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Sustainable Manufacturing: Metrics, Standards, and Infrastructure - NIST Workshop Report

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National Institute of Standards and Technology
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National Institute of Standards and Technology
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Sustainable Manufacturing: Metrics, Standards, and Infrastructure - NIST Workshop Report

Abstract

This report summarizes the presentations, discussions, and recommendations of the NIST Workshop "Sustainable Manufacturing: Metrics, Standards, and Infrastructure" held at NIST, Gaithersburg, Maryland, USA, October 13th through October 15th, 2009. The primary objective of this workshop was to bring together experts and various stakeholders to identify and discuss measurement and standards enablers that positively affect the social, economic, environmental, and technological aspects of designing sustainable production processes and products. The workshop was well attended and consisted of thirty presentations organized under five sessions: 1) Government Initiatives; 2) Industry Perspectives; 3) University Research; 4) Non-Government Organizations (NGOs) research; and 5) Solution Provider's Views. Two breakout sessions and an industry panel provided a set of recommendations for addressing critical issues in sustainable manufacturing.

Keywords: *Sustainable Manufacturing, Environmental impact, Life Cycle Assessment, Product Life Cycle, RoHS, REACH, ISO, Standards, NIST workshop*

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Executive Summary

Background: Next generation product design and manufacturing will be strongly influenced by life cycle environmental impacts and resource depletion. Hence, sustainable manufacturing[1] practices will play an important role in "meeting the needs of the present without compromising the ability of future generations to meet their own needs[2]." Sustainable manufacturing is causing companies to implement new design and analysis procedures, energy reduction methods, material reduction efforts, and improved materials handling practices. Thus, minimizing environmental impact has become a critical manufacturing industry requirement throughout the product life cycle. To foster sustainable practices, there needs to be a *measurement methodology* to assign the energy and environmental cost at each stage in that life cycle. Information must be available at the early design stage about the ultimate costs of each design decision for a new product, and the decisions themselves must be available at the end of product life to ascertain how to properly dispose of or reclaim the components.

Objective: The primary objective of this workshop was to bring together experts and various stakeholders to identify and discuss measurement and standards' enablers that positively affect the social, economic, environmental, and technological aspects of designing sustainable production processes, products, and services.

Presentation Summaries: The workshop consisted of three keynote presentations, five technical sessions, two breakout discussions, and an industrial panel discussion that addressed important issues necessary for the production of sustainable systems. The keynote speakers included Mary Saunders, Assistant Secretary Manufacturing and Services, International Trade Administration (ITA), Department of Commerce; Mark Cohen**,** Vice President for Research at Resources for the Future; and Bob Bechtold, CEO of HARBEC Plastics Inc.. Mary Saunders described recent developments in the Sustainable Manufacturing Initiative of the Manufacturing and Services (MAS), while Mark Cohen gave an overview on sustainability reporting and the Global Reporting Initiative (GRI). Bob Bechtold presented a case study of small and medium-sized enterprises (SMEs) and lessons learned from implementing sustainability practices.

The five technical sessions consisted of thirty presentations, organized into five sessions: *1)*

[1] Sustainable manufacturing is a systems approach for the creation and distribution (supply chain) of innovative products and services, that: minimizes resources (inputs such as materials, energy, water, and land); eliminates toxic substances; and produces zero waste that in effect reduces green house gases, e.g., carbon intensity, across the entire life cycle of products and services.

[2] Our Common Future: Report of the World Commission on Environment and Development, Oxford University Press, 1987.

Government Initiatives; 2) Industry Perspectives; 3) University Research; 4) Non-Government Organizations (NGOs) Research; and 5) Solution Providers Views. Sustainable manufacturing initiatives at the National Science Foundation (NSF), National Institute of Standards and Technology (NIST), and National Aeronautics and Space Administration (NASA), were presented in the *Government Initiatives* session. The *Industry Perspectives* session involved participation from industry leaders, focusing on the costs, benefits, and challenges in incorporating sustainability in the industry. The session had presentations from various industries, including Ford, GM, GE Aviation, Lockheed Martin, Rockwell Automation, P&G, Xerox, URS, and Masco Retail Cabinet Group. The *University Research session* provided workshop participants an opportunity to discuss academic research issues in sustainable manufacturing. This session included presentations from Rochester Institute of Technology, Purdue University, University of Kentucky, Stanford University, Georgia Institute of Technology, Portland State University, and Texas Tech University. The *Non-Government Organizations (NGO) Research* session involved participation from various NGOs, Standards Developing Organizations (SDOs), and industry consortia, focusing on various standards development efforts, harmonization of standards, and sustainability reporting mechanisms and standards. The American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM), World Resource Institute (WRI), National Center for Manufacturing Sciences (NCMS), National Council For Advanced Manufacturing (NACFAM), and Cadmus Group gave presentations in this session. The *Solutions Providers* session predominantly focused on the need for tool support for sustainable manufacturing, currently available tool support, and the standards compliance of the applications presented. Companies are becoming increasingly interested in adhering to standards such as RoHS, REACH, and WEEE to compete globally. Major software solution providers, such as Parametric Technology Corporation (PTC), Digital Enterprise Lean Manufacturing Interactive Application (DELMIA), Siemens PLM Solutions, Siemens R&D, presented their suite of software tools and their current capabilities and future extensions.

Breakout Sessions: The breakout sessions consisted of two groups: 1) Critical factors driving sustainable manufacturing, and 2) Decision support systems for sustainable manufacturing. Group 1 focused on the following themes: business case for sustainability, promoting eco-innovation, standards and metrics, tool support, promoting reduced energy consumption, and positioning of standards, while the focus of Group 2 was on: standards harmonization, science of sustainability, greening the supply chain, data availability, and needs.

Challenges: The following major challenges faced by the manufacturing industry in its pursuit of sustainability goals were identified as a result of the workshop:

1. Industry is unable to measure economic, social, and environmental impacts and costs of their products accurately during the entire life cycle and across their supply chain. The main reasons for this are the lack of data traceable to a neutral organization. Even if the data is available, industry is finding it difficult to aggregate and disaggregate data to compute sustainability metrics.
2. Full life cycle analysis or assessment (LCA) of products requires new methods to analyze, integrate, and aggregate information across hierarchical levels, organizational entities, and supply chain participants. Existing methods of aggregation do not take into account sustainability issues.
3. Industry lacks neutral and trusted standards and programs to demonstrate, deploy, and accredit new sustainable manufacturing practices, guidelines and methods. Information standards are necessary to enable interoperability collectively among engineering tools, business enterprise tools and Life Cycle Assessment (LCA) tools. Focus on sustainability in the SDOs is relatively new terrain.
4. There are too many metrics; they need consolidation and harmonization. In addition, they need to be 'monetized' as appropriate. There is no single authority on evaluating or choosing from existing metrics, nor has there been an assessment of existing metrics to ensure the entire life cycle evaluation is addressed.
5. Regulations need to be supported by industry standards (e.g., RoHS and IPC-1752). These regulations/standards should be harmonized. Existing regulations were developed independent of ensuring industry standards were in place to support such regulations.

Action items: Key recommendations to address the above challenges are given below, in no particular order. Many of the opportunities can be addressed in the short term, and others the longer term if follow-on activities to the workshop are formalized and available resources are identified.

Metrics (or indicators):

- Pursue a multi-level approach for metrics, with aggregated metrics at the highest level
- Consolidate and harmonize the diverse set of existing metrics, and identify the gaps where metrics are yet to exist.
- Monetize metrics.

Standards:

- Support regulations with industry standards (e.g., RoHS and IPC-1752).
- Develop a strategy for the harmonization of those standards and directives for sustainability that currently exist.

- Create brand values of sustainability standards for eco-labeling and maintain the brand values. Similar to ISO 9000 certification branding, manufacturers may use branding to get a market edge.

Infrastructure:

- Create a software infrastructure for gathering, analyzing, exchanging, and aggregating information for sustainability, including support for global data repositories.
- Develop a simple and transparent methodology for life cycle assessment
- Develop a science of sustainability, including open source models that are generic, extensible, verifiable, and easy to build and share.

Best Practices:

- Create a new business model for companies to apply voluntarily the methodology developed for LCA, which maximizes profits while minimizing costs.
- Develop best practices for eco-innovation, i.e., design of products and processes that are sustainable or contribute to sustainable development.
- Create eco-labeling for manufacturing processes and machines.
- Develop sustainability reporting standards for suppliers, and provide education and training to suppliers in simple terms, stressing the importance of compliance.
- Develop traceable life cycle inventory data to enable life cycle analysis of products, processes, and services and to enable verification and validation of life cycle impact measurements, and benchmarking.

1. Introduction

We are witnessing an increased interest in ensuring that future generations have adequate resources to maintain a high standard of living. The World Commission on Environment and Development defines sustainable development as, "*development that meets the needs of the present without compromising the needs of future generations to meet their own needs."*[3] According to the US National Research Council, it is "*the level of human consumption and activity, which can continue into the foreseeable future, so that the system that provides goods and services to the humans persists indefinitely*."[4] Others have argued that any definition of sustainability should include dynamic efficiency throughout the life cycle of a product, process, and service; should consist of total welfare (accounting for intergenerational equity), and should represent consumption of market and non-market goods and services. It is important to understand that sustainability is a global issue. There are other definitions of sustainability, but we generally agree with the following observation by Daniel Sitarz[5]: *"In the final analysis however, agreeing on a formal definition of the term is not as important as coming to agreement on a vision of a sustainable world."*

From the general notion of sustainability, an idea that is gaining traction in industry is the notion of a "sustainability index" for products, process, and services. It is clear that the world is moving forward aggressively to achieve sustainable design and manufacturing with life cycle considerations. Design engineers of successful enterprises are confronted with the challenges of designing sustainable products, processes, and services. Achieving sustainability is no more an option during product development; it has become a part of the design requirement.

1.1 Background

To achieve sustainability, products, processes, and services should meet the challenges not only related to their functions and performance but also to environment, economy, and social issues. Currently, researchers from different perspectives using various approaches are addressing these challenges. Companies interested in developing products with sustainability characteristics should be sensitive to sustainability related standards, design, and manufacturing techniques and tools used for assessing sustainability.

[3] Report of the World Commission on Environment and Development: Our Common Future, http://www.un-documents.net/wced-ocf.htm

[4] Our Common Journey: A Transition Toward Sustainability, National Academy of Sciences, http://www.nap.edu/catalog.php?record_id=9690

[5] Sustainable America, America's environment, economy, and society in the 21st Century, Published in 1998, Earth Press.

Ensuring a sustainable future requires an integrated system of systems approach. Interlinked pathways of interaction at various levels characterize such systems. These levels span technical, economic, ecological, and societal issues. The interactions within and across these levels are critical to the fundamental understanding of sustainable design and manufacturing, because tackling any one of the issues in isolation could result in unintended consequences.

The systems approach of sustainability requires life cycle thinking. The life cycle of a product starts with raw material extraction and processing, continues with the pre-design and fabrication of the relevant semi-finished products, includes manufacturing and assembly of the final product as well as its transportation, use and maintenance, and concludes with the end-of-life operations. This last stage includes recycling of materials and, after adequate treatment, final disposal of waste. This cycle is repeated as shown in Figure 1. The figure shows two cycles. The first cycle depicts the extraction of material from the Earth and putting waste back into the Earth. We would like to minimize this cycle and in particular, achieve zero landfill. The second cycle includes pre-design, production, use, and post-use stages of the product life cycle. The systems approach to sustainable manufacturing will enable the optimization of this second cycle. The thick green arrows represent material and information flow between these stages. The reverse arrow from use stage to production stage denotes the field data from product use into the design and manufacturing to improve the design.

1.2 Overview of the workshop

The primary objective of this workshop was to bring together experts and various stakeholders to identify and discuss measurement and standards enablers that positively influence the social, economic, environmental, and technological aspects of designing sustainable production processes and products.

The workshop consisted of technical sessions (which included three keynotes), breakout discussions, and industrial showcases that addressed important issues necessary for the production of sustainable systems.

The topics for the technical sessions included (subtopics are given as examples):

1. Develop General Notion of sustainable manufacturing
   - Including indicators, indices, metrics for sustainability, Sustainable Manufacturing Maturity Model, macro level and micro level sustainability, the notion of triple bottom line, corporate social responsibility.

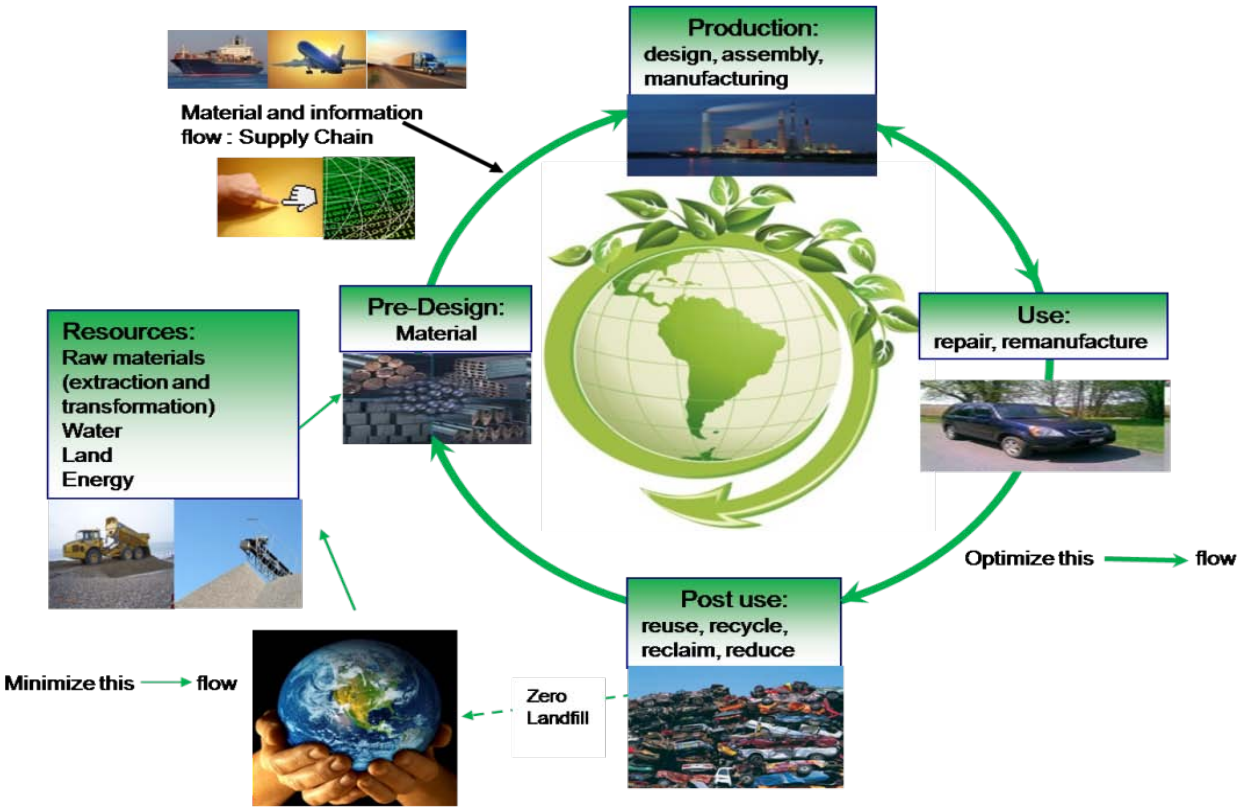

Figure 1: Sustainable Manufacturing - A closed loop view

2. Design of sustainable products, services, and manufacturing systems
   - Integrating environmental aspects into product design and development, design for process and product sustainability, product life cycle management and life cycle analysis, material science, advanced manufacturing technologies, nano-manufacturing, energy efficiency, conservation for production and use of products, reduce, reuse, and recycling, information infrastructure including advanced models and semantics for product and process, and manufacturing simulation.
3. Establish standards and industry best practices for sustainable systems
   - To include standards landscape for product, process representation, national and international standards and regulations for sustainability (e.g. ISO 14000, RoHS, REACH, and WEEE)[6], risk analysis of policy instruments (cap and trade), regulations, and cost of compliance.

[6] Acronyms are spelled out in the context of this document, and a reference list of those used can be found in Appendix D.

4. Develop next generation information and communication technologies (ICTs) for sustainable manufacturing
   - ICT for design, manufacturing and supply chain optimization for sustainable manufacturing
   - Large scale data modeling and semantic technologies for sustainable manufacturing
   - Tools, standards, and industry best practices for sustainable systems
   - Interoperability among PLM (Product Life cycle Management) and LCA tools to support energy and material monitoring and saving

1.3 Inaugural Session

Dr. Howard Harary, Acting Director, Manufacturing Engineering Laboratory (MEL), chaired the inaugural session, where he stressed the importance of sustainable manufacturing and the role of metrics and standards. He also gave a brief overview of some of the research and standard activities of MEL, in particular in the area of sustainable manufacturing. Dr. Howard Harary requested the participants to focus their attention on business perspectives of sustainable manufacturing, regulations and their local and global impacts, various academic initiatives; and encouraged the participants to explore and leverage various government initiatives on sustainable manufacturing. Dr. Patrick Gallagher, Director, National Institute of Standards and Technology (NIST), in his inaugural address underscored NIST's commitment to realizing the Department of Commerce's high-priority performance goal in sustainable manufacturing. He emphasized that the goal of NIST is to help U.S. industry to be the leader in the development and manufacture of innovative, sustainable products and related services. Dr. Patrick Gallagher also gave a brief overview of several ongoing sustainability programs at NIST, which address other sustainability issues such as energy efficient buildings, waste reduction in the semiconductor industry, measurement techniques for accurately determining greenhouse gas content, and innovative materials research. Vijay Srinivasan, Chief, Manufacturing System Integration Division (MSID), outlined how business and research communities are viewing sustainability in general and in particular sustainable manufacturing. Synthesizing various surveys and studies, he underscored the level of commitments shown by senior level business executives in implementing sustainability programs in their enterprises. Vijay drew a parallel between sustainability efforts with the quality movement, as noted in this quote, "*We are in the sustainability movement where we were with the total quality management (TQM) nearly 30 years ago. It will be a long, but useful journey."* Appendix B contains a more detailed analysis of the workshop and its outcomes by Dr. Vijay Srinivasan. Dr. Sudarsan Rachuri gave an overview of the workshop, its goal, and

the agenda. The rest of this report provides summaries of the keynote presentations, technical session presentations, and breakout groups' action items.

2. Keynote Presentations

There were three keynote presentations, one each from industry, government, and non-government organizations.

***Industry Keynote Presentation**: **Mr.* **Bob Bechtold**, CEO of **HARBEC Plastics, Inc**., presented a case study of how SMEs are implementing sustainability practices. His company, which makes high quality injection-molded parts, has made a considerable commitment to being green. Bob mentioned how his company disproved a common misconception *"Being Green is nice but we can't afford it"* through eco-economic factors implemented at HARBEC. He discussed the current progress and implemented systems, equipment, sustainable building elements, renewable energy, manufacturing equipment choices, lighting system upgrade, vehicle fleet management, water management alternatives, and practices at HARBEC, namely, CHP (Combined Heat and Power). He pointed to the gains realized since July 9, 2001. For example, in the CHP project, the microturbines are capable of generating 100 % of HARBEC power requirements and have provided air conditioning and heat for an injection molding facility, while grid connection is maintained for back up. Apart from these results, he also mentioned the secondary results such as air-conditioning provided by an absorption chiller, which turns exhaust gas waste heat into free air conditioning.

In the area of renewable energy, HARBEC installed a 250 kW wind generator to accomplish wind/microturbine hybrid electricity generation. Bechtold mentioned that the projected energy production is 300,000 to 350,000 kWH per year, or about 20 % of the total HARBEC annual energy requirements.

HARBEC, over a seven-year time span, replaced all standard hydraulic type equipment with all-electric injection molding machines. The advantage of electric machines is that these machines do not use power when they are in a static state, which is a significant portion of the time; the machines are capable of doing the same or a better job than the hydraulic machines, using as much as 50 % less energy. Bechtold showed the results they got by improving the lighting systems. They replaced every fixture, ballast, and high bay sodium lamps with new T-8 type fluorescent bulbs and reflectors. These sustainable manufacturing practices allowed HARBEC to ensure that the lighting energy consumed was reduced by 48 % on average company-wide. He

emphasized the overall lesson learned: *"If you want to make an environmental impact, and save money, use energy efficiently."* HARBEC is a big proponent of LEED, although not LEED (Leadership in Energy and Environmental Design) certified, HARBEC implemented LEED principles wherever it could.

HARBEC has significantly improved their water treatment system by installing a bi-metallic water treatment plant, which does not require any chemicals for water treatment. This enabled them to save thousands of dollars per year on chemicals, and eliminated the need for people to handle them. This new water treatment plant provided 3 217 600 liters (850,000 gallons) of fresh water input to their pond, which in turn provides water capacity sufficient for their sprinkler system, and also provides cooling. Bob Bechtold concluded his talk with the following statement, "*Sustainability can be a cost effective opportunity for business today which insures a viable and comparable world to live in for future generations.*"

Government Keynote Presentation: **Ms. Mary Saunders**, Assistant Secretary for Manufacturing and Services, International Trade Administration (**ITA**), Department of Commerce, described the recent developments in the Sustainable Manufacturing Initiative (SMI) of the Manufacturing and Services (MAS) division. SMI is looking for new areas where MAS can strengthen U.S. industry's global competitiveness. The main goal of SMI is to identify critical sustainability needs and challenges faced by the US industry and coordinate public and private sector efforts to address those challenges. As a first step, the MAS division held an industry stakeholders' event in 2007 to identify the critical sustainability needs and challenges faced by the U.S. industry and what role DOC should play in the area of sustainable manufacturing. This initiative is broadly supported by other federal agencies like EPA, DOE, CEQ, and NIST. Saunders also discussed some of the projects undertaken under SMI, namely,

- Creation of an Interagency Working Group on Sustainable Manufacturing
  This working group includes Department of Commerce (DOC), Environmental Protection Agency (EPA), National Institute for Standards and Technology (NIST), Department of Energy (DOE), Department of Labor (DOL), U.S. Department of Agriculture (USDA), Council on Environmental Quality (CEQ), Department of the Treasury, Department of State, Department of Justice (DOJ), Department of Defense (DOD),Office of Management and Budget (OMB),Department of Education, Small Business Administration (SBA), and Department of Veterans Affairs (VA).
- Clearinghouse of Government Programs/Resources
  This will be a central portal of U.S. government programs and resources: www.manufacturing.gov/sustainability

- Sustainable Manufacturing American Regional Tours - "SMARTs"
  The main goal is to increase awareness of the benefits of sustainable manufacturing and other business practices for U.S. industries. Commerce's SMART effort involves Assistant Secretary-led, regional manufacturing facility tours across the U.S., aimed at enhancing awareness of the benefits of sustainable manufacturing practices.
- Metrics for Sustainable Manufacturing
  The United States, working with other countries through the Organization for Economic Cooperation and Development (OECD), has begun an effort to address critical information gaps in sustainable manufacturing. The OECD's project on "Sustainable Manufacturing and Eco-Innovation" aims to accelerate sustainable manufacturing by transferring knowledge and providing industry with a means to benchmark their products and production processes. The first phase of the OECD project was concluded in April 2009. Short and long summaries of the project report are now available at http://www.oecd.org/dataoecd/34/27/42944011.pdf.

NGO Keynote Presentation: **Mark Cohen, Resources for the Future,** Vice President for Research, gave an overview on sustainability reporting and the Global Reporting Initiative (GRI). The vision of GRI is "to ensure that the reporting on sustainability performance becomes as mainstream and as transparent as reporting on financial performance." The framework is applicable to organizations of any size, type or location, and has been used already by hundreds of organizations around the world as the basis of their sustainability reporting.

The Reporting Framework[7] provides guidance on how organizations can disclose their sustainability performance. The Guidelines ("G3") are the foundation of the framework. The G3 are the "Third Generation" of the GRI's[8] Sustainability Reporting Guidelines. They were launched in October 2006 at a large international conference that attracted thousands. As of January 2009, more than 1,500 organizations from 60 countries use the Guidelines to produce their sustainability reports.

The GRI framework consists of two parts:
Part 1 – Reporting Principles and Guidance

- Principles to define report *content*: materiality, stakeholder inclusiveness, sustainability context, and completeness

[7] http://en.wikipedia.org/wiki/Global_Reporting_Initiative
[8] The GRI was formed by the United States based non-profits Ceres (formerly the Coalition for Environmentally Responsible Economies) and Tellus Institute, with the support of the United Nations Environment Programme (UNEP) in 1997.

- Principles to define report *quality*: balance, comparability, accuracy, timeliness, reliability, and clarity
- Guidance on how to set the report *boundary*

Part 2 – Standard Disclosures[9]

- Strategy and Profile
  - Disclosures that set the overall context for understanding organizational performance such as its strategy, profile, and governance
- Management Approach
  - Disclosures that cover how an organization addresses a given set of topics in order to provide context for understanding performance in a specific area
- Performance Indicators
  - Indicators that elicit comparable information on the economic, environmental, and social performance of the organization

The complete details are available at GRI's website www.globalreporting.org.

3. Government Initiatives

The objective of this session was to get an overview of the sustainable manufacturing initiatives taken by the government, with some insights into ongoing work at various government organizations. Following Ms. Saunders keynote address, the other presenters in this session were George Hazelrigg from the National Science Foundation (NSF), Gordon Gillerman from the Standards Services Division (SSD), Ram Sriram from the National Institute of Standards and Technology (NIST) and Kevin Watson from the National Aeronautics and Space Administration (NASA).

Before beginning his presentation (Thoughts on Manufacturing for Sustainability), **Hazelrigg, NSF,** pointed out that NSF seeks to fund fundamental research in education, but sustainability has not been specifically identified as a funding area within NSF. At the current consumption and population growth rates, George estimates that our energy reserves (fossil, nuclear, and solar) will last another 1000 years. On the other hand, we will soon run out of air, water, food, and space. Manufacturing must use less water, less energy, less scarce and toxic materials, and produce less waste. He introduced the concept of "Energy Manufacturing," which considers energy as a manufactured commodity. Feedstocks, capital, and labor are inputs and energy is the output. George also talked about optimizing design for manufacturing. Knowing the type of

[9] http://www.globalreporting.org/NR/rdonlyres/DDB9A2EA-7715-4E1A-9047-FD2FA8032762/0/G3_QuickReferenceSheet.pdf

facility that will be used for manufacturing at design time can help to optimize both the design and the manufacturing process. However, this calls for better modeling of the manufacturing processes, and better understanding of decision making under uncertainty. He noted that in the quest for a definition for sustainability, we must be mindful of Arrow's impossibility theorem. Hazelrigg identified that science and engineering can help to define the impact of manufacturing on the environment, estimate the consequences and present opportunities for change, and estimate their costs. Hazelrigg felt NIST could make crucial contributions in these areas.

Gordon, **NIST**, whose presentation was entitled "Standards Conformity and Assessment," opened by stating that delivery of services in a supply chain requires uniform understanding between the actors in the supply chain. We need standards for achieving this and NIST can contribute in this area. We also need quality standards and product performance standards in many areas, such as body armor covering[10], production management and supply chain. Gordon noted that globalization has turned standards into an international business, and NIST must play crucial roles in both policies and standards. Gordon suggested that we must look to industry/private consensus standards first, and government unique standards as the last resource. When the toy industry delivered unsafe goods to the retailers, Wal-Mart reacted by doing their own testing. However, it is very inefficient for retailers to test themselves. It is important for government organizations to take these initiatives forward by working closely with the industry. Gordon concluded by saying that green products need a lot of standards work, and expected NIST to deliver in this area.

Ram Sriram, NIST, gave an overview of the Sustainable and Life cycle Information-based Manufacturing (SLIM) program at NIST. Sriram felt that our personal destiny is our choice, and the same can be said about sustainability. When talking about sustainability, Ram felt that we must talk in terms of the whole life cycle of the product. The three dimensions of a product life cycle are business, process, and product. The SLIM program focuses on the information technology aspects associated with these dimensions. The historical view of products has centered around geometry – today, we need to focus on other semantic aspects as well, including form, function, behavior and constraints. Some of the challenges addressed in the SLIM work are: 1) evolving STEP to be compliant with OMG and W3C standards; 2) a core product modeling framework that supports form, function, and features; 3) organization and harmonization of standards; 4) long term knowledge retention; 5) indicators for sustainable manufacturing and 6) simulation of manufacturing enterprises.

[10] http://www.nist.gov/cgi-bin/view_pub.cgi?pub_id=33027

The final presentation of the session was by **Kevin Watson** from **NASA,** and entitled "NASA Manufacturing Supply Chain Sustainability Issues." A new executive order released a week before this workshop requires NASA to report scope 3 emissions[11], which include emissions from NASA's supply chain. Kevin pointed out that DOE has given guidance on the definition of quantitative indicators to determine a baseline and measure of progress towards goals. The indicators must be meaningful, additive and must have readily available data or use existing data. There must be an allocation of goals into the supply chain and integration of supply chain contributions to the achievement of these goals. Kevin mentioned that the way forward is in the identification of mechanisms for encouraging the prime contractors to accept the defined goals and to flow them down through their supply chain, find mechanisms for collaboration with contractors, and other government agencies, and provide assistance in achieving the defined goals. Kevin concluded by describing some technologies developed at NASA, including a rapid metal fabrication process that requires a minimum amount of machining and a green manufacturing technology that makes efficient use of feedstock and energy, while producing minimal waste.

4. Industry Perspectives

This session involved participation from industry leaders, focusing on the costs, benefits and challenges in incorporating sustainability in the industry. The objectives for this session were multifold: identify the major concerns in the industry regarding energy efficiency, waste etc.; get an insight into industry practices affecting sustainability factors such as environmental impact and social impact; gauge industry response to sustainability directives such as RoHS and REACH; and get industry feedback on regulatory directives and standards and the way forward. Following Bob Bechtold's keynote address (described earlier) for this session, presentations were given by participants from various industries, including the automotive industry (Ford, GM), aerospace industry (GE Aviation), high-tech industry (Lockheed), engineering consulting (Rockwell Automation), consumer goods industry (P&G), office products (Xerox), process industry (URS Corporation) and home products (Masco Retail Cabinet Group).

11 GHG (green house gas) Protocol identifies three potential "scopes" for a corporate GHG inventory. Scope 1 encompasses a company's direct GHG emissions, whether from on-site energy production or other industrial activities. Scope 2 accounts for energy that is purchased from off-site (primarily electricity, but can also include energy like steam, compressed air). Scope 2 emissions physically occur at the facility where electricity is generated. Scope 3 is much broader and can include anything from employee commute, to "upstream" emissions embedded in products and processes, to "downstream" emissions associated with recycling, transporting and disposing of products. Scope 3 is an optional reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company.

The presentations from the industry participants covered sustainability initiatives taken by the respective companies, describing steps taken in reducing carbon emissions, improving energy efficiency, and reducing waste. Summaries of the individual presentations are described below. One important observation, acknowledged by all the participants, is that NIST and other standards bodies should play a central role in addressing these concerns.

Margaret Lindeman, Lockheed Martin (LM), presented an overview of LM's *Go Green*[12] program. The main drivers for this program were reducing business risk by reducing dependency on natural resources and managing future regulatory expectations, while supporting customer objectives on environmental impact reduction, and being a good corporate citizen. Lockheed Martin's objectives for 2012 are to reduce carbon emissions, waste to landfill, and water usage by 25 %. Internally developed survey tools are measuring LM's performance, but the company plans to migrate to SAP Carbon Impact[13]. LM's energy efficiency projects have already yielded savings of 37.8 million kWh and $3.3 million in cost avoidance, and the company has reduced carbon emissions by over 4,800 metric tons, resulting in savings of more than $500,000. LM saved 11 million kWh and $1.2 million in operating costs by consolidating 1,700 IT servers. By 2008, the company had reduced carbon emissions by 3 % (by energy management and lighting upgrade), waste to landfill by 9 % (partnering with a vendor to recycle waste, which means that less than one percent of the site's waste will be sent to landfills) and water consumption by 11 % (by repairing leaks, improving efficiency, recycling process water and innovative landscaping projects).

Korhan Sevenler, Xerox, in his presentation entitled "Environmental Printing and Compliance Management at Xerox" described a new printer developed at Xerox that uses cartridge-free solid ink to reduce waste by 90 %. Korhan Sevenler identified regulatory compliance pressure, such as RoHS and REACH, as the leading reason for companies to take action on material content restrictions. He pointed out that Xerox cannot sell their products in Europe without meeting regulations like REACH, and this requires coordination and oversight of their supply chain --- over 2000 suppliers --- to ensure compliance. Xerox uses InSight[14] software for compliance management. Korhan also noted that there is some confusion about the directives coming from EU and other organizations, and that organization like NIST can play a significant role in

[12] Lockheed Martin's Go Green program: http://www.lockheedmartin.com/aboutus/energy_environment/going-green.html

[13] SAP CARBON IMPACT: Carbon Management Software to Measure & Offset Greenhouse Gas Emissions, http://www.sap.com/solutions/sustainability/offerings/carbon-impact/index.epx

[14] InSight Environmental Compliance: http://www.ptc.com/products/insight/environmental-compliance

coordinating and knowledge sharing.

Stephan Biller, General Motors, talked about the energy challenges in automotive manufacturing. About 36 % of the energy consumption in manufacturing is in painting. Transmission assembly accounts for 19 %, engine 13 %, stamping of sheet metal 12 %, and body structure and general assembly 10 % each. Painting is therefore a good candidate for energy reduction. Stephan proposed real-time control, better process design, and better equipment design as paths to energy savings. Part of the energy consumption in painting may be reduced if reentry time (for maintenance purposes) into the painting booth is reduced. GM found that the measured safe reentry time is much shorter than originally thought. To identify opportunities such as these, we need better data, better standards, and better measurement methods. Stephan observed that NIST could make valuable contributions in this area. He identified research opportunities in creating information models for energy decision-making, determining the level of carbon generated in the production of a specific vehicle configuration and methods to optimally allocate credits when considering developing remanufacturing supply chains.

Mary Burgoon, Rockwell Automation, gave a presentation entitled "Sustainable Production and Supporting Standards." Rockwell Automation is the leading global provider of industrial automation, power control and information solutions products which are used to control manufacturing processes. Mary observed that sustainability is a natural extension to Rockwell Automation's business goals of improving cost, quality, and productivity. The company's sustainability portfolio addresses not only energy and environmental concerns, but also workplace and product safety. Rockwell Automation's intelligent motor control portfolio (*PowerFlex* [15] and *IntelliCENTER* [16]) and software for continuous emissions monitoring (*Pavillion CEM*[17]) help address energy efficiency and environmental safety needs. The company also provides pre-engineered safety solutions and safety engineering services to address machine safety, process safety and worker protection. Mary pointed out that Rockwell Automation actively participates in standards activities for Smart Grid[18], energy management, environmental standards, and social responsibility standards.

Robert Crawford, Proctor & Gamble (P&G), provided an overview of the sustainability

[15] Allen-Bradley PowerFlex family of drives from Rockwell Automation, http://www.ab.com/drives/
[16] IntelliCENTER Software from Allen-Bradley, http://www.ab.com/mvb/intellicenter.html
[17] Pavilion8 Software CEM: Pavilion's Predictive Emissions Monitoring System, http://www.pavtech.com/index.php?option=com_content&task=view&id=200&Itemid=117
[18] Smart Grid: http://www.nist.gov/smartgrid/

program at P&G. Robert noted that 75 % of their customers are interested in sustainability, but they are not willing to pay more for it. P&G's cost reduction strategies for their products include condensed detergent, slimmer diapers, packaging reduction etc. The company created a resource conservation measures system. On average, 96 % of all materials are converted to a finished product. P&G uses the EPA transport distribution system to minimize traffic transport.

Todd Rockstroh, GE, reflected on GE Aviation's perspectives on sustainability. Todd described the Overall Equipment Efficiency (OEE) [19] as one affordable solution for measuring sustainability. This allows GE Aviation to find the most common and most expensive energy leaks. Intelligent manufacturing must use upstream information to reduce rework, scrap, and variation. Additive fabrication is a GE initiative that reduces raw material and machining required to make a part, and simplifying large components and combining multiple small components. Todd identified the main challenges for a regulated industry as the need for tools to assess carbon impact when changing manufacturing parameters, and tools to assess the risks and financial impacts of changing manufacturing processes. The value of information models cannot be realized without the capability to use them in real time, and identifying measurement touch points. Todd recommended that NIST should work with the industry and other partners in developing these information models.

Kathi Futornick, URS Corporation, focused on industrial regulations and standards, in particular metrics for sustainable performance. Kathi Futornick noted that environmental regulations should go beyond the EU directives and should be the major driver for sustainable and global environmental compliance programs. The supply chain is the weakest link for compliance management. Most supply chain partners do not see a linkage between the environment and their operations, and do not use metric to measure sustainability. The reason cited by suppliers is that their contract does not mention sustainability. As an approach to compliance, Kathi suggested self-declaration by manufacturers, which can be enforced by market surveillance. URS Corporation looks at declarations, performs destructive and non-destructive tests, and develops fishbone diagrams showing what feeds into product quality. Kathi described Wal-Mart's supported Sustainable Product Index (SPI)[20] program, which has three phases: the first phase addresses its supply chain (*15 Questions for Suppliers*); the second phase is life cycle assessment, which involves a comprehensive assessment of raw material production, manufacturing, distribution, use, and disposal including all transportation and environmental impacts; and in the third phase the SPI is displayed on products on the shelf for consumers to see

[19] OEE: An effective benchmarking tool in making sound decisions, http://wcm.nu/OEE/oee.html
[20] Wal-Mart's Sustainability Index: http://walmartstores.com/Sustainability/9292.aspx

and use in their buying decisions. Kathi also listed some other voluntary programs that address vendor/supplier requirements and related issues. Finally, Kathi stressed the need for a systems approach to sustainability, and widespread industry alignment with regulations as a catalyst for achieving sustainability.

Gahl Berkooz, Ford Motor Company, spoke on the opportunities for information standards in sustainability and compliance. Gahl began by listing some of Ford's achievements: Ford Fusion Hybrid, rated best mid-size hybrid sedan in America; and Ford Fiesta ECOnetic, rated UK's greenest family car. The Ford Rouge Complex[21] in Michigan has one of the world's largest green roofs. Gahl identified the main information challenges to sustainability, namely, the cost of regulatory compliance and reporting, and the cost of assessment of the environmental footprint of products in transit. Gahl observed that standards could play a significant role in reducing these costs. He also noted that regulations were reactive in the past (pollution control), then became anticipatory (pollution prevention), and are moving towards high integration and transparency (eco-efficiency, environmental cost accounting systems). The challenge for IT is to develop proactive frameworks that are flexible, decrease compliance costs, and help assess risks. Reactive IT frameworks are costly, have redundant information flow, and new systems must be built for new regulations. Gahl felt that standards organizations could help industries in environmental reporting by mapping the regulations to available standards. Another significant problem is to build a bridge between information standards and legacy data, to avoid duplication and improve risk assessment. Gahl recommended that NIST play a significant role in the development of these standards.

The final presentation of the session was by **Denise Van Valkenburg, Masco Retail Cabinet Group (MRCG)**, which was entitled "Integrating Sustainability into Manufacturing Systems." Denise pointed out that we need to get past the idea of using regulations as a catalyst. She described "Design for the Environment" (DfE) as a method of identifying major environmental concerns regarding product design, manufacturing process, direct productive materials, and indirect processing materials. The main drivers for this are environmental regulations, green product initiatives, and customer demand. DfE ensures continuous environmental improvement by a process of review of existing designs and environmental audits and improvement goals. The MRCG Manufacturing Management Operating System (MRCG MMOS) is a standardized process designed to align goals, drive performance, measure compliance, and stimulate continuous improvement from the shop floor up to and including the executive scorecard. The

[21] The Ford Rouge Complex: http://www.thehenryford.org/rouge/index.aspx

primary categories it addresses are health and safety, environment, quality, performance, and schedule attainment. MRCG MMOS includes total employee involvement; uses structured reporting and integrates environmental metric scorecards. Lean Information Control System (LINCS)[22], a web based software tool, is used to support it, and the resulting improvements have led to substantial reductions in waste and earned awards for MRCG.

Summary of the Industry Perspectives

While each of the above presentations covered the activities of a particular company, many common issues were raised that swept across industrial sectors. The most important observations are summarized below.

Need for improved standards and regulations: Current sustainability related standards and directives are evolving, and more work is needed to produce mature standards. Much of this work is related to improving the science behind the standards, and balancing the scientific and metric aspects to the associated business aspects. The business impact of such a standard must be carefully addressed. For instance, Korhan Sevenler from Xerox noted that while RoHS mentions six substances, REACH covers thousands. Mary Burgoon from Rockwell Automation stressed the importance of machine and electrical safety, and maintaining worker protection and productivity. The participants agreed that these directives must be carefully formulated to ensure compliance and be of value to the industry. Stephan Biller from General Motors argued for better standards that can drive the design and implementation of manufacturing processes. For example, well-developed standards and better measurement technologies could lead to reduced down times during production. In addition, Denise Van Valkenburg from Masco Retail Cabinet Group and Korhan Sevenler claimed that regulations are necessary to drive the industry towards sustainable practices. NIST could be one of the primary institutions that could play a leading role in developing and championing these standards.

Guidelines for regulations and reporting: While there was a feeling that the regulations themselves are not fully developed, there is an urgent need for guidelines on reporting and information management related to compliance. Korhan Sevenler highlighted the need for coordination and knowledge sharing to cope with the different directives coming from different organizations. Todd Rockstroh emphasized the importance of being able to use information models in real time to assess risks, while Gahl Berkooz added that we need proactive IT

[22] Lean Information Control System, LINCS , http://www.usccg.com/tech/lincs.php

frameworks that are flexible and will result in reduced compliance costs. Kathi Futornick illustrated some examples such as Wal-Mart's Sustainable Product Index. It was observed that NIST and other government agencies should play a significant role in taking these initiatives forward, while ensuring that there is a fair and level playing field for all businesses.

Compliance management in the supply chain: One of the recurring themes in the presentations was compliance management in the supply chain. Korhan Sevenler noted that American companies face supply chain disruptions in Europe due to REACH restrictions. Kathi Futornick called the supply chain the "weakest link," noting that most supply chain partners do not see a connection between environment and sustainability and their operations. There was a consensus on the challenge of managing the supply chain, and the need for standards and practices directly addressing compliance in the supply chain. Sevenler suggested that NIST could contribute towards the development of such a standard.

5. University Research

The university session provided workshop participants an opportunity to articulate various research issues in sustainable manufacturing. Most speakers agreed that sustainable manufacturing issues are challenging, and emphasized the necessity of a system approach that can synthesize the triple bottom line, life cycle views for metrics, and information systems. Since many of the speakers in this session have touched on breadth of research issues, we provide the summary according to the broad research topics.

System approaches: Bert Bras, I.S. Jawahir, and John Sutherland collectively pointed out that closed-loop material flow should be considered in making a system more sustainable. A closed-loop material flow could be expressed as a process consisting of extracting materials from nature, manufacturing, supply chain, and through the 3Rs (reuse, recover, and recycle processes). Closed loop material flow encourages recovery, reuse, and recycling of materials. I.S. Jawahir expanded the closed-loop material flow to 6Rs, viz. redesign, reduce, remanufacture, reuse, recover, and recycle processes.

Bert Bras also discussed the emphasis that industry places on various aspects of the closed loop product life cycle. The initial focus is on improving the manufacturing process. After manufacturing processