Sustainable Manufacturing Advances in
Research and Technology (SMART) Coordination Network

Roadmap Workshop on Sustainable Manufacturing

Kingsgate Marriott, Cincinnati, OH
August 15-16, 2013

Workshop Preparation Package

1.0 Setting the Stage

The Sustainable Manufacturing Advances in Research and Technology Coordination Network (SMART CN) project seeks to build a roadmap as a foundation for sustainable manufacturing. To that end, a workshop will be held at the Kingsgate Marriott Hotel in Cincinnati, OH, on August 15 and 16, 2013. The workshop will begin at noon on the 15th and end at 3:00 p.m. on the 16th.

In 2011, a partnership of multiple universities, operating under a banner of a not-for-profit organization called CACHE Corporation, received a five-year grant from the National Science Foundation to establish the SMART Coordination Network. The premise of the project is that:

- The U.S. manufacturing sector is greatly challenged as global competition has moved away from large-scale cheap labor to advanced manufacturing techniques.
- Energy and environmental issues, such the availability and cost of petroleum and greenhouse gas constraints, heighten the pressures.
- In academia, issues such as engineering sustainability, advanced manufacturing theory, and alternative energy and biofuels have become active research areas.
- The awareness of related work and the coordination and collaboration of ongoing work is inadequate.

To bridge the gap between the academic knowledge discovery and industrial technology innovation for sustainable manufacturing, we have created an interdisciplinary, international research coordination network to promote SMART. SMART reflects the theme of the joint effort among a number of leading academic laboratories, centers, non-government organizations, and major manufacturing industries.

During this project, we will 1) conduct a comprehensive review of leading-edge research and technological development for sustainable manufacturing; 2) define a roadmap towards manufacturing sustainability and identify the bottlenecks in selected research areas via several workshops; 3) coordinate research through sharing of knowledge, resources, software, and results; 4) establish partnerships with industrial groups to expedite technology introduction; and 5) conduct education and outreach to a wide range of stakeholders.

The SMART CN collaboration is guided by a Principal Investigator (PI), four Co-PIs, and a Steering Committee selected from the leaders of the sustainable manufacturing academic community. The Steering Committee was selected with a strong emphasis on diversity of expertise and assuring broad coverage of the sustainable manufacturing domain. The committee is bolstered by collaboration with researchers from six other countries (Table 1).

Table 1. The SMART CN Steering Committee and Collaborators

Steering Committee Members		
Name	**Affiliation**	**Expertise**
Allen, David	University of Texas	• Atmospheric chemistry, green engineering
Bakshi, Bhavik	Ohio State University	• Industrial ecology, energy analysis, LCA
Davidson, Cliff (Co-PI)	Syracuse University	• Aerosol physics, sustainable engineering
Eden, Mario (Co-PI)	Auburn University	• Process and product design, biorefineries
Edgar, T. (Co-PI)	University of Texas	• Process control, smart manufacturing, smart grids
El-Halwagi, Mahmoud (Co-PI)	Texas A&M University	• Process and product design, process integration
English, Burton	University of Tennessee	• Economics and policy, biomass and feedstocks
Fasenfest, David	Wayne State University	• Sociology, labor and workforce development
Grossman, Ignacio	Carnegie Mellon University	• Enterprise-wide optimization, process/water/energy systems
High, Karen	Oklahoma State U.	• Environmentally benign process design, K-12 outreach
Huang, Yinlun (PI)	Wayne State University	• Engineering sustainability, multiscale system integration
Jawahir, Ihrahim S.	U. Kentucky	• Manufacturing process, computer integrated manufacturing
Maravelias, Christos	University of Wisconsin	• Supply chain management, production scheduling
Ogden, Kim	University of Arizona	• Feedstock, biofuel manufacturing, K-12 outreach
Rezac, Mary	Kansas State University	• Sustainable bioenergy, biorefineries
Shadman, Farhang	University of Arizona	• Environmentally benign semiconductor manufacturing
International Collaborators		
Gani, Rafiqul	Tech. University of Denmark, Denmark	• Computer-aided design, process sustainability
Hertwich, Edgar	Norwegian University of Science & Tech., Norway	• Energy systems, greenhouse gas analysis, risk analysis
Hu, Shanyin	Tsinghua University, China	• Industrial ecology, industrial park evaluation
Jin, Qun	Waseda University,	• Computing sustainability, informatics&

	Japan	networking
Karimi, Iftekhar A.	National University of Singapore, Singapore	• Production scheduling, biomass systems
Lee, Jay H.	KAIST, Korea	• Process modeling and control, energy systems
Qian, Yu	South China University of Technology, China	• Coal/biomass for energy production
Wozny, Gunter	Technical University of Berlin, Germany	• Process systems science, thermodynamic analysis

2.0 SMART CN COORDINATION

Working together for multiplied value in sustainable manufacturing is the mantra of SMART CN. Each of the Steering Committee members is coordinating their research activities for a comprehensive, multiscale integration of sustainability principles and methodologies into process-product-integrated manufacturing systems. The committee also is reaching out to the broader community to learn from the international collaborators and to bring the sustainable manufacturing community closer together, and is engaging the entire community in defining the path forward for a sustainable future.

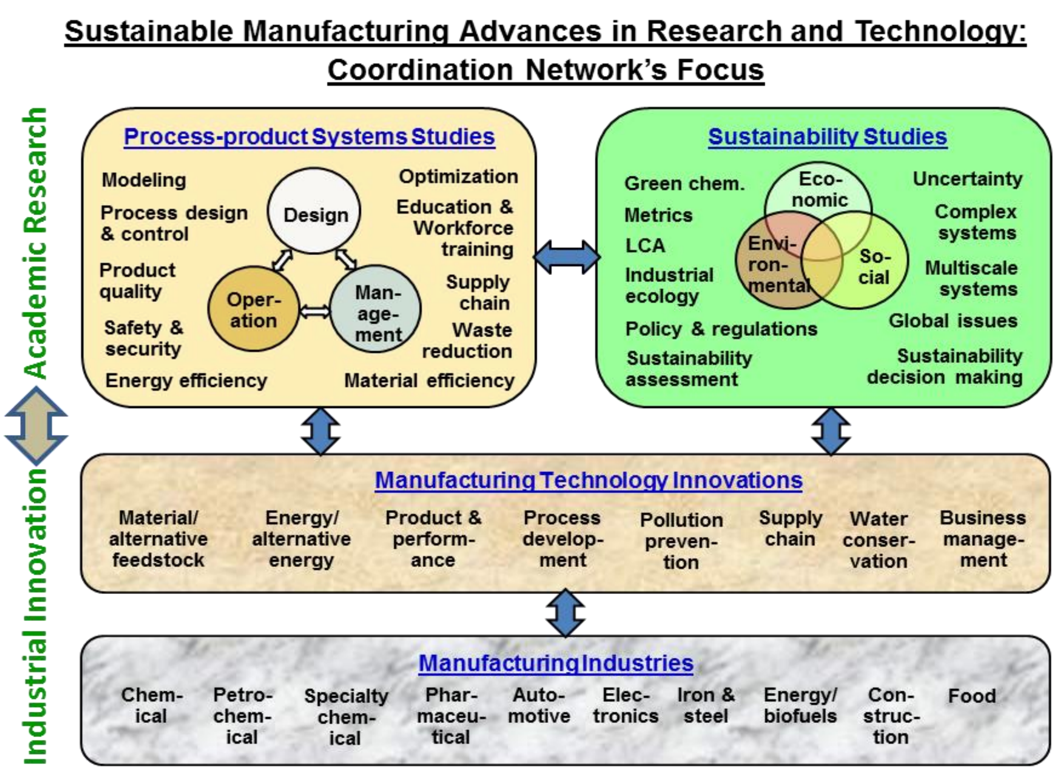

Figure 1: SMART CN presents a comprehensive approach to resolving sustainability issues. By considering the various perspectives and requirements, by understanding what's being done, by coordinating research and development activities, and by working together to coordinate activities, progress can be greatly accelerated.

To support the coordination activities, the Steering Committee analyzed existing roadmaps to build a structure for focusing the research efforts (Figure 1).

The areas of focus include:

Process-Product Systems Studies – This area addresses the integration of the design and optimization of products and processes, the conduct of manufacturing operations, and management of all the components of a sustainable manufacturing environment. This study area goes beyond the development of the best products and processes to include education and training, supply chain management, safety and security – the entire "system" of creating and managing products and processes, from requirements to supported products.

Sustainability Studies – All priorities in the manufacturing systems must be understood and balanced. The balanced equation addresses economic issues, environmental issues, and social consciousness and responsibility. This perspective addresses the consideration of the factors that must be integrated for sustainability and the tools that are needed to ensure understanding and balance.

Manufacturing Technology Innovations – The end goal of sustainability research is to achieve an economically competitive, environmentally benign, socially responsible, and technically advanced manufacturing environment. To meet this goal, new tools and technologies must be developed and applied. The systematic definition of the needs and a structured approach to meeting those needs through focused research is the message of this perspective.

Manufacturing Industries – The fourth area of emphasis addresses customer needs across different sectors. There are common needs and infrastructural capabilities that crosscut all sectors, and there are needs that intersect with other sectors wherein flexible solutions can be adapted to specific requirements. By considering the common needs of the sectors, efficiency in solutions can be realized.

3.0 Coordination Areas

Related to the four focus areas, and with consideration of the specific interests of the collaborators, SMART CN has defined four initial areas for coordinated research and collaboration. These areas are not all-inclusive, and they do not communicate any limit on collaborative topics. They provide examples of active and effective collaboration to stimulate additional inputs and leveraging opportunities for the workshop participants. By mapping existing research to a needs assessment and a roadmap, voids can be identified and solutions can be expedited.

1) Methodological Studies on Engineering Sustainability – Research is being done in a number of areas related to methodologies that support sustainable engineering and manufacturing. Multiscale assessment and decision making methods that include the quantification and impact of uncertainty are being developed and applied to support sustainable design and operations. Green chemistry/green engineering principles, methodologies, technologies, and tools are emerging. From the social science viewpoint, issues related to social responsibility, labor and human impacts in manufacturing, economic development impacts, and policy issues in the U.S., and in the global community, are being evaluated. Integration and coordination of these activities can lead to better and more mature theories and methodologies for sustainable manufacturing research.

2) Studies on Sustainable Design and Integration –Total product and process optimization demands that all perspectives be addressed. In today's research community, great work is being done in understanding the components of sustainable design, but integration of total value systems has yet to be achieved. Key areas of active research include:

- Environmental process design theories and optimization methods
- Process (mass and heat) integration
- Emerging material, product, and process development and design problem studies
- Sustainability metrics, assessment, and decision making for sustainable design.

3) Research in Sustainable Operation, System Management – Operational sustainability is a cornerstone of smart manufacturing that draws on significantly improved information and communication within and across manufacturing operations. Energy and material research is clearly important for operational efficiency and optimization. Production scheduling and planning, including the integration of product quality and process performance control methodology into the planning and execution processes, is critical to manufacturing optimization. The management of information access across the enterprise-wide supply chain, with assurance of the right information to the right location and information security, completes the operational requirements. By addressing operations holistically, the value of the research can be multiplied.

4) Energy and Alternative Energy Research – Natural gas, coal, and biomass-based energy are expected to play a dominant role in process industries in the future. Advanced combustion systems such as combined cycle can produce low-cost electricity at efficiencies higher than those of current power plants. Such facilities can be designed as near-zero discharge plants, with minimal emissions escaping into the environment. Carbon dioxide could be concentrated and disposed of in a geologically permanent manner or converted into industrially useful products. Research collaboration in this area includes:

- Sustainable cultivation of oleaginous microalgae
- Efficient methods for harvesting and extracting fuel feedstocks
- Integrated process to support widespread commercialization of value-added co-products resulting from algal biomass
- Integrated biorefineries
- Natural and biomass co-firing for power and transportation fuel development
- Strategic planning of biofuel manufacturing and coal-biomass co-fired transportation fuel and electricity production
- Sustainable grids – integrating and managing all viable forms of energy generation and management.

