NSF RCN-SEES: Sustainable Manufacturing Advances in Research and Technology (SMART) Coordination Network

REPORT ON SUSTAINABLE MANUFACTURING ROADMAP DEVELOPMENT WORKSHOP

Cincinnati, OH, Aug. 15-16, 2013

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(Workshop Outcomes Compiled by IMTI, Inc.)

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TABLE OF CONTENTS

Executive Summary i

1 Introduction 1

1.1 Prioritized Findings 3

1.2 Key Themes 6

2 Technology Development 19

2.1 Vision for Technology Development 21

2.2 Barriers and Challenges for Technology Development 24

2.3 Goals for Technology Development 29

2.4 Priority Goals for Technology Development 32

3 Process and Systems Management 34

3.1 Vision for Process and Systems Management 36

3.2 Barriers and Challenges for Process and Systems Management 38

3.3 Goals for Processes and Systems Management 41

3.4 Priority Goals for Process and Systems Management 44

4 Enterprise Management 46

4.1 Vision for Enterprise Management 48

4.2 Barriers and Challenges for Enterprise Management 51

4.3 Goals for Enterprise Management 56

4.4 Priority Goals for Enterprise Management 60

Appendix A. Workshop Organizing Committee 60

Appendix B. Workshop Agenda 61

Appendix C. Workshop Participants 62

Appendix D. Participants' Biographical Sketches and Position Statements 64

EXECUTIVE SUMMARY

The Sustainable Manufacturing Advances in Research and Technology Coordination Network (SMART-CN) is funded by the National Science Foundation (NSF) as part of the Research Coordination Networks program. It is a coalition of national leaders who have joined together to promote collaboration. The purpose of SMART-CN is to bridge the gap between academic knowledge discovery and industrial technology innovation to advance sustainable manufacturing. To accomplish this goal, the SMART-CN team is conducting an in-depth review of research and technological development for sustainable manufacturing, defining a roadmap for moving toward sustainable manufacturing, and identifying bottlenecks in research areas. The workshop documented here is typical of SMART-CN activities in bringing together academia, industry, and government to explore both the challenges and the solutions for a more sustainable and profitable future. The ultimate achievement of SMART-CN will be the delivery of prioritized and coordinated R&D portfolios that improve the economic competiveness, environmental cleanness, and social responsibility of U.S. manufacturing.

The Workshop and Roadmap

On August 15-16, 2013, SMART-CN conducted a roadmapping workshop. Fifty three participants, specifically selected for their expertise and representing a mix of academic, industry, and government interests, participated in a structured process of information gathering and knowledge extraction. Much of the workshop was conducted in small groups addressing three areas: Technology Development, Process and Systems Management, and Enterprise Management. Crosscutting topics of Workforce Education and Management; Water Management, Land, and Air Quality; and Life Cycle Assessment and Design for Sustainability were addressed by all three groups. The groups addressed the vision for future success, the barriers and challenges, and corresponding goals for a sustainable future. The final output from the workshop was a set of prioritized goals.

The information from the workshop was then compiled into the document presented here. The opening chapter provides foundational materials and presents the key themes and roadmaps. The subsequent chapters present the detailed work of the small groups.

Key Themes

After the workshop, the workshop facilitation team of The Integrated Manufacturing Technology Initiative (IMTI, Inc.) conducted an in-depth analysis distilling the 10 key themes that encapsulate the most important content – and hence the most important topics to be addressed. Because all of the workshop content is important, the vision elements, barriers and challenges, and goals were mapped to the key themes in a matrix. From this matrix, technology roadmaps were produced for the key findings. The definition of the key themes and the roadmaps are presented in this document.

The key themes represent high-level needs that should be addressed by the sustainable manufacturing community. The themes include:

1) Standards and Platforms for Information Exchange. Standard structures for data and toolsets related to sustainable manufacturing are essential for addressing the key issues in an inclusive and systematic way. Platforms and frameworks that enable interoperability of diverse

data sets and tools are prerequisite to addressing the scope of the challenge and supporting common communication.

2) Clear Definition and Semantic Understanding. A deep understanding of the terms and scope of sustainable manufacturing is foundational for integrated solutions. That definition should include the creation of a common taxonomy and an ontology that enable a common semantic understanding.

3) Pervasive Adoption of Sustainability Practices. The issues associated with sustainability include technical challenges, business process requirements, and a culture of value assessment and investment in sustainability. This key theme embraces all areas of need for pervasive adoption, but focuses mostly on the cultural challenges.

4) Comprehensive Characterization and Quantification of Manufacturing Processes. The complete understanding of materials and their interaction in manufacturing processes enables optimized design of products and processes. Quantification of processes is a major factor in product development, and characterization of processes facilitates rapid quantification.

5) Comprehensive Life-Cycle Assessment. Life-Cycle Assessment (LCA) has become common in product development. Unfortunately, in many cases, it has become more of an administrative and accounting requirement than a value-added design aid. The adoption of a systems engineering methodology and the inclusion of a rich enabling technology toolset can allow LCA to move forward as a keystone in sustainable design.

6) Sustainable Manufacturing Education. The pervasive adoption of sustainability practices requires education of all stakeholders in the global community. This key theme specifically addresses the necessity of sustainability education in all educational disciplines, with an emphasis on the engineering community.

7) Model-Based Assessment and Control for Sustainability. A model-rich environment is essential for efficiently developing material systems, products, and processes and for managing the manufacturing enterprise. Model development for LCA, materials evaluation, process development, and all other applications tends to be ad hoc. There does not exist a structure to define modeling priorities and systematically fill the voids. The use of modeling systems for process control is, likewise, applied on a case-by-case basis. A coordinated systems approach is needed.

8) Data and Model Access for Sustainability. Characterization of materials and processes requires a rich underpinning of data and models. While there are excellent examples of data management, there is no comprehensive system by which data is developed, screened, and managed. The result is that most researchers and developers must invest their energies in data access at the expense of applications development. A shared repository for managed access to data and models to support sustainable manufacturing is needed.

9) Optimized Design for Sustainability. A systems approach to product and process design should begin with product requirements and extend, in a seamless digital thread, through the evaluation of alternatives and the selection of the best solutions, to mature designs. The system should be integrated to ensure that best total value takes clear priority over point optimization.

10) Systematic Sustainability Achievement. While the key themes are important individually, coordinated implementation of a fully integrated roadmap is required for success. This key theme acknowledges that a well-managed, collaborative effort is needed.

Path Forward

The delivery of this document is one step in the work of SMART-CN and the pursuit of manufacturing sustainability. Perhaps it is a major milestone in the provision of a foundational roadmap that can be socialized, refined, and integrated with other documents to produce a comprehensive and integrated guide for collaboration. One of the most important messages is that manufacturing sustainability is not a goal that can be pursued in isolation. Sustainability must always be balanced with profitability, manufacturability, and socio-economic success. Many organizations are working on the digital threads of manufacturing competitiveness and their integration into a tapestry. It makes no sense, for example, to produce a national repository for sustainability data while investments are being made to create such repositories for all of manufacturing. It makes perfect sense for the sustainable manufacturing community to establish partnerships and work alongside these organizations to assure that the sustainability needs are met.

1 INTRODUCTION

A workshop on sustainable manufacturing was conducted in Cincinnati, Ohio on August 15 and 16, 2013. The workshop was sponsored by the Sustainable Manufacturing Advances in Research and Technology (SMART) Coordination Network (CN), which is funded by the National Science Foundation (NSF). The mission of SMART CN is to bridge the gap between academic knowledge discovery and industrial technology innovation in order to improve manufacturing sustainability. This mission is accomplished in part by sponsoring and supporting activities, such as this roadmapping activity, that bring the academic community together with industry, government, and all stakeholders in an open exchange of ideas and the pursuit of activities that deliver value to U.S. industry in both economic and sustainability measures.

The workshop was attended by 53 invited participants. The goal and the reality was that participation was almost evenly split between academics and other stakeholders. Special guests included Bruce Hamilton of the National Science Foundation and Darlene Schuster of the AICHE Institute for Sustainability (AIChE). The stakeholders represented a strong contingent from industry, several Government representatives including strong support from the Environmental Protection Agency, and from national labs and research organizations. The participants divided themselves into three groups according to interest and expertise. Figure 1 presents the functional model that was the guide for the workshop, and serves as the framework for organization and presentation of the materials.

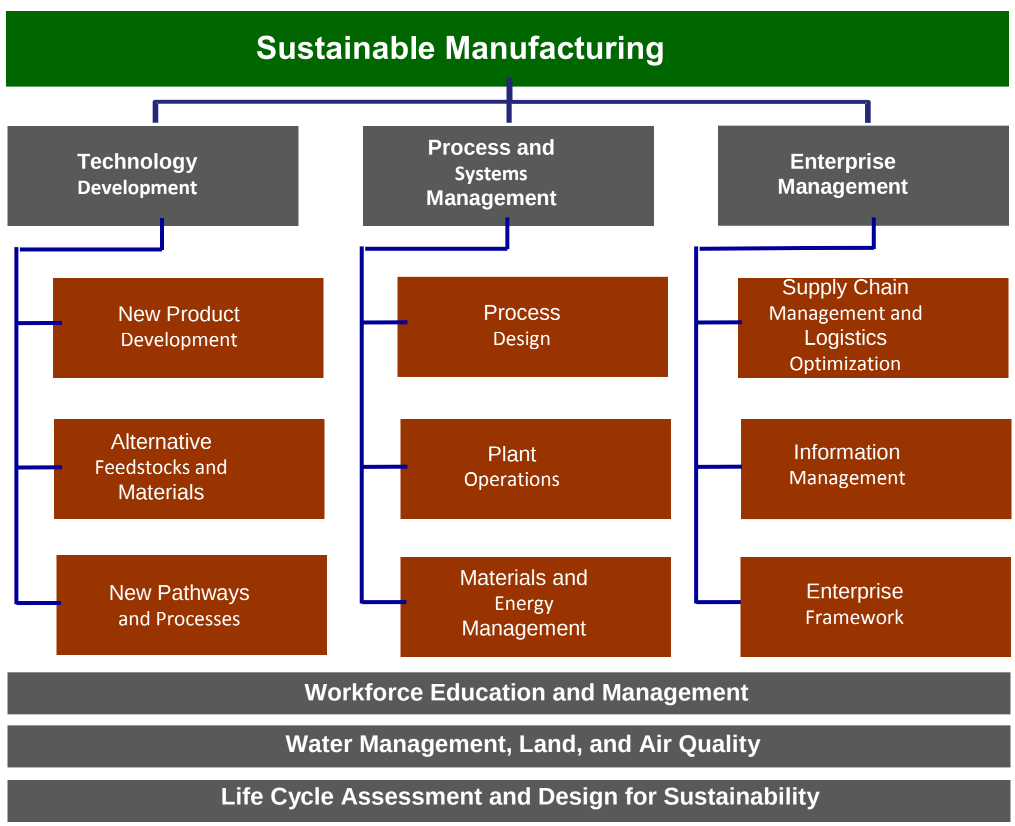

Figure 1-1. The functional model provided the structure for the workshop.

Small groups were formed around the following three "pillars" of sustainable manufacturing.

- Technology Development
- Processes and Systems Management
- Enterprise Management

It is important to note that these are not presented as the definitive structure for gathering information, nor is the model presented as the best approach. Instead, the test that should be applied is whether the functional model provides an adequate and complete structure under which all important topics related to sustainable manufacturing can be aligned. The conclusion from the performance of the workshop is that this model does meet that requirement.

The three groups addressed the three pillars. Each group also addressed the crosscutting enablers as they were related to their pillar.

The workshop was a facilitated process of discovery and information collection following the methodology that is illustrated in Figure 1-2.

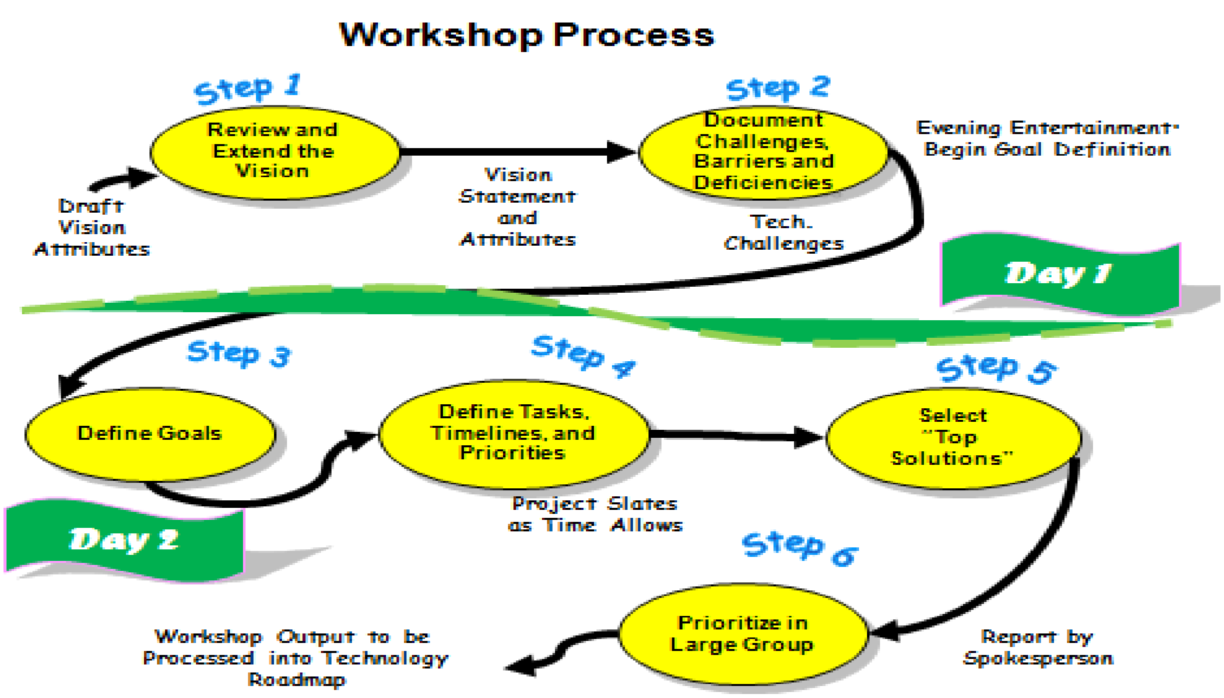

Figure 1-2. Small groups were guided through a methodology of reviewing the vision, identifying barriers and challenges, and defining and prioritizing goals.

The workshop started with a review of the vision. A preparatory exercise was conducted in June, 2013, by the SMART CN's Workshop Organizing Committee. In that meeting, key attributes of the vision for each pillar were defined. Therefore, the assignment to the small groups was to extend and confirm the vision. The next step in the methodology was the definition of barriers and challenges. With the vision for a future state of excellence as the foundation, the hindrances that must be overcome to achieve the vision were listed.

The vision for a future state helps point to capabilities that are required. The barriers and challenges require new and extended capabilities to overcome them. These needed capabilities are defined as "goals". The test for an adequate goal set is this: if all of the goals were satisfied and the capabilities achieved, would the vision be realized?

The goals are tabulated and then prioritized. The most important and highest priority goals become the topics for a project slate which will be adopted by SMART CN as a guide for future activities. The work related to each pillar is captured in Sections 2-4 of this document.

1.1 Prioritized Findings

As the closing activity from the workshop, each group presented its slate of priority goals, and a prioritization process was conducted. The results of that process are shown below, with the goals ranked in descending order based on the number of votes each received.

Rank	Goal	Pillar	Count
1	G4.2.3 Create standards and information platforms (tools/data/information) for a sustainable enterprise	Enterprise Management	18
2	G3.C.1 Develop consensus across disciplines as to a working definition of sustainable manufacturing in terms of tangible, well defined terms that has a common utility	Process & Systems Management	17
3	G4.3.1 Enterprise Framework Sustainability: Create a sustainability culture that pervades the behavior and decisions of all levels of manufacturing enterprise and its supply chain	Enterprise Management	16
4	G3.4.2 Standardize and make LCA easier (and faster) so that the tools and results can be better incorporated into design	Process & Systems Management	15
5	G3.C.5, 6 Develop an ability to characterize manufacturing processes that includes the quantification of system boundaries and externalities. Develop tools that include all relevant factors in supporting manufacturing process development.	Process & Systems Management	13
6	G2.4.3.1 Develop comprehensive interoperable LCA and sustainability assessment tools matching the LCA outputs with the inputs for decision-making. Provide a standard structure/framework for defining the needed inputs/outputs for necessary decisions.	Technology Development	11
7	G2.4.1.2 Make sustainability thinking pervasive in all academic disciplines	Technology Development	11

Rank	Goal	Pillar	Count
8	G2.1.4 Develop model-based systems that utilize a complete understanding to optimize the product development process including sustainability issues. Develop models that include LCA based metrics and indicator data for making decisions on sustainability for a product.	Technology Development	10
9	G2.1.3 Gather data for a complete understanding of the structure/ property/activity/functionality/impact relationships enables informed design and development. Include product performance and performance against sustainability metrics.	Technology Development	9
10	G2.1.8 Sustainable manufacturing and product design framework that supports collection of data, decision support and product definition, delivering optimized value added in product development	Technology Development	9
11	C3.C.19 Systematize the sustainability challenge: Develop a maturity model that quantifies the achievement of sustainable manufacturing. Develop a compendium of methodologies, practices, and tools to support achievement of the goals of the maturity model.	Process & Systems Management	9
12	G4.1.2 Conflicting priorities: New decision framework to incorporate multiple conflicting (non-financial) objectives in a unified framework, configurable and visible	Enterprise Management	9
13	G4.2.1 Better Data: Ensure that collecting new information and current data is accurate, relevant, and cost-effective (cheap, good data?) require on-going maintenance in a cost-effective way	Enterprise Management	8
14	G2.2.3 Develop tools to support MFA (material flow analysis) and SFA (substance flow analysis) to enable reduction, reuse, and remanufacturing of the materials and their substitutes including alternatives that do not recycle	Technology Development	7
15	G3.2.4 Bridge the scales of modeling from models based in first principles to continuum models	Process & Systems Management	7
16	C3.C.16 Better data collection and analysis and better definition of the data requirements for sustainability analysis	Process & Systems Management	7
17	G4.1.1 Supply Chain models that include sustainability considerations and externalities along with technical & business issues	Enterprise Management	7
18	G3.1.4 Develop sustainability performance standards, not just a design standards	Process & Systems Management	5

Rank	Goal	Pillar	Count
19	G3.3.6 Include social and political implication of sourcing material and energy supplies and consumption	Process & Systems Management	5
20	G3.C.8, 10 Quantify the scope of sustainable manufacturing related to systems and sectors. Identify the key stakeholders for each system/sector, including societal representation.	Process & Systems Management	5
21	G3.C.13 Develop modeling tools that predict and model consumer behavior to support the innovation/ideation process, including the reaction to sustainability practices and the extent to which they will respond e.g. paying more for protecting the environment	Process & Systems Management	5
22	G4.2.2 Sharing data: Trust: Reporting Sustainability Data across the supply chain	Enterprise Management	5
23	G2.4.1.5 Improve the sustainability calculation/analysis capabilities across the basic industrial workforce (and all workers) - combination of user friendly tools and education	Technology Development	4
24	G2.1.6 Integrate LCA tools with existing and emerging design and manufacturing toolset (PLM plus)	Technology Development	4
25	G3.1.1 Infuse sustainability factors into plant design and automation	Process & Systems Management	4
26	G3.3.3 Integrate ecosystem (industrial symbiosis) opportunities in materials and energy management	Process & Systems Management	4
27	G2.3.2 Develop metrics, tools, data, standards (capabilities and competencies) that enable quantification and trades regarding how sustainable	Technology Development	3
28	G3.1.2 Develop design capability for control for sustainable design and operation – including stochastic control (uncertainty). This means that sustainability factors are captured in the monitor, analyze and control methodologies and toolsets.	Process & Systems Management	3
29	G3.4.6 Include end of life issues such as product reuse, remanufacture, and redesign into the product design process.	Process & Systems Management	3
30	G2.4.3.2 Provide coordination of national R&D efforts to define present toolsets, voids and communication failures and focus on building to solution	Technology Development	2
31	G3.4.4 Extend present LCA toolsets to include uncertainties and explore the alternative results from various boundary selections	Process & Systems Management	2

Rank	Goal	Pillar	Count
32	G3.C.11 Find synergistic options and new services (such as product LCA monitoring) that give both economic, environmental and social benefits	Process & Systems Management	2
33	G4.4.3 LCA and Design for sustainability: Create mechanism to assess current manufacturing business decisions against available metrics and tools to select optimal for sustainability.	Enterprise Management	2
34	G3.3.5 Extend energy and material balances to the manufacturing realm for existing manufacturing processes and transformational new processes.	Process & Systems Management	1

1.2 Key Themes

The top twelve goals were refined into ten key themes. All of the workshop materials were then mined for rich content related to the key themes and roadmaps were developed for each of those themes. The key themes are presented in the order of the voting priority, followed by the individual roadmaps. It is noted that the timelines are notional, and that they do not imply that all projects begin in the same timeframe. Prioritization is mandatory, and the timeline begins when that activity is launched.

The key themes and the individual roadmaps define a rich research and development agenda. As a next step, white papers will be written about each key topic. SMART CN will embrace the research agenda and will define cooperative programs around the key themes.

The next step in the roadmapping process is the compilation and integration of the individual roadmaps into one composite plan in which redundancies are mitigated precedence is established, and priorities are assigned. Since, at this point, SMART CN lacks the mandate for coordinating such a comprehensive R&D agenda, this major step forward is reserved pending proper empowerment and enablement.

The Key Findings are:

1) **Standards and Platforms for Information Exchange**. Among the foundation enablers for sustainable manufacturing are commonality in structure and data and information interoperability. There is a critical need for a set of standards, perhaps de facto standards, that assure that solutions can be shared.

2) **Clear Definition and Semantic Understanding.** Foundational to the development of standards, but mandatory at even a more fundamental level, is a clear definition of sustainable manufacturing and a “flow down” from that definition to the identify the attributes. Beyond a simple lexicon, a taxonomy and a rich ontology will enable a deeper understanding of needs, activities, and solutions.

3) **Pervasive Adoption of Sustainability Practices**. The key finding deals with the understanding of a total value equation across economic, technical, and cultural domains. It

supports a complete understanding of all factors that contribute to a value equation, including all related costs or "externalities".

4) **Comprehensive Characterization and Quantification of Manufacturing Processes**. The ability to optimize decision processes is dependent on the ability to understand material/process interactions and the impact of those interactions on product attributes. By characterizing important interactions and capturing those interactions in open repositories, the cycle of duplication of efforts can be replaced with an environment on which knowledge is built from a higher foundation.

5) **Comprehensive Life-Cycle Assessment.** LCA is broadly perceived as an administrative tool focused on the satisfaction of contractual requirements instead of a toolset that supports the evaluation and optimization of life-cycle performance and value. To change this perception and reality, additional functionality is needed that will enable the use of an LCA toolset to predict the performance of a product or process and support the optimization of critical success parameters.

6) **Sustainable Manufacturing Education.** Global economic and environmental realities dictate that everyone be educated regarding the imperatives of sustainable manufacturing. This key finding specifically addresses the infusion of sustainable manufacturing education across the U.S. education structure.

7) **Model-based Assessment and Control for Sustainability.** The ultimate goal of sustainable manufacturing is the development and implementation of methodologies and toolkits that will assure total value optimization in design and manufacturing. Perhaps the most important enabler is a comprehensive model set that supports the evaluation of option and the selection of the best alternatives. This key finding is focused in providing the modeling and simulation foundation that enables this total optimization environment.

8) **Data and Model Access for Sustainability.** Access to data and models is critical for accelerated progress. Systematic acquisition of the right data and population of open repositories enables the investment to be shifted from everyone developing their own data to the development of best solutions via shared data access. Secure collaboration and management is imperative. The same argument applies to access to models and knowledge.

9) **Optimized Design for Sustainability.** The ability to understand requirements and to quantitatively evaluate alternatives for meeting the requirements enables a design environment wherein cost, performance, and risk are visible. A "trades" environment is envisioned in which alternatives can be evaluated and the best total value designs of products, plants, and processes can be assured.

10) **Systematic Sustainability Achievement.** The challenges are great and resources are limited. To maximize progress, a systems approach is essential. A maturation model for sustainable manufacturing is needed to provide a tangible measure of goals and achievements. A consensus technology roadmap can provide a guide for prioritization and project definition. SMART CN provides an umbrella under which a consensus technology roadmap can be developed, and against which coordinated programs can be executed.

Key Finding 1: Standards and Platforms for Information Exchange

Timeline (Years from start)	1	2	3	4	5	6
1 Standards and Platforms for Information Exchange - Define, extend, and develop needed standards for supporting commonality in sustainable manufacturing mandates and activities. Create standard platforms to support the functionalities needed for establishing and maintaining a sustainable manufacturing environment						
1.1 Conduct a standards assessment and void identification, documenting the results and defining critical voids. Develop a standards roadmap for sustainability. Specifically address performance standards	Conduct assessment and identify voids. Develop association partnership/champion					
	Develop a sustainability standards roadmap. Define and prioritize critical standards set					
1.2 For defined needs, develop/adopt defacto standards. Work through NIST and with standards organizations to move to official standards (association approved standards are an attractive alternative).		Develop defacto standards - initial set				
		Develop and implement additional standards				
			Transfer responsibility to partner organization and support deployment			
1.3 Develop an architecture for information management for sustainable manufacturing. Leverage existing architectures and activities as a first priority	Define requirements for communications and interoperability across a supply chain					
	Define existing programs for leverage/partnership					
		Develop a sustainable manufacturing platform for supply chain management and optimization				
1.4 Develop/adopt a framework for data models, and create a systematic method for capturing the data models for sustainable manufacturing		Define the attributes of sustainable manufacturing to be captured in data models				
		Define a set of products/sectors/processes for initial population				
			Populate and manage			
1.5 Levarage existing activities to develop and implement a secure collaboration network across the supply chain	Define requirements and benchmark existing activities e.g. NNMI Institutes					
	Adopt/adapt/leverage a secure collaboration environment for application in sustainable manufacturing					
		Deploy and manage a secure collaborative environment				

Key Finding 2: Clear Definition, Semantic Understanding

Timeline (Years from start)	1 2 3 4 5 6
2. Clear Definition and Semantic Understanding - Establish a comprehensive and common definition for all of the attributes of sustainable manufacturing. Embrace this definition as a common foundation for understanding, and extend the understanding to a rich shared knowledge environment.	
2.1 Develop a clear, consensus definition and lexicon of sustainable manufacturing including a comprehensive glossary	Develop and publish the lexicon Maintain the lexicon
2.2 For each term in the lexicon define the attributes of sustainability in a taxonomy	Review existing taxonomies and extract relevant information Develop and publish the taxonomy Maintain the taxonomy
2.3 Extend the taxonomy of 2.2 to define the context and associations in an ontology	Develop Ontology Maintain the ontology
2.4 Produce a scoping document/data repository - sector by sector and system by system - quantifying the key stakehoders and key need areas (perhaps similar to the sector by sector and tier by tier activity mandated by the government for defense manufacturing	Develop Structure for data collection and management Conduct initial surveys Establish and populate repositories fordata management Manage access and use of information
2.5 Utilize the ontology to develop a definitive repository of, and instant access to, sustainability activities e.g. projects, publications, etc.	Evaluate available alternatives Develop and Deploy System Manage and Maintain access

Key Finding 3: Pervasive Adoption of Sustainability Practices

Timeline (Years from start)	1	2	3	4	5	6
3 Pervasive Adoption of Sustainability Practices - Provide a change methodology and model that quantifies the cost and benefit of adopting sustainability practices, including the inclusion of externalities and risks in business case assessment.						
3.1 Develop a change model and change management process that supports the transition process and value equation for sustainable manufacturing	Define the attributes of a positive business model for sustainability Capture these attributes in an analysis capability that supports decision processes - create a business model Develop an academic/industry partnership for implementation of this business model - including supplier participation					
3.2 Create a sustainability culture across the manufacturing community including the supply network and the customer base	Evaluate the "saftey model" as a foundation for the business case for sustainable manufacturing Develop a cooperative alliance in sustainable manufacturing within the society/association community Execute an awareness campaign from "the hill" to the consumer regarding the value proposition for national sustainability engagement					
3.3 Understand and quantify externalities and incorporate them into the business model and decision process	Define the cost factors regarding sustainability, including externalities Develop a business model for sustainable manufacturing Develop design methodologies and expert advsiors to support the sustainability model implementation Support the currency and implementation of the business model					
3.4 Provide a framework for risk assessment and mitigation of sustainability factors in the manufacturing enterprise (perhaps within the extended LCA framework of key finding 4.	Define and document the risk factors by materials type, sector, process, and application as is appropriate Benchmark current practice and identify and document best practices Develop a common framework and provide algorithms and expert advisors that support risk assessment and mitigation Extend and deploy					

Key Finding 4: Comprehensive Characterization and Quantification of Manufacturing Processes

Timeline (Years from start)	1	2	3	4	5	6
4 Comprehensive Characterization and Quantification of Manufacturing Processes - Provide a structure for characterization of material, process and product interactions. Prioritize applications and produce characterization data and provide for open access.						
4.1 Survey existing programs for materials and process characterization activities. Form alliances to enable partnerships or harmonization with these activities. Begin with the National Network of Manufacturing Innovation Institutes and DARPA activities.	Conduct a study of existing manufacturing materials and process characterizations. Produce a report Create alliances/awareness across the various projects/activities to assure synergy and collaboration					
4.2 Develop a framework for characterization emphasizing the attributes of sustainable manufacturing, founded and compatible with the platform of Key Finding activity 1.3 Include all system boundaries and externalities.	Document the attributes of sustainable manufacturing that are essential for full characterization. Include the rationale for the define attributes - specifically address boundaries and externalities Provide a structure/architecture, compatible with 1.3, that enables the sysetmatic characterization of sustainable materials. products, and processes - particularly the material process interactions.					
4.3 For selected processes, characterize feedstocks and related processes to define the attributes and boundaries of uncertainty. Quantify and model the impact of those attrutes on process performance and product outcome (quality, quantity, cost, etc.)	Coodinate assignments across the SMART Coordinating Network for specific products and processes "Characterize" the selected materials and processes and coordinate the results Utilize the results of the characterization to develop a model structure and to create composite models that can be adapted to specific applications. Extend across materials, products, and processes					
4.4 Extend and systemitize the characterization process to support full characterization of programs, products, and processes and establish an open repository for broad access to the data, information, and knowledge	"Systemitize" the characterization process by defining procedures, linking to standards and creating tools to support the creation of data in common formats (linked to 1.4) Eatablish and manage an open repository of characterization data - Key Finding 8					

Key Finding 5: Comprehensive Life-Cycle Assessment

Timeline (Years from start)	1	2	3	4	5	6
5 Comprehensive Life-Cycle Assessment - Transition Life-cycle assessment from an administrative and accounting function to a comprehensive value assessment methodology and toolset.						
5.1 Change the mindset and application of LCA from an administrative requirement and accounting tool to a toolset that enables the assessment of business decisions against defined metrics as a forward looking predictive tool (or offer another toolset under a new mantra)		Include the redefinition of LCA application in the pervasive adoption strategies of Key Finding 3	Establish linkages to the Model-based capabilities of Key Finding 7			
5.2 Develop tools to support MFA (material flow analysis) and SFA (substance flow analysis) to enable reduction, reuse, and remanufacturing of the materials and their substitutes including alternatives that do not recycle. Include these capabilities in a LCA toolset.			Develop a toolset to support MFA and SFA based on rules/metrics Integrate MFA and SFA in the LCA methodologies and toolsets			
5.3 Achieve interoperability between LCA systems and data. Standardize the protocols.	Define and document the input/output parameters and requirements for the exchange of LCA data	In concert with Key Finding 1, develop standard protocols for LCA data management, similar to MTConnect Implement a combination of applications interfaces and standards to achieve interoperability for LCA systems	Develop interfaces and "wizards" to achieve interoperability for multiple LCA systems and applications			
5.4 Develop criteria and evaluation methods to determine the key metrics and boundaries for both short and long term sustainability priorities for multiple applications and multiple perspectives e.g. small and large businesses, delivering valuable and useful assessment.		Develop templates and "wizards" that enable the definition of project requirements and adaptation of key metrics and priorities Develop rule sets for specific applications and pilot applications, and apply in determining metrics and priorities Extend to multiple applications. Integrate with LCA Toolset				

Key Finding 6: Sustainable Manufacturing Education

Timeline (Years from start)	1	2	3	4	5	6
6 Sustainable Manufacturing Education - Establish programs and curricula whereby sustainability awareness will be a part of every educational experience.						
6.1 Benchmark Current Practices	Identify incubator universities and benchmark; Capture the composite curriculum from leading universities					
6.2 Educate the Educators in a Layman's Understanding		Conduct pilot programs and refine curricula	Grow, refine, and extend			
6.3 Educate Prospective Engineers		Incorporate sustainability/sustainable manufacturing in the multidisciplinary introductory engineering curriculum	apply sustainability practices in product design at both the multidisciplinary level and in the fields of specialty; Assure that sustainability is a component of senior level capstone projects			
6.4 Apply Across the Curriculum			Strategically insert, and assure insertion, of sustainability thinking throughout the educational experience – not just in engineering			
6.5 Instill in lifelong Learning			Orient students to support the application of sustainable design after graduation and in industrial practice – whatever the pursuit			
6.6 Disseminate the program		Conduct a public relations campaign and extend the program througout the educational and industrial structure				

Key Finding 7: Model-based Assessment and Control for Sustainability

Timeline (Years from start)	1	2	3	4	5	6
7 Model-based Assessment and Control for Sustainability - Provide the needed modeling and simulation capability to enable the envisioned inclusion of all sustainability factors in design, production (including across the supply chain), and in lifecycle support and end of life activities. The enablers should address technological, business, economic, and environmental and energy issues						
7.1 Define and prioritize the model-based enablers that are essential in supporting the needed fuctionalities for sustainable manufacturing	Utilizing the taxonomy of 2.2 and the elements of this roadmap, define the models needed to support a model-based functionality Utilize the convening authority of SMART CN to establish a prioritized R&D agenda for model development With industry champions, develop, depploy, and extend the model-based capability					
7.2 Mature the existing model set to provide technical functionality beyond what is now available, consistent with 7.1.	Utilize the prioritization of 7.1 to define specific technology advancements. Launch development of systems to fulfil technical priorities defined in this roadmap Move beyond first principles to continuum models that include all factors (uncertainty) Capture and model consumer/customer reaction to sustainability issues					
7.3 Specifically address the modeling capability needed to mature and extend LCA functionality as is defined in Key Finding 5 including indicators and metrics	As an extension of 7.1, specifically define the pathway for model-based and extended functionality LCA as is defined in 5 Implement a model-based, compehensive LCA development and pilot program					
7.4 Develop core models that support common understanding of groups of feedstocks and are adaptable for specific applications	Define the "workflows" for feedstock preparation and conversion for classess of product Develop the capability to evaluate model performance of classes of feedstocks and specific feedstocks based on attributes Mature and pilot model-based feedstock selection and performance					
7.5 Establish business and enterprise models that support total value assessment and decision making	Develop the methodology and templates for total-value business case assessment, including the supply network Develop a structure for modeling the total value stream for business case assessments, with individual assessments feeding an integrated assessment. Develop needed models. Pilot the methodology and model set in specific applications and with industry engagement					
7.6 Establish a monitor, analyze, and control mechodology and capability to address sustainability issues by sector and apply to applications	Benchmark current activities (e.g the Smart Manufacturing Leadership Coalition) to define and document the state of practice Establish a pilot program with multiple testbeds to devel op a model-based control methdology. Extend and deploy in industry-led applications					

Key Finding 8: Data and Model Access for Sustainability

Timeline (Years from start)	1	2	3	4	5	6
8 Data and Model Access for Sustainability - Provide for the capture and management of needed data and models to support sustainable manufacturing. As a first priority, seek a partnership that would include sustainability data and models within an emerging structure						
8.1 Define and implement a data structure/repository for sustainable manufacturing	Seek alliances to maximize leverage Utilizing the structures of 1.3 and 1.4, establish a data and model repository Define the "rules" and protocols for data and model management Create a business environment in which the short and long term management of data and models is assured Implement a data/model repository					
8.2 Create a structure to assure that the data generated, stored, and utilized for sustainable manufacturing is of high quality and useful data that satisfies all required funtionality.	Develop data collection, granulation, and compression schemes for SCM applications Develop uncertainty descriptions for data in categories of SCM applications Develop methods to guide users in defining data requirements, based on sensitivity analysis on performance metrics for SCM, including the development/use of new visualization techniques Develop methods for data cleaning, handling of outliers(abnormal data), data reconciliation, treatment of missing data, and interplay of data analytics Develop validation, verification, and management practices to assure data quality					
8.3 Establish a secure collaborative environment that properly manages the storage of and access to data and models	Define leveraging opportunities e.g. NNMI Define access/control requirements and develop a controlled access data and model repository Identify a trusted neutral broker host and pilot the system Begin with SMART CN and grow to broad deployment					
8.4 Specifically address the provision and management of data needed to support enhanced LCA	Develop the data dictionary and data models necessary to implement the goals of key finding 5 Establish and manage, within the data repository, a dynamic capability to support enhanced LCA					
8.5 Assure that the data provided covers the full span of activities from the creation and conversion of raw material to the optimized delivery and support of product, including end of life factors	Develop process flow (workflow) models for the full product lifecycle by classes of product and process, including end of life Based on the requirements of the comprehensive design system of key finding # 9, define the data flow models to support the process flows Implement a data and model management system for the full product lifecycle					
8.6 Integrate the data access and modeling environments to assure that the data, information, and knowlegde requirements for model-based sustainability assurance are met	Utilizing the model requirements of 7.1, assure that the data and model repository address all need areas, Implement a model and knowlegde capability as part of the repository that provides all needed access control and management functions.					

Key Finding 9: Optimized Design for Sustainability

Timeline (Years from start)	1	2	3	4	5	6
9 Optimized Design for Sustainability - Provide an integrated toolset that addresses all needed functionality for sustainable manufacturing in the context of total value design and manufacturing						
9.1 Develop and mature an integrated sustainable manufacturing design platform	Establish sustainable manufacturing metrics and design guidelines for incorporation in design systems Establish (include) end of life metrics and advisory tools in the design platform (including knowledge-based advisors) Conduct pilots programs to demonstrate integration with PLM systems Integrate sustainable manufacturing design prinicples into PLM systems and broadly deploy					
9.2 Integrate LCA into the product, process, and plant design methodologies and systems	In concert with key finding 5, and working within the platform of 9.1, define the requirements for a LCA/design system that integrates product, process, and plant design. Create and demostrate an system in which enhanced LCA provides a front end to an integrated design system Pilot and deploy an integrated design optimziation system					
9.3 Develop a design for control methodology in which the process monitoring and control attributes are produced as part of the design process	In concert with 7.6, and consistent with emerging standards, develop a methodololgy for intelligent, closed-loop process control Develop a sense, monitoring, and control model as part of the design system, tnat, when populated, generates control limits, models, and methods. Pilot the design to control models in multiple product, plant, and process applications					
9.4 Provide systems that assure the inclusion of all important factors in a unified product and process design environment **• Risks and uncertainty** **• Safety by design** **• Design for "X"** **• Near-perpetual material flows** **• Resolution of conflicting priorities**	Define and prioritize the various attributes of product and process that must be addressed in a comprehensive design for sustainability system Develop a total value understanding, including the documentation and value assessment of externalities and methods of quanitfying and resolving conflicting priorities Address the priorities one-by-one, and in synergistic goupings, but within the design framework for assured integration and interoperability					
9.5 Establish requirements-based conceptual assessment and optimization - early in the development process - to evaluate and quantify cost, performance, and risk, and to support total value optimization	Consistent with 9.1, develop a web enabled platform for knowledge-assisted advisors systems for design optimization Develop a cost, performance, and risk trades environment in which total value optimziation can be realized Establish a modular system in which various perspectives can be readily engaged e.g. environmental compliance and to which the trades environment can be applied. Develop and deploy the modules. Integrate the components in an total optimization environment					

Key Finding 10: Optimized Design for Sustainability

Timeline (Years from start)	1	2	3	4	5	6
10 Systematic Sustainability Acheivement - Integrate the functions of this roadmap in a systems approach that delivers a comprehensive and profitable sustainable manufacturing environment (this is a higher level, enterprise view of other key findings)						
10.1 Embrace a systems engineering foundation for all of the work of SMART CN and for achieving pervasive adoption of sustainable manufacturing practices	Establish sustainable manufacturing metrics and design guidelines for incorporation in design systems					
	Establish (include) end of life metrics and advisory tools in the design platform (including knowledge-based advisors)					
	Conduct pilots programs to demonstrate integration with PLM systems					
	Integrate sustainable manufacturing design prinicples into PLM systems and broadly deploy					
10.2 Establish and deploy a maturity model. Apply that model in concert with the SMART CN roadmap to manage the maturation and deployment of critical capabilities	Utilize the technology readiness level model to define a sustainability maturity model					
	Conduct a maturity assessment for the goals defined in the SMART CN roadmap and update the roadmap					
	Systematically map progress against the roadmap					
10.3 Adopt practices that support a total systems approach (as oppposed to point optimization) for all manufacturing enterprises	Establish exchange systems that support synergistic materials and alternative feedstocks across company boundaries.					
	Create tools that support industrial symbiosis and support quantified value for business case analysis					
	Define key stakeholders and document their perspectives/needs in a value equation					
	Develop tools that intelligently resolve competing priorities for total vaklue optimization					
	Develop an integrated system that embraces all concepts in the roadmap					
10.4 Establish and extend the fundamental understanding of the science of manufacturing transformations, leading to foundational improvement	Develop knowledge-based systems that capture the cause and effect relationship in product and process design and in process control					
	Develop heuristics for sustainability for conceptual design					
	Understand and quantify the system of material, process, product interactions					
10.5 Embrace a model and knowledge based, total optimization grand challenge goal for sustainability	Create a consensus roadmap (including this input) as a seminal plan for action. Build a public/private partnership to fulfill the promise of total value manufacturing					

2 TECHNOLOGY DEVELOPMENT

Technology Development Group Participants

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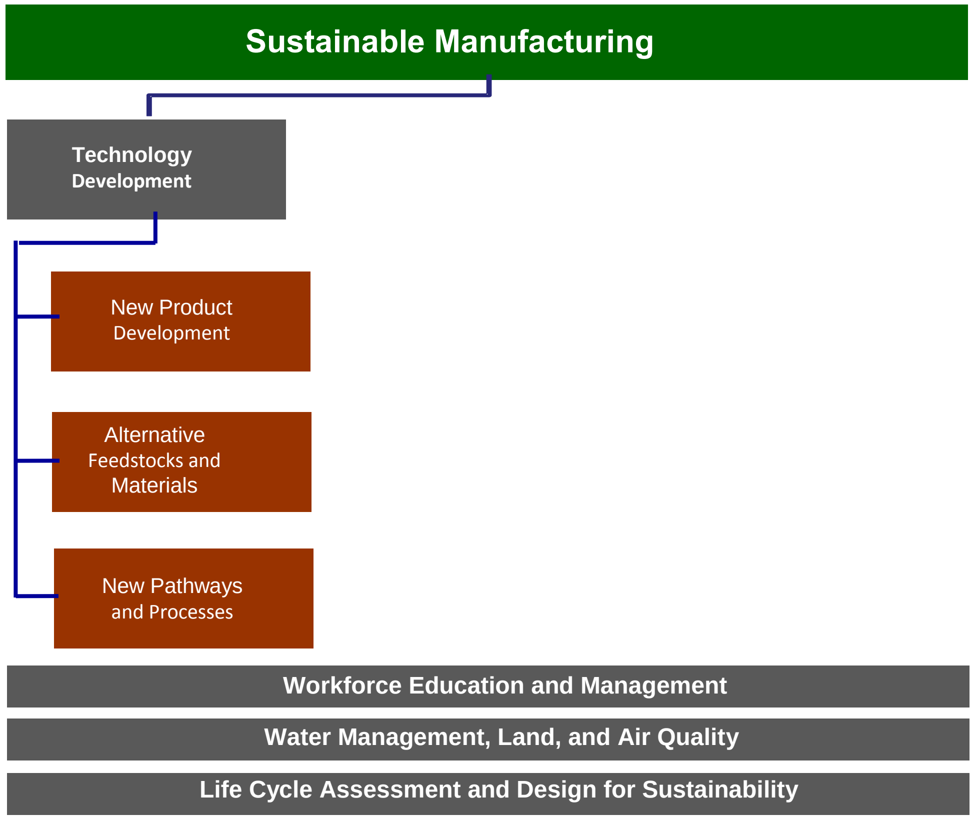

Figure 2-1: The functional model for Technology Development in support of Sustainable Manufacturing

Pillar 1 - Technology Development includes all activities associated with R&D in materials, products, and processes, with the intent to ensure an efficient and sustainable manufacturing environment. It comprises three major sub-elements as follows.

- **New Product Development.** Addresses all activities in which needs, requirements, and desires are processed to define, design, and refine solutions that become new products. This includes methods and tools that support improvements to existing products.
- **Alternative Feedstocks and Materials.** Focuses on the identification of alternatives that meet present and future requirements. Includes emerging areas such as materials genomics and Integrated Computational Materials Engineering.
- **New Pathways and Processes.** Includes all activities associated with the systematic discovery and development of new reactions and interactions of materials to form new products or to provide alternatives for producing existing products. It further includes the pathways by which products are created, addressing innovation in the supply chain.

2.1 Vision for Technology Development

The workshop attendees were challenged to "dream the dream" of the perfect world of technology-enabled sustainable manufacturing and to capture, for each pillar of the functional model, the attributes of that ideal state.

V2.1 New Product Development

- Simulation and modeling is the basis for new product development and improvement of existing products.
- A complete understanding of structure-property-activity-functionality-impact relationships enables evaluation of product performance and performance against sustainability metrics.
- Innovative products are rapidly taken to market.
- Process development and product design are unified.
- Sustainability metrics and assessment are built into every product design. The metrics are inclusive enough and generic enough to support multiple products and applications enabling standardization/harmonization of the assessment process.
- Quality by design; the quality of a product is designed into the product and is understood and predictable, lessening the length of the qualification process and assuring product sustainment and life-cycle value.
- Modeling and simulation systems support the ability to predict the quality and performance of a product as part of the development process, shortening time for market penetration; i.e., modeling and simulation enables quality by design.
- Virtual high-throughput screening of candidate products enables the evaluation of many options and the rapid selection of the best alternatives for further development.
- Product development includes an evaluation of what could be possible, including the evaluation of conceptual scenarios and the modeling of environmental and energy management issues.
- The product development environment is inclusive, extending to include virtual and physical prototypes and customer evaluation and field testing, and engaging the product life cycle in the evaluation.
- Safety by design, extended across the product life cycle, is an integral component of the product development process for every product.
- "Design for X" is a reality, where X includes all factors related to product performance, including the full evaluation of sustainability issues.
- Product development embraces the long-term impacts of sustainability issues, considering the impacts in hundreds of years.
- Product design supports near-perpetual material flows.
- Product development incorporates the risks associated with uncertainty in sustainability performance.

- The “window of what we don’t understand” is continually tightened to ensure that the impacts of emerging materials, processes, and technologies is well understood, predicted, and managed (e.g. nanomaterials) – minimizing and eliminating uncertainty.
- Innovative products are conceived from an understanding of requirements and function and a full understanding of the product use cycle (including evaluation of all available alternatives). Product use cycle understanding requires awareness by all stakeholders of all aspects of the product supply and use chain whether it is positive or negative.

V2.2 Alternative Feedstocks and Materials

- The full understanding of the processes (chemical, physical and molecular processes) supports the trading of renewable, commodity, or scarce constituents as a product – enabling processes and products to be designed at the constituent level, enabling feedstock neutral/agnostic processing.
- Prevalent environmentally unsound materials are replaced by environmentally beneficial products and feedstocks.
- Linear processing is replaced with cyclic processing and reuse creating closed systems.
- Feedstocks are tailored for product and pathway.
- Cross-linkages are established for feedstock development and utilization. Competitions between use of feedstock for energy production, chemical feedstocks, and food are resolved, (e.g., shale gas).
- A secure, diverse, and sufficient supply of suitable feedstocks is ensured. The ensured supply will be compliant with requirements and needs for purity, utility, and price.
- The listed attributes of materials are inclusive of all needed data, information, and knowledge.
- Feedstock supply is managed all the way to the origin including impacts on soil, air, water, and other factors.
- Resource scarcity is eliminated as a factor in sustainable manufacturing by better provision, broader understanding (of material flows) and wiser use of resources that are inherently essential and by development of alternative resources.
- Policy level understanding and drivers are reflected in decisions at the product and micro level (including economic and social impacts).

V2.3 New Pathways and Processes

- New pathways and manufacturing systems will enable the performance of the same or improved function from sustainable feedstock.
- Sustainability metrics and assessment will be built into every pathway.

- Rapid development or synthesis of new pathways and processes will enable cost-effective production of new products.
- New methods will support economic chemical conversion e.g., use of CO_2.
- Mass and energy efficiency improvement will be realized inclusively across pathways and processes.
- A "trades" environment for processes and products addresses all factors including sustainability.

V2.4.1 Workforce Education and Management

- Workers graduating at all levels of progression are well prepared for the jobs that they are pursuing, with a total competence in sustainable engineering and sustainable living.
- The workforce and public are technology and sustainability literate. This includes the existing workforce and public and the emerging workforce and public.
- The workforce is continually aware of the emerging opportunities, challenges, and requirements related to sustainable manufacturing and are equipped for proper response to any circumstance.

V2.4.2 Water Management and Air Quality

- Societal and ecosystem externalities are routinely included in overall production costs (holistic costing).
- Effective and efficient use of water is broadly achieved with overall improvement in water quality and minimum chemical, biological and thermal pollution of the water.
- Contaminants emitted to the air are eliminated.
- CO_2 conversion to value added products minimizes greenhouse gases released from manufacturing industries.

V2.4.3 Life-Cycle Assessment and Design for Sustainability

- Complete Life-Cycle Assessment of every product and process is reflected in the design of that product and process.
- Widely and publicly available databases support Life-Cycle Assessment.
- Designs are within the boundaries of ecological constraints.
- Standard and accepted metrics are available to support sustainability assessment and support concrete conclusions/actions from those assessments.

2.2 Barriers and Challenges for Technology Development

B2.1 New Product Development

To achieve the vision of products that are sustainable, there are many hindrances, barriers, and challenges that must be acknowledged and addressed. The operative question for this portion of the workshop was, what stands in the way of the ability to create innovations that are sustainable, create designs that are sustainable, and develop new products that are sustainable over their life cycle? The following is a tabulation of the barriers and challenges. The categories are natural groupings that emerged from the tabulation.

Category	Barriers and Challenges
Collaboration	• Confidential business information inhibits sharing and suppresses cooperation. • Lack of standards by which to ensure and quantify sustainability • The necessity and challenge of validation in computational materials and product engineering • Mistrust between industries, governments, and NGO (non-governmental organization) • Proprietary information and models hinder development of products that are sustainable. • Lack of willingness (or business case) for companies to work together
Education and Workforce	• Inadequate product design instruction for chemical engineering education. Most of the focus is placed on process development at the expense of products. • The "industry commons" or shared knowledge related to sustainability is insufficient.
General	• Global cost competition drives a short term profit focus. • The time to deployment of new product ideas is too long.
Metrics	• Good sustainability metrics for which there is common agreement do not exist. • A clear definition and semantic understanding of sustainability is required to support the development of metrics, and that understanding is not in place. • The fundamentals such as weighting factor and assessment tools do not exist to support management of performance against metrics. • There are no uniform metrics that are consistently applied across sectors and corporations.
Perceptions	• It is difficult to predict the reaction to and acceptance of products. • There is a perception that being "green" or supporting sustainable manufacturing means paying more for less. • Sustainability is viewed as a "fad" and not taken seriously.

Category	Barriers and Challenges
Product Life Cycle	• There is a long pathway and a high investment to commercial acceptance of new methods that support sustainability. • Sustainability assessment for emerging products is difficult due to paucity (scarcity) of data and information. • Focus should be placed on reengineering at end of life.
Tools	• Product models are needed that support the trade-offs of all factors including sustainability. • An integrated design toolkit is needed that accommodates legacy data and systems and supports the assessment of sustainability in product development. • Common practices for sharing information in scale-up do not exist. • Models do not interoperate across various systems, making the development and use of models unduly expensive. Sub-models do not interoperate to support complete product evaluation. • The toolset for total Life cycle Assessment, including the needed models, is deficient. • We don't know everything that we need to know about chemicals and molecular processes to support the understanding of the resulting products. This extends to the understanding of the structure/property/activity/functional relationships. • Tools to support a priori properties/function outcome predictions are not available.
Trade-offs	• The incentives are not in place for manufacturers to address use-phase impact. Focus is placed on the production and purchase price and not on the overall life-cycle costs and environmental impact. • Human behavior such as consumer responses and social impacts are not often included in the product decision process.
	• We lack the ability to quantify trade-offs between economic and environmental aspects in product development.

B2.2 Alternative Feedstocks and Materials

In defining the barriers and challenges for alternative feedstocks and materials, the operative question is, "what prevents us from having access to materials that specifically and best satisfy the requirements for the product?"

Category	Barriers and Challenges
Collaboration	• The best choices for alternative feedstock require input from multiple stakeholder and disciplines. The needed input may be hard to define.
Competition for Feedstock	• Effective bio-based energy production requires a low cost and consistent supply of feedstock that does not compete with food or contribute to water scarcity. • For renewable energy sources, farmers want an open market while biorefiners want to lock down a long term and stable supply. • There is not enough land to supply the world's population with food plus support the production of biofuels.
Insufficient Understanding	• There is insufficient access to real production data regarding processes and outcomes to support the quantification and selection of alternative materials. • Agreement and alignment around which feedstocks are considered "renewable", varies by Non-Government Organizations (NGOs), region, country. • Sustainability assessment metrics for feedstocks are inadequate. • There is a lack of understanding of the full supply chain for sustainable feedstocks and of the total impact of the full development and use cycle. • The complete understanding of the conversions is limited by voids in the understanding of the chemical processes.
Process/feedstock Inadequacies	• The feedstocks are not easily refined. • Safety and environmental damage in processing limits biofuel development • There is a large variability in feedstocks. "Commodity" is not defined. • The process of developing new feedstocks, testing them, testing products/materials after using new feedstocks, etc. is lengthy and costly. • Low bulk density plagues biofuel producers.
Recycle	• Metals are often well dispersed and are difficult to recover. • Many materials are not recyclable and there is no effective use for some of the materials that can be recovered.
Availability of Resources	• The availability of materials, both plentiful and scarce, impacts recycling decisions and the cost of the materials and it fluctuates for many reasons. • Alternative feedstocks are not available at the needed scales (biofuels mostly but can be broadly applied). • Processing or supply is often outside the control of US sources (e.g. rare

Category	Barriers and Challenges
	earths). • Production of feedstock may deplete nutrients. • Feedstock production is influenced by many factors that cannot be controlled e.g. weather.
Tools	• Product life-cycle tools that can be adapted to accurately analyze the product/process stream and support decision processes are lacking.
Vested Interests	• Interactions between various members of the supply chain are governed by many factors, some of which are not visible or reasonable. • Pressures are exerted toward non-optimal solutions e.g. ethanol. • Political pressures preserve the status quo.

B2.3 New Pathways and Processes

What are the barriers to the discovery of new reactions or processes that deliver new products or what are the barriers to defining new and improved methods for producing existing products, keeping in mind that our goal is to achieve sustainability in products and processes?

Category	Barriers and Challenges
Incomplete Understanding	• Difficulties in fully understanding the functionality of the end product that drives process and pathway development • Lack of scientific basis/understanding for the simplification of complex models
Metrics	• Lack of metrics to quantify "greenness" in pathways • Lack of scientifically-based metrics for sustainability
Perceptions	• Consumers lack the knowledge to make the best decision concerning sustainable products e.g. cold versus hot water.
Trade-offs	• The cost of changing processes or introducing new pathways after processes/infrastructure is in place • Green materials at brown prices • Public good versus economic realities e.g. ridership on public transit • Short term profits versus long term good
Tools	• Integration of sustainability practices into the existing tools and technologies infrastructure on-line • Lack of an infrastructure for rapidly processing of complex models at various scales • We need better tools/methods to identify sub-optimal "local" solutions to global problems in design/materials optimization. • LCA as a forward looking, predictive tool that impacts product and process design instead of using it for evaluating environmental sustainability retrospectively

Vested Interests	• Government policy is an uncertainty variable that is unstable and hard to manage. • Social concerns receive low priority.
General	• Impact of international competition

B2.4 Crosscutting Barriers and Challenges

For the critical crosscutting enablers of Workforce Education and Management, Water Management and Air Quality, and Life-Cycle Assessment and Design for Sustainability, what are the hindrances that prevent us from achieving our vision?

Category	Barriers and Challenges
Workforce Education and Management	• Lack of suitable curriculum and associated training materials • Lack of a trained workforce to train the future workforce in sustainable engineering • Lack of continuing education for practitioners and leaders in the industry (particularly top leadership) • Lack of awareness of complexity and breadth of sustainability • Lack of interdisciplinary knowledge/silo effects • Pressure to compress existing curriculum makes it far more difficult to include sustainability in the education process
Water Management and Air Quality	• Multiple contributing waste streams that are unrelated • Our use tradition is misplaced (drinking water is the standard for all uses). • Interrelationship between air and water management (e.g. acid rain, mist from industrial operations like metal cutting fluid and coolants) • Media specific regulations create opportunity to bypass good sustainability practices (the practices may address compliance and miss the real issues). • The mindset regarding compliance is "only good enough to satisfy prevailing regulations" (related to above). • Emerging technologies and materials e.g. nano, create new challenges • Lack of collaboration between industry, govt. agencies, and other stakeholders • Reliance on end-of-pipe treatments instead of prevention • Water is an excellent coolant and hence overused in industrial processes. • Lack of incentives to invest in water management when alternative availability might be more convenient (location selection favors abundant water supply, when alternatives to using so much water or alternative water supply might be better for the environment) • Government regulations for cleanliness and purity are leading to industrial practices that are forcing the use of more hot water with additives.

Category	Barriers and Challenges
	• Lack of understanding between water quantity and quality (sometimes reduced quantity is not the best goal) • Perception is difficult to change (e.g., all water should be clean water).
Life-Cycle Assessment and Design for Sustainability	• LCA to its practitioners is just an accounting exercise and has far reaching implications and potential that is not fully realized. • The necessity of subjectivity in coming up with weighting factors discounts the benefits of LCA • Subjectivity in defining system boundaries enables a variety of results and conclusions, casting doubt on the validity of the findings. • Lack of interoperability in existing tools makes LCA studies more difficult and expensive • Lack of commonality of tools that support moving information across disciplines • Moving from design for environment to design for sustainability is a challenge • Decision-makers at different levels require different level of granularity from the analysis. • Traditional LCA ignores social and economic aspects. • Complexity of LCA results and strategies make clear interpretation difficult. • Claims of sustainability are quite often false (greenwashing).

2.3 Goals for Technology Development

To realize the vision and to overcome the barriers and challenges, there are capabilities that must be provided. These are the goals for technology development for sustainable manufacturing.

G2.1 New Product Development

- G2.1.1. Develop and document the semantics and the ontologies to fully define the sustainability issues.
- G2.1.2. Develop tools that quantify the relationship between product attributes and the total performance of the product (including sustainability impacts) enabling informed and integrated decision making (promoting value added vs. cost).
- G2.1.3. Provide the needed data for a complete understanding of the structure-property-activity-functionality-impact relationships supporting better informed design and development. Include product performance and performance against sustainability metrics.
- G2.1.4. Develop model-based systems that utilize a complete understanding of product attributes to optimize the product development process including sustainability issues.

- G2.1.5. Develop models that include LCA based metrics and indicator data for making decisions on sustainability for a product.
- G2.1.6. Integrate LCA tools with existing and emerging design and manufacturing toolset (for example integrate LCA with product life-cycle management and enterprise resource management systems).
- G2.1.7. Develop metrics, standards, and communication mechanisms that support a complete and adequate product definition. Complete product definition means that all data, information, and knowledge that is needed to drive downstream applications (including sustainability assessment and optimization) is available.
- G2.1.8. Develop a sustainable manufacturing and product design framework that supports collection of data, decision support and product definition, delivering optimized value added in product development.
- G2.1.9. Create a systems engineering approach to sustainability (or ensure that sustainability is properly included in existing approaches) based on a rigorous understanding of appropriate factors that must be considered in optimized design.
- G2.1.10. Develop technologies that ensure access and interpretation of regulatory and other requirements (a holistic view) accelerating the product development/compliance approval processes.
- G2.1.11. Provide tools and technologies that support the determination of ensured safety practices in all aspects of product development and improve product safety across the life cycle.

G2.2 Alternative Feedstocks and Materials

- G2.2.1. Develop core models that support a common understanding of groups of feedstocks that can be adapted to specific needs.
- G2.2.2. Develop data and tools that support the evaluation of the use of a specific feedstock against the requirements that the product and process places on that feedstock.
- G2.2.3. Develop tools to support MFA (material flow analysis) and SFA (substance flow analysis) to reduce, reuse, and remanufacturer the materials and their substitutes including alternatives that do no recycle.
- G2.2.4. Create new technologies to guide the processing of renewables to deliver the correct mix of products (feedstocks, materials, etc.) closing the cost gaps between renewables and non-renewables.
- G2.2.5. Develop technologies for biobased feedstocks that support blending of different feedstocks to reduce supply risks and allow larger economies of scale.
- G2.2.6. Establish exchange systems that support synergistic materials and alternative feedstocks across company boundaries. As an example, Procter and Gamble has a program called "waste to work" which actively seeks opportunities to move byproducts to any or all applications.

G2.3 New Pathways and Processes

- G2.3.1. Exploit emerging technologies (e.g., nano, new generation of biotechnologies, multifunctionality) in defining new pathways and processes.
- G2.3.2. Develop metrics, tools, data, and standards (capabilities and competencies) that enable quantification and trades regarding the degree to which alternative processes satisfy sustainability goals and requirements.
- G2.3.3. Create tools and systems to facilitate industrial symbiosis, quantifying the business case.
- G2.3.4. Redefine the value proposition between industry and academia to strengthen the business case for R&D investment. This includes the development of new and improved mechanisms for management of intellectual property.

G2.4.1 Workforce Education and Management

- G2.4.1.1. Promote the idea of sustainability and not the science of sustainability in education (the mindset here is that we deliver the details and miss the concepts that matter to those who will not be sustainability professionals).
- G2.4.1.2. Extend sustainability thinking and education to all academic disciplines.
- G2.4.1.3. Improve technology capabilities of the graduating workforce.
- G2.4.1.4. Promote mission focused engineers (in all disciplines) with a broad view of sustainability issues and capable of working across disciplines.
- G2.4.1.5. Provide user-friendly tools and educational programs to improve the sustainability calculation/analysis capabilities across the basic industrial workforce.
- G2.4.1.6. Develop tools to improve the ability to understand and respond to the cause and effect relationships related to industrial processes. This could be addressed with knowledge based systems and knowledge discovery tools.

G2.4.2 Water Management and Air Quality

- G1.4.2.1 Create a balance between water-energy-material nexuses (sustainability mass balance).
- G2.4.2.2 Develop cost effective new technologies for reducing release of air pollutants.

G2.4.3 Life-Cycle Assessment and Design for Sustainability

- G2.4.3.1. Develop comprehensive interoperable LCA and sustainability assessment tools matching the LCA outputs with the inputs for decision-making. Provide a standard structure/framework for defining the needed inputs/outputs for necessary decisions.
- G2.4.3.2. Provide coordination of national R&D efforts to define present toolsets, voids and communication failures and focus on building to solution.

2.4 Priority Goals for Technology Development

The goals were prioritized by a group voting process. The results of that prioritization are:

Goal Statement	No of Votes
1) G2.4.3.1 Develop comprehensive interoperable LCA and sustainability assessment tools matching the LCA outputs with the inputs for decision-making. Provide a standard structure/framework for defining the needed inputs/outputs for necessary decisions.	11
2) G2.2.3 Develop tools to support MFA (material flow analysis) and SFA (substance flow analysis) to reduce, reuse, and remanufacturing of the materials and their substitutes including alternatives that do no recycle	10
3) G2.4.1.5 Improve the sustainability calculation/analysis capabilities across the basic industrial workforce (and all workers)- combination of user friendly tools and education	8
4) G2.4.1.2 Make sustainability thinking pervasive in all academic disciplines	8
5) G2.1.3 Gather data for a complete understanding of the structure/ property/activity /functionality /impact relationships enables informed design and development. (Include product performance and performance against sustainability metrics).	7
6) G2.1.4 Develop model-based systems that utilize a complete understanding to optimize the product development process including sustainability issues. Develop models that include LCA based metrics and indicator data for making decisions on sustainability for a product.	9
7) G2.4.3.2 Provide coordination of national R&D efforts to define present toolsets, voids and communication failures and focus on building to solution	7
8) G2.1.8 Sustainable manufacturing and product design framework that supports collection of data, decision support and product definition. Delivering optimized value added in product development.	6
9) G2.3.2 Develop metrics, tools, data, standards (capabilities and competencies) that enable quantification and trades regarding how sustainable	5
10) G2.1.6 Integrate LCA tools with existing and emerging design and manufacturing toolset (PLM plus).	5
11) G2.1.2 Develop tools that quantify the relationship between product and the global economy enabling informed and integrated decision making (promoting value added vs cost)	4
12) G2.2.4 Create new technologies to guide the processing of renewables to deliver the correct mix of products (feedstocks, materials, etc) closing cost gaps between renewables and non-renewables	4
13) G2.2.6 Establish exchange systems that support synergistic materials and alternative feedstocks across company boundaries (Waste to work, P&G, byproduct synergies)	4

14) G2.4.2.1 Create a balance between water-energy-material nexuses (sustainability mass balance)	4
15) G2.3.1 Exploit emerging technologies (e.g., nano, new generation of biotechnologies) for existing and new products (e.g. nano and multifunctionality)	4

It is important to note that all of the goals are important, not just the ones that received the most votes! The additional goals are reflected in the roadmaps that result from this workshop.

3 PROCESS AND SYSTEMS MANAGEMENT

Process and Systems Management Group Participants

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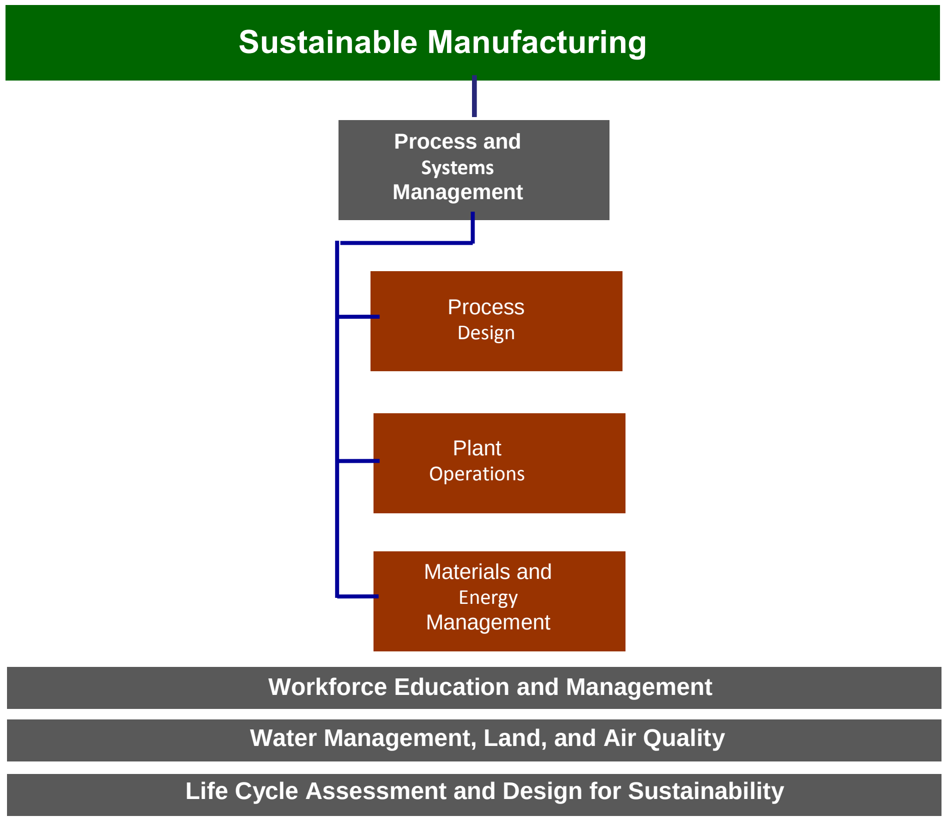

Figure 3-1: The functional model for Process and Systems Management in support of Sustainable Manufacturing

Pillar 2 - Process and System Management, comprises the design and development of manufacturing processes, the operation and control of those processes, and management of the invested resources. It has three functional sub-elements:

- **Process Design.** Addresses the progression by which requirements and innovative ideas are transitioned to detailed descriptions of manufacturing processes, including all information needed to support process execution.
- **Plant Operations.** Encompasses all activities associated with executing manufacturing processes, including operation and management of equipment, equipment control, and the management of a safe, secure, and sustainable manufacturing environment.
- **Materials and Energy Management.** Includes all activities associated with the delivery, control, and optimization of the materials required to execute the manufacturing processes, with a special emphasis on the resources that have the strongest impact on sustainability. These special emphasis areas include the efficient delivery and management of materials that impact the environment and the management of energy for maximum operational efficiency and optimized net consumption.

3.1 Vision for Process and Systems Management

Sustainability is no longer "siloed". Process Design, Plant Design and Plant Operations are all integrated; each informing the other to create a totally optimized processing environment.

V3.1 Process Design

- First principles understanding and molecular-based modeling are pervasive and support new and better methods of process design. Comment: the understanding should definitively answer and quantify issues such as the impact of proposed process designs on important issues, such as greenhouse gases.
- Sustainability transcends boundaries: integration of process design and sustainability transcends disciplines beyond the engineering world to include economics, sociologists, health professionals, biologists and other disciplines.
- Processes are designed and developed for optimized mass and energy efficiency.
- Process intensification enables the accomplishment of more with less space and lower asset utilization.
- Accounting for energy and mass efficiency in process development moves from a manual process of optimization to an automated process – including the environmental effects.
- The work and methodology for creating a process design is systematized, automated, optimized and managed.
- All important attributes such as safety, air and water quality, environmental issues, etc. are quantified and addressed in process design.
- Process integration is a holistic view of all parameters and impacts as opposed to individual and point optimization.
- Process design is integrated with control design to ensure that the product is produced as required and as designed.

V3.2 Plant Design and Operations

- Plants are designed and automated to the level of total value achievement and operate within a safety envelope.
- Just-in-time utility (energy/power) access ensures continued and efficient operations.
- Enhanced mass and energy efficiency in operations (resulting in lessened downtime and lower cost performance).
- Model-based operation is the norm, including model-based control for plant-wide operations.
- Abnormal situations are systematically and consistently controlled and eliminated.
- Effective and efficient production scheduling is achieved for multiple-product plants.

- Integration and optimization is a continuous reality across operating functions – assuring that the best total solutions are realized. The optimized operation includes the best management of uncertainty.
- The resources within the system are managed for total best value, with proper attention given to environmental issues. The factory will approach "closed system" operation with outputs that leave the system having no detrimental effects.
- Waste elimination and renewable resources are designed into the Plant.
- Small scale plants will be economically viable and sustainable and will be scalable.

V3.3 Materials and Energy management

- Maximum utilization (approaching 100%) of raw materials to value added product with no waste.
- Energy consumed will be renewable energy.
- Heat and power integration will be maximized to the point that heat will not be released as an unused by-product.
- Cost effective energy storage is readily and widely available enabling efficient harnessing of intermittent energy sources.
- Minimize or eliminate toxicity in products and processes.
- Create a symbiotic relationship across larger and larger boundaries moving toward a total waste free environment (e.g., Kalundborg in Denmark).
- Instill industrial ecology and control through redundancy while preserving economies of scale.

V3.4.1 Workforce Education and Management

- Workers graduating are well prepared for the jobs that they are pursuing, with a competence in sustainable engineering and sustainable living.
- A technology literate workforce and public: this includes the existing workforce and public and the emerging workforce and public.

V3.4.2 Water Management, Land, and Air Quality

- Societal externalities are included in the overall production costs (holistic costing).
- Water consumption and chemical, biological and thermal pollution of the water are minimized.
- Air born contamination is eliminated.
- Greenhouse gases (CO2) are converted to value added products.

V3.4.3 Life-Cycle Assessment and Design for Sustainability

- The design of every product and process reflects the response to an appropriate Life-Cycle Assessment
- Databases to support Life-Cycle Assessment are widely and publically available

- Product and process designs, and operations against those designs, are within ecological constraints
- Standard and accepted metrics are available to support sustainability assessment and to support concrete conclusions/actions from those assessments.

3.2 Barriers and Challenges for Process and Systems Management

The vision for processes and equipment management reflects a major migration from today's capabilities to the enablers that will make that vision a reality. There are barriers and challenges that must be overcome in mapping the migration from the current state to the vision state. The following table tabulates some of those areas that must be addressed.

It is noted that the barriers and challenges are tabulated for the pillar topic – processes and system management – and not at the subtopic level as is the case in the other two pillar chapters. The result in defining the goals and building the project slates is unchanged.

Category	Barriers and Challenges
Definitions	• Lack of a workable rigorous definition of sustainability that includes the objective function, constraints, and variables • Lack of a coherent science of sustainability • Inadequate understanding of the science of sustainability
Externalities and Boundaries	• Lack of global scale accounting including boundaries and global reach • Subjectivity in defining boundaries and the definition of the wrong boundaries • Short term political and industrial pressures • Lack of an awareness and evaluation of the full implication of societal and social impacts • Externalities are not quantified and used to justify required incremental investments. • Externalities are not (but should be) included in design, operation and materials and energy management of processes. • Difficulties in defining the best tradeoffs between components of sustainability. Multiple considerations are difficult to balance • Lack of cross boundary common goals for sustainability - "Silo" effect drives individual optimization, not system optimization (work/successes in one area not shared within a company and not shared outside of a company) • Challenge to include impacts beyond the local scale in process design • The focus on Recycle, Reuse, Remanufacture issues seems to have given way to "sustainability" with some loss of why and what should be accomplished. • Poor understanding of the full implication of material and energy use beyond the manufacturing plant

Category	Barriers and Challenges
	• There are real limits on the ability to efficiently produce energy from certain materials. Understanding these realities is important.
Systems Thinking	• Systems thinking and systems engineering principles need to be applied in managing materials and energy.
Incentives	• Renewable energy solutions are generally more costly than conventional alternatives. • There is a need for a cultural change in manufacturing decision making. Sustainability is not a priority when compared with economic trade-offs and subjected to ROI analysis. • There is a lack of innovation in process design and an unwillingness to implement novel control methods • Redesign of existing manufacturing facilities; focus on tweaking versus redesign with assessment of financial return • There is a scarcity of individuals in the manufacturing community who have expertise and interests in sustainability. • Sustainability parameters (energy, environmental impact, minimization, raw materials, etc) are not a priority when compared to other production drivers. • Adequate consideration of realities is often omitted in evaluating goals against the technical feasibility – "reality check".
Data and Uncertainties	• Feedstocks are often not well defined which sometimes provides an unmanageable uncertainty regarding the input parameters. • Needed data is often not available for valuating new process alternatives e.g. biomass. Needed computational tools may not be available. • Process models are specific to company practices and boundaries. Much of the data is proprietary. It is not yet reasonable to develop "generic process models" that can be easily adapted to meet specific needs. • Protection of proprietary data – lack of willingness to share models and data • Data quality is often not adequate to support predictions and good analysis. Uncertainty is not well managed in models. • There is insufficient knowledge of the chemistry, physics, and metallurgy to support optimized process designs. • Variabilities in the feedstock and the manufacturing environment present management and operations challenges. • Insufficient emphasis is placed on the longer term impact of present decisions.

Category	Barriers and Challenges
Tools and Methods	• Development of new processes does not include sustainability indicators very early in the development process. • Operation/operability concepts, objectives, and constraints are often not properly considered during the design phase. • Design for X, where X includes producibility is not pervasive. • The ability to upgrade process designs and attributes for continuous improvement is lacking. • Design tools are designed for conventional raw materials. These tools need to be upgraded to support alterative materials. • Improved process models are required for individual processes and components AND for integration across processes.
Change Management	• Limited adaptability of people, systems and decision makers – resistance to change • Difficulties in gaining agreement and implementing design changes – for many reasons
Metrics	• Evaluation of sustainability indicators is not systematically and regularly performed. • There is no strong basis in science for most metrics and indicators of sustainability. • There are no threshold methods to choose appropriate sustainability metrics in process design.
Education	• The educational system is not prepared to deal with highly trans-disciplinary topic of sustainability. • Present educational systems and structures do not place an emphasis on training sustainability professionals and experts. • Belief by some that regulatory compliance equals sustainable performance
Business Alignment	• Speed of business inhibits time for innovative solutions. • The status quo is an easier path.
Regulations	• Lack of clear definition of "what constitutes an innovation" leading to patent constraints • Government regulations and rules inhibit progress in sustainable manufacturing. Often the regulations are counterproductive from both the good of the environment and economic viability. • Societal pressures create conflicting priorities and uncertainties. • Regulatory performance does not necessarily mean sustainable performance.
Knowledge	• We do not understand the capacities of our human bodies and of the environment to handle various stressors. • Lack of expansive consideration of catastrophic events and impacts

3.3 Goals for Processes and Systems Management

To realize the vision and to overcome the barriers and challenges, there are capabilities that must be provided. These are the goals for processes and systems for sustainable manufacturing. The Processes and Systems group rigorously tabulated the requirements to achieve the vision in goal statements and they specifically addressed what is required to address the barriers and challenges. In addition, they addressed the crosscutting enablers within the other topic areas.

G3.1 Plant Design and Operation

- G3.1.1. Infuse sustainability factors into plant design and automation.
- G3.1.2. Develop design capability for control for sustainable design and operation – including stochastic control (uncertainty). This means that sustainability factors are captured in the monitor, analyze and control methodologies and toolsets.
- G3.1.3. Affect a change in operation and management culture such that sustainability is as important a constraint as is quality. Empower operations to optimize sustainability.
- G3.1.4. Develop sustainability performance standards, not just design standards.

G3.2 Process Design

- G3.2.1. Improve access to computing power for advanced analytics in process modeling and optimization.
- G3.2.2. Establish mechanisms and programs by which processes are fully characterized, process and process/materials interaction data is captured, and data is made broadly available.
- G3.2.3. Provide better property data for things like environmental impacts and transport data (beyond molecular models). Emphasize multiscale modeling.
- G3.2.4. Bridge the scales of modeling from models based in first principles to continuum models.
- G3.2.5. Develop heuristics for sustainability for conceptual design. Create expert, knowledge-based systems for process design and development.
- G3.2.6. Develop optimization for sustainability based on the collection and processing of real-time data and the use of that data for in-process control. Such control systems are now available, but modification and extension is required.
- G3.2.7. Utilize multi-agent optimization (agent based modeling to incorporate different stakeholders) and modeling including crowd sourced solutions for process design.
- G3.2.8. Infuse systems-based engineering design methodologies with quantified sustainability considerations.

G3.3 Materials and Energy Management

- G3.3.1. Develop and extend the macro scale modeling capabilities and applications.

- G3.3.2. Extend the applications of renewable energy in manufacturing processes.
- G3.3.3. Integrate eco-system (industrial symbiosis) opportunities in materials and energy management.
- G3.3.4. Extend the application of modeling in all aspects of manufacturing including materials and process interactions and energy management.
- G3.3.5. Extend energy and material balances to the manufacturing realm for existing manufacturing processes and transformational new processes.
- G3.3.6. Include social and political implication of sourcing material and energy supplies and consumption.

G3.4 Life-Cycle Assessment and Design for Sustainability

- G3.4.1. Embrace LCA as a tool for improved designs and not as a requirement to be satisfied. Rhetorically speaking, determine whether LCA follows design or design follows LCA. Design following LCA – as a useful exploration of life-cycle value – is an important goal.
- G3.4.2. Standardize and make LCA easier (and faster) to apply and interpret so that the results can be better incorporated into design.
- G3.4.3 Incorporate "life cycle thinking"- not just LCA into the design process. What this means is apply a sustainability mindset in all aspects of design.
- G3.4.4. Extend present LCA toolsets to include uncertainties and explore the alternative results from various boundary selections.
- G3.4.5. Infuse sustainability/life-cycle impact assessment into product life-cycle management.
- G3.4.6. Include end of life issues such as product reuse, remanufacture and redesign into the product design process.

G3.C Goals from Barriers and Challenges

- G3.C.1. Develop consensus across disciplines as to a working definition of sustainable manufacturing in tangible, well defined terms that have a common utility.
- G3.C.2. Find scope and guidance values on sustainability – not necessarily a precise definition.
- G3.C.3. Develop methods for including ecosystem service valuation into the manufacturing process.
- G3.C.4. Develop methods for including resource depletion into the manufacturing process.
- G3.C.5. better define, quantify and understand the externalities (including social / societal impacts and resource depletion) that affect the sustainability of a manufacturing process.
- G3.C.6. Develop an improved understanding of the sustainability boundaries of manufacturing processes.

- G3.C.7. Recognize and quantify the value add for manufacturing at the process level and product level and develop systems that incorporate these factors in the design of products and processes.
- G3.C.8. Better define, understand, and quantify the scope of sustainable manufacturing including the definition of the systems/sectors we should be focusing on (under the umbrella of manufacturing).
- G3.C.9. Include dynamics in LCA – not just steady state – to lead to real time measurement and control. Address micro and macro level interactions.
- G3.C.10. Identify the key stakeholders in each phase of the system – couple system and stakeholders – include community/society.
- G3.C.11. Find synergistic options and new services (such as product LCA monitoring) that provide economic, environmental and social benefits.
- G3.C.12. Change the way economic models are developed to include all factors related to product performance and provide a measure of true value of goods and services.
- G3.C.13. Develop modeling tools that predict and model consumer behavior to support the innovation/ideation process including the reaction to sustainability practices and the extent to which they will respond e.g. paying more for protecting the environment.
- G3.C.14. Based on clear definitions, establish metrics and measures that ensure validity of sustainability claims and eliminate the practice of "greenwashing" (false claims of environmental benefit).
- G3.C.15. Integrate the components of sustainability – social, economic, and environmental – into a discipline that can be supported by practices, technologies, and tools.
- G3.C.16. Better data collection and analysis and better definition of the data requirements for sustainability analysis
- G3.C.17. Characterize feedstocks and related processes to define the attributes and boundaries of uncertainty and the impact of those attributes on process performance and product delivery/quality
- G3.C.18. Establish mechanisms for create, capture and manage data related to the full span of the conversion of raw material to product enabling the optimization and control of those processes
- G3.C.19. Systematize the sustainability challenge: Develop a maturity model that quantifies the achievement of sustainable manufacturing. Develop a compendium of methodologies, practices, and tools to support achievement of the goals of the maturity model.

3.4 Priority Goals for Process and Systems Management

The goals were then refined and prioritized to reflect the most compelling needed capabilities. They are listed in order of priority.

Goal Statement	No. of Votes
1) G3.C.1 Develop consensus across disciplines as to a working definition of sustainable manufacturing in tangible, well defined terms that have a common utility.	17
2) G3.4.2 Standardize and make LCA easier (and faster) to apply and interpret so that the results can be better incorporated into design.	15
3) G3.C.5, 6 Develop an ability to characterize manufacturing processes that includes the quantification of system boundaries and externalities. Develop tools that include all relevant factors in supporting manufacturing process development.	13
4) G3.C.19 Systematize the sustainability challenge: Develop a maturity model that quantifies the achievement of sustainable manufacturing. Develop a compendium of methodologies, practices, and tools to support achievement of the goals of the maturity model.	9
5) G3.2.4 Bridge the scales of modeling from models based in first principles to continuum models.	7
6) G3.C.16 Better data collection and analysis and better definition of the data requirements for sustainability analysis.	7
7) G3.1.4 Develop sustainability performance standards, not just design standards.	5
8) G3.3.6 Include social and political implication of sourcing material and energy supplies and consumption.	5
9) G3.C.8, 10 Quantify the scope of sustainable manufacturing related to systems and sectors. Identify the key stakeholders for each system/sector, including societal representation.	5
10) G3.C.13 Develop modeling tools that predict and model consumer behavior to support the innovation/ideation process including the reaction to sustainability practices and the extent to which they will respond e.g. paying more for protecting the environment.	5
11) G3.1.1 Infuse sustainability factors into plant design and automation.	4
12) G3.3.3 Integrate eco-system (industrial symbiosis) opportunities in materials and energy management.	4
13) G3.1.2 Develop design capability for control in sustainable design and operation – including stochastic control (uncertainty). This means that sustainability factors are captured in the monitor, analyze and control methodologies and toolsets.	3

14)	G3.4.6 Include end of life issues such as product reuse, remanufacture and redesign into the product design process.	3
15)	G3.4.4 Extend present LCA toolsets to include uncertainties and explore the alternative results from various boundary selections.	2
16)	G3.C.11 Find synergistic options and new services (such as product LCA monitoring) that give economic, environmental and social benefits.	2
17)	G3.3.5 Extend energy and material balances to the manufacturing realm for existing manufacturing processes and transformational new processes.	1

4 ENTERPRISE MANAGEMENT

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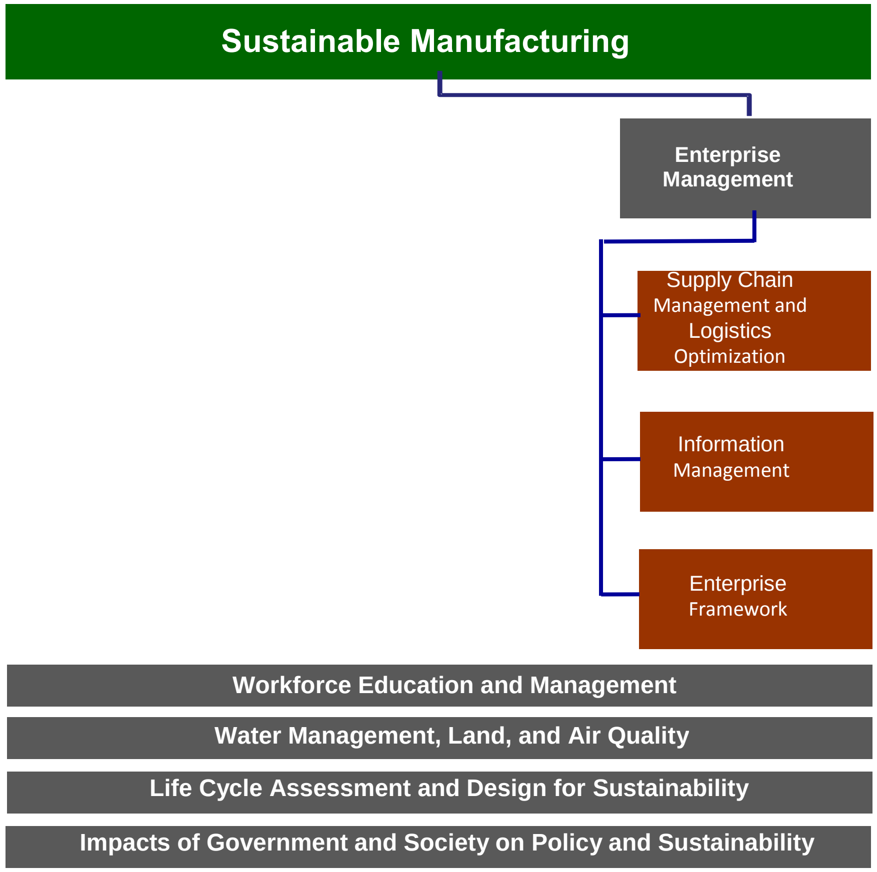

Figure 4-1: The functional model for Process and Systems Management in support of Sustainable Manufacturing

Pillar 3 - Enterprise Management includes all activities[1] associated with assuring that the enterprise operates in a sustainable manner, including the allocation and management of resources to ensure environmental responsibility and energy efficiency.

- **Supply Chain Design & Management and Logistics Optimization.** Embraces emerging modeling and simulation tools to enhance the understanding of the operation of the supply chain, identifies opportunities for improvement, and supports the evaluation of alternatives. Logistics Optimization addresses all activities associated with the considerations of sustainable manufacturing practices in planning and controlling the flow and storage of goods, services, and related information between the point of origin and the point of consumption and possible recovery in order to meet customer's requirements. This element includes not just analysis toolsets, but also the use of data, information, and knowledge to support best decisions.

[1] The Enterprise Management group believes that crosscutting enabler related to water and energy should include energy management and that a new crosscut should be added to address the impacts of government and society on policy and sustainability. The work recorded in this section reflects these modifications, but, since the work that was done by the workshop groups was done in parallel, this feature is unique to this group. The test of the functional model is not whether it is "definitive", but whether it provides a useful and adequate structure for capturing the needed information. All of the groups found this test of adequacy to be fulfilled.

- **Information Management.** Supports the provision of the right information, promptly and cost-effectively, with assurance of information accuracy and security. Supports the use of unified datasets and compatible models in interoperable systems shared across the supply network over the full product life cycle. Includes ability to incorporate social and cultural metrics as well as technical/financial information in support of business decisions.
- **Enterprise Framework.** Embraces the notion that the enterprise framework and decision processes for a sustainable manufacturing enterprise must be resilient to respond to changes and improved understanding of products and processes plus environmental and societal issues. It must consider not only environmental impacts of its operation and downstream product use, but must realize that every decision it makes must be a good business decision that will have a positive sustainability impact.

4.1 Vision for Enterprise Management

V4.1 Vision for Supply Chain Design & Management and Logistics Optimization

- Planning and scheduling operations automatically include sustainability considerations (e.g. emission/waste reduction and other externalities) for optimized operation of the supply chain.
- Transportation systems are optimized to minimize emissions and achieve optimized energy efficiency.
- Uncertainties are handled efficiently; they will always exist but are better modeled and understood, resulting in greatly reduced forecast error rates. Risk is confidently quantified for robust operation of the supply chain.
- Supply chain disruptions are modeled, enabling resilient operation of the supply chain in the event of an actual disruption.
- Energy efficiency and environmental impacts are modeled and the linkages are established to enable balancing and optimization of the total value equation.
- Production planning and product distribution are coordinated to ensure a match across the enterprise.
- Life-Cycle analysis and cataloging of all by-products (sources) enables many instances of closed-loop operations among single and multiple manufacturing entities.
- Near-zero inventory and fast response to market changes are realized with improved and integrated supply chain practices and comprehensive communication capabilities.
- The flow of material through the supply chain is perfectly matched between the supply side and the demand side - minimizing wastes. Full detail on material characterization and possible material variability enables more effective sustainability decisions.
- Supply chain models interoperate to allow integrated optimization from extraction of raw material to delivery of all resulting products or services.

- Routine use of reverse supply chain operations (e.g. product recovery, recycling, remanufacturing) optimizes the sustainability of many manufacturing industry sectors.
- When new products are proposed, the impact on existing and emerging supply chains and customer bases is well understood (technically and with respect to externalities), enabling a more sustainable and profitable manufacturing environment. (Example: corn as food vs. fuels).
- Manufacturing business decisions around a product are based on analysis over the entire life-cycle network (supply, production, customer use, recovery).
- Robust and scalable technologies enable match of feedstock availability to continuous or fluctuating product demands enabling leveled operations across seasons and locations.
- A comprehensive set of clear and meaningful metrics for evaluating sustainability is available across the supply chain network and understood by the consuming public.

V4.2 Vision for Information Management

- Information is transparent throughout the supply and manufacturing network. Effective systems boundaries within the supply chain protect proprietary information while sharing sustainability and appropriate productivity information in effectively real time.
- Comprehensive sustainability measures for a product are based on aggregated information communicated throughout the supply chain.
- Big data and data analytics enable convenient but secure multi-level access to all needed information and data to support supply chain decision-making, government regulatory reporting, and communication with shareholders and the public.
- Models and data connect the consumer to the realization process for the product, enabling production of exactly what product or service is needed with optimal sustainability.
- Data and information that is needed for decision support is available, accurate, timely, and accessible in useful formats.
- Statistical models, methods, and software extract knowledge from data sets, information files, crowd and cloud sourcing and other forms of big data. In this way, systems create and capture the knowledge and wisdom to support sustainable business decisions.
- The data architecture, data management and physical data storage mechanisms are planned and implemented to allow long-term availability for future needs or reporting requirements.
- The quality of information collected via economic input–output life-cycle assessment (EIO LCA) for various manufacturing sectors is sufficient to enable accurate and effective evaluation of the environmental impact of new products or proposed production/resource changes.

V4.3 Vision for Enterprise Framework Sustainability

- Sustainability is an important component of manufacturing business decision making. It takes its rightful place along with technological and financial issues, risk assessment and other factors.
- The enterprise framework and business model for a sustainable manufacturing enterprise are resilient to respond continually to changes and improved understanding of not just technology but also environmental and societal issues.
- The enterprise business model and decision processes support manufacturing sustainability analysis and what-if modeling over long-term time scales of many decades.
- The manufacturing business and its surrounding community have aligned objectives and they flourish within ecological constraints, all going well into the sustainable future.
- The manufacturing enterprise and its supply network have a common understanding of risk and are cooperating to mitigate that risk.
- Based on deep understanding of externalities and sustainability requirements in the enterprise framework, future resource shortages can be foreseen and ameliorated in advance, for example by product redesign or by developing recovery/reuse of materials.
- The urge toward sustainability and dematerialization drives many manufacturing enterprises toward radically different production processes, and the promotion of different products to serve functions formerly served by much more resource-expensive creations.

V4.4.1 Vision for Workforce Education and Management

- The workforce is prepared for the jobs that they are pursuing, with full competence in sustainable engineering as well as traditional manufacturing skills.
- Workers increasingly pursue broad, multidisciplinary knowledge beyond engineering to ensure readiness for the different jobs that emerge with technology developments.
- Continuing education and public awareness programs maintain a technology-literate workforce and public with an understanding of and motivation for sustainable living. This includes both the current and emerging workforce and public.
- Sustainable manufacturing practices allow growth of a middle class of workers and increased social equality.

V4.4.2 Vision for Water and Energy Management and Air Quality

- The costs and impacts of societal externalities are routinely included in overall production costs (holistic costing).
- Sustainable manufacturing practices result in optimal water and energy use and minimum chemical, biological and thermal pollution of the water or air.
- There are no contaminants emitted to the air.

- The by-products or wastes from manufacturing processes are matched with other manufacturing entities that can use those wastes as resources, creating closed-loop manufacturing communities. (Waste-to-wealth through byproduct synergies)

V4.4.3 Vision for Life-Cycle Assessment and Design for Sustainability

- The design of every product/service and process reflects a complete Life-Cycle Assessment of sustainability and other business/technological factors.
- Widely and publicly available databases support Life-Cycle Assessment for all major manufacturing sectors.
- Standard and accepted metrics are available to support sustainability assessment and support concrete conclusions/actions from those assessments.
- A frequent update process modifies the framework of ecological and sustainability constraints based on the growing understanding of environmental factors.

V4.4.4 Vision for Impacts of Government and Society on Policy & Sustainability

- Government incentives and subsidies to various manufacturing sectors are strongly influenced by a full Life-Cycle Assessment of the impact on the entire manufacturing sector (e.g. energy from corn) and other sectors that might also be impacted (e.g. food).
- Federal and state governments support development of several competing technologies in critical manufacturing sectors (e.g. energy, healthcare, food) to the commercialization stage, in order to ensure a robust slate of possibilities and resilience to changing circumstances and externalities (local to global).
- Growing focus on sustainability provides new types of jobs for the workforce, plus it improves the environment for the benefit of all.
- Growing awareness and understanding by the public of environmental and other sustainability issues creates improved acceptance of required changes and enables the inclusion of externalities in pricing and decision making.

4.2 Barriers and Challenges for Enterprise Management

The vision for enterprise management is certainly forward looking, and there are many capabilities that must be provided to achieve that ideal state. Also, there are many realities that must be acknowledged and addressed in improving the state of manufacturing sustainability. We group all of these hindrances and deficiencies under the heading of "barriers and challenges". The following tables tabulate those barriers and challenges against the topics of the functional model.

B4.1 Barriers for Supply Chain Design and Management and Logistics Optimization

The vision of fully modeling, monitoring, and controlling the supply chain for total optimization, which includes sustainability, is the context. The operative questions include:

- What prevents us from completely modeling and optimizing the supply chain?

- Why can we not quantify risks and uncertainties in our models to the point that disruptions are predictable and more manageable?
- What keeps us from modeling production attributes, including energy and waste management, for total optimization?

These and other questions give rise to the following barriers and challenges:

Category	Barriers and Challenges
Models	• Better optimization models for supply chain design and management are required: • Integrating multiple play functions • Account for uncertainty • Account for sustainability constraints and metrics. • Lack of accounting framework for calculation of cross-company economic benefits • Portfolio management tools do not include sustainability/externalities (all financial based) – add sustainability in traditional financial accounting (financial vs. sustainability). • Supply Chain approaches and models are not presently capable of determining optimal decisions for closed-loop temporal and spatial scales.
Algorithms	• Better optimization algorithms are required to solve large, more complex problems for supply chain design and management.
Conflicting Priorities	• Deficiencies exist in the ability to manage conflicting priorities in cost, service, sustainability, externalities, etc. • "Me" thinking needs to be eliminated in deference to a broader business community perspective. • Effective policy/incentives are required to promote sustainability practice across the supply chain. • The artificially low cost of traditional energy sources in internal rate of return (IRR) analysis of sustainability issues leads to conclusions/actions that are not supportable long term. • Need to understand uncertainties well enough to do risk assessments of them.
Technology Understanding	• Technology is needed to enable the reduction and optimum management of water consumption in the supply chain. • Technology is not affordable or sometimes available to make future decision. • Insufficient knowledge about implications of using different methods/materials/technologies

B4.2 Barriers for Information Management

The vision for information management embraces a ubiquitous view that all needed information, is provided to those and only those who need it, at the right time, in the right place, and in a useful format. This vision includes the satisfaction of all information requirements related to sustainable manufacturing. Questions from which barriers and challenges are derived include:

- Why can we not provide exactly the information that is needed, in exactly the right format, at exactly the right time, and interoperable with all systems?
- Why can we not provide total transparency across the supply chain?
- Why can we not capture the knowledge and rules that are needed to make and quantify the best decisions?

Category	Barriers and Challenges
Data access and quality	• A data gap exists within and between supply chain partners. • Too much needed data is either unavailable or inaccessible. • The lack of communication concerning what data are needed, and at what level, is deficient, undermining the ability to manage the enterprise • The uncertainty level of data greatly impacts the results. This uncertainty factor is usually unknown and often not considered. • The state and quality of the data is usually not known - including accuracy and currency. • The advent of Big Data presents challenges in maintenance, validation, and use.
Data Sharing - Trust	• Sharing data and information across the supply chain is a difficult and sometimes impossible challenge. • There is not enough transparency for all relevant elements and entities in the supply chain. • The confidence levels and levels of security are not in place to support sharing critical information with business partners, while assuring the protection of proprietary information, including trade secrets. • Difficulty of integrating systems and data among external partners • Different business partners are unwilling to share or trust each other; a barrier to collaboration. • There are legal/legislative barriers to data sharing of some important information across companies (ITAR restrictions and health records are examples). • The need for sharing confidential business information in a secure environment and the lack of systems to support secure sharing
Data Sharing - Architecture	• There is a challenge in integrating data and systems with external partners, and with changing sets of partners. • There is no common data model to align around to share/use information.

Category	Barriers and Challenges
	• Information systems do not interoperate easily or sometimes at all. • Lack of design tools, mainly software tools, that facilitate information sharing • There are multiple standards efforts that are not always well integrated e.g. in Europe.
Better Tools	• LCA tools are too complicated and controversial; tools need to be universally agreed and not always debated. • Software systems are too expensive, slow to produce, and incompatible. • Design tools, mainly software tools, do not adequately facilitate information sharing. Whether the design tools themselves facilitate sharing or plug into an infrastructure for this function (enterprise hub), the function needs to be satisfied.

B4.3 Barriers for Enterprise Framework sustainability

This topic area addresses the use of models and decision processes to ensure that the enterprise is sustainable, specifically from the standpoint of energy and environmental issues. However, the barriers and challenges addressed also recognize the critical role of models in assuring a sustained and economically viable business enterprise. Some questions for consideration include:

- Why do our business models and decisions fail to respond effectively to changing environmental and societal pressures?
- Why are environmental and social impacts of business decisions treated only in an ad hoc manner?

Category	Barriers and Challenges
Business Models	• Processes are not understood well enough to effectively model, or by the time we get the model the process has changed! The timing of all aspects of the product/process development cycle is challenging. Timing the technology maturation and deployment cycle is critical. • Changing and uncertain markets and the willingness to pay for environmental features is a variable that is difficult to understand. Regional differences also add to the uncertainty and challenge. • Economic models are incapable and incompatible for performing very long term evaluation. • Inadequate understanding of complex systems: economic, social and ecological
Externalities	• Conflicting priorities and costs of service, sustainability etc. • Lack of accurate data to support the full assessment of costs • The cost of environmental responsibility is not properly evaluated and

Category	Barriers and Challenges
	"priced" to ensure protection. • Difficulty in quantifying social/societal implications • Public acceptance of environmental degradation, e.g. climate change • Inadequate understanding complex systems: economic, social and ecological

B4.4 Cross Cutting Topics

There are four crosscutting topics Related to Enterprise Management that are important for all three of the elements of the functional model. The questions addressed in populating the table include:

- What are the barriers to an educated workforce across all levels?
- What barriers and challenges must be addressed to achieve water, energy and air quality goals?
- What prevents us from being able to effectively conduct life-cycle analysis and design for sustainability? What prevents its use across industry?
- What government/regulatory/policy issues inhibit success in realizing the vision for sustainable manufacturing?

Category	Barriers and Challenges
Workforce Education and Management	• Lack of the proper education needed for current and future jobs, and lack of motivation to pursue more education. • The challenge of providing continuing education programs for workers, operators, technological engineers • Increased workforce challenges with increased technology/environmental components to the jobs. • Continuing increased gaps in society based on different education/technology capabilities
Water & Energy Management and Air Quality	• Lack of effective coordination of industrial and residential use of energy resources • Re-inventing technologies • Lack of communication of pre-competitive technologies, e.g. water recycle
Life-Cycle Assessment and Design for Sustainability	• Complexity of the concepts of sustainability and a lack of a shared, clear, comprehensive definition for sustainability • Lack of agreed definitions on ecological constraints for LCA • Lack of standard metrics and units of measurement for sustainability and life-cycle assessment; may be impossible to define standard metrics due to the nature of the problem

Category	Barriers and Challenges
	• Current data sets are inadequate for calculation of environmental metrics, especially as a function of geography. • There are no clear social metrics relevant for product supply chains. • Many possible environmental metrics exist; how do we select and use the most relevant for a given supply chain? The most relevant might not be the easiest ones to use. • There is a lack of data on which to base LCA.
Impacts of Government and Society on Policy/ Sustainability	• Continuing increased gap in society, as societal/environmental impacts of manufacturing are given little or no consideration • Increased workforce challenges, with insufficient training to fill many emerging jobs, and unemployment or under-employment levels way too high • Subsidies are not based on fair assessment, which tends to stifle development of new technologies and unduly sustain established technologies. • Lack of public acceptance of methods for pricing externalities

4.3 Goals for Enterprise Management

The Vision points to needed capabilities. The Barriers and Challenges define hindrances that must be overcome to achieve the vision. The Goals define those capabilities that move toward the vision and overcome the hindrances.

G4.1 Supply Chain Design and Management and Logistics Operation

G4.1.1 Better models: Provide optimization models that include sustainability considerations/ issues and externalities along with technical/business issues.

- Systems model integration
  - Create tools to combine existing models and data sets for advanced analysis
  - Incorporate initial results from biomass/biofuels projects (Univ. Arizona, UTK, General Mills, Northwestern) – spatial distribution leads to a need for analysis and optimization of sourcing/transportation and supply chains
  - Spatial/temporal dependent inputs and impacts
  - Analyze, generalize and build on initial results of earlier projects
- Develop new frameworks and tools for creating integrated models capable of considering the many issues involved, and which can be used by any specific application or manufacturing sector.
  - Need to be timely and relevant
  - Need to quickly indicate the right direction for the decision (perhaps not highly precise)

- Develop streamlined models for quick decision-making with variable levels of precision and the resilience to respond to changing externalities
- Make models platform-based, instead of problem-based (increase flexibility)
- Use relevant models to help business make speedy decisions (responsiveness)
- Make models less debatable
- What-if analysis – scenario analysis, perhaps with different levels of sensitivity
- Will require significant improvements in computational speeds (algorithms and hardware) to support fast, real-time decision-making
- May use multi-thread analysis.

G4.1.2 Conflicting priorities: Provide a new decision framework to incorporate multiple conflicting (non-financial) objectives in a unified framework, configurable and visible

- Portfolio management tools do not include sustainability/externalities (all financial based) – add sustainability in traditional financial accounting (financial vs. sustainability)
- Flexibility of tools needs to allow variables in multiple objective functions (multiple Pareto optimal solutions on economics vs. greenhouse gas emissions)
- Reduce dimensionality (e.g. Global Warming potential to combine all GHG emissions)
- Educate/encourage consumers to make more sustainable choices in product features and reduce demand for non-sustainable manufacturing
- Implement intelligent agents for use at all levels (supply network to consumers) to help decision-making and remind the users of sustainability issues
- Support collaboration between academia and industry (perhaps industrial consortium) to develop new tools and use them. Example: Aspen Plus started as an academic project.
- Bridge the gap to implementation of sustainability tools. Academic research does not extend to commercial tools that are needed for enterprise management.

G4.2 Information Management

G.4.2.1 Better Data: Information/Data Treatment and Management

- **Ensure that data collected are accurate, relevant, cost-effective, and maintainable.**
- Many types of models need different types of data; e.g. growth of big data, data science, analytics.
- Need to know and communicate what data and levels of granularity are needed–may be scientific data, experimental data, operational equipment readings, etc.
- Data should have clearly associated uncertainty information as well as values

- To assess the accuracy and completeness of dataset, need confidence levels and means of identifying abnormal/suspicious data among data values
- Good data requires on-going maintenance in a cost-effective way
- Need data cleaning capability: redundancy or different ways of getting the answer would be helpful
- Data visualization techniques greatly help detection of trends, outliers in data, etc.
- Need parameter/data ranking and selection capability to identify what data is critical and merits the cost of closer maintenance/collection

G4.2.2 Sharing Data: Ensure full reporting of sustainability data across supply chain

- The issue is Trust. Industry will not and should not share trade secrets, but much other information must be shared.
- Robust sharing mechanisms for operational and business data exist, but do not include sustainability.
- Create standards and platforms for sustainable manufacturing data
- Temporal and spatial data
- Get upstream and downstream business partners to work together and talk to each other to share data, including impacts from raw material inputs.
- 90-95% of sustainability impacts are not in the supply chain. They are owned by the food companies (e.g. upstream water used in crop growth is controlled by farmers but not the industry)
- Need new public agency to gather and publish industrial sustainability data
  - Companies report financial data and some sustainability to government, but that is not communicated up/down through the supply chain
  - There are some cases of vendor managed inventory type for sustainability (e.g. P&G)

G4.2.3 Create standards and platforms (tools and data/information) for a sustainable enterprise

- Define sustainability and its data attributes and data model.
- Develop the standards and information system platform that enable all participants in a supply chain to collaborate, operate and make effective decisions in a sustainable manner.
- Develop security model for sharing need-to-know data across companies.
- Build on pre-existing standards efforts for tools and data collection and unified formats (e.g. European efforts, – ecospold; open LCA to make data publically available).

G4.3 Enterprise Framework Sustainability

G4.3.1 Enterprise Framework Sustainability (understanding and quantifying externalities)

- Design and develop a Change Management Process for a model-based manufacturing enterprise that can sustain and support the business as it evolves and reacts to the changing business, environmental, and social environment.
- Create a Sustainability culture that pervades the behavior and decisions of all levels of manufacturing enterprise and its supply chain
- Sustainability and a long term view/planning perspective has to be included for long-term existence of the business
- Understand and quantify the externalities, and incorporate them and longer-term sustainability issues and impacts into the business model and decisions
- Use analogy to process safety as implementation model (e.g. DuPont) – there are groups on safety but not on sustainability, which is widely discussed across the business
- Maintain and use enterprise framework and business model to adjust/adapt to the changing business environment.
  - *The Stone Age didn't end because lack of stones; rather, better technology became available.*
- There is a parallel to reversibility; a process that can be reversed at any given time. If we use reversible processes throughout the supply chain we end up being more sustainable. E.g., the solution to CO2 issue is to not to make it in first place because you can't convert it back.
- Also need research around connection of thermodynamics – in part this has been done in exergy analysis. (Exergy is the thermodynamic measure of the ability to do work, or the "available energy").

G4.4.3 Life-Cycle Assessment and Design for Sustainability

G4.4.3.1 Effective use of LCA and design for sustainability in business decisions

- Create mechanisms to assess manufacturing business decisions for optimal sustainability using relevant data, metrics and tools.
- Need better understanding and definition of "sustainability" for guiding manufacturing business.
- Survey existing and proposed metrics, data and tools, with emphasis on environmental methods.
- Acknowledge "sustainability" is not a point but a direction that can be optimized and improved
- Develop criteria and evaluation methods to determine the most relevant sustainability metrics for a business for both short and long term. This may involve synthesis of new metrics as combinations of others, to reduce dimensionality.

- Boundary conditions for sustainability.
- Comfort and convenience of the community (and market demand) may drive negative sustainability decisions (e.g., growing popularity of Greek yogurt which is much less sustainable than regular yogurt). Educating the public is important.

4.4 Priority Goals for Enterprise Management

Goal Statement	No.of Votes
1) G3-2 Information Management - Create standards & Platforms (tools/data/information) for a sustainable enterprise.	18
2) G3.3 Business Model Sustainability - Create a Sustainability culture that pervades the behavior and decisions of all levels of manufacturing enterprise and its Supply Chain	16
3) G3.1 Supply Chain Design and Management and Logistics Operation: Conflicting priorities: Provide a new decision framework to incorporate multiple conflicting (non-financial) objectives in a unified framework, configurable and visible	9
4) G3.2 Information Management - Better Data: Ensure that collecting new information and current data is accurate, relevant, and cost-effective (cheap, good data?) require on-going maintenance in a cost-effective way.	8
5) G3.1 Supply Chain Design and Management - Develop Supply Chain models that include sustainability considerations and externalities along with technical & business issues and Logistics Operation]	7
6) G3.2 Information Management - Sharing data: Trust: Reporting Sustainability Data across the supply chain	5
7) G3.4.3 Life-cycle Analysis and Design for Sustainability - LCA and Design for sustainability: Create mechanism to assess current mfg business decisions against available metrics and tools to select optimal for sustainable.	2

Appendix A. Workshop Organizing Committee

- David Allen, University of Texas, Austin, TX
- Bhavik Bakshi, Ohio State University, Columbus, OH
- Cliff Davidson, Syracuse University, Syracuse, NY
- Mario Eden, Auburn University, Auburn, AL
- Thomas Edgar, University of Texas, Austin, TX (Chair)
- Mahmoud El-Halwagi, Texas A&M University, College Station, TX
- David Fasenfest, Wayne State University, Detroit, MI
- Ignacio Grossman, Carnegie Mellon University, Pittsburgh, PA
- Yinlun Huang, Wayne State University, Detroit, MI
- Richard Neal, The Integrated Manufacturing Technology Initiative, Oak Ridge, TN

Appendix B. Workshop Agenda

August 15, 2013

11:00 am	Registration
12:00 pm	Lunch and Welcome
1:00 pm	Welcome and Introductions (Yinlun Huang and Thomas Edgar)
1:20 pm	Instruction for Breakout (Richard Neal)
1:30 pm	Breakout Session 1 • Vision Review • Challenges Definition
3:15 pm	Break
3:30 pm	Breakout Session 1 (cont'd)
5:30 pm	Adjourn

August 16, 2013

8:30 am	Review of Day 1 (Teams)
9:00 am	Breakout Session 2 • Goals • Project Definition
12:00 pm	Lunch in Small Groups
1:00 pm	Complete Project Definition and Prepare Presentation
2:00 pm	Reports and Prioritization
2:45 pm	Next Steps and Path Forward (Yinlun Huang and Thomas Edgar)
3:00 pm	Adjourn

Appendix C. Workshop Participants

The workshop has 53 participants. During the breakout discussion, the participants signed in three different technical groups that are listed below.

Luke Achenie	Virginia Polytechnic Institute and State University, Blacksburg, VA
Fazleena Badurdeen	University of Kentucky, Lexington, KY
Bhavik Bakshi	Ohio State University, Columbus, OH
Wididul Biswas	Curtin University, Bentley, Australia
Jose Bravo	Shell Global Company, Houston, TX
Heriberrto Cabezas	EPA National Risk Assessment Research Laboratory, Cincinnati, OH
Jun-ki Choi	University of Dayton, Dayton, OH
Prodromos Daoutidis	University of Minnesota, Minneapolis, MN
Cliff Davidson	Syracuse University, Syracuse, NY
Bayou Demeke	EPA Office of Research and Development, Cincinnati, OH
Urmila Diwekar	Vishwamitra Research Institute, Clarendon Hills, IL
Russell Dunn	Vanderbilt University, and Polymer and Chemical Technologies, LLC, Nashville, TN
Delcie Durham	University of South Florida, Tampa, FL
Mario Eden	Auburn University, Auburn, AL
Thomas Edgar	University of Texas, Austin, TX
Mahmoud El-Halwagi	Texas A&M University, College Station, TX
Soner Emec	Technische Universität Berlin, Berlin, Germany
Burton English	University of Tennessee, Knoxville, TN
Timothy Gutowski	Massachusetts Institute of Technology, Cambridge, MA
Bruce Hamilton	National Science Foundation, Arlington, VA
Troy Hawkins	EPA National Risk Assessment Research Laboratory, Cincinnati, OH
Rich Helling	The Dow Chemical Company, Midland, MI
Yinlun Huang	Wayne State University, Detroit, MI
Ibrahim Jawahir	University of Kentucky, Lexington, KY
Sara Jordan	The Integrated Manufacturing Technology Initiative, Oak Ridge, TN
Vikas Khanna	University of Pittsburgh, Pittsburgh, PA
Christos Mavavelias	University of Wisconsin, Madison, WI
James McCall	Procter and Gamble, West Chester, OH
Manish Mehta	National Center for Manufacturing Sciences, Ann Arbor, MI
Rajib Mukherjee	EPA National Risk Assessment Research Laboratory, Cincinnati, OH
Charlie Neal	The Integrated Manufacturing Technology Initiative, Oak Ridge, TN

Richard Neal	The Integrated Manufacturing Technology Initiative, Oak Ridge, TN
Kim Ogden	University of Arizona, Tucson, AZ
Doug Pontsler	Owens Corning, Toledo, OH
Mizanur Rahwan	Michigan Technological University, Houghton, MI
Mary Rezac	Kansas State University, Manhattan, KS
Alan Rossiter	Rossiter and Associates, Bellaire, TX
Clayton Sadler	UOP LLC, Des Plaines, IL
Barclay Satterfield	Eastman Chemical Company, Kingsport, TN
Darlene Schuster	AIChE Institute for Sustainability, New York, NY
Jeff Seay	University of Kentucky, Paducah, KY
Dusan Sekulic	University of Kentucky, Lexington, KY
Debalina Sengupta	EPA National Risk Management Research Laboratory, Cincinnati, OH
Jeff Siirola	Purdue University, West Lafayette, IN, and Carnegie Mellon University, Pittsburgh, PA
Subhas Sikar	EPA National Risk Assessment Research Laboratory, Cincinnati, OH
Ray Smith	EPA National Risk Management Research Laboratory, Cincinnati, OH
David N. Thompson	Idaho National Laboratory, Idaho Falls, ID
Graham Thorsteinson	General Mills Inc., Covington, GA
Jorge Vendries	University of Pittsburgh, Pittsburgh, PA
George Walchuk	ExxonMobil Research and Engineering Co., Annandale, NJ
Jim Wetzel	General Mills, Covington, GA
Trevor Zimmerman	Strata-G, Knoxville, TN
Fengqi You	Northwestern University, Evanston, IL

Appendix D. Participants' Biographical Sketches and Position Statements

NSF Officer
Bruce Hamilton
Director, Environmental Sustainability Program
National Science Foundation
4201 Wilson Boulevard
Arlington, Virginia

Biographical Sketch

Bruce Hamilton is a program director at the National Science Foundation (NSF), Arlington, VA. Among various activities at NSF, he is an Engineering Research Center (ERC) program director and a member of the cross-NSF Implementation Group for the Science, Engineering, and Education for Sustainability (SEES) investment area. He also is program director of the Environmental Sustainability program in the Engineering Directorate (ENG), and a managing program director in ENG's Emerging Frontiers in Research and Innovation Office (EFRI). Additionally, he is a program director for the Water Sustainability and Climate solicitation (WSC), the Sustainability Research Networks (SRN) solicitation, the Research Coordination Networks - SEES (RCN-SEES) and SEES Fellows activities, the CyberSEES solicitation, the Cyber Physical Systems solicitation, and the joint DHS/NSF Academic Research Initiative on Domestic Nuclear Detection (ARI). In 2012, he received the NSF Director's Award for Meritorious Service in the area of sustainability. Before joining NSF 16 years ago, Bruce held R&D management positions in the chemical and biotechnology industries for 20 years. He has a B.S. in Chemical Engineering and a Ph.D. in Biochemical Engineering, both from MIT.

Position statement

Bruce is the program manager for the NSF grant that supports the RCN-SEES project on Sustainable Manufacturing Advances in Research and Technology (SMART) Coordination Network for which Yinlun Huang (Wayne State University) is Principal Investigator (PI). Bruce is also program manager for the NSF grant (PI is Tom Edgar, CACHE Corp. and UT-Austin) that helps to support the Smart Manufacturing Leadership Coalition (SMLC). As part of SMLC membership, Bruce serves on SMLC's Working Group on Workforce Development and Education.

WORKSHOP ATTENDEES

Luke E. K. Achenie
Professor, Department of Chemical Engineering
Virginia Polytechnic Institute and State University
Randolph Hall 133, Blacksburg, Virginia 24061

Biographical Sketch

Dr. Luke E.K. Achenie is a Professor of Chemical Engineering at Virginia Polytechnic and State University. Dr. Achenie is a member of several major professional societies and has served on several federal pier-review panels. He served as the Program Director of the Reaction and Engineering Program within the NSF Division of the National Science Foundation in the 2012 calendar year.

Dr. Achenie's work is in several different interdisciplinary fields including process design, molecular modeling, multi-scale modeling, bioinformatics and uncertainty analysis. He is a pioneer in molecular design, a subset of computer aided product design. This is an advanced simulation model that addresses the systematic design of chemical compounds with desired physical and chemical properties, with the goal of producing computer based "designer" compounds. Molecular design is a valuable tool used to aid bench chemists in narrowing down the range of compounds to synthesize for particular applications. Dr. Achenie has also worked to develop new formulations for flexibility analysis that takes into account accuracy of uncertain parameters in physical models. This theory has been applied to the analysis of the direct methanol Proton Exchange Membrane (PEM) fuel cell, an area that has attracted a lot of research interest over the last decade for its use in portable electronics, as well as in stationary and mobile power generators and electric vehicles.

His current research effort is in molecular dynamics (MD) modeling, computational modeling of fast pyrolysis of biomass and systems biology. In systems biology he has collaborative efforts in (1) modeling of oral drug delivery, (2) modeling of drug transport across the blood-brain-barrier, and (3) machine learning algorithms for early diagnosis of autism in little children.

Dr. Achenie is honored by:

- Induction into Connecticut Academy of Engineering (2007)
- Board Member, Scientific Journals International (SJI) (2008 to present)
- Board Member, AIChE Board of Trustees (2009 to present)
- AIChE Award for Excellence & Service as Minority Affairs Committee Chair (2004)
- The Rogers Outstanding Teaching Award (1992, 1997).

Position Statement

Energy sustainability, resource sustainability and environmental sustainability are all top concepts in the area of sustainability. Politicians, policy makers, thought leaders, educators/researchers and all world citizens have either bought into the concepts or will in the foreseeable future. Increasingly computational modeling and scientific computing will play an integral part in sustainability research and products.

Dr. Achenie is employing molecular dynamics for the simulation of organic/inorganic membranes and their role in the separation of gas blends ($CO_2/CH_4/H_2$), which are products/byproducts of pyrolysis and shale gas processing. Membrane separation is a low energy process; pyrolysis of biomass leads to "green" bio-oil and fracking (shale gas) provides a path to energy independence. Thus all these have implications in green and/or sustainable energy. We have modeled the gas permeation process within four hybrid inorganic-organic membranes at the micro level using molecular dynamics (MD) and at the mesoscale level using a diffusion mechanism. The predicted permeances and relative selectivity of CO_2 and CH_4 compared very favorably with the experimental data from our collaborator's lab. In the MD simulation a single-pore silica crystal framework model with and without inserted phenyl groups were used to define two membrane structures. To mimic the diffusion of gas across the membrane, a three-region system with a repulsive wall potential on the edge is employed.

We have also studied kinetic modeling of fast pyrolysis under uncertainty induced by (a) incomplete characterization of reacting and product species, (b) incomplete characterization of reactions paths and (c) incomplete knowledge of or varied composition of lignin, cellulose, hemicellulose and other fractions within woody biomass. Here we have used fuzzy-logic modeling and stochastic modeling.

In closing here is food for thought. The Human Genome Project is allowing among other things faster discovery of therapeutic interventions. Likewise the Materials Genome Project is expected to accelerate materials discovery. Is a Sustainability Genome Project far behind?

Bhavik R. Bakshi, Professor
Lowrie Department of Chemical and Biomolecular Engineering
The Ohio State University
Columbus, OH 43210

Biographical Sketch

Bhavik R. Bakshi is a Professor of Chemical and Biomolecular Engineering and Research Director of the Center for Resilience at The Ohio State University. His research is developing scientifically rigorous methods for understanding and enhancing the sustainability of human activities. This includes new methods for analyzing the life cycle of existing and emerging technologies, and developing integrated models of industrial, ecological and economic systems for designing engineered systems and supporting policies. A major focus of his research is on understanding the role of ecosystem services in supporting industrial activities, and on designing integrated networks of technological and ecological systems. 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 in both, developed and emerging economies. He has published extensively and is on the editorial boards of various academic journals. In addition to university courses, Prof. Bakshi offers short courses to practicing professionals on various aspects of sustainability. His work has been recognized through awards from the American Institute of Chemical Engineers, the U.S. National Science Foundation, and several best paper awards at various conferences. Prof. Bakshi received his Bachelor of Chemical Engineering degree from the University of Bombay, MS in Chemical Engineering Practice and Ph.D. in Chemical Engineering from the Massachusetts Institute of Technology. While in graduate school, he also completed a minor in Technology and Environmental Policy and conducted research at Harvard's Kennedy School of Government.

Position Statement

Two major shortcomings of existing methods for sustainable engineering are, (1) their focus on enhancing eco-efficiency, and (2) their ignorance of ecosystem goods and services. Approaches for enhancing eco-efficiency include life cycle assessment and design. These methods tend to encourage continuous improvement by reducing various footprint and life cycle measures. While this may enhance sustainability, it also encourages or prolongs the use of inherently unsustainable systems, as opposed to encouraging breakthrough innovation that is inherently sustainable. This focus on doing "less bad" is not good enough for sustainable development. The ignorance of ecosystem goods and services means that the very foundation of human well-being is ignored by existing methods. Examples of ecosystem goods include water, food, genetic resources and biomass, and services include biogeochemical cycles, pollination, and maintaining soil fertility. Ignoring them can result in perverse decisions that increase reliance on degraded ecosystems. My group's research is motivated by the need to overcome these shortcomings, and has resulted in the approach of Ecologically-Based Life Cycle Assessment (Eco-LCA) that accounts for the role of a large number of ecosystem goods and services. Thermodynamic methods based on the concept of exergy have been used to define metrics that include ecosystem services. A model of the U.S. economy based on this approach is available at http://resilience.osu.edu/ecolca/. This approach quantifies the demand for ecosystem services generated by various economic activities. However, it does not consider the availability or supply of these services. To overcome this shortcoming, we are developing methods for the analysis and design of synergies between networks of technological and ecological systems. This techno-ecological synergy analysis or Eco-Synergy analysis approach quantifies the available ecosystem services in a selected region by using models for ecosystems such as forests, soil, and wetlands. The supply and demand of ecosystem services is compared at multiple spatial scales. If the demand for an ecosystem service at the selected scale is smaller than the supply then the system may be considered to be sustainable for that service at the selected scale. Eco-Synergy design encourages the development of technological systems that operate within local ecological constraints, and benefit from the ability of ecosystems to provide needed goods and services in a manner that is often economically and environmentally superior than systems designed without including ecosystems.

Beth Beloff
Principal, Beth Beloff & Associates
President, BRIDGES to Sustainability Institute
Santa Fe, NM

Biographical Sketch

Beth Beloff has been a thought leader in formulating the concepts and practice of sustainable development since the early 1990s. She consults through Beth Beloff & Associates on how to integrate sustainability into strategy, operations and supply chains, and develops new approaches and methodologies through the 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 of 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 Global Environmental Management Initiative (GEMI) organization. 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 InterScience 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.

Ms. Beloff has a B.A. in Psychology from University of California at Berkeley, a Master of Architecture degree from UCLA, and an MBA from the University of Houston.

Position Statement

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.

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Biographical Sketch

Heriberto Cabezas is the Senior Science Advisor to the Sustainable Technology Division in the U.S. EPA's Office of Research and Development. He is responsible for the scientific oversight of the various research teams under the guidance of the division director. He is also a former Acting Director (2008-2010) of the Division which consists of approximately 55 scientists, engineers, and support staff – some forty of the staff at the doctoral level. He also organized and led as Chief (2000-2008) the Sustainable Environments Branch, a multidisciplinary research group of some seventeen scientists and engineers - thirteen at the doctoral level. Dr. Cabezas has served as Chair of the Environmental Division of the American Institute of Chemical Engineers (AIChE) for 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, the 2011 Research Excellence Award in Sustainable Engineering by the American institute of Chemical Engineers (AIChE), the ORD Sustainability Award (team) at the EPA's Office of Research and Development, and has been selected for the 2013 Lawrence K. Cecil Award in Environmental Chemical Engineering given by the AIChE. Dr. Cabezas received his Ph.D. in chemical engineering from the University of Florida in 1985 in thermodynamics and statistical mechanics. He holds a M.S. from the University of Florida (1981) and a B.S. (magna cum laude) from the New Jersey Institute of Technology (1980), all in chemical engineering. His publications include over sixty peer-reviewed articles. His published areas of expertise include: (1) complex fluid property theory and experiment[1,2], (2) purification of biological molecules including aqueous two-phase extraction and chromatography[3], (3) computer-aided chemical process design for the environment , (4) computer aided solvent replacement design for the environment[4], (5) sustainability metrics for managing regions for sustainability[6,7], and (6) the design of sustainable supply chains[8]. He is a Fellow of the American Institute of Chemical Engineers, a member of the American Association for the Advancement of Science, and a Board Certified Member of the American Academy of Environmental Engineers and Scientists. Dr. Cabezas is a decorated U.S. Navy veteran of the Vietnam Conflict.

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Jun-Ki Choi
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Biographical Sketch

Dr. Jun-Ki Choi is an Assistant Professor in the Department of Mechanical and Aerospace Engineering at the University of Dayton. He is working as an Assistant Director in the University of Dayton’s Industrial Assessment Center funded by the U.S. Department of Energy. Before he joined University of Dayton, he was a scientific staff at the Brookhaven National Laboratory and performed projects with U.S. DoE and global renewable energy industries for four years. He serves as a member of International Energy Agency (IEA)’s Technical Committee for Task 12. Before joining BNL, Dr. Choi worked as a post-doctoral researcher in the Center for Resilience at the Ohio State University where he worked on some NSF’s projects. Dr. Choi received his master’s, and Ph.D. degrees from Mechanical Engineering at the University of Michigan and Purdue University respectively.

Position Statement

Successful development of a sustainable engineering system design requires the consideration of its complex interaction with other systems (i.e. ecosystem, economic system, and human). New energy standards such as ISO 50001 require industries to commit to the efficient energy use on their production processes and supply chain management while meeting their emission abatement goals. In addition, different energy policies such as market-based carbon mitigation instruments, subsidies, and renewable portfolio standards (RPS) affect the supply and demand of energy commodities both directly and indirectly. Dynamic changes of the energy prices and the limited availability of resources have direct impact on the economics of any industrial production process which uses energy and various materials as an input. Both policy makers and industrial managers/designers need to understand the life cycle economic and environmental profiles of the engineering systems in order to prepare effective energy policies and strategic corporate management decisions respectively. Dr. Choi has been working on developing methodologies on interfacing engineering decisions with the broader implication of economic and environmental externalities through multi-scale modeling framework. His area of interest includes but not limited to Sustainable Product Design and Manufacturing, Industrial Energy Efficiency, Life Cycle Assessment, Photovoltaic, Recycling Infrastructure Planning, Policy Analysis with macroeconomic tools such as Input-Output Analysis and MARKAL.

Prodromos Daoutidis
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Biographical sketch

Prodromos Daoutidis is Professor in the Department of Chemical Engineering and Materials Science at the University of Minnesota. He received a Diploma degree in Chemical Engineering (1987) from the Aristotle University of Thessaloniki, M.S.E. degrees in Chemical Engineering (1988) and Electrical Engineering: Systems (1991) from the University of Michigan, and a Ph.D. degree in Chemical Engineering (1991) from the University of Michigan. He has been on the faculty at Minnesota since 1992, having served as Director of Graduate Studies in Chemical Engineering (1998-2004) and Chair of the Physical Sciences Policy and Review Council (2000-03), while he also held a position as Professor at the Aristotle University of Thessaloniki (2004-06). He has received several awards and recognitions, including the NSF CAREER Award, the PSE Model Based Innovation Prize, the Ted Peterson Award of CAST, the George Taylor Career Development Award, the McKnight Land Grant Professorship, the Ray D. Johnson / Mayon Plastics Professorship and the Shell Chair at the University of Minnesota. He has also been a Humphrey Institute Policy Fellow. He has served as Program Coordinator in Areas 10B and 10D of the CAST Division of AIChE, and AIChE Director and Alternate Director in AACC. He was the co-chair of CPC-VIII. He has co-authored 4 books and over 190 refereed papers, and has supervised 30 graduate students and post-docs. His recent research activities are in the control of tightly integrated process networks, the control of energy systems, the power management of microgrids, and the systems engineering of biorefinery processes.

Position statement

Energy efficiency and sustainability are major factors towards mitigating the depletion of fossil fuel reserves and the environmental impact of their consumption. Tight integration is a key enabler towards achieving these goals, both in existing chemical plants, but also in emerging technologies for power generation and for production of fuels and chemicals from renewable resources.

Research in the Daoutidis group has studied the impact of integration on the dynamics and control of process plants. It has established that tight integration, achieved through large material and / or energy recycle, leads to multi-time-scale dynamics, with individual units evolving in a fast time scale and the entire plant over a slower one. It has developed a model reduction method to obtain low-order nonlinear models of the dynamics in the different time scales, and a hierarchical control framework which enables nonlinear model-based supervisory control strategies for effective plant transitions. Applications include reaction-separation networks, reactor – heat exchanger networks, heat integrated and thermally coupled distillation columns, and hybrid power production systems.

