NSF Workshop on Sustainable Manufacturing: Urgent Research Needs and Multidisciplinary Collaboration Held at NSF on Aug. 20-21, 2015

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U.S. manufacturing, a key component of national economic development and prosperity, has been greatly challenged by competitive trends, as global manufacturing competition shifts towards rapid technology innovation and fast implementation in manufacturing, frequent product transitions, and technical personnel training to meet changing needs. Further burdens are being placed on industries owing to uncertain energy and material prices, greenhouse gas constraints, etc. Revitalization of U.S. manufacturing is of utmost importance to the national economy. Since 2012, seven federally supported, industry driven advanced manufacturing institutes have been created; these are AmericaMakes (for additive manufacturing), PowerAmerica (for wide bandgap semiconductors), LIFT (for lightweight technology), DMDII (for integrated digital design and manufacturing), IACMI (for advanced fiber-reinforced polymer composites), AIM Photonics (for manufacturing integrated photonics), and Flexible Hybrid Electronics. Two more institutes for Smart Manufacturing and Revolutionary Fibers and Textiles are to be announced. Six additional institutes are expected to be created in 2016. In the PCAST report on "capturing domestic competitive advantage in advanced manufacturing" in July 2012, sustainable manufacturing is listed as a top cross-cutting technology area. According to the DOC, sustainable manufacturing is defined as the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers. Over the past decade, numerous innovative technologies have been developed for designing and manufacturing novel, high-performance products using energy-material efficient processes. However, a serious concern is how these and future technologies can ensure manufacturing sustainability. This creates a need to pursue fundamental studies on sustainable manufacturing. For instance, AmericaMakes, the first advanced manufacturing institute created in 2012 has identified a need to address some key environmental sustainability issues. An NSF workshop on Environmental Implications of Additive Manufacturing was held in Oct. 2014. Most recently, DOE organized a workshop specifically on Sustainable Manufacturing, which was held in Portland, OR, Jan. 6-7, 2016.

The Sustainable Manufacturing Advances in Research and Technology Coordination Network (SMART-CN), funded by NSF, 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. On Aug. 20-21, 2015, the SMART-CN organized the NSF Workshop on Sustainable Manufacturing: Urgent Research Needs and Multidisciplinary Collaboration. An important objective of this workshop is to identify urgent research and to suggest the best strategies for achieving research goals that can make a long-term impact on advanced manufacturing. The workshop was attended by 49 invitees from academia, industry, national labs, and government agencies. During the workshop, Dr. Mark Johnson, Director of Advanced Manufacturing Office of DOE, delivered a keynote, "Sustainable Manufacturing: Advanced Manufacturing & Clean Energy Manufacturing," and the keynote by Dr. Michael Molnar, Director of Advanced Manufacturing Office of DOC, is titled "The National Network for Manufacturing Innovation: A U.S. Initiative for Sustainable Collaboration." In addition, Dr. Michael Zentner of Purdue University gave a keynote, "nanoHUB: How to Create and Maintain a Successful National HUB". It is evidenced that nanoHUB becomes a national research and educational platform in the emerging field of nanotechnology, which could be a model for creating a sustainable manufacturing focused hub. Two NSF division directors (Dr. JoAnn Lighty of CBET and Dr. George Hazelrigg of CMMI) and four program directors (Dr. Bruce Hamilton of Environmental Sustainability, Dr. Khershed Cooper of Nano Manufacturing, Dr. Zhijian Pei of Manufacturing Machines and Equipment, and Dr. Chris Paredis of Engineering and System Design and Systems Science) introduced NSF divisions/programs' funding focus on manufacturing and sustainability. The workshop also invited leading scholars to share their experience and observations on urgent research needs in sustainable manufacturing; they are Dr. Thomas Edgar (University of Texas Austin), Dr. Ignacio Grossmann (Carnegie Mellon University), Dr. Timothy Gutowski (MIT), Dr. Richard Helling (Dow Chemical), Dr. Sudarsan Rachuri (NIST), and Dr. Gintaras Reklaitis (Purdue University). Most presentation materials at the workshop are accessible at the SMART-CN's website (http://www.research.che.utexas.edu/susman/workshop.html#NSF).

The keynote speeches, panel discussions and NSF officers' introductions of their program stimulated the workshop participants' thinking within and across the areas of Sustainable Manufacturing. There three breakout sessions organized to provide opportunities for them to discuss in depth sustainability implications in advanced manufacturing research and practice, and then to identify urgent, specific research and educational needs that are critical in sustainable manufacturing research. The breakout sessions were designed as follows:

Breakout Session 1 – Sustainability Implications in Manufacturing. The participants were divided into three groups with different topics: Group 1.1 – Technology Management; Group 1.2 - Product/process Development, and Group 1.3 - Enterprise Management.

Breakout Session 2 – Research and Education Need Specifics, which had also three groups: Group 2.1 - System Design for Sustainability, Group 2.2 - Sustainable Manufacturing, and Group 2.3 - Sustainable Industrial Networks.

Breakout Session 3 – Major Collaboration Needs and Platforms. All the participants were divided into two groups: Group 3.1 - Multidisciplinary Collaboration, and Group 3.2 - Academic and Industrial Collaboration.

Note that prior to the workshop, the participants were guided to review a report on sustainable manufacturing roadmap that was developed by the SMART-CN through an NSF workshop on roadmap development in Cincinnati, OH, Aug. 14-15, 2013. The ten key themes described in that report were the basis for discussion of this workshop.

While the breakout groups have different technical foci, group discussions were designed to derive answers to the following four general questions:

(1) What are the significant sustainability implications in advanced manufacturing and how can sustainability principles be fully applied in advanced manufacturing innovations?

(2) What are the key fundamental research areas critical to the progress of sustainable advanced manufacturing technologies and how should they be prioritized?

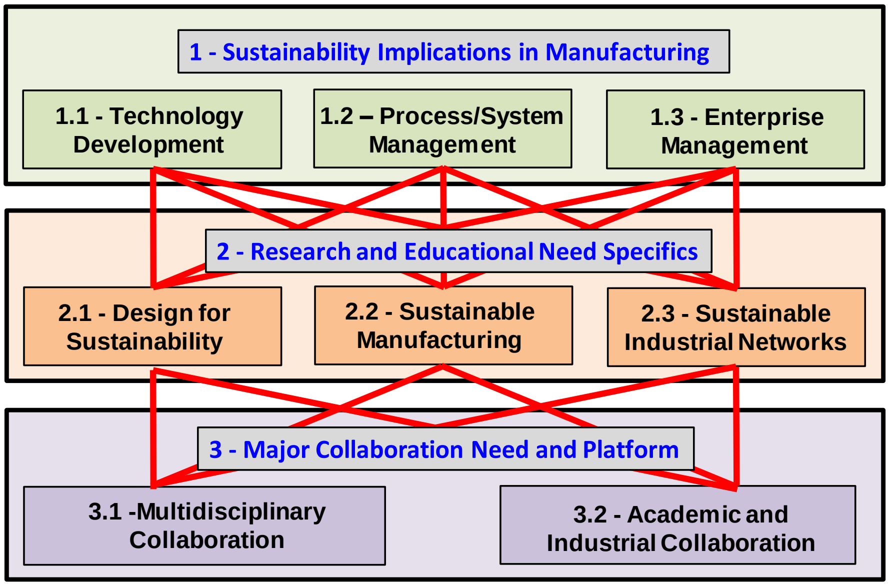
(3) What are the effective approaches for multidisciplinary collaboration among sustainability communities and advanced manufacturing communities, and between academic institutions and industries to achieve the priority research areas?

(4) What kind of major platform could be created to promote national research and educational collaboration in the field of sustainable advanced manufacturing?

The workshop discussion was very productive. A workshop report summarizing the identified challenges, recommended urgent research, collaboration strategies, and suggestions to funding agencies will be published at the SMART-CN's website soon.

SUMMARY OF BRAISTORMING DISCUSSION RESULTS
From the NSF Workshop on Sustainable Manufacturing:
Urgent Research Need and Multidisciplinary Collaboration,
Arlington, VA, Aug. 20-21, 2015

1. BRAINSTORMING SESSION DESIGN



2. SUMMARY OF BRAINSTORMING DISCUSSION RESULTS

The discussion results are summarized in three categories: (1) sustainability implication in manufacturing, (2) Research and educational need specifics, and (3) major collaboration need and platform.

2.1 Sustainability Implication in Manufacturing

2.1.1 Working definition of sustainable manufacturing
- Develop consensus across disciplines as to a working definition of sustainable manufacturing in terms of tangible, well-defined terms and measurable metrics that have a common utility
- Need sustainability as a focus of advanced manufacturing in addition to performance
- Challenges of working at the boundaries of disciplines (languages, methods, definition of a system)

2.1.2 How to measure manufacturing sustainability
- Sustainability metrics (relate toxicity to liability, green chemistry selection) with balancing decisions
- Specific metrics for various manufacturing sectors
- Sustainability metrics appropriate for the TRL (technology readiness level)

2.1.3 Multiscale nature of sustainability

- Multi-scale approaches to solving these problems
- Define systems, scale, structure, and boundary for supply chains of products, including broader scale components such as GRI reporting
- Develop ability to characterize manufacturing processes that emphasize the quantification of system boundaries and externalities.

2.1.4 Sustainability in product and system design

- Product design connected early decision making (energy tradeoffs, water use, regulations, and global forces)
- Understand connection of design decisions from process level to larger system

2.1.5 Collaboration with industry

- Develop collaborative framework with industry, academia and government
- Benchmarking needed to set goals and targets
- Difficult to guarantee byproduct volumes and compositions
- Need to focus on sustainable development in industry
- Maximize availability, alignment, integration, expression, and transparency of data

2.1.6 Effective methods and tools

- Overall there is a lack of standardized and/or certifiable tools and methods for the collection of data in plants and manufacturing facilities.
- Develop tools that include all relevant factors in supporting manufacturing process development
- Early LCA of products are beneficial before scale-up and setting of network
- LCA applied at the systems level as well

2.1.7 Social aspects in sustainable manufacturing

- Social aspects of sustainable manufacturing are important

2.2 Research and Education Areas

2.2.1 Fundamental study on manufacturing sustainability

- Multi-scale sustainable systems knowledge discovery
- Quantification, metrics, models for environmental and social LCA; enhance uncertainty/risk assessment through third party quality checks
- Connect research at smaller scales (materials design/discovery) to systems level; decision support tools at all levels for industry and academic use
- Metrics for looking at process intensification;
- Challenge of defining boundaries and integrating social data

2.2.2 Sustainable system study

- Enhance decision makers' scope of analysis / Systems boundary
- Develop aggregated macroeconomic approach or hybrid approach to use soft and hard data
- Reuse, recycling, and recovery; sustainable/critical materials SCs
- Predicting down-the-line issues of new Advanced Manufacturing processes

- Infuse sustainability factors into plant design and automation. Include reduce, reuse, recycle, repair, remanufacture in "system design"
- Adopt some of the DOE identified research priority areas and align the research activities with sustainable manufacturing research needs to include the following topics: Flow of material through industry (sustainable manufacturing), Combined heat and power, Advanced sensors, controls, modeling and platforms (smart manufacturing), Process heating, Waste heat recovery (especially low-grade heat), Water management, Carbon footprint, LCA
- Include product use phase
- Develop strategies, models and advanced processes for product recycle and reuse
- Waste heat, water, energy nexus
- Develop strategies to right source water in advanced manufacturing processes
- Emissions allocation is a challenge to be addressed
- Technology composite materials, industrial-food processing wastes and other waste valorization

2.2.3 Sustainability assessment and decision-making methods and tools
- Development of sustainability assessment and decision support tools for different phases of product and process design
- Classification, consistency in definition and standards to develop Measurement, Benchmarks, and Metrics
- The conundrum of short term (e.g. quarterly profits) vs. long-term sustainable outcomes
- Revive research on EIO-LCA as a measure of macroeconomic lifecycle method

2.2.4 Social aspects in manufacturing
- Integration of social science research into technology, product design and manufacturing decisions
- Consumer behavior: what makes people choose sustainable products?
- Stakeholder value vs. shareholder value
- Social impacts of greener cradle-to-gate supply chains on industrial practices (e.g. LEED certification impacts on the building industry, attributional LCA), and customer satisfaction.
- Shifting consumer behavior toward more sustainable choices (education, marketing)

2.2.5 Data and cyber-infrastructure
- Development of cyber-infrastructure, and instrumentation for complex data collection, processing and reconciliation
- Data—collection and management across supply chains
- Data transparency

2.2.6 Technology demonstration
- Fund "risky" or early stage research/prototyping to the point of commercialization to avoid the "valley of death"

2.2.7 Education
- Continue to fund education efforts of all stakeholders from the general public, policy makers, students and interactions between academia and industry.
- Common language/knowledge across disciplines

- Educational: Introduce sustainability in manufacturing hubs ; Multi-objective optimization to evaluate advantages/risks of greater network cooperation; Incentives/education for companies to explore industrial network opportunities

2.3. Major Collaboration Needs and Platform

2.3.1 Academic collaboration

- Collaboration between *academic institutions and industries* to achieve the priority research areas
- Clear *multidisciplinary* statement of the problem
- Focus on multidisciplinary collaborations

2.3.2 Collaboration with industries and communities

- Industry-academia collaboration group/consortium
- Strategy for active industrial mentors of university projects
- Bridge the gap between industry and academics through exchange of personnel.
- Collaboration among *sustainability communities and advanced manufacturing communities*
- Identify best practices—what are the challenge problems for industry
- Building consensus among trade groups
- Strategic exchanges of personnel , traineeships , diversity
- Incentives to promote collaboration between academic-industry without monetary transfer
- Industrial case studies for academic research
- Grow interdisciplinary researchers, removal of barriers to learning, organizational structures
- Link with business schools, e.g., operations management, for more interdisciplinary SC/logistics case studies.
- Challenge problems such as NIST academic collaboration on passive houses
- Accessibility of validated data bases
- Test beds enabling scenario planning
- Establish better communication platforms for industry and academia aligned with industry needs
- Encourage industry to support research through internships and scholarships targeted towards sustainable manufacturing
- Current industry sustainability is qualitative, with few quantitative indicators denoting corporate sustainability, sustainable technology innovations are not duly recognized over all manufacturing sectors
- IP issues such as violation, ownership, perception of technology readiness level
- Identification of stakeholders within industry and academia is a challenge; infrastructure for such collaborations do not exist
- Project timescales, deliverables are not aligned for students to work on industry projects
- Academic impact is measured by research products, not technology adaptation
- DOD-Tech innovation summit, ARPA-E summit type of platforms for sharing industry, government and academic research

2.3.3 Sustainability education

- Discuss with ABET on sustainability incorporation
- Move to specialization on sustainability (infuse in graduate education)

- Educate the educators
- Develop textbooks and case study based modules
- Case studies for network advantages and share with education community
- Need for mechanisms for re-training faculty to accept multidisciplinary models of scholarship
- Educational impacts are shared
- Educational/academic tool development
- Add manufacturing to educational platform, e.g., ABET
- Community building

2.3.4 Platform

- Need for a forum for academia and industry to communicate
- Platform for research, education, and collaboration information exchange
- Platform for proprietary data access
- Communication of key metrics to manufacturers
- Case studies for network advantages such as at manufacturing hubs
- Build projects around demonstrating sustainability studies at each institute
- Leverage current platforms, especially USBCSD, suppliers partnership for environment, sustainable apparel coalition, green chemistry roundtable, ISIE, Ohio byproduct synergy network
- Professional society chapter on advanced manufacturing and sustainable industrial networks
- Understanding of circular commodity management concept
- Financing of equipment and businesses for waste valorization
- Life cycle concept as a basis for a variety of platforms (prospective, exploratory, evaluative, etc.)
- Effective regulatory platform

2.3.5 Recommendation to federal agencies

- Require a sustainability component in major proposal calls, e.g., DOE
- More GOALI funds, or SBIR
- Granting agencies to offer targeted calls and realistic budgets to match requirements for collaboration
- NSF and other sponsors for webinars of interest to industry and academia through professional societies
- Funding agencies need to track research outcomes
- Requirements for funding may include SBIRs to be supported by large companies too