4.0 THE WORKSHOP

The August workshop is an important milestone in bringing the community together to create a roadmap for sustainable manufacturing. By building on the foundation of knowledge from existing roadmaps, and by bringing experts from around the world together in intense exploration, key challenges will be defined, a common vision will be established, and goals for realizing the vision will be captured. These goals define the pathways for success in achieving a pervasive awareness and practice in support of energy efficiency and environmental responsibility in every aspect of manufacturing. After the workshop, a document will be produced and be made available to all participating organizations.

As a foundation for the workshop, the Workshop Organizing Committee developed a functional model (Figure 2) to guide the gathering of information and provide a structure for the roadmap document. Three major areas are designated as the "pillars" of sustainable manufacturing: Technology Development, Process and Systems Management, and Enterprise Management, each with an underpinning set of subtopics. In addition, several crosscutting enablers must be considered in each area: Workforce Education and Management, Water Management and Air Quality, and Life Cycle Analysis and Design for Sustainability. These elements are defined in the following discussion.

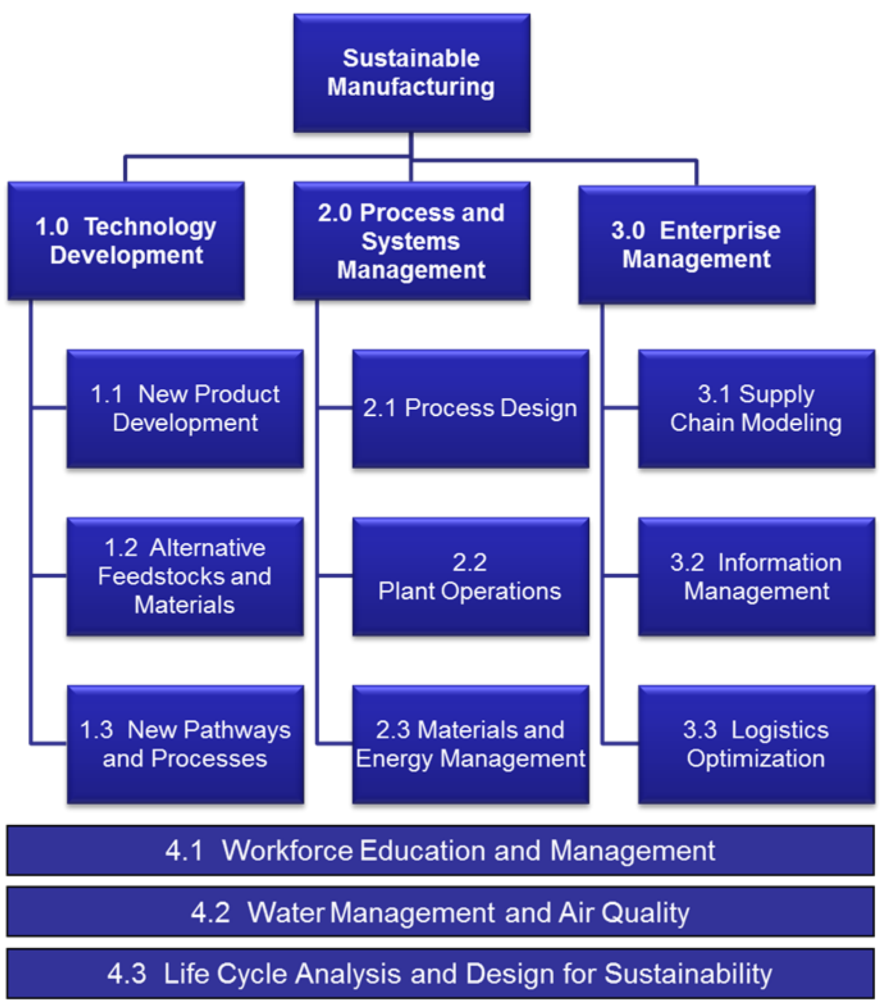

Figure 2. The functional model provides a logical framework to guide exploration and knowledge discovery in the workshop.

Pillar 1: Technology Development – Includes all activities associated with R&D in materials, products, and processes, with the intent to assure an efficient and sustainable manufacturing environment.

- **New Product Development –** Addresses the process by 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 genome 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.

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.

- **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.

Pillar 3: Enterprise Management – Includes all activities associated with assuring that the enterprise functions in a sustainable manner, including the allocation and management of resources to assure environmental responsible and energy efficiency.

- **Supply Chain Design and Management –** Embraces emerging modeling and simulation tools to enhance the understanding of the operation of the supply chain, identify opportunities for improvement, and support the evaluation of alternatives. Supply chain management is not limited to the analysis toolset, but includes the access to and use of data, information, and knowledge to support best decisions.
- **Information Management –** Supports the provision of the right and needed information, the assured access to that information at the right place and at the right time, and the assurance of information security.

- **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 in order to meet customer's requirements.

Three key cross-cutting enablers were identified that support each of the Pillars:

1) **Workforce Education and Management –** Includes all activities associated with providing a knowledgeable workforce and making use of that workforce. People are the most important asset in a manufacturing enterprise, and protecting and applying that asset is imperative for a sustainable future.
2) **Water Management and Air Quality** – Comprises all activities associated with assuring that water resources are not harmed and that air quality is not reduced.
3) **Life Cycle Analysis and Design for Sustainability –** Addresses the inclusion of sustainability factors early in the product and process development cycles. Starting with requirements definition, all activities that support product and process decisions include consideration of sustainability. Life-cycle analysis supports the decision process.

5.0 VISIONARY THOUGHTS CONCERNING THE KEY TOPICS

Recognizing that the task of the roadmap development workshop is a formidable one, the Workshop Organizing Committee contemplated the attributes of the future-state vision for each of the topics. The following is not a definitive list, but rather an initial capture of relevant ideas in each area to help stimulate the thought processes of the experts who will participate in the workshop.

1.0 Future Vision for Technology Development

1.1 New Product Development

- Simulation and modeling is the basis for new product development and improvement of existing products.
- A complete understanding of the structure/property/activity/functionality relationships enables informed design and development.
- 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 for are inclusive enough and generic enough to support multiple products and applications enabling standardization/harmonization of the assessment process.
- Quality by design – the ability to predict the quality of a product and lessen the length of the qualification process.

- 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.
- Virtual high-throughput screening of candidate products enables the evaluation of many options and the rapid selection of the best alternatives for further development.

1.2 Alternative Feedstocks and Materials

- The full understanding of the processes (chemical and molecular processes) supports the trading of biomass constituents as a product – enabling processes and products to be designed at the constituent level, enabling feedstock agnostic processing.
- Prevalent environmentally unsound materials are replaced by biodegradable products/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 and as chemical feedstocks are resolved, e.g., shale gas)
- A secure and sufficient supply of suitable feedstocks is assured. The assured supply will be compliance with requirements/needs for purity, utility, and price.

1.3 New Pathways and Processes

- New pathways and new pathway systems will enable the production of the same materials from different (more cost effective) 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.

2.0 Future Vision for Process and Systems Management

2.1 Process Design

- First principles understanding and molecular-based modeling are pervasive and support new and better methods of process design.
- Rapid synthesis, screening, selecting and designing of processes.
- Processes are designed and developed for optimized mass and energy efficiency.
- Process intensification to accomplish more with less footprint and 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 impact.
- The work process for design is automated, optimized and managed.
- All important attributes such as safety, air and water quality, all environmental issues 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 assure that the product is produced as required and as designed.

2.2 Plant Operations

- Plants are automated to the level of total value achievement and operate within a safety envelope.
- Just-in-time utility (energy/power) access assures continued and efficient operations.
- Enhanced mass and energy efficiency in operations (resulting in lessened downtime and lower cost performance).
- Pervasive, model-based operation including model-based control for plant-wide control.
- Systematic management of abnormal situations such as operational failures, disasters, safety issues, cyber and physical security, etc.
- Effective production scheduling for multiple-product plants.
- Integration and optimization across operating functions – assuring that the best total solutions are realized.
- Closed system operation including water.
- Elimination of waste.
- How do you design a small scale plant that is economically viable (including biofuels and natural gas?

2.3 Materials and Energy management

- 100% conversion of raw materials to desired products (no waste).
- All energy consumed will be renewable energy.
- Maximum heat and power integration.
- Cost effective energy storage is available enabling harnessing intermittent energy sources.
- Minimize/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).

- Industrial ecology and control through redundancy while preserving economies of scale.

3.0 Enterprise Management

3.1 Supply Chain Modeling

- Planning and scheduling is integrated for coordinated operation of the supply chain.
- Uncertainties are understood, quantified for robust operation of the supply chain.
- Supply chain disruptions are modeled and the supply chains are modeled for robust and resilient operation.
- Energy efficiency and environmental impacts are modeled and the linkages are established to enable balancing of the total value equation.
- Production planning and product distribution are coordinated to assure a match across the enterprise.
- Inventory management is optimized realizing near-zero inventory.
- Supply chain models interoperate to allow integrated optimization from extraction of raw material to delivery of all resulting products.

3.2 Information Management

- Information is transparent throughout the supply chain.
- Big data and data analytics enables access to all needed information and data to support supply chain modeling.
- Models and data connect the consumer to the realization process for the product, enabling exactly what is needed.
- Data and information that is needed for decision support is available, accurate, and accessible in useful formats.
- Statistical models, methods, and software extract knowledge from data sets and information files realizing the creation and capture of knowledge and wisdom including cloud sourcing and collective learning from big data.

3.3 Logistics Optimization

- The flow of material through the supply chain is perfectly matched between the supply side and the demand side minimizing wastes.
- Transportation systems are optimized to minimize emissions and achieve optimized energy efficiency.
- Optimal transportation of water for shale gas operations– yielding minimal impact.
- Robust and scalable technologies enable match seasonal feedstock availability to continuous product demands (enabling leveled operations across seasons and locations.

Cross-Cutting Enablers

1. Workforce Education and Management

- Workers graduating who are perfectly prepared for the jobs that they are pursuing, with a total 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.

2. Water Management and Air Quality

- Inclusion of societal externalities in overall production costs (holistic costing).
- Minimum water consumption and minimum chemical, biological and thermal pollution of the water.
- Eliminate contaminants emitted to the air.
- Greenhouse gas conversion to value added products.

3. Life-Cycle Analysis and Design for Sustainability

- Complete life-cycle analysis of every product and process– reflected in the design of that product and process.
- Widely and publicly available databases to support life-cycle analysis.
- Designs that are within ecological constraints.
- Standard and accepted metrics available to support sustainability assessment and support concrete conclusions/actions from those assessment.

6.0 Workshop Methodology

The workshop will be attended by invited experts who have extensive knowledge to lend to the sustainable manufacturing discussion. Therefore, the agenda will maximize the time for small-group exploration and capture.

The functional model will be used to guide the process. Small groups will address the three major areas. For each topic and sub-topic, plus the Crosscutting Enablers, three categories will be explored:

1. **Vision –** By "standing in the future" and defining what might constitute ultimate success, the attributes of the perfect state will be captured and used to create group consensus concerning the future state.
2. **Barriers and Challenges –** This category explores the hindrances that must be addressed and overcome. Consideration should be given to deficiencies in our present capabilities, the present state of practice, and emerging solutions that point to the ultimate successes.
3. **Goals –** These are the critical capabilities that must be in place to realize the vision. As time allows, the goals will be fleshed out to define a notional project slate to deliver the defined critical capabilities.

The workshop process will seek to maximize knowledge capture and ensure that all participants have an equal opportunity to share. This will be accomplished by introducing a topic area and sequentially accepting input until that topic is fully explored. All participants are urged to respect the fact that there will be much to do in a very short time and to cooperate with concise statements and succinct, focused explanation.

The flow of the workshop is illustrated in Figure 3.

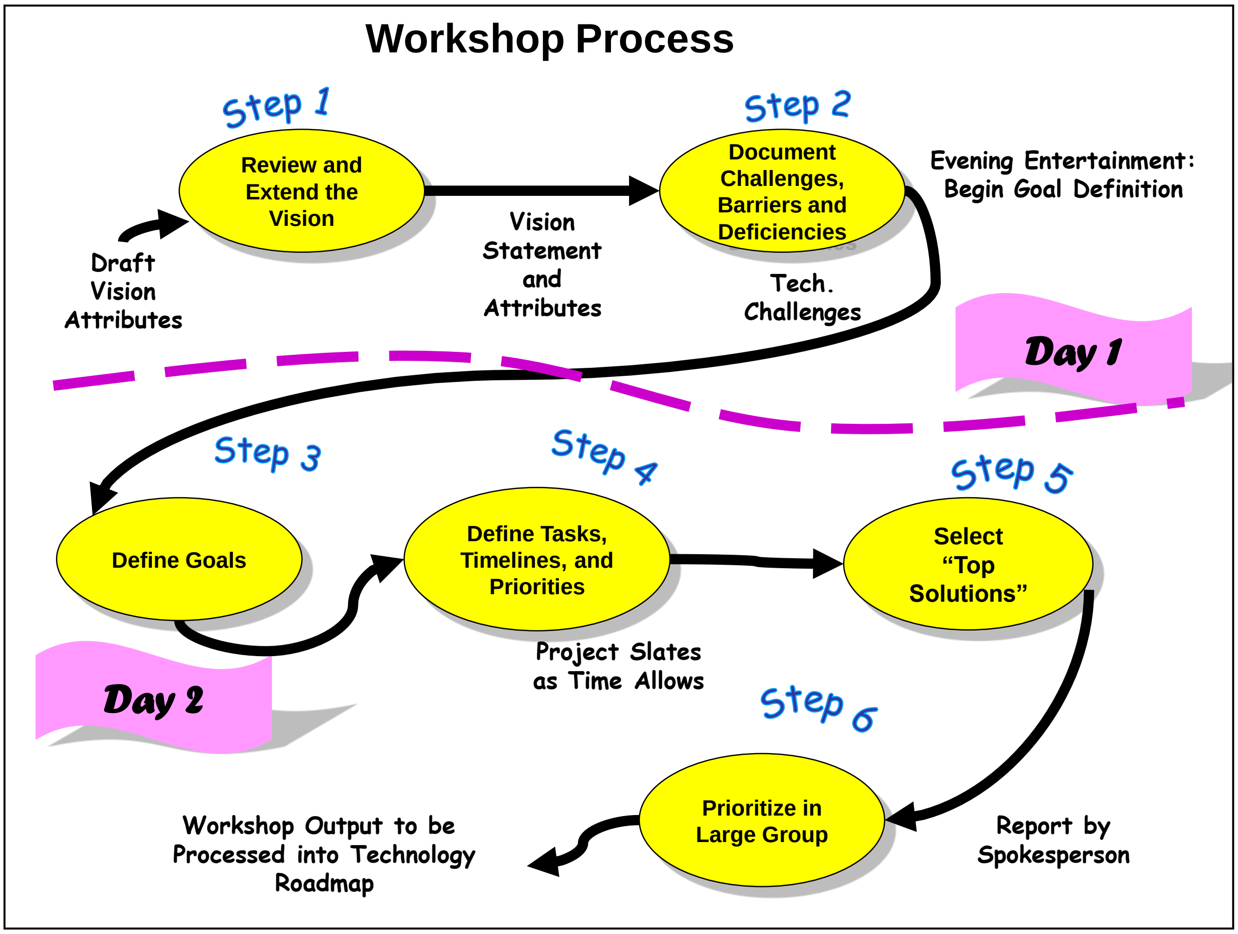

Figure 3: The workshop will follow a structured methodology to capture the information needed for the roadmap.

7.0 The Path Forward

The compiled notes will be distributed shortly after the workshop and an initial summary of results will be distributed within 2 weeks. Within 6 weeks, a document will be produced that captures both the direct content and the essence of the results and points the way to a future sustainable manufacturing environment. This document will join the results of ongoing research and documentation in the continuing conversation about sustainable manufacturing that is supported by the SMART Coordination Network.

Appendix
Input from Existing Roadmaps

There is a strong body of work captured in technology roadmaps and strategic documents produced by various organizations and groups. This work provides a great foundation for the work that SMART CN contemplates. Some of the documents that are useful as background material include:

- U.S. Executive Office of the President President's Council of Advisors on Science and Technology: *A National Strategic Plan for Advanced Manufacturing,* Washington, D.C., February 2012.
- U.S. Executive Office of the President President's Council of Advisors on Science and Technology: *Report to the President on Ensuring American Leadership in Advanced Manufacturing,* Washington, D.C., June 2011.
- U.S. Department of Commerce, *Manufacturing in America: A Comprehensive Strategy to Address the Challenges to U.S. Manufacturers*, Washington, D.C., January 2004.
- Davis, J. and T.F. Edgar, *Smart Process Manufacturing Operations and Technology Roadmap*, Version 4.0, 2008. http://www.smart-process-manufacturing.ucla.edu.
- Smart Manufacturing Leadership Coalition, *Implementing 21st Century Smart Manufacturing*, Workshop Summary Report, March 2011.
- U.S. Department of Energy, *Technology Roadmap for Plant/Crop-Based Renewable Resources 2020*, DOE/GO-10098-385, Washington, D.C., 1999.
- U.S. Department of Energy, *Roadmap on Manufacturing R&D for the Hydrogen Economy*, Washington, D.C., July 2005.
- U.S. Department of Energy, *Technology Roadmap for Energy Reduction in Automotive Manufacturing*, Washington, D.C., Sept. 2008.
- U.S. Department of Energy, S*olid-State Lighting Research and Development: Manufacturing Roadmap*, Washington, D.C., Sept. 2009.
- California Energy Commission, Pier Renewable Energy Technologies Program: *Research Development and Demonstration Roadmap*, CEC-500-2007-035, August 2007.
- Materials Technology Institute, *Technology Roadmap for Materials of Construction, Operation and Maintenance in the Chemical Process Industries*, Materials Technology Institute of the Chemical Process Industries, New York, December 1998.
- National Association of Manufacturing, *Manufacturing Strategy for Jobs and a Competitive America*, Washington, D.C., June 2010.
- National Science and Technology Council, *Manufacturing the Future, Interagency Group on Manufacturing R&D*, Washington, D.C., March 2008.

The following tables are abstracted from two of the most relevant existing technology roadmaps – *Chemical and Allied Industry Vision 2020* and the *Smart Manufacturing Technology Roadmap*. They are included to provide relevant information related to the same and similar topics that will be addressed in the SMART CN workshop.

Chemical and Allied Industry Vision2020	
Technical Area	**Technical Development**
1 - Alternative Feedstocks	• Biomaterial growing, harvesting, supply, and feedstock preparation infrastructure
	• New chemical pathways
	• New chemical processing technologies
2 - Energy Efficiency	• Low cost, low risk energy material
	• Energy-efficiency equipment
	• Energy-efficient systems
	• Low-quality waste heat recovery
	• Tools for monitoring, management, and optimization of energy and material flows
3 - Materials For Sustainable Manufacturing	• Development of energy-efficient materials
	• Production of raw and finished advanced materials
	• Innovative, low-cost material manufacturing
4 - New Generation Chemical Manufacturing	• New production methods
	• New control methods
	• New computational methods
	• Advanced analytical methods
5 - Waste Reduction and Recovery	• Internal process waste reduction
	• Downstream waste reduction
	• Material rediscovery
6 - Water Conservation, Recycling and Reuse	• No-zero discharge of water
	• Process, heating and cooling water consumption minimization
	• Water use and reuse

Smart Manufacturing Roadmap	
Action Area	**Prioritized Actions**
1 - Industrial Community Platforms	• Open source community platforms for virtual plant enterprise modeling
	• Next-generation toolbox of models and architectures for mfg decision making
	• Integration of human factors and decisions into model frameworks
	• Energy decision tools for multiple industries and diverse skill levels
2 - Affordable	• Establishment of common data models

Industrial Data Collection and Mgmt Systems	• Methods for robust data collection (IT, sensors, knowledge capture) across the mfg enterprise
3 - Enterprise-Wide Integration: Business Systems, Manufacturing Plants, and Supplies	• Optimization of supply chain performance through common reporting and rating mechanisms
	• Open platform for integration of small and medium enterprises with OEMs
	• Integration of product and manufacturing models
4 - Education and training	• Enhancement of education and training to build workforce for smart manufacturing