His research has also focused on the emerging concept of biorefinery, which aims at the production of fuels and chemicals from renewable resources (biomass). Although considerable emphasis has been given to the "upstream" conversion of biomass to intermediate platforms (sugars or syngas), progress in "downstream" conversion to chemicals and intermediates is still lagging. Due to the oxygen present in biomass and the diversity of raw materials derived from biomass, the necessary downstream reaction and separation processes are different from existing ones based on fossil fuels. Furthermore, there is limited data available on physical properties of such molecules, and on their full array of chemical transformations, and their kinetics and thermodynamics. These challenges lead to several emerging opportunities for systems research that can have a major impact on the realization of the ambitious concept of an integrated biorefinery. Daoutidis' research has addressed: i) the automated generation and thermochemical analysis of the reaction pathways involved in biomass conversion, ii) the design and optimization of novel reaction-separation processes for biomass-based chemical synthesis, and iii) the optimal supply chain and product design of biofuels.

Cliff I. Davidson
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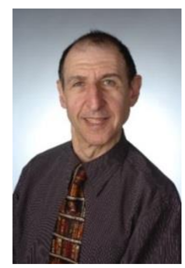

Biographical Sketch

Dr. Cliff Davidson is the Thomas and Colleen Wilmot Professor at Syracuse University in Syracuse, NY. He currently holds appointments in the Civil & Environmental Engineering Department and at the Syracuse Center of Excellence in Environmental & Energy Systems. He is the founding Director of the Center for Sustainable Engineering. Davidson received his BS in Electrical Engineering (1972) from Carnegie Mellon University and his MS (1973) and PhD (1977) in Environmental Engineering Science from the California Institute of Technology. He was on the faculty at Carnegie Mellon in the Departments of Civil & Environmental Engineering and Engineering & Public Policy for 33 years before coming to Syracuse University in 2010. His research interests span a variety of topics in air quality, water resources, sustainable development, and engineering education. He served as President of the American Association for Aerosol Research and is active in several professional organizations. He has organized two major international conferences on aerosol science and engineering, and has conducted more than a dozen workshops for professors on introducing sustainability concepts into engineering courses and curricula. He has written/edited several books and over 100 journal papers. He has led environmental monitoring campaigns in the Himalaya Mountains of Nepal, the Greenland Ice Sheet, and U.S. National Parks, as well as in rural and urban areas within the U.S. Dr. Davidson is a Fellow of the American Association for Aerosol Research. He received the Jubilee Chair Professorship from Chalmers University in Gothenburg, Sweden in 1997, the Outstanding Educator Award from the Association of Environmental Engineering and Science Professors in

2007, the Outstanding Paper Award from Emerald Publishing Group in 2009, and the William and Frances Ryan Award for Meritorious Teaching from Carnegie Mellon University in 2009.

Position Statement

The world is at a crossroads: more than seven billion people inhabit the planet, using huge amounts of natural resources and producing huge amounts of waste. Despite widespread understanding that this is likely to cause hardship for future generations, no country has been successful in enacting laws that move its population sufficiently rapidly toward a sustainable civilization. This is true both in developed countries where per capita resource consumption is highest and in the developing world where the environmental impact of each person is much less. One way to make progress in solving these difficult problems is for engineers to design implements of civilization following principles of sustainability, using less energy and materials while at the same time producing less wastes. This requires educating engineering students about the new constraints of sustainable engineering design and production. To help accomplish this task, Davidson and his group have been developing educational materials and conducting workshops for professors teaching engineering courses around the country. Related to this effort, Davidson is leading a project to fully instrument a large green roof (1.5 acres) where data on temperatures, soil moisture, water flows, and evapotranspiration will ultimately be accessible on the web, and where teachers in K-12 as well as college will be able to use the data in exercises about how the green roof performs under a variety of weather conditions. The research group is also studying problems of unsustainable water management in cities by examining the amount of precipitation runoff from city hardscape and measuring chemical pollutants in the runoff.

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Biographical Sketch

Dr. Urmila Diwekar is currently President of the Vishwamitra Research Institute (VRI, www.vri-custom.org), a non-profit research organization that she founded in 2004 to pursue multidisciplinary research in the areas of Optimization under Uncertainty and Computer aided Design applied to Energy, Environment, and Sustainability. From 2002-2004, she was a Professor in the Departments of Chemical Engineering, Bio Engineering, and Industrial Engineering, and in the Institute for Environmental Science and Policy, at the University of Illinois at Chicago (UIC). From 1991-2002 she was on the faculty of the Carnegie Mellon University, with early promotions to both the Associate and the Full Professor level.

In chemical engineering, she has worked extensively in the areas of simulation, design, optimization, control, stochastic modeling, and synthesis of chemical processes. Uncertainties are inherent in real world processes. Recognizing this, she started working in 1991 on stochastic modeling, efficient methods for uncertainty analysis, and optimization under uncertainty. These led to productive contributions in fields as diverse as advanced power systems, sustainability, environmental management, nuclear waste disposal, molecular modeling, pollution prevention, renewable energy systems, and biomedical engineering. The interdisciplinary nature of the field developed into several research collaborations and in 1999 she founded the Center for Uncertain Systems: Tools for Optimization and Uncertainty (CUSTOM) to foster interactions between various industries, national laboratories and various academic disciplines. She is the author of more than 130 peer-reviewed research papers (*65 of these research papers are related to green and clean energy, design for environment, and sustainability*), 6 books (*one book on pollution prevention and one recent e-book on sustainability by Bentham Science*), and 12 chapters, and has given over 330 presentations and seminars, and has chaired numerous sessions in national and international meetings. She has been the principal advisor to 20 Ph.D. students, and has advised several post-doctoral fellows and researchers. During the past 10 years, her students have won 6 best student paper awards from various AIChE and INFORMS sections (including separations division) at their respective meetings. These awards include number of awards from environmental division of AIChE and one award from Sustainable Engineering Forum. One of her student's Ph.D. thesis on sustainability is published as a monograph.

For her work in green solvent selection and solvent recycling in pharmaceutical industries, and ecological sustainability that led to her election as a Fellow of American Institute of Medical and Biological Engineering (AIMBE) in 2009. In the same year, she was elected a Fellow of AIChE. In October 2011 she received the prestigious Cecil Award for Environmental Chemical Engineering from the Environmental Division of AIChE for her work in design for environment and sustainability including her work on green separations. She is the first woman to receive this national award in its 39-year history. In November 2011, she received the Thiele award for outstanding contributions to chemical engineering, awarded by the Chicago chapter of AIChE.

Position Statement

Green engineering means green processes, green products, green energy, and eco-friendly management. In industrial ecology, this decision making changes from the small scale of a single unit operation or industrial production plant to the larger scales of an integrated industrial park, community, firm or sector. Then the available management options expand from simple changes in process operation and inputs to more complex resource management strategies, including integrated waste recycling and reuse options. The concept of overall sustainability goes beyond industrial ecology and brings in the time dependent nature of the system. Decisions regarding regulations and human interactions with system come into picture. It involves dealing with various time scales and time dependent uncertainties which require appropriately modeling these. The systems analysis approach to sustainability is to find efficient methods for solving these decision making problems at various spatial and temporal scales in the face of uncertainties. This is the focus of Dr. Diwekar's group. In design for environment, uncertainties are inherent and the problems are no longer single objective problems. Her work in this area started in 1991. This includes efficient sampling technique for uncertainty and risk analysis, and new algorithms for multi-objective and optimization under uncertainty. Systems analysis approach to green design and green energy involves starting decisions at molecular level, extending it to plant level and then to sector level (industrial ecology). She has worked in all these levels to bring in greener design for chemical as well as power sector systems. In green energy, she has contributed to clean coal technologies (like NOx and SOx and mercury control, IGCC systems), biofuels (like biodiesel and bioenergy in power systems), and fuel cells technologies. She has further extended this approach to ecological and integrated ecological-economical systems sustainability where uncertainties are time dependent and forecasting is essential. She has proposed a novel approach based on financial theories and optimal control to solve these problems. This work received attention from Stanford Innovation Review (http://www.vri-custom.org/pdfs/Research_EndofWorld.pdf) and recently discovery channel contacted her for including her work in their documentary.

Russell F. Dunn
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Biographical Sketch

Dr. Russell Dunn joined Vanderbilt University in 2011 as a Professor of the Practice of Chemical and Biomolecular Engineering where he directs the Undergraduate Chemical Engineering Laboratory and co-directs the Chemical Product and Process Design Programs. His main research areas are process and product design, process integration, chemical product and process safety, and polymer product failure analysis. His work in industry includes Ampex Corporation, General Electric, and Monsanto Chemical Company/Solutia. At Solutia, he was appointed Fellow in 1999. In 2004, he founded an engineering consulting company, Polymer and Chemical Technologies, LLC that has been involved in over 140 consulting projects to date. While working in industry, and then through his consulting company, he has applied process integration technology in numerous chemical process plants over the past two decades. He has also testified as an expert witness approximately 30 times and has authored over 75 expert reports on polymer and chemical product failure analysis and chemical process safety. In addition to his over 20 years of industrial and consulting experience, Dr. Dunn was a member of the chemical engineering faculty at auburn University from 1989-1994 and was a Guest professor at the Technical University of Denmark in 2000. Dr. Dunn received his B.S. and M.ChE. degrees in chemical engineering from Auburn University in 1984 and 1988, respectively. Dr. Dunn earned his Ph.D. in chemical engineering at Auburn University in 1994 where he completed his doctoral research under the direction of Prof. Mahmoud El-Halwagi. Dr. Dunn is a registered professional engineer in the state of Florida.

Position Statement

Sustainability is a key component of the chemical engineering profession. Much of Dr. Dunn's efforts in industry, consulting and academia have been devoted to three key issues in sustainable design: industrial water use minimization, industrial energy conservation, and process/product safety. These issues are emphasized in the chemical engineering design and laboratory curriculum at Vanderbilt University. Significant attention is devoted to solving large-scale industrial problems that are often difficult with existing design methodologies; however, these are often the scale of problem facing the practicing engineer in industry. In addition, chemical product safety, vastly different from chemical process safety, is often not addressed in detail in chemical engineering curriculums and in chemical engineering design textbooks. Product safety specifically affects company sustainability via public perception of the manufacturer, financial implications associated with failure, legal implications, and human injuries and/or deaths. Dr. Dunn has broad experience in the application of numerous design tools to address these issues of sustainability.

Delcie R. Durham, Ph.D., PE, FSME
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Biographical Sketch

Dr. Delcie Durham, Professor of Mechanical Engineering at the University of South Florida, brings more than 30 years of experience working in academia, industry and the National Science Foundation to her teaching, research and service activities. Dr. Durham's interests focus on bringing issues of sustainability and green engineering into integrated product and process development. She currently has been teaching courses in Sustainable Design and Materials, and Advanced Materials Processes. Her research is directed at using thermodynamic principles of energy and exergy efficiency to improve engineering design and manufacturing processes in terms of environmental impacts and cost. Dr. Durham earned her Ph.D. from the University of Vermont, is a fellow of SME, serving on the Board of Directors and as former president of NAMRI, promoting sustainable manufacturing. While Program Director at NSF from 1997 – 2006, she led the multi-agency activity that sponsored a WTEC study in Environmentally Benign Manufacturing, and represented NSF Engineering Directorate on an OSTP interagency committee for Science of Sustainability. While at NSF, Dr. Durham directed the PREMISE and MUSES programs that funded interdisciplinary research in sustainable materials, design and manufacturing.

Mario Richard Eden
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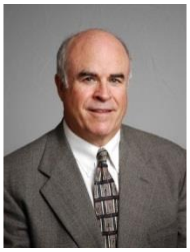
Biographical Sketch

Dr. Mario Eden is the Department Chair and Joe T. & Billie Carole McMillan Professor in the Department of Chemical Engineering at Auburn University. Dr. Eden is also the Director of an NSF-IGERT Program on Integrated Biorefining. His main areas of expertise include chemical process design, integration and optimization; molecular synthesis and chemical product design; as well as integrated biorefinery optimization and alternative fuels production via thermochemical conversion and gas to liquids (GTL) technologies. Dr. Eden has published extensively in these areas and his research has been supported by the National Science Foundation, Department of Energy, Department of Defense, Department of Education, Environmental Protection Agency, Department of Agriculture, and industrial sponsors. Dr. Eden is the recipient of several awards including the National Science Foundation CAREER award (2006), the Auburn Engineering Alumni Council Junior Faculty Research Award (2006), the William F. Walker Superior Teaching Award (2007), the Fred H. Pumphrey Teaching Award for Excellence (2009 and 2011), the SGA Award for Outstanding Faculty Member in the Samuel Ginn College of Engineering (2009 and 2011), the Outstanding Faculty Member in the Department of Chemical Engineering (2009, 2011, 2013, and 2014), and the Auburn Engineering Alumni Council Senior Faculty Research Award (2012). As one of the founding members of Auburn University's Center for Bioenergy and Bioproducts, Dr. Eden and his collaborators received the AU President's Outstanding Collaborative Units Award (2012). Finally, Dr. Eden was selected to participate in the 2010 National Academy of Engineering Frontiers of Engineering Education Symposium. Dr. Eden received his M.Sc. (1999) and Ph.D. (2003) degrees from the Technical University of Denmark, both in Chemical Engineering. He has organized, chaired and presented in numerous sessions and conferences, e.g. ESCAPE and PSE symposium series as well as AIChE meetings. Dr. Eden was selected to co-chair the Foundations of Computer Aided Process Design (FOCAPD) conference in 2014. He serves on the editorial boards for Chemical Process & Product Modeling, the Journal of Engineering, and Frontiers in Process & Energy Systems Engineering; is a member of the International Peer Review College for the Danish Council for Strategic Research; the International Energy Agency Annex IX on Energy Efficient Separation Systems.

Position Statement

Process and product design problems by nature are open ended and may yield many solutions that are attractive and near optimal. An additional complicating reality is that properties of materials are controlled by a multitude of separate and often competing mechanisms/phenomena that operate over a wide range of length and time scales. As a result it is becoming increasingly difficult to interface fundamental mechanistic models with computational tools for sustainable engineering design. It is incumbent upon the PSE/CAPE community to help bridge the gap between fundamental science and engineering applications as new research areas continue to emerge. At Auburn University, Dr. Eden is leading a group focused on the development of systematic methodologies for sustainable process and product synthesis, design, integration, and optimization. By combining fundamental chemical engineering principles and process systems engineering approaches, novel methods are developed that enable targeted solution of process/product design problems in the chemical, petrochemical, biochemical, pharmaceutical and related industries. Dr. Eden is the Director of an NSF Integrative Graduate Education and Research Training (IGERT) program that supports an integrated, interdisciplinary graduate education and research program focused on biorefining concepts for sustainable production of fuels and chemicals from renewable resources. The program aims to optimize the entire fiber to fuel lifecycle by developing novel thermochemical and biochemical conversion technologies that will lead to technically viable, efficient and sustainable fuels and chemical production strategies. Dr. Eden also serves as one of the Co-PI of the NSF RCN-SEES project, Sustainable Manufacturing Advances in Research and Technology (SMART) Coordination

Network, which includes 21 domestic and foreign universities and 10 national organizations/university centers.



Thomas F. Edgar
George and Gladys Abell Chair in Engineering
McKetta Department of Chemical Engineering
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Austin, TX 78712

Biographical Sketch

Thomas F. Edgar is Professor of Chemical Engineering at the University of Texas at Austin and Director of the UT Energy Institute. Dr. Edgar received his B.S. degree in chemical engineering from the University of Kansas and a Ph.D. from Princeton University. For the past 40 years, he has concentrated his academic work in process modeling, control, and optimization, with over 200 articles and book chapters. Edgar has co-authored two leading textbooks: Optimization of Chemical Processes (McGraw-Hill, 2001) and Process Dynamics and Control (Wiley, 2010) and has received major awards from AIChE and ASEE. Dr. Edgar was the 1997 President of AIChE. Tom Edgar is co-founder of the Smart Manufacturing Leadership Coalition (SMLC; https://smart-process-manufacturing.ucla.edu/), which developed a research roadmap to address smart, zero-emission, energy-efficient manufacturing. SMLC recently received an $8 million award from the Energy Efficiency and Renewable Energy program of DOE to develop software for saving energy in two industrial test beds. Another NSF-funded project where Tom is the Co-PI (with Yinlun Huang and others) is to develop a research coordinating network for sustainable manufacturing. This project will develop sustainable manufacturing case studies and disseminate software.

Position Statement

Process control has become increasingly important in the process industries to address improving energy efficiency, rapidly changing economic conditions, and more stringent environmental and safety regulations. Process control and its allied fields of process modeling and optimization are critical in the development of more energy-efficient processes for manufacturing high value-added products and this is closely coupled with sustainability. Tom is the UT PI on a large U.S. DOE demonstration project on smart grids (www.pecanstreet.org) in Austin, TX, which focuses on new automation techniques and big data analytics for managing distributed solar energy generation and energy storage and involves six faculty from EE, ME, and CAEE departments. This smart grid demonstration is particularly notable because it involves data collection from over 300 homes with solar panels and 60 electric vehicles in one neighborhood, the densest concentration of such users in the U.S. Simultaneously, Tom has been PI of a large NSF IGERT grant, which is connected to the Pecan Street effort. The 20 students work in an interdisciplinary research and educational framework to address sustainable grid integration of distributed and renewable energy systems, a crucial priority for greenhouse gas reduction. Edgar believes private-public partnerships Pecan Street and SMLC can push sustainable manufacturing forward, requiring the cooperation of industry, universities, government, and non-government organizations.

Mahmoud M. El-Halwagi
Professor and Holder of the McFerrin Professorship
The Artie McFerrin Department of Chemical Engineering
Texas A&M University
College Station, Texas 77843-3122

Biographical Sketch

Dr. Mahmoud El-Halwagi is the McFerrin Professor of Chemical Engineering at the Artie McFerrin Department of Chemical Engineering, Texas A&M University. He received his Ph.D. in Chemical Engineering from the University of California, Los Angeles and his M.S. and B.S. from Cairo University. Dr. El-Halwagi has more than 25 years of experience in the areas of process integration, synthesis, simulation, design, operation, and optimization, techno-economic analysis, sustainable process design, and molecular/product design. In addition to the theoretical foundations he helped lay down in these areas, he has been active in education, technology transfer, and industrial applications especially in the area of hydrocarbon processing. He has served as a consultant to a wide variety of gas, chemical, petrochemical, petroleum, pharmaceutical and metal finishing industries. He is the coauthor of about 175 papers and 55 book chapters. He is also the author/co-autohr/co-editor of nine books including three textbooks on sustainable process design and integration. He is the recipient of several awards including the American Institute of Chemical Engineers Sustainable Engineering Forum (AIChE SEF) Research Excellence Award, the DuPont Excellence Award in Safety, Health and the Environment, and the National Science Foundation's National Young Investigator Award.

Position Statement

According to El-Halwagi (2012), ***Sustainable design*** of industrial processes may be defined as the *design activities that lead to economic growth, environmental protection, and social progress for the current generation without compromising the potential of future generations to have an ecosystem which meets their needs.* The following are the principal objectives of a sustainable design:

- Resource (mass and energy) conservation
- Recycle/reuse
- Pollution prevention
- Profitability enhancement
- Yield improvement
- Capital-productivity increase and debottlenecking
- Quality control, assurance, and enhancement
- Process safety

Because of the integrated nature of manufacturing processes, the field of process integration can play a major role in achieving sustainable designs. ***Process integration*** is a holistic approach to process design, retrofitting, and operation which emphasizes the unity of the process (El-Halwagi, 1997). In light of the strong interaction among process units, resources, streams, and objectives, process integration offers a unique framework along with an effective set of methodologies and enabling tools for sustainable design. The strength and attractiveness of process integration stem from its ability to systematically offer the following:

- Fundamental understanding of the global insights of a process and the root causes of performance limitations
- Ability to benchmark the performance of various objectives for the process ahead of detailed design through targeting techniques
- Effective generation and screening of solution alternatives to achieve the best-in-class design and operation strategies

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Burton C. English
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Biographical Sketch

Burton English is a professor of Agricultural Economics and has 34 years of experience researching the adoption of new technologies, the impact of Agricultural Policies and its impact on sustainability issues, producers and consumers. He has conducted a multitude of studies on economic feasibility and the impact new technology will have on rural America. He received his Ph.D. in Agricultural Economics from Iowa State University in 1981. He has taught a number of courses including Agricultural and Trade Policy, Agricultural Production, Agricultural Finance, Research Methods, Economics of Renewable Energy, Mathematical Programming, Agribusiness Operations Research, Advanced Quantitative Methods and Agricultural Supply Analysis, and Managerial Economics for Agribusiness. He has been a PI or senior project researcher on over $7 million in grant and contract funding with 4.5 of that occurring in the past 10 years. Funding has come from a variety of agencies, such as USDA, DOE, EPA, Tennessee Department of Agriculture, Tennessee Valley Authority, 25 x 25, The Energy Foundation, and others. He is an author or co-author on over 350 publications and presentations, 18 book chapters and 7 books. He has received numerous awards such as the USDA's Certificate of Appreciation, 1989; UTK Chancellor Award for Research, 1994; Neal and Trice Peacock Teaching/Learning Merit Certificate, April 1992 and 2000; Dutch and Marilee Cavendar Award for Best Research Publication, July 2000; Delta Sigma Delta Research Award, Fall 2008; and UT AgResearch Research Impact Award, 2010. He is a co-founder of AIM-AG, (Agri-Industry Modeling & Analysis Group) and BEAG, (Bio-Based Energy Analysis Group) at the University of Tennessee.

Position Statement

I have for my entire research life sought to create a sustainable agricultural system. Trained as an Economist, sustainable technology to me is a chair with four legs. The first leg is economics. To be sustainable, a system must be economical. Which means that the net returns of the system must be greater than 0 and that other enterprises using similar resources would not provide a better net return. The second leg is environmental. If the system is a new one, then it should create a more sustainable environment than the previous one. In deed once employed, the environment should improve. This would be seen as a movement towards sustainability. A sustainable system would either maintain or improve the environment that it impacts. The third leg is concerned with the people that it affects. Is the system acceptable from a cultural perspective? Does it improve the quality of life for individuals that are impacted by the technology? I do not do much in the area of this third leg except examine changes in value added, total industry output, and employment opportunities as the technology is adopted. The final leg is an evaluation of the technology itself. Will the technology survive? Are there threats to the technology? These are questions that need to be asked to address the fourth leg of sustainability. The demand for energy is huge and could trump all if society is not careful. Developing alternatives to fossils is a critical need as we move into a more sustainable future. Burdens are being placed on all industries as a result of uncertain energy prices and possible greenhouse gas constraints. The surfacing questions require research coordination among many disciplines within the academic community and networking with industries is needed. Resources available to address these questions are severely limited; yet the need ever increases.

At the University of Tennessee Burton English is a professor of Agricultural and Resource Economics. He has 34 years of experience researching the adoption of new technologies, the impact of policies on rural America, and on the impacts of sustainability issues on producers and consumers. He has conducted a multitude of studies on economic feasibility and the impact new technology will have on rural America. He is currently the director of the Bio-based Energy Analysis Group (BEAG). His current research activities focus on biofuel development and bio/wind/solar/hydro power. He has worked with 25x25 in evaluating the potential of achieving a 25% renewable energy portfolio by the year 2025. He has consulted with USDA, DOE, and EPA. Working with the bipartisan Policy Center, he evaluated the abilities of several states potential to achieve a portion of their electricity from renewables. He is an author or co-author on over 350 publications and presentations, 18 book chapters and 7 books.

Timothy G. Gutowski
Professor
Department of Mechanical Engineering
Massachusetts Institute of Technology (MIT)
Cambridge, MA

Biographical Sketch

Timothy G. Gutowski is a Professor of Mechanical Engineering at the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA. His research interests focus on the relationship between manufacturing and sustainability at various scales. His recent work looks at global manufacturing and its economic benefits as well as energy/carbon challenges*.

He was the Director of MIT's Laboratory for Manufacturing and Productivity (1994-2004), and the Associate Department Head for Mechanical Engineering (2001-2005). From 1999 to 2001 he was the chairman of the National Science Foundation and Department of Energy panel on Environmentally Benign Manufacturing. He has over 150 technical publications, two books and seven patents and patent applications. His most recent book is: “Thermodynamics and the Destruction of Resources” Cambridge University Press, 2011(with Bhavik R. Bakshi and Dusan P. Sekulic).

*see for example;

T.G. Gutowski, S. Sahni, J.M. Allwood, M.F. Ashby, and E. Worrell, “The Energy Required to Produce Materials: Constraints on Energy Intensity Improvements, Parameters of Demand," *Phil. Trans. R. Soc. A, 2013* 371, 2013, and

T.G. Gutowski, J.M. Allwood, C. Herrmann, and S. Sahni, A Global Assessment of Manufacturing: Economic Development, Energy Use, Carbon Emissions, and the Potential for Energy Efficiency and Materials Recycling, *Annual Review for Energy and Resources,* forthcoming 2013.

Position Statement

Sustainability is a new problem for society. The principal feature of the sustainability dilemma is that it is of a global scale. That is, the scale of humanity’s use of materials, land, water and energy resources, and its emissions, principally of carbon, methane, nitrogen, phosphorous, nitrous oxide, and still other pollutants now interfere with natural ecosystem processes. The result is that we are now degrading global ecosystem services such as clean air and water, stable climate, and healthy oceans. These are services that have been provided essentially for free throughout human history. It is not at all clear to what extent we can compensate for these loses.

This problem presents several special challenges. For one, up to this point the erosion of global ecosystem services has generally occurred gradually and often in distant locations, so a sense of an impending threat is mitigated. As a result, many people do not feel a strong incentive for action. Secondly, the connections between human activities and global consequences can be very complex, resulting in confusion about what is the right thing to do. And thirdly, for those who study these problems, they can see that in many cases actions to reduce pollutants, or energy use, or carbon emissions may conflict with other goals of society such as economic development or social wellbeing. This suggests that the solution to sustainability may not be an easy fit, and will require cooperation, in fact, cooperation on a global scale.

Engineers can help to address these problems by making the connections between human activities and global impacts more apparent, and by developing technology and business solutions. But because of the nature of the sustainability problem, engineers will also have to work closely with other disciplines, in particular, the physical scientists who study global scale problems (such as climate change, ocean acidification etc.) as well as economists, biologists, and social scientists, and others. Most important, engineers will need to understand the global consequences of their actions in absolute measures. Relative measures can mislead.

Manufacturing as an important subset of human activities, can play a pivotal role in moving society toward a more sustainable position. From a very broad perspective, there appear to be four imperatives for the manufacturing sector in a sustainable society. These include: 1) supply the technologies for sustainability solutions (for example to reduce climate change or ocean acidification), 2) supply the economic opportunities for the developing world so that they may improve their standard of living, 3) help maintain a quality standard of living in the developed world, and 4) constrain our own (manufacturing sector) sustainable impacts (for example reduce absolute carbon and greenhouse gas emissions) through efficiency improvements, recycling, new technology and almost certainly, demand reduction.

Troy R. Hawkins
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio

Biographical Sketch

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 several projects focused on (1) the development of open source software tools and approaches for improving the availability, interoperability, and capability of public domain LCA models and (2) addressing key barriers to incorporating a life cycle perspective in decision-making. I earned a BS in Physics from the University of Michigan in Ann Arbor, Michigan in 1999 and a PhD 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 PhD 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 performed a comparative assessment of electric and conventional vehicles (E-CAR) and worked on the development of an environmentally-extended multi-regional input-output model for the harmonized calculation of carbon, ecological, and water footprints across international supply chains under the OPEN EU Project.

Position statement

The key to providing a successful roadmap for sustainable manufacturing is to clearly outline a path to defining an appropriate framework for reliably quantifying the prospective sustainability of a larger system while connecting these future outcomes to specific decisions made by actors within the system today. This is not an easy task. Any roadmap based on current wisdom regarding how this can best be accomplished should allow for course corrections in response to future developments.

My perspective is based on what I have observed through working on the development of the models and *data-related infrastructure* for understanding the sustainability of various product systems and consumption scenarios primarily from the environmental and economic *pillars* of the triple value model of sustainability. Two years ago I led a workshop on the Design of Sustainable Supply Chains and Product Systems. In the context of that workshop I identified four challenges to moving forward which also serve as the basis for my position going into this workshop. I present a slightly updated version of these challenges here. While none of these challenges are insurmountable; addressing them will require shifting the approaches we use to support science-based decision-making.

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 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 together models. To do 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 way in which much attention 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 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 should not delay progress on the development of the new methods, which are needed. A better approach would be to demonstrate best practice through carrying out high quality analyses, which 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 as 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 is primarily in the area of life cycle assessment (LCA). There are many unexploited opportunities for application of LCA and within the research community we already have many of the datasets and models needed to support sustainable manufacturing. The problem is the lack of well-organized and publicly available data and especially high quality datasets, which 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 they can be easily integrated into consecutive modeling efforts by others.

A fourth challenge is the network tying together modeling efforts relevant for the design of sustainable product systems and supply chains is not sufficiently interconnected or efficient. Often only, a small group of experts know how to run the appropriately complex models of economic and environmental systems. These individuals may be connected with their counterparts working with other similar 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 which promotes interaction across levels of detail and which recognizes the contribution of interfaces, which simplify access to complex models and streamline interaction between models.

As an outcome of this workshop, I hope we can identify and define steps to the creation of new mechanisms to support coordination and collaboration across U.S. and international efforts to aid decision-making for sustainable outcomes in the context of manufacturing engaging industry, academic, government, and societal stakeholders.

Richard K. Helling
Associate Director, Sustainability & LCA
2020 Building, Ofice D210
The Dow Chemical Company
Midland, Michigan

Biographical Sketch

Rich Helling is Associate Director of Sustainability/Life Cycle Assessment (LCA) for The Dow Chemical Company, located in Midland, Michigan. Rich joined Dow in 1987 and has held a variety of roles in process research, development and manufacturing. He developed and improved technologies at Dow's Pittsburg, California, manufacturing site for waste reduction, reaction selectivity and purification of chlorinated pyridines that are used in a broad range of Dow AgroSciences' products, becoming the leader for Process & Environmental Technology in Pittsburg. He led the process development for SiLK™ dielectric materials in Midland, Michigan, and was the Dow AgroSciences European contract synthesis leader and global fungicides technology leader when based in Drusenheim, France. Rich returned to Midland in 2003, when he began his use of life cycle assessment to complement economic evaluations of new technologies, especially the use of renewable feedstocks for chemical production, becoming an associate R&D director. Rich has a B.S. from Harvey Mudd College with majors in Engineering and History, a S.M. in Chemical Engineering Practice from MIT, and a Sc.D. in Chemical Engineering, also from MIT. He was an Assistant Professor with the MIT Chemical Engineering Practice School in Midland prior to joining Dow. He is an author of 12 papers and holds 2 patents, is a registered Professional Engineer in Michigan, and is a LCA Certified Professional. He is a member of the State of Michigan's Green Chemistry Roundtable, and active in working groups of The Sustainability Consortium.

Position Statement

Rich is part of Dow's Sustainability Programs group, within Dow's corporate EH&S & Sustainability organization. This group brings a broad array of skills and a passion for sustainability and the future of the company, industry and planet to diverse projects within Dow and with external partners, such as The Nature Conservancy and The Sustainability Consortium. The group quantifies and describes Dow's performance for internal and external audiences, such as with The Dow Chemical Sustainability Footprint Tool™ (*http://pubs.acs.org/doi/abs/10.1021/sc300131e*), a sustainable chemistry index used as part of the 2015 corporate sustainability goals (http://www.dow.com/sustainability/commit.htm), and our annual Sustainability Report (http://www.dow.com/sustainability/pbreports/annual.htm). Rich advises Dow businesses on the use of LCA and related tools to identify opportunities for innovation, to differentiate products in the marketplace and create sustainable value for Dow. He has led and reviewed many LCA of Dow products and processes, building on extensive data and insights from Dow's Manufacturing & Engineering organization.

Yinlun Huang
Professor
Department of Chemical Engineering and Materials Science
Wayne State University
Detroit, MI 48202

Biographical Sketch

Dr. Yinlun Huang is Professor of Chemical Engineering and Materials Science 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 (sever) uncertainty. He has published widely in these areas. In the past few years, he has co-organized/co-chaired six 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 is Technical Advisor of the AIChE-SEF. Among many honors, Dr. Huang was the recipient of the Michigan Green Chemistry Governor's Award in 2009, the AIChE Sustainable Engineering Forum's Research Excellence in Sustainable Engineering Award in 2010, and the NASF Scientific Achievement Award in 2013. 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.

Position Statement

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 and process systems 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, Huang is leading a group to study multiscale systems modeling, analysis, and decision-making and develop methodologies and tools for design of sustainable physical systems, such as nanomaterials at the microscale, products with needed properties at the mesoscale, process systems at the macroscale. His 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. His group has also introduced the Collaborative Profitable Pollution Prevention design methodology, which can advise synergistic efforts among industrial entities to maximize economic gains while minimizing 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 for future sustainability performance prediction and/or short-to-long-term sustainable development. Recently, Huang's group developed an interval-parameter-based decision-making methodology has been introduced to develop short-to-long-term sustainability improvement strategies for industrial zonal development problems. Huang has been served as the PI of the NSF RCN-SEES project, Sustainable Manufacturing Advances in Research and Technology (SMART) Coordination Network, which includes 21 domestic and foreign universities and 10 national organizations/university centers.

I. S. Jawahir
James F. Hardymon Chair in Manufacturing Systems,
Professor of Mechanical Engineering, and
Director of Institute for Sustainable Manufacturing (ISM)
University of Kentucky
Lexington, KY 40506

Biographical Sketch

Dr. I.S. Jawahir received PhD in mechanical and manufacturing engineering from the University of New South Wales (Sydney, Australia) in 1986. His current research interests are: (a) modeling and optimization of sustainable manufacturing processes; and (b) product design for sustainability, both focusing on developing predictive performance models for products, processes and systems. He has produced 290 refereed technical research papers, including over 120 refereed journal papers, and has been awarded 4 U.S. patents. He directed 28 PhD and over 70 MS graduates. He has received significant research funding from Federal Agencies such as the National Science Foundation (NSF), National Institute for Standards and Technology (NIST), Department of Defense, NASA, and from major U.S. manufacturing companies such as General Motors, Ford, Toyota and General Electric - Aviation. He is a Fellow of three major professional societies: CIRP (International Academy for Production Engineering), ASME (American Society of Mechanical Engineers), and SME (Society of Manufacturing Engineers); Technical Editor of the Journal of Machining Science and Technology; Founding Editor-in-Chief of the International Journal of Sustainable Manufacturing; Member of the ASME Board for Research and Technology Development (BRTD); and Vice Chairman of ASME Research Committee on "Sustainable Products and Processes" (He founded this research committee in 2005, and served as the Chairman for six years previously). He served as the Chairman of the CIRP's International Working Group on "Surface Integrity and Functional Performance of Components" during 2007-11. He has delivered 28 keynote papers in major international conferences, and over 100 invited presentations in 28 countries. He recently received the *ASME's 2013 Milton C. Shaw Manufacturing Research Medal* for his fundamental work on manufacturing, including achievements in sustainable manufacturing.

Position Statement

Professor Jawahir has been actively engaged in manufacturing research for over three decades. His original work on 6R-based (Reduce, Reuse, Recycle, Recover, Redesign and Remanufacture) innovation principles for sustainable manufacturing, incorporating the entire life-cycle with four life-cycle stages (pre-manufacturing, manufacturing, use and post-use), has been widely applied at the product, process and systems/enterprise levels. Within the newly established Institute for Sustainable Manufacturing at the University of Kentucky, he currently leads a group of over 20 faculty from four engineering departments (mechanical, materials & chemical, biomedical, and electrical & computer engineering), and non-engineering academic units (College of Business, School of Architecture, College of Arts and Sciences) and research centers, engaged in applied and fundamental research in sustainable manufacturing. In a recent NIST-sponsored three-year project on developing metrics for sustainable manufacturing, his research team established relevant metrics for manufactured products and manufacturing processes, and developed an integrated, comprehensive sustainability evaluation methodology for products and processes hrough Product Sustainability Index *(ProdSI)* and Process Sustainability Index *(ProcSI).* This methodology was validated in industry applications through case studies in aerospace, automotive and consumer electronic product manufacturing. He has also been engaged in developing sustainable manufacturing processes/technologies for improved product quality, performance and sustainability, focusing on dry, near-dry and cryogenic machining processes. Cryogenic machining of lightweight automotive and aerospace alloys, including *Al*, *Mg* and *Ti* alloys, novel/advanced materials such as *NiTi* alloys, *Co-Cr-Mo* biomaterial, *AISI 52100* hardened steels, porous tungsten, and a range of stainless steels, has resulted in significantly improved product quality, performance and sustainability in terms of enhanced wear and corrosion resistance and fatigue life. Several of these materials also produce desirable nanostructured surface layers. Professor Jawahir has also established international collaborative research with several major universities in Germany, France, Italy, United Kingdom, Australia, Portugal, Spain, Slovenia, and Malaysia, involving student/faculty exchange programs with several of these universities. He has developed, conducted, and participated in numerous sustainable manufacturing forums, strategic planning sessions, and roadmapping workshops sponsored by professional societies such as ASME and DoD, aimed at dual applications (commercial and defense).

Vikas Khanna
Assistant Professor
Department of Civil and Environmental Engineering
University of Pittsburgh

Biographical Sketch

Vikas Khanna is an Assistant Professor of Civil and Environmental Engineering at the University of Pittsburgh. Dr. Khanna received his PhD from the Ohio State University in 2009, and a BS from Panjab University in 2004, both in Chemical Engineering. His doctoral work focused on the life cycle environmental evaluation of emerging nanotechnologies and multiscale modeling for environmentally conscious process design. While in graduate school, he won several best paper and poster awards at national and international conferences such as the IEEE International Symposium on Sustainable Systems and Technology and the Gordon Research Conference. He also received a science and technology policy fellowship from 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 as an Assistant Professor in 2010. His research and teaching interests are in the general areas of sustainability science and engineering, industrial ecology, applied statistics, and complex systems. His group's research focuses on the development of life cycle oriented methods for evaluating the environmental impacts of engineered products and processes. Recent applications include emerging drop-in replacement biofuels, nanomaterials, and critical materials. In addition, his group is developing graph theory based methods for understanding resilience in complex engineered systems.

Position Statement

Sustainability encompasses and entails 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 developing sustainable technologies and products. 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. While life cycle approaches represent an important step in the context of sustainable process design, most of these are retrospective in nature offering little opportunity for design intervention.

My group is developing and applying life cycle based approaches to evaluate and understand the environmental impacts of emerging technologies early in the research and development phase before inefficiencies become embedded. Our recent work on application of life cycle and thermodynamic based methods for sustainable engineering has resulted in novel insights for emerging microalgal biofuels, advanced terrestrial biomass derived fuels, and critical materials. We have also demonstrated multiple tradeoffs that exist between environmental impacts for emerging biofuels while remaining cognizant of spatial variability. Such insights are especially useful for guiding environmentally conscious life cycle design of technologies at early stages of research.

In my opinion, a significant challenge and knowledge gap for sustainable engineering is a better integration and utilization of information available at multiple scales. 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. An improved understanding of tools and techniques across scales can aid in recognizing patterns and developing heuristics for sustainable manufacturing and technologies.

I expect to learn more at the workshop in Cincinnati about sustainable manufacturing and hear different perspectives from academia, industry, and national labs. It could lead to synthesis of new ideas and foster new collaborations for addressing the challenges facing sustainable manufacturing that cannot be addressed by a single discipline in isolation.

Christos T. Maravelias
Associate Professor
Department of Chemical and Biological Engineering
University of Wisconsin – Madison
Madison, WI, 53706

Biographical Sketch

Dr. Maravelias was born in Athens, Greece. He obtained his Diploma in Chemical Engineering from the National Technical University of Athens and an MSc in Operational

Research from the London School of Economics (London, UK). After completing his military service in Greece, he went to Carnegie Mellon University where he obtained his PhD under the supervision of Professor Ignacio Grossmann. In the fall of 2004 he joined the faculty of the Department of Chemical and Biological Engineering at the University of Wisconsin – Madison. Dr. Maravelias is the recipient of the Inaugural Olaf A. Hougen Fellowship, an NSF CAREER award, as well as the 2008 W. David Smith Jr. and the 2013 Outstanding Young Researcher Awards from the Computing & Systems Technology (CAST) division of AIChE. He organized the 2011 Pan American Advanced Studies workshop on *Process Modeling and Optimization for Energy and Sustainability*, and he serves as a Director of the CAST division of AIChE. Dr. Maravelias' research interests are in the areas of a) production planning and scheduling, b) chemical supply chain optimization, c) process synthesis and technology assessment for renewable energy, and d) computational methods for novel material discovery.

Position Statement

One of the main research thrusts in Dr. Maravelias' lab is the development of methods for the synthesis, analysis, and optimization of chemical processes. He has developed a surrogate-based superstructure framework that results into computationally tractable optimization models, thereby enabling the effective synthesis of chemical processes. In parallel with his method-development efforts and in collaboration with various experimental groups, Dr. Maravelias studies novel strategies for renewable energy, including: a) thermochemical splitting of water and carbon dioxide (collaboration with Sandia National Laboratories); b) catalytic strategies for the production of liquid hydrocarbons from lignocellulosic biomass (with Jim Dumesic, U of Wisconsin – Madison); c) biomass pretreatment technologies using ionic liquids (with Ron Raines, U of Wisconsin – Madison); d) production of value-added chemicals using cyanobacteria (with Brian Pfleger, U of Wisconsin – Madison); e) production of solar fuels using plasmonic catalysis (multi-institution collaborative project); and f) fractionation and catalytic upgrading of pyrolysis-derived *bio-oil* (with University of Oklahoma). Also, Dr. Maravelias recently developed a systems-level framework for the identification and assessment of novel biomass-to-fuels conversion strategies. Finally, Dr. Maravelias develops methods for the optimization and analysis of chemical supply chains, as well as methods for the optimization of chemical operations.

Manish Mehta
Director, Strategic Projects and Sustainability
National Center for Manufacturing Sciences
Ann Arbor, MI 48108-3266

Biographical Sketch

Dr. Manish Mehta is Director of Strategic Projects and Sustainability at the National Center for Manufacturing Sciences (www.ncms.org - USA's largest cross-industry manufacturing R&D consortium). He has over 20 years' experience in organizing and managing strategic ventures and cross-industry cluster collaborations based on high-risk, high-payoff research in areas such as advanced materials, design/manufacturing automation, energy efficiency and sustainable manufacturing. As principal investigator on four NSF/National

Nanotechnology Initiative-sponsored studies (2003, 2006, 2009 and 2013), he regularly surveys and benchmarks US manufacturers and industrial sectors on development trends, commercial readiness and applications of nanotechnology, and assesses their impact on US competitiveness. He obtained his BS (Mechanical Engineering) from Bangalore University, India and MS and Ph.D degrees in industrial engineering from University of Cincinnati, and has completed the Executive Program at University of Michigan Ross Business School. He is a Fellow of the Engineering Society of Detroit, and a past member of the National Academies Board on Manufacturing and Engineering Design. He has been a peer reviewer for state-sponsored programs such as Michigan's 21st Century Jobs Fund, Ohio's Third Frontier Fund, and Singapore SPRING business plan competitions.

Position Statement

In participating in the Roadmap Workshop, Dr. Mehta will promote the need for the systematic and standardized enterprise-wide application of life cycle thinking in all major functions in a manufacturing organization, so that critical life cycle phase perspectives are considered for decision-making, and thereby, unintended consequences and negative impacts may be avoided or minimized. NCMS has organized the Sustainable Manufacturing Strategic Interest Group (SM SIG) in 2012 to provide cross-industry stakeholders with innovative approaches on how sustainable thinking strategies and tools can be applied across nascent technology value-chains.

Climate change and the negative impact that various human activities can have on our ecosystem are among the most urgent and pervasive challenges corporations are facing. For example, it is estimated that the automotive industry is responsible for roughly 15% of global carbon emissions, equating to roughly eight billion metric tons per year. Although environmental protection has been cited as the primary driver for the sustainability movement, other socio-political factors such as the price volatility of fossil fuels and energy independence goals have also helped perpetuate a shift towards alternative materials and renewable energy sources for mobility systems and other applications. Many components and sub-systems for these seemingly cleaner technologies may be greatly enhanced for superior performance using disruptive paradigm-shifting advances such as nanotechnology, additive manufacturing and lightweighting.

The design of a product must begin with the end in mind. To be able to produce a truly sustainable product, its carbon footprint, health, safety and socio-economic impacts must be anticipated and understood up front through all key phases. Maximizing the efficiency of manufacturing-related operations is far more complex to achieve even after a company commits itself to sustainability goals. Optimizing quality and costs is hard enough in an ever-changing business and regulatory environment. Due to many unknowns across life cycles, the manufacturers of nano-enabled products face an even tougher challenge in achieving multi-attribute sustainability targets, such as minimizing water and energy use, CO_2 emissions and waste, while simultaneously attaining the highest levels of conduct on workforce practices, safety, ethical sourcing and social justice.

Kimberly Ogden
Professor, Department of Chemical and Environmental Engineering
University of Arizona
Tucson, AZ

Biographical Sketch

Kimberly Ogden is a professor of chemical and environmental engineering at the University of Arizona. She received her BS degree from the University of Pennsylvania and her MS and PhD degrees from the University of Colorado. Prior to joining the UA in the fall of 1992 she was a postdoctoral fellow at Los Alamos National Laboratory. She is currently on the managing board of SBE and recently completed her term as the secretary of AIChE. Kim's research focus includes bioreactor design for production of alternative fuels from algae and sweet sorghum and microbiological water quality. She is the engineering technical lead for the National Alliance for Advanced Biofuels and Bioproducts or NAABB. As the final report is being written for the NAABB consortium, her research in algae to biofuel continues through a Regional Algal Feedstock Testbed program funded by the Department of Energy. The goal of this 4 year project is to obtain long term outdoor algal cultivation data that will be available to the public for use in modeling and other research efforts, and demonstrate the feasibility of year round cultivation. Furthermore, industrial and other universities will be able to use the testbeds to test new technologies such as novel harvesting and extraction systems.

Kim is also involved in teacher outreach programs. She has run a NSF Research Experiences for Teachers Program for over ten years, where teams of teachers spend 5 to 6 weeks in the summer doing research in the UA laboratories and transfer what they learn directly to the K-12 classroom through relevant lesson plans. She is also the principal investigator for a NSF GK-12 engineering program. The focus of the GK12 is water and energy sustainability. Graduate students from 7 different engineering disciplines have been GK12 fellows and worked in junior high and high school classrooms in the Tucson area. Some of these school districts have up to 90% of their student population from diverse backgrounds and have 70 to 80% of the students receiving free or reduced meals.

Position Statement

Kim is interested in the systems approach to sustainability. New industries such as the algal biofuels industry will only be viable if they integrate with existing systems. Co-locating algal cultivation systems near cheap or free sources of carbon dioxide, nitrogen and phosphorous is highly desirable. Water recycle and use of non-potable water sources is required in areas of abundant sunlight like the Southwestern United States. Furthermore, using existing refining infrastructure allows for slow integration of bio-oils. Simultaneous production of high value products such as omega fatty acids, nutriceuticals, and pharmaceuticals; fertilizer; fuel; and food is essential in Kim's opinion. Integration will assure a cost effective and environmentally friendly integrated new industry.

Douglas C. Pontsler
Vice President, EHS & Operations Sustainability
Owens Corning
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Biographical Sketch

Doug Pontsler is Vice President of EHS & Operations Sustainability for Owens Corning. He was named to his current position in August 2009. In this leadership role, he has responsibility for directing safety and environmental matters within Owens Corning globally. His role was expanded in October 2011 to include responsibility for foundational compliance and sustainability operations performance.

Mr. Pontsler joined Owens Corning in 2002 as Director of Corporate Services, was named Director of Global Sourcing in 2004 and Vice President of Global Sourcing in 2008. Prior to joining Owens Corning, Mr. Pontsler spent 23 years with Eaton Corporation. While at Eaton, he held various roles of increasing responsibilities in accounting, finance, production and inventory control management, factory management and sourcing.

Mr. Pontsler is involved in the community as a Board Member of the Regional Growth Partnership promoting economic development, a member of the Board and Executive Committee of the Marathon Classic LPGA Tournament, and a Cabinet Member of the United Way 2013 Campaign Committee for Northwest Ohio.

Originally from Rockford, Ohio, Mr. Pontsler received a BA in business administration from Miami University in Oxford, Ohio with a major in accounting.

Position Statement

At Owens Corning we regard Operations Sustainability as a combination of both our Environmental, Health & Safety performance and the reduction in our Footprint.

Our commitment to safety is unconditional and everything begins with creating a safe workplace for our employees. Over the last 11 years we have reduced the number of injuries in the workplace by over 95% and we regard our job not done until that number is zero.

From the footprint standpoint, we just completed in 2012 our first set of 10 year goals that were base lined against 2002, and we were successful in reaching all of the goals that we had established in reducing waste, the amount of water we use, and the impact from an air emissions standpoint. We have begun our second set of 10 year goals beginning at a baseline in 2010 and we have been successful through the first 2 years of improvement in all of the aspects that we have established so far. We regard our footprint reduction as an important element of our manufacturing strategy. Footprint reduction brings cost improvement, it helps us meet the expectations that our customers have, and it also creates the opportunity for us to be a responsible citizen in the communities in which we operate. We are proud of the performance that we have achieved. Achieving that performance is dependent upon a high level of employee engagement, allowing us to gain all of the great ideas that exist in our workforce on the things that we can do that will really make a difference.

Mary Rezac
ConocoPhillips Professor of Sustainable Energy
Department of Chemical Engineering
Kansas State University
Manhattan, KS 66506

Biographical Sketch

Dr. Mary Rezac is Professor of Chemical Engineering and ConocoPhillips Professor of Sustainable Energy at Kansas State University. She is the director of the Kansas State University Center for Sustainable Energy. She has more than 25 years of experience in energy and related applications, including renewable energy, process system efficiency, bioenergy, and petrochemical refining and processing. Dr. Rezac has been responsible for leading energy research and development, managing and developing programs, and planning and evaluating technical programs. Her research focuses on the design and use of permselective membranes including their use in reactive applications. Recently, her group has examined the importance of separations and reactor design on improving the sustainability of biorefineries. Dr. Rezac holds multiple patents, has authored over 70 publications in diverse fields and technical journals, and presented over 100 papers at international, national, and other meetings. Dr. Rezac has served on numerous policy-making groups, including as a director of the Council for Chemical Research and of the Separations Division of the American Institute of Chemical Engineers. She has served on a National Research Council committee evaluating the Potential Impacts of High End Computing in Selected Areas of Science and Engineering. She has helped plan the future of Chemical Engineering as a member of the Strategic Planning Committee of the AIChE. Currently, she serves as past-president of the North American Membrane Society. Dr. Rezac holds a B.S. degree from Kansas State University, in 1987, and a M.S. and a Ph.D. degree from at the University of Texas at Austin, in 1992 and 1993, respectively, all in chemical engineering. She was a research engineering for the Phillips Petroleum company from 1987 – 1990. She joined the chemical engineering faculty of the Georgia Institute of Technology in January 1994 and moved to Kansas State University in 2002.

Position Statement

The development of sustainable energy sources requires an appreciation for and integration of the entire supply chain of these systems. Sustainability must encompass not only the technical aspects of the question but the economic and social implications as well. Within the field of biorefining or bioenergy, one must consider questions relating to sustainability of the agricultural fields where biomass is produced; the processes used to harvest, transport, and convert the biomass to fuels and chemicals; the rural communities which host the agricultural production sites and perhaps the conversion facilities; and the global carbon balance that utilizes carbon dioxide as a feedstock for the production of biomass but also produces greenhouse gases. Furthermore, while monitoring carbon dioxide is valuable, other greenhouse gases (including nitrous oxide emitted from fertilizer) and the sustainability of soils and water are equally important. At Kansas State University, Dr. Rezac is leading a group to study these questions. Dr. Rezac serves as the PI of the NSF IGERT project, From Crops to Commuting: Integrating the Socioeconomic, Technical and Agricultural Aspects of Renewable and Sustainable Biorefining which includes researchers from nine departments in three colleges and partners from five continents.

Alan Rossiter, Ph.D.
Founder and President
Rossiter & Associates
Bellaire, Texas

Biographical Sketch

Alan Rossiter is the founder and president of Rossiter & Associates (Bellaire, Texas), a process improvement consulting company working primarily in the field of industrial energy efficiency. He served as a consultant to ExxonMobil for both their GEMS (Global Energy Management System) and POEMS (Production Operations Energy Management System) programs from 1998 to 2010. He has also provided consulting services to numerous other industry majors, including ConocoPhillips, Sasol, LyondellBasell, BP, Valero and Hess.

Alan was born and raised in Rhodesia (now Zimbabwe), and received his B.A., M.Eng. and Ph.D., all in chemical engineering, from the University of Cambridge, England. He has more than 30 years of process engineering and management experience. He worked with ICI (Imperial Chemical Industries) for nine years in process design, technical support and research, before joining Linnhoff March (energy efficiency consultants), where he led consulting projects for eight years. He founded Rossiter and Associates in 1997.

Alan has more than 60 publications, including the ‘Energy Management’ article in the Kirk-Othmer Encyclopedia of Chemical Technology, 5th Edition (John Wiley & Sons, 2005), and the book “Waste Minimization through Process Design,” (McGraw-Hill, New York, 1995) for which he served as editor. He was the 2010 Chair of the South Texas Section of the American Institute of Chemical Engineers, and he is the current Chair of the AIChE Southwest Process Technology Conference.

Position Statement

The concept of sustainability has come a long way in recent years. It merges energy efficiency, pollution prevention/waste minimization, social responsibility and profitability into a unified whole, and sets lofty goals for industry. I feel privileged to be a part of this effort, and specifically the Roadmap Workshop on Sustainable Manufacturing.

Over the years my work has mostly focused on energy efficiency, with some ventures into broader aspects of waste minimization. As a consultant I have been able to see the realities of applying waste reduction and energy efficiency programs in both process design and plant operation. These activities can be drastically different from the ideas that are conceived in academia. Capital is always constrained, data is never complete, personnel are invariably over-committed, and commercial factors trump all other considerations.

Most of the sustainability work in industry relies on the insights and experience of engineers, supported by simulations, plant data historians, supply chain software and other computerized systems. I have seen many great successes – for example, simple heat integration projects and comprehensive real-time optimization systems that are saving millions of dollars each year while also helping to reduce energy demands and eliminate waste. However, there is still much to be done to establish a sustainability culture and a more comprehensive toolbox for sustainable engineering. This is the challenge that confronts us.

Clayton Sadler
Manager, Process Design Development
UOP LLC
Des Plaines, Illinois

Biographical Sketch

Clayton Sadler is currently the manager of the Process Design Development group within UOP's Research and Development organization. This group develops engineering solutions for new refining, petrochemical, renewable and gas processing technologies from their inception in

R&D through commercialization. He has 18 years of experience with UOP and has held positions in R&D, Engineering, Field Operating Services and Optimization Services. Clayton holds a Bachelor of Science degree in chemical engineering from the University of Wisconsin.

Position Statement

UOP is dedicated to developing innovative technologies that meet the current and future needs of our customers. Client requirements are varied and span the range of sustainability dimensions. The process design development function at UOP integrates state of the art simulation and modeling capabilities to synthesize, optimize and design process technologies that maximize customer value. In addition, these capabilities are further leveraged to identify new directions for R&D.

Darlene S. Schuster, Ph.D.
Executive Director
The Institute for Sustainability
AIChE

Biographical Sketch

Darlene Schuster serves as the Executive Director of the Institute for Sustainability an AIChE Technological Communities and oversees the operations of the AIChE Industry Technology efforts in Energy (Center for Energy Initiatives), Water (International Society for Water Solutions) and Biological engineering (Society for Biological Engineering).

Previously, she served as a Science Policy Fellow for the American Chemical Society, where she worked to educate congressional staff and Congress on technical policy issues. Dr. Schuster held the Clare Boothe Luce Chair of Chemical Engineering at Bucknell University, and held various engineering positions with Gulf Oil Research and Development company, which subsequently became Chevron Oil Field Research Company. As a professor, Dr. Schuster integrated design methodology and systems analysis into the undergraduate courses on chemical kinetics and reactor design, process control, statistics, and transport phenomena , and incorporated societal ethics with engineering design courses, and was the coordinator of the team taught multidisciplinary freshman engineering course. She developed and introduced graduate level courses on her research areas related to oil production, fluidization, and particle technology. She also coordinated the team taught, multidisciplinary freshman engineering program. Additional energy research projects addressed enhancement of waxy and heavy oil domestic production (i.e. upstream flow assurance), and advancing technologies for produced water/oil separations and three phase flow measurements applicable to produced oil streams. She has been the PI or co-PI on multiple funded research and development projects. Dr. Schuster was also awarded the 2004 Technical Achievement Award from the Pennsylvania Engineers Council in part for contributions to novel technology product development and commercialization by her company, DP Enterprises Group, Inc. She is also a member of NeuroSpine Ventures, LLC, an angel investment group specializing on medical technology start-ups. She holds a BSChE (WVU), MSChE (University of Pittsburgh),and PhD. (West Virginia University).

Position Statement

When discussing Sustainable Manufacturing, it is important to address what is it we are trying to sustain—the enterprise, the process, the environment and/or the workforce and society? Optimization and tradeoffs are often inevitable when looking at the triple bottom line of economics, environment and society. Key metrics are needed to help with the optimization. In this regard, total cost thinking and analysis is a very appropriate and useful approach. Total Cost Assessment was developed in 1991 by the Tellus Institute for the EPA and New Jersey Department of Environmental Protection. It is based on methods and programs developed by GE to better select and justify waste management investment decisions that are environmentally sound and reduce long-term liabilities. A sequence of studies provided the theoretical background for Total Cost Assessment. Later, the AIChE developed a full methodology around the TCA concept. The AIChE methodology for Total Cost Assessment is the consideration of all environmental and health (E&H) (and begins to include societal) costs associated with a decision, including direct costs, risks and liabilities, and costs borne by others. The TCA methodology prompts the user to consider all these costs, but the user may also select a subset of costs to consider.

§ Direct costs (recurring and non-recurring) Manufacturing site costs; capital investment, labor, raw materials, and waste disposal costs; capital, operating, and maintenance costs.

§ Indirect costs (recurring and non-recurring) Corporate and manufacturing overhead costs not directly allocated to product or process.

§ Future and contingent liability costs Costs including fines and penalties caused by non-compliance; clean-up, personal injury and property damage lawsuits; natural resource damages; industrial accident costs.

§ Intangible internal costs (Company-paid) Includes difficult-to-measure costs such as promoting consumer acceptance, customer loyalty, worker morale, worker wellness, union relations, corporate image, and community relations.

§ External costs (Not directly paid by company) Costs borne by society, including deterioration of the environment by pollutant dispersions that comply with applicable regulations.

Jeffrey R. Seay, PhD, PE
Assistant Professor
Department of Chemical and Materials Engineering
University of Kentucky
Paducah, Kentucky 42001

Biographical Sketch

Dr. Jeffrey Seay is Assistant Professor of Chemical and Materials Engineering at the University of Kentucky College of Engineering Paducah Extended Campus program. Dr. Seay joined the University of Kentucky in 2008 after a 12 year career as a process engineer in the chemical industry. His research interests include the integration of sustainable biomass supply chains with thermochemical modeling of biomass utilization processes as well as the application of appropriate technology to the production of biofuels in underdeveloped regions. Dr. Seay leads the University of Kentucky Appropriate Technology and Sustainability (UKATS) research group at UK. Dr. Seay is the past Education Committee Chair for the AIChE Sustainable Engineering Forum (2009 – 2011) and the current SEF Vice-Chair, rising to Chair in 2014. In the last several years he has served on the organizing committee for several international sustainability focused conferences. Dr. Seay is the recipient of the inaugural recipient of the AIChE SEF Sustainability Education Award (2013) and has been awarded the Outstanding Teaching Award in Chemical Engineering at the University of Kentucky (2013). Dr. Seay has a BS from Auburn University (1996), an MS from the University of South Alabama (2005) and a PhD from Auburn University, all in chemical engineering.

Position Statement

Sustainability is a critical skill for graduating chemical engineers entering the work force. As such it is critical that sustainability concepts be integrated into the core curriculum of chemical engineering programs across the country. In additional to technical and analytical tools, students must also be able to evaluate the societal impacts of their design decisions. For practicing engineers, it is important to develop competencies in the tools of sustainability. Dr. Seay has developed and presented several professional development courses aimed at introducing working professional to the tools and concepts of sustainability.

In addition to education, developing renewable process for underdeveloped regions is critical to meet the growing energy crisis worldwide. Dr. Seay's research group is focused on developing sustainable, renewable energy solutions for underdeveloped regions, particularly sub-Saharan Africa. His group has collaborated with the African Center for Renewable Energy and Sustainable Technology (ACREST) in Cameroon to develop a sustainable process for producing biodiesel from locally available resources. In addition his group is working to develop metric to evaluating the impacts for renewable energy processes in developing regions. Dr. Seay is a past faculty advisor to two US EPA funded People, Prosperity and the Planet projects focused on sustainable biofuel.

Dusan P. Sekulic
G.J. Morris Professor
Department of Mechanical Engineering
University of Kentucky
Lexington, KY

Biographical Sketch

Professor Dusan P. Sekulic holds the Secat J.G. Morris Aluminum Professorship at the College of Engineering, Department of Mechanical Engineering, University of Kentucky, Lexington, U.S.A. Dr. Sekulic is also a professor at the Harbin Institute of Technology as well as the University of Belgrade. Professor Sekulic is Fellow of the American Society of Mechanical Engineers. Dr. Sekulic's professional interests are in transport phenomena in (i) materials processing for manufacturing, in particular related to bonding processes, brazing and soldering, (ii) thermodynamics and sustainability, and (iii) theory and design for manufacturing of heat transfer devices. Dr. Sekulic's and his co-authors' books on these topics, i.e., heat exchanger design, thermodynamics and destruction of resources, and science, technology and applications of brazing, have been published by Wiley, USA; The Cambridge University Press, Cambridge, United Kingdom; China Machine Press, Beijing, China; and Woodhead Publishing, Cambridge, United Kingdom, respectively.

Position Statement

Multifaceted aspects of many problems associated with sustainable development inherently require problem framing within the context of multiple disciplines. This is in particular apparent in the domain of what has been termed sustainable manufacturing. The associated problem of the related analysis is that many of such problems have been considered through partitioning (of what we call a wicked problem) into multiple (tame) problems, distributed within a set of disciplines. This analysis step, however, requires a rigorous system definition and recognition of an adequate positioning of the system boundary to uncover the adequate set of interactions.

It is of a great concern that many attempts to approach such a rigorous definition in a study of a particular problem, to perform the analysis, and to devise a solution of such a problem, often involves a marginal attention to the system definition. Equaly important is a realization that sustainability represents a particular state of the system. Hence, there is an urgent need to approach a study of sustainability, including sustainable manufacturing, with much more rigor. Moreover, claims about “sustainable processes”, “sustainable products”, and even “sustainable manufacturing” may be devoid of full meaning if an inadequate boundary of the ill-defined system is promoted.

I would argue that sustainability is not a new problem of humanity. It has been manifested multiple times within the scope of different populations and it has been associated with different problems and/or systems. What is new is a need to attack the problem of human impact at the global scale. In that context, partitioning the problem of sustainable development deserves more attention.

Jeffrey J. Siirola
Eastman Chemical (Retired)
Kingsport TN 37660
Purdue University
West Lafayette IN 47907
Carnegie Mellon University
Pittsburgh PA 15213

Biographical Sketch

Jeff Siirola retired in 2011 as a Technology Fellow at Eastman Chemical Company in Kingsport Tennessee where he had been for more than 39 years. He now holds half time positions as Professor of Engineering Practice at Purdue University and Distinguished Service Professor of Sustainable Energy Systems at Carnegie Mellon University. Siirola received a BS in chemical engineering from the University of Utah in 1967 and a PhD in chemical engineering from the University of Wisconsin-Madison in 1970. His areas of interest include chemical process synthesis, computer-aided conceptual process engineering, design theory and methodology, chemical process development and technology assessment, resource conservation and recovery, sustainable development and growth, carbon management, and chemical engineering education. Siirola is currently Secretary and a member of the Executive Committee of ABET and a trustee and past president of CACHE (Computer Aids for Chemical Engineering Education). Siirola is a member of the National Academy of Engineering and was the 2005 President of the American Institute of Chemical Engineers.

Position Statement

Controlling carbon emissions is perhaps the most critical sustainability challenge. Carbon dioxide from heat and power generation is the principal source of carbon emissions from the chemicals production industries. Although various technologies for carbon capture and storage are being developed, none is at the present time economically competitive in the absence of universal mandating regulations. In the meantime, alternative carbon emissions reduction strategies should be considered, but all face difficult challenges. One approach is energy conservation or minimization. However process retrofits are difficult to justify economically in the absence of increased production. And paradoxically energy-optimal design alternatives for new plants generally do not change even with increasing energy prices (or taxes), as new equipment capital costs tend to increase linearly with increased energy process. Other approaches to lower net carbon emissions include use of biomass for chemical process energy (limited by availability, sparseness, and gathering transportation costs), other renewable sources including solar and wind (limited by extreme variability and poor match with chemical processing energy needs), and nuclear (limited by public acceptance, inexperience with nuclear as a source of process heat, isolation and security concerns, and unique configurations to give the service reliability required for chemicals production). Yet another route to lower carbon emissions is to where possible substitute increasingly available and affordable natural gas for oil and coal for heat and power generation for chemicals production. This option is relatively easy to implement with minimal capital expenditure, although some degradation in boiler performance should be expected. However, for new equipment especially incorporating advanced natural gas combined cycles, even greater thermodynamic efficiencies and carbon emissions reductions could be expected. Finally, although sustainability issues are often a focus when choosing and optimizing among alternatives and conditions in the design phase of chemical processes, they are rarely direct objectives in the operation and control of the resulting processes. Rather, energy and raw material consumption and emissions and waste disposal are often the independent variables manipulated to reject process disturbances and to maintain production rate, product quality, and other fitness-for-use attributes. Smart or intelligent manufacturing would allow an increased emphasis on the control and optimization of sustainability issues including carbon emissions during process operations. This could involve the installation of many additional process sensors, complex real-time computer algorithms to analyze, interpret, and propose action based on this additional process information, and process design modifications to generate additional degrees of freedom to enable operational manipulation to directly optimize sustainability parameters in addition to the usual business objectives of production rate, cost, and product fitness-for-use.

Subhas K. Sikdar, Ph.D.
Associate Director for Science
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
26 W. M.L. King Dr., Cincinnati, OH 45268

Biographical Sketch

Subhas Sikdar is the Associate Director for Science at EPA's National Risk Management Research Laboratory. From 1990 until 2000, he held the positions of Director, Water and Hazardous Waste Treatment research Division and Sustainable Technology Technology Division, respectively at the same laboratory. In his present capacity he oversees science quality of research done in the Laboratory. Prior to joining EPA, he held management positions at the National Institute of Standards and Technology (1984-1990) in Boulder, Colorado, and at General Electric Corporate Research and Development Center in Schenectady, New York (1979-1984). He started his career in 1975 as a Senior Research Engineer at Occidental Research Corporation in Irvine, California. He completed his Ph.D. in chemical engineering in 1975 from the University of Arizona, Tucson. At EPA he championed technical approaches of pollution prevention and sustainability for twenty years. He founded a NATO Pilot Project on Clean Products and Processes in 1988 and led this pilot over 11 years and held meetings in various European cities of up to 27 member countries, and produced reports that are available from NATO. He also founded a journal (Editor-in-Chief)h , Clean Technologies and Environmental Policy (Springer), which is in its 15th year of publication now. He has edited 14 books and published more than 80 archival papers in peer-reviewed publications. He has 27 U.S. patents awarded to him. Subhas Sikdar was elected Fellow of American Association for the Advancement of Science, American Institute of Chemical Engineering, American Chemical Society, and Indian Institute of Chemical Engineering. He has won several awards from EPA and AIChE.

Raymond L. Smith
Chemical Engineer
Lead, Sustainable Supply Chain Design
U.S. Environmental Protection Agency
26 W. Martin Luther King Dr.
Cincinnati, OH 45268 USA

Biographical Sketch

Ray Smith is a Chemical Engineer within the Systems Analysis Branch, Sustainable Technology Division, of the Office of Research and Development at the U.S. EPA. He obtained his PhD in Chemical Engineering in the area of process design from the University of Massachusetts Amherst. Ray has worked for the EPA for 15 years with focus areas including life cycle assessment, biofuels, industrial ecology, process design, sustainability indicators, optimization, and decision making. He is currently a lead for the Sustainable Supply Chain Design team and is co-inventor and developer of the GREENSCOPE process sustainability methodology and tool. Within the American Institute of Chemical Engineers Ray has held volunteer positions including Local Section Chair, Membership Committee Chair of the Sustainable Engineering Forum, and most recently Chair of the Environmental Division. He is on the board of AIChE's Center for Energy Initiatives and serves on the editorial board of the journal *Environmental Progress & Sustainable Energy*.

Position Statement

Sustainable manufacturing can be a complex multifaceted endeavor. Anyone choosing to design or operate their manufacturing process or supply chain in a more sustainable way needs to define what that means. One's perspective can be very influential in determining what more sustainable means. From an operator's unit operation to a manager's supply chain and product network (or from product conception to delivery of substantial quantities), the need for an appropriate problem statement (i.e., set of objectives) and method of analysis for the decision context are critical to the pursuit of sustainable manufacturing. One might design and optimize on certain criteria, or pursue a life cycle assessment to inform decisions. In each case the criteria need to be matched with analyses and associated data needs. In a specific case, that for process development and design, we at the U.S. EPA have developed the GREENSCOPE methodology and tool to offer ~140 indicators in four bases: environment, economics, efficiency, and energy. The indicators chosen for analysis represent value choices, as do any weights (either written out explicitly or noted mentally) placed on the indicators. Specific data used in calculating these indicators are required (either measured or approximated) so that analyses can be performed. While we do not propose what the weights should be for the various indicators, the process of trading off various aspects in a complex multifaceted process or supply chain does occur, and understanding the objectives, analyses, data needs, and tradeoffs can lead to more sustainable manufacturing.

David N. Thompson
Distinguished Staff Engineer
Biological and Chemical Processing
Idaho National Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-3570

Biographical Sketch

Dr. David N. Thompson is a Distinguished Staff Engineer at the Idaho National Laboratory, where he directs research teams working on cutting edge research in the areas of biological transformations of renewable feedstocks for processing to value-added biofuels, biochemicals and bioproducts. His research and development focus is on collaborative interdisciplinary projects at the intersection of basic and applied science/engineering. Since coming to the Idaho National Laboratory (INL) in 1995, he has worked to develop and improve distributed methods for handling and processing renewable feedstocks, including industrial, municipal, and forest products process effluents and wastewaters, and renewable lignocellulosic agricultural residues such as cereal straws and corn stover. In other applications, he has applied biodegradation of lignocellulosics to the distributed bioremediation of acid mine drainage and to the biofiltration of volatile organic contaminants. He has served on project teams whose work has twice been nominated for R&D 100 Awards, winning in 2006. He is a co-inventor on nearly 30 patents and several pending U.S. and international applications. He is author or co-author of 31 peer reviewed journal articles and more than 110 reports, technical presentations, and other publications. He serves on the Advisory Board of the Forest Bioproducts Research Institute at the University of Maine, and is the current Chair of the AIChE Sustainable Engineering Forum (Group 23). He is a past programming chair of Area 15c (Bioengineering) and Area 23b (Sustainable Biorefineries) in AIChE, and also past chair of the Sustainable Biorefineries Topical Conference at the AIChE Annual Meeting. He served on the Organizing Committee of the annual Symposium on Biotechnology for Fuels and Chemicals from 2002-2011. Dr. Thompson holds a B.S. degree from Purdue University, in 1987, and M.S. and Ph.D. degrees from Michigan State University, in 1989 and 1994, respectively, all in chemical engineering.

Position Statement

With the recent discussions of a potentially impending peak in worldwide oil production, the search for alternative energy sources has intensified. Because of the severe social and economic impacts derived from high oil prices, there is a strong driver to develop economically competitive technologies and processes that can compete with fossil fuels over a wide range of energy prices. Further, the ecological significance of shifting dependence on oil to other fossil fuels including coal, natural gas, methane hydrates, etc. increases carbon dioxide emissions and avoids development of a truly sustainable energy supply that can be passed on to future generations. Beyond the development of technologies that are economically competitive with oil and other fossil energy options, it is important that solutions to the energy problem be sustainable with regard to a number of factors. When one traditionally considers sustainability from a technological sense, the factors that immediately come to mind include sustainable resource utilization (e.g. efficiency of water and energy use), wastewater treatment and reuse, and greenhouse gas emissions. There are also additional important economic, environmental, and social factors that are equally important to consider. Economic sustainability may depend on such factors as current and future product values, availability and cost of feedstocks, availability and cost of energy, product mix, net income, job creation, and others. Besides greenhouse gas impacts, environmental sustainability may depend on factors such as the net energy balance, other environmental impacts, effects on wildlife habitats, and competition for resources and land. Social sustainability may depend on health impacts, impacts related to industrial development, and the development of a workforce skilled in the operation of the needed technologies. As we move forward with the development and commercialization of biorefineries, each of the above factors must be considered. Additional factors that will impact the development of biorefineries and renewable energy in general include climate change, global politics, resource constraints, and the health of both regional and global economies. In each case, sustainability will play a key role in the success or failure of the biorefinery concept for the future.

Graham Thorsteinson
Cereal Division Energy Leader
General Mills Inc
Covington, GA

Biographical Sketch

Graham has worked for General Mills for 6 years, predominantly on energy reduction with additional experience in project engineering and reliability engineering. Graham has delivered a total of $5,000,000 in energy savings at one General Mills cereal plant including a 29% BTU per pound of product reduction. As the first Energy Engineer in the company, Graham advocated to senior leadership to hire energy engineers in all 7 cereal plants, and he now leads this team. He developed the 5 Step Energy Reduction Process for this team to follow, which has resulted in $3,700,000 in savings in one year including a 8% BTU/lb reduction for the cereal division, with similar results expected over the next couple years. This significantly exceeded the 1.4% reduction per year that the division has averaged since 2005. The energy reduction program is being rolled out to another division this year with a plan to eventually cover entire supply chain, further proliferating the savings.

Position Statement

Energy reduction in an industrial setting is a huge opportunity that is largely untapped. A focus on energy reduction in General Mills has paid significant dividends. The first step in reduction is engaging a dedicated resource and proper sub metering of the facility's largest energy users. This leads itself into understanding the energy map of the facility. The next step is to conduct deep dive optimizations of large energy users and then redeploy the learnings across similar unit operations in the facilities. The key to success is developing a tool set to make the redeployment as easy as possible, including all solutions and calculations. Lastly, in order to sustain results, energy needs to be viewed as an ingredient in every step of the process. It should be tracked that way and managed that way real time against production numbers instead of looking at monthly bills.

Jim Wetzel
Technical Director
System Engineering and Platform Reliability
General Mills Inc.
Minneapolis, MN

Biographical Sketch

Jim is currently the Technical Director –System Engineering, Reliability Engineering, Platform Center of Excellence and Maintenance at General Mills Inc. He has 34 years of industry experience, starting with 6 years in the Plastics Industry and 28 years in the Food Industry with GMI. While at General Mills, Jim has had roles in proprietary machine design, Manufacturing System Improvement and Optimization, Cheerios and Wheaties Product Improvement, System Engineering, Control System Application Development, MES Application Development and Platform Center of Excellence.

In Jim's current role he is responsible for improving the existing asset base in GMI Manufacturing Plants across the Globe. (Specifically centered on our strategic operating platforms) Our mission is to improve, extend and sustain our assets. This function is responsible for platform technology and standardization, energy and water reduction, system engineering, reliability engineering and maintenance. It was newly formed in June, 2012. In addition, Jim is responsible for developing the technical mastery for all of engineering.

In Jim's most recent role he was responsible for Manufacturing Execution Systems, Enterprise Manufacturing Intelligence, Maintenance Applications, Engineering Tools (Enterprise project and portfolio management, Process Simulation and Sharepoint /Collaboration for the Technical Community), Control and Information Technical Innovation and Next Generation Application Architecture.

Jim is an Executive Board member of the SMLC, Smart Manufacturing Leadership Coalition.

Position Statement

Our focus in GMI Sustainability is to reduce our environmental footprint and drive business results. We have established aggressive 10 year goals FY2005 - 2015 . (Energy, GHG and Water 20% reductions). In order to achieve these reductions we have focused our efforts where we can have the greatest impact, both within our operations and outside of the them, primarily in agriculture and ingredient production.

Inside of GMI Supply Chain my team has focused on Manfacturing. The largest single factor is cultural. We must consider Energy and Water as ingredients to our product, not just utilities. When they are treated with the same dilengence as valued consumables you begin to develop strategies and solutions to optimize their use/consumption. At GMI we have developed a 5 step process to reduce the consumption of Energy. Last year alone we drove the reduction in energy by 8% in our cereal division. Through this process we systematically analyze energy use at each facility, line, unit operation and develop standardized improvement plans that are redeployed across the organization.

Fengqi You
Assistant Professor
Department of Chemical and Biological Engineering
Northwestern University
Evanston, IL 60208-3120, USA

Biographical Sketch

Fengqi You is an Assistant Professor of Chemical and Biological Engineering at Northwestern University. His research focuses on the development of novel computational models, optimization techniques and systems analysis & design methods for process systems engineering, energy systems and sustainability. His research accomplishments have been highlighted by multiple news media and journal covers, as well as publications in high-impact journals. He received several competitive awards, including the W. David Smith, Jr. Award from AIChE, the Director's Fellowship from Argonne National Laboratory and the 2013 Northwestern-Argonne Early Career Investigator Award. Fengqi You received his PhD from Carnegie Mellon University in 2009 and a BS from Tsinghua University in 2005, both in chemical engineering. From 2009 to 2011, he was an Argonne Scholar at Argonne National Laboratory before joining the faculty of Northwestern University in 2011.

Position Statement

The process – energy – environmental systems engineering (PEESE) lab directed by Fengqi You has been actively investigating a number of practical and fundamentally important problems in sustainable engineering. On-going research activities involve (1) Sustainable design and synthesis of chemical processes and energy systems, including biomass-to-biofuels processes and carbon capture and utilization; (2) Sustainable manufacturing, sustainable operations (planning & scheduling) and control of manufacturing systems, (3) Life cycle energy, environmental, and economic systems analysis and optimization of manufacturing/energy supply chains, and (4) Sustainability analysis of nanotechnology and advanced materials, e.g. organic photovoltaics and biomass-based chemical products (in collaboration with Argonne National Laboratory).