2012 EL Program: Sustainable Manufacturing

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Strategic Goal: Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure

Date Prepared: September 29, 2011

Summary:

To support industry’s drive to remain globally competitive and maximize innovation, this program will develop and deploy advances in measurement science to achieve sustainability across manufacturing processes thus enabling manufacturing resource efficiency and production network resiliency\(^1\). Currently, industry lacks accurate metrics and the needed measurement science to evaluate sustainable performances such as energy and material efficiencies, emissions, waste, and water usage of manufacturing processes. Accordingly, the critical solution-enabling measurement science activities for the program includes the development of methodologies for sustainable processes and resources; and the integration infrastructure for sustainable manufacturing. The methodologies will focus to characterize unit manufacturing and assembly processes, including supplier capabilities, enabling industry level manufacturing assessments to improve production efficiency. The integration infrastructure will enable the systematic and functional integration of unit manufacturing systems and subsystems to perform as a holistic sustainable system for improved production efficiency while being economically competitive.
Objective: To develop and deploy advances in measurement science to achieve sustainability across manufacturing processes enabling resource efficiency and production network resiliency by 2016.

What is the problem?
Industrial interest in sustainable manufacturing has increased dramatically in recent years yet the supporting infrastructure and methodologies are lacking. Global competition requires American manufacturers to implement sustainability practices in their manufacturing operations. A recent Office of Science and Technology Policy (OSTP) report stressed the “need for accessible and affordable measurement systems and analytical tools for assessing and managing sustainability across the production process.” A myriad of sustainability indicators have been proposed to measure the impact of those changes. Three of the most critical indicators are energy efficiency, material efficiency, and resiliency. A number of metrics and associated computational methods have been suggested for those indicators. However, innovative best practices and the underlying measurement science for assessing the validity of those metrics, evaluating the accuracy of those methods, and documenting the results of the computations do not exist.

U.S. industry does not have the necessary measurement science capabilities to assess the sustainability performance of existing manufacturing operations and predict the impact of proposed supplier, plant, process, or product actions. This includes evaluating sustainable performances such as energy and material efficiency, emissions, waste, and water usage of manufacturing processes. These evaluations are further challenged by multiple stakeholder requirements or company sustainability objectives such as marketing and profitability. Implementing new sustainability methodologies frequently demands innovation in manufacturing technologies and associated new measurement capabilities.

A NIST industry workshop report stated that “Industry is unable to measure economic, social, and environmental consequences of their activities and products accurately during the entire life cycle and across their supplier network.” Addressing this challenge will require new, science-based methods for performing these measurements at the supply chain, enterprise, process, and product levels. These methods will facilitate the development of new optimization techniques crucial to improving both the design and manufacturing phases of the product life cycle.

Why is it hard to solve?
Ensuring sustainable manufacturing requires an integrated systems approach and spans technical, economic, ecological, and societal issues. Interactions within and across these issues are critical to the fundamental understanding of sustainable manufacturing, because focusing on any single issue could result in suboptimal solutions and unintended consequences. Industry recognizes that (1) sustainability challenges in manufacturing can only be addressed through multi-disciplinary methodologies and (2)
implementing these methodologies can have significant economic benefits for sustainability in general and sustainable manufacturing in particular.6

Although a number of such methodologies exist, the measurement science necessary to determine their accuracy does not exist. Also, the necessary standards to represent and report the information used and processed by these methodologies are yet to be developed. Additionally, since these methodologies can be expensive to implement, many companies – particularly small- and medium-sized companies – do not use them. Consequently, most companies have no way to track and aggregate sustainability-related data of individual processes, factories, and supplier networks.

How is it solved today, and by whom?
Within the U.S, an increasing number of companies are realizing the importance of implementing sustainability practices in their manufacturing operations.7 However, typical implementation strategies define stand-alone, narrowly scoped projects. These projects are prioritized and generally planned on a case-by-case basis. They usually perform an assessment of a selected sustainability metric and recommend changes to improve that metric. There is, however, no systematic, generalized approach to doing the assessment based on measurement science. Furthermore, changes are implemented with limited understanding of their broader sustainability impacts.8 This typically results in local optimization that can miss opportunities and potentially cause larger, unintended, negative consequences.

International research efforts in the European Union, Japan, and Korea are promoting energy and material efficiency through a list of directives that require the elimination of toxic materials, a reduction in waste going to landfills, and improvements in energy usage. They are also making huge investments for research and technological development9 in sustainability-related research, innovation, and education. Finally, they have incorporated mandatory performance targets and provide financial incentives to help companies meet those targets.

Why NIST?
This program is aligned with the Engineering Laboratory (EL) mission to promote U.S. innovation and industrial competitiveness in areas of critical national priority. It is also aligned with the “Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure” strategic goal. The program researchers have developed extensive measurement science expertise in life cycle assessment, product and process information modeling, interoperability of engineering applications, best practice guidelines, and standards-related research. All are necessary to implement the technical idea and research plan described below.

Recent studies conducted by Harvard Business School10 and the MIT Sloan School of Management11,12 concluded that sustainable product and process development across all industry sectors “is essential to remaining competitive.” Further industrial organizations that predict and plan for a sustainable future are

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6 Climate Group’s SMART 2020 report estimates that improvement in energy efficiency and reduction of GHG can potentially drive $1 trillion in savings per year by 2020 and 7.8 gigatons of CO2 abatement globally
7 Sustainable Manufacturing: Metrics, Standards, and Infrastructure – Workshop Summary
(http://www.nist.gov/customcf/get_pdf.cfm?pub_id=905837)
10 “Why sustainability is now the key driver of innovation,” Harvard Business Review, Sept. 2009, pp. 56-64
11“The business of sustainability”, MIT Sloan Management Review Special Report, 2009,
http://www.mitsmre-zine.com/busofSustainability/2009/pg1
more likely to survive into the next generation\textsuperscript{13}. The US Congress, in passing The America COMPETES Reauthorization Act of 2010\textsuperscript{14}, mandated NIST to “develop accurate sustainability metrics and practices”, “to advance the development of standards”, and “create an information infrastructure to communicate sustainability information about suppliers.”

**What is the new technical idea?**

The new technical idea involves (1) innovative measurement science for characterizing manufacturing processes with respect to sustainability and (2) assessment methods that use those characterizations to evaluate and optimize selected energy, material, and resiliency\textsuperscript{15} metrics. The program focuses on process characterization at three levels: unit, factory, and network. It will develop an engineering information system architecture that enables aggregation of metrics across all levels. This architecture will easily integrate optimization algorithms with those characterizations and assessments – this will serves as an enabler for improved decision support. It will also allow industries to run analytical computations and simulations that result in reliable and traceable measurements.

**Why can we succeed now?**

There is a heightened awareness of the economic and competitive importance of sustainable manufacturing technologies by U.S. manufacturing. In response there is an emerging body of research results that will support incorporating sustainability considerations (including an increasing number of indicators, and their associated weighting and uncertainty factors) in manufacturing processes. There has also been an increased effort by the manufacturing sector to collect sustainable manufacturing information using energy management systems, data collection systems, material declaration systems, and best practices. This, coupled with advances in engineering information systems, information modeling, integration technologies, and decision support methodologies, provides the critical foundation for success in characterizing manufacturing processes and aid performance assessment and decision making at all levels. EL staff has the necessary mission and expertise to further the advances and trends listed above and leveraging relationships with key industry stakeholders and standards development organizations.

**What is the research plan?**

The research plan is defined to implement the technical ideas described above. It is organized into two main thrusts and six research projects.

The **Methodologies for Sustainable Processes and Resources Thrust** focuses on sustainability characterization, assessment and aggregation of unit and assembly processes, factories, and supply networks. This thrust will provide the mathematical foundations needed to develop process models that focus on sustainability. It will define a variety of metrics associated with energy, materials, and resiliency; and, it will develop computational methods for computing those metrics using the process models. Finally, it will produce new techniques for aggregating these metrics across all of the process levels. The effort will enable industry level manufacturing assessments to improve sustainability performance by characterizing unit manufacturing and assembly processes, including supplier capabilities.

1. **Sustainability of Unit Manufacturing Processes**: This project will develop the necessary analytics for sustainability characterization of unit manufacturing processes including various computational methods that will be used to compute various sustainability performance metrics.

\textsuperscript{13} Towards a sustainable industrial system, http://www.ifm.eng.cam.ac.uk/sis/industrial_sustainability_report.pdf

\textsuperscript{14} http://www.govtrack.us/congress/bill.xpd?bill=h111-5116

\textsuperscript{15} The ability of suppliers, manufacturing processes, and reduce consequences of, and recover from, various types of man-made or natural disruptions.
2. **Sustainable Metrics for Unit Assembly Processes:** This project will develop the necessary analytics for sustainability characterization of unit assembly processes including various computational methods that will be used to compute various sustainability performance metrics.

3. **Integrated Production Processes:** This project will develop the integrated methodology and computational approach for aggregation of sustainability metrics computed at the unit and assembly process levels.

4. **Production Network Supplier Characterization:** This project will develop sustainability characterizations, and associated computational methods, of the suppliers that make up the production network. This will include manufacturing and logistics suppliers. These characterizations and methods will provide the foundation for an optimization algorithm that can be used to add new suppliers to existing production network or to replace suppliers in the case of some unforeseen disruptions. The results of this project will increase the resiliency of these networks.

The **Integration Infrastructure for Sustainable Manufacturing Thrust** focuses on sustainability metrics, modeling and optimization. It will provide the architecture and information structure needed to (1) compute, declare, track, and exchange sustainability metrics and (2) analyze, simulate, and optimize the processes that generate those metrics. This effort will enable the systematic and functional integration of unit manufacturing systems and subsystems to perform as a holistic sustainable system for improved production efficiency while being economically competitive. This includes tracking and optimization for material and energy efficiency.

5. **Sustainability Metrics for Manufacturability:** This project will focus on three crucial aspects of the sustainability problem as it relates to manufacturability: definition of sustainability related energy and material information and close association of this with design specifications, methodology for energy and material use assessment for manufacturability, and the test methods for data and the computation of energy and material efficiency at the product level.

6. **Sustainability Modeling and Optimization:** This project will develop the architecture that integrates required engineering information systems, computational tools, and simulation software to aid performance assessment and decision making at all levels.
How will teamwork be ensured?
Researchers working on the six preceding projects are all located within the Systems Integration Division (SID). Most reside within the Life Cycle Engineering Group. The project descriptions in the Research Plan section illustrate the interactions between the projects and the team members. The Project Plans provide specific information regarding the coordination of Project activities and the information exchange (type and timing) required between Projects and with external collaborators. External collaborations are an essential element for the program and each project will establish relationships with the most relevant professional societies, industrial consortium, and standards development organizations (SDOs). There will be quarterly program meetings where project leaders report on the status of work and the progress toward milestones. Periodic meetings with the Project leaders will serve as a forum to identify potential problems or opportunities for interactions within NIST or external activities with outside groups.

What is the impact if successful?
U. S. industry consumes approximately 30 quadrillion Btu of energy per year\textsuperscript{16} – almost one third of all energy used in the United States. It is essential that U.S. industry achieve significant increases in energy and material efficiency, while also creating value and enhancing competitiveness. This program will provide solutions that facilitate these increases, thus ensuring U.S. manufacturers lead the world in

\textsuperscript{16}http://www.eia.gov/totalenergy/data/monthly/pdf/sec2_3.pdf
modern production technologies. Further, developed manufacturing measurement sciences will support the growth and development of new industries in the United States.

The Sustainable Manufacturing Program will enable advanced manufacturing processes that include new manufacturing methodologies, manufacturing information systems, and effective industry standards. The Program results will advance U.S. leadership in sustainable manufacturing, resulting in technologies that support the application of Key Performance Indicators (KPI’s) to access and decide on production networks which require much less energy and materials, reduced waste and optimal logistics. By using these technologies industries are ideally positioned to optimize their processes and maximize their efficiency and resilience.

Key customers in these efforts will be the automotive and aerospace sector, food and consumer products sector. Other sectors include the paper manufacturing sector, the petroleum, and the chemical manufacturing sector (pharmaceutical and medicine manufacturing). Key partners in these efforts will be federal national laboratories, industry consortia, and university researchers. Stakeholders include partners from other federal agencies (DoD, EPA, DoE), standards development organizations (ASME, ASTM, IEEE), industry end-users and industry associations (NAM, NACFAM, IPC, AIAG, AIA, NCMS, NDCMM).17

Impact anticipated:

- SM engineering information systems that provide manufacturers the capability to measure, improve, maintain, and report sustainability performance. This supports efforts for minimizing energy and material use, reducing waste, and eliminating toxic materials. These actions will result in lower costs and automation efforts will support a higher paid workforce and the ability to better innovate due to tool integration and knowledge capture.
- Improved supply chain competitiveness through understanding and managing energy, material, and waste within these chains reducing energy use and overall costs, while simultaneously increasing a firm’s competitive advantage.
- Continuous improvement through enhanced analysis and optimization capabilities. The economic return – for any company willing to embrace the values of sustainability – in operational efficiencies and the achievement of cost savings will free up capital for re-investment into new technologies.18
- Engineering information exchange utility to Building for Environmental and Economic Sustainability (BEES) and other analysis applications for incorporating specific industry manufacturing data derived from plant floor and supplier operations with other databases for evaluating economic performance.

What is the standards strategy?

Industrial interest in sustainable manufacturing has increased dramatically only recently, and hence it offers NIST an opportunity to lead in the creation of important new standards and to influence their early directions to best support U.S. manufacturers. Broad industrial acceptance will initially come from automotive, aerospace, consumer products, apparel, and food processing industries. The approach and methodology are expected to be applicable to continuous manufacturing industries as well.

The SM Program focuses on the measurement science and standards that enable the energy and material efficiencies of the U.S. manufacturing industry so as to improve its innovation and competitiveness. Listed below are seven top standards development needs identified by the SM program through various workshops and industrial engagements, along with the fiscal years they are needed. They provide the

foundation from which industry can characterize their production processes from basic building blocks (i.e., unit manufacturing processes), automate and document the aggregation of energy and material sustainability, and assess, simulate, and optimize total energy and material sustainability performance at the supplier, plant, and equipment level. The SM program has identified key SDO’s/standards to transition NIST measurement science and standards efforts effectively to satisfy the industry needs N1 through N7 identified below.

**Top Standards Development Needs**

**Integration Infrastructure for Sustainable Manufacturing Thrust:**

- **N1.** Key terminology, definitions, technical specifications, and representations for describing sustainable manufacturing resources and processes and their performance, needed by FY13.
- **N2.** Infrastructure and standardized methods to assess the sustainability of manufacturing processes and manufactured products, needed by FY15.
- **N3.** A standards testing framework and benchmarking strategy that will help industry to measure, manage, validate, and report product impact for sustainability, needed by FY15.

**Methodologies for Sustainable Processes and Resources Thrust:**

- **N4.** Standard methods and supporting tools that enable manufacturers to characterize their manufacturing unit processes and contribute these models to an open library of standard manufacturing unit processes, needed by FY14.
- **N5.** Standardized data aggregation methods that will work with manufacturing process characterization (using manufacturing and assembly unit processes) from part level to the product assembly level with defined measurement uncertainty quantification, needed by FY15.
- **N6.** Standard methods that enable the computation and comparison of energy and material efficiency metrics within a manufacturer and across the supply chain, needed by FY15.
- **N7.** A standardized approach to rapidly configure production unit process models that will enable sustainability assessment including critical aspects of life cycle analysis/inventory (LCA/I), needed by FY16.

The SM program will work with several industries, universities, and other government agencies in the standards development and deployment process. In particular U.S. manufacturing industry (including industry consortia) will be engaged in all three phases of (1) initial needs assessment, (2) measurement science execution, and (3) deployment of the standards.

Our current strategy is to focus on the following set of standards:

1. **ASTM E60 – Sustainability:** At this time this standard is primarily an infrastructure/buildings standard. Our objective is to define a new manufacturing thrust in ASTM E60. We will serve in a leadership/convener role in the creation of a Sustainable Manufacturing standard in ASTM that would encompass many of the planned activities such as characterized manufacturing resources, energy and material efficiencies, manufacturing assessment, and sustainability reference data. It will address the needs N1, N2, N4, and N5.

2. **ISO 50001 – Energy Management:** Under this new energy management standard, NIST will provide critical technical contributions, provide tools to improve standards and accelerate their development, convene/lead a working group effort (ISO committee TC 242 Energy Management) focusing on energy efficiency standards. Our objective is to define a new manufacturing thrust in this standards committee, and define relevant terminology and energy efficiency measurements. It will address the needs N1 and N6.

3. **ISO 14025 – Environmental labeling:** A significant focus of this standard is on life cycle analysis. It enables purchasers to make comparisons between products fulfilling the same function, and encourage improvement of sustainability performance. The NIST effort in this standard will focus on
the manufacturing phase. NIST will provide critical technical contributions, provide tools to improve standards and accelerate their development, and convene/lead a working group effort focusing on material efficiency standards. It will address the needs N2, N3 and N7.

Fit to Criteria for Selecting Standards Development Involvement
The standards stated above are aligned with the EL mission and the SM Program objectives. The standards support the strategic EL Goal “Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure”, which is to enable sustainable and energy efficient manufacturing, materials, and infrastructure through advances in measurement science. The focus of the SM standards work is relevant and important to OEMs and their suppliers. Through industry consortia and MEP partners the standards results will reach broad industry sectors from aerospace and automotive to consumer and food products. The impact will occur through standards development that defines critical infrastructural needs to support methodology for sustainability performance assessment (see standards needs N1 through N7 above). The SM program’s focus on energy and material efficiencies is an essential element of our contributions to standards. Our efforts will be a catalyst to the collection and use of rigorous and traceable data for energy and material standards for optimizing manufacturing efficiency and resiliency, and third party verification and validation to reduce the trust gap between claims and performance. Many of the efforts in the area of sustainability related standards are now being brought under the umbrella of ISO 14000. The efforts of ASTM E60.x needs to expand to sustainable manufacturing and will be coordinated with ISO efforts.

How will knowledge transfer be achieved?
Knowledge transfer will be accomplished through (1) technical publications, workshops and conferences, technical societies, technical efforts in SDO’s and standards, development of best practices, and (2) collaborations (formal and informal) with MEP, academia, industry, consortium, other national labs, and international partners. Industries participating include Stanley Black and Decker, Boeing, General Motors, 3M, Dow, Procter and Gamble, Xerox, and InterCAX. Universities participating include Wichita State University, Washington State University, Georgia Tech University, and University of Maryland – College Park.

Major Accomplishments:

Integration Infrastructure for Sustainable Manufacturing Thrust:

Industry directed
• New, easily implemented assessment methodology available to industry which incorporates sustainability characterization across unit process-, product-, and facility-level.
• Scalable integration framework that connects key manufacturing applications, tools, and databases for sustainability analysis of processes and products.
• Information models made available to stakeholders. Models represent, manage, and exchange shared data among engineering applications, production databases, LCI databases, and simulation systems.
• Library of reusable models, algorithms, and tools for family of sustainable manufacturing processes are publicly available.
• Methodology available that enables industry to measure its progress in terms of its sustainability performance impact

SDO directed
• Draft standard on material declaration within ISO 1402x.
• KPI’s and supporting methodologies for measuring and calculating key sustainability metrics for manufacturing processes.
• Methods and testbeds that capture, organize and validate product sustainability data and declarations
Industry tools that allow aggregation of sustainability factors across manufacturing processes and supplier network to support decision making at the product level.

**Methodologies for Sustainable Processes and Resources Thrust:**

Industry directed
- Repository of reference manufacturing process data for use by industry to build manufacturing process models
- Risk mitigation procedure for ensuring content and timing of standards development and deployment
- Proven methodologies and infrastructure that support decision making based on product level sustainability and promote green supplier network.
- Sustainability characterization repository for use by sustainable manufacturing decision support tools

SDO directed
- Draft standard for manufacturing process characterization (ASTM E60) and energy efficiency (ISO 50001).
- Methodology and tools for sustainability characterization of unit manufacturing and assembly processes
- Standardized assessment process for evaluating manufacturing sector performance at various levels.

**Recognition of EL:**

**NIST Sustainability Standards Portal:** Department of Commerce International Trade Administration recognized NIST EL’s work by creating a link to the NIST Sustainability Standards Portal. The NIST portal provides a comprehensive list of standards with details and links to the original standard developer website, a facility to search standards based on various categories, a framework for analysis of standards from different perspectives, and a mechanism for understanding gaps and overlaps of standards.

**Core Manufacturing Simulation Data (CMSD) Information Model Standard:** The CMSD Information Model defines a data specification for efficient exchange of manufacturing data in a manufacturing simulation environment. It became a standard in 2011, providing a neutral data format for integrating manufacturing applications and simulation. It has been successfully applied to estimate quantitative energy efficiencies in manufacturing activities by trying various plant floor scenarios.

**IPC 1752 Material Declaration Standard:**
With SIMA funding and support from MEL, NIST EEEL developed a materials data model used in the IPC 1752 Material Declaration standard. It was one of the earliest sustainable manufacturing standards. It has been widely used by the U.S. manufacturers to maintain their global competitiveness. It was the most downloaded standard from the IPC web site in 2010, and the NIST researchers involved in this standard were recognized with a Rosa award and a Bronze medal.

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