECHNOLOGY

Session III Overview

Theme: Cross-disciplinary needs and challenges

Thoughts on overall approach :
- Easy to identify needs in “an ideal world”
- Consider constraints/challenges for needs and challenges
- Area of opportunity = large impact/difficulty

Importance	Socio-economic constraints
helpful	minor
important	substantial
critical	huge

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Session III Sub-topics for groups

Theme: Cross-disciplinary needs and challenges

1. Economic drivers and sustainable design
2. Technologies/tools and integration: status and needs
3. Stakeholder roles and need for cooperation
4. New/emerging technologies and organizational roles
5. Education and training

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Group 1: Economic Drivers

Question: How does sustainable design affect or impact economic drivers?

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Group 2: Technologies/tools and integration: status and needs

Question: What technologies/tools and their integration are needed, where is the expertise, and what is the state of technical capability?

Clarification of scope:
•Technology here meant as "software" (e.g. analytic tools) as opposed to "hardware" (easy to recycle plastic)

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Group 3: Stakeholder roles and need for cooperation

Question: What are the respective roles of industry, government, and academia and how should they interrelate? What partnerships/coalitions are needed?

Group 4: New/emerging technologies and organizational roles

Questions: How will new and emerging technologies and capabilities need to affect organization roles and responsibilities – academia/industry, researcher/research teams, etc?

Clarification of scope:
• technology specific issues (e.g. nanotech) versus generic technological progress

Schedule for Session II

Today:
4:15-5:15
Discuss your question, notetaker takes notes
5:15-5:30
Write up powerpoint slides presentation for tomorrow morning. If anyone wants to submit additional notes, write up.

Tomorrow morning: group presentations

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September 12–13, 2011
Arlington, Virginia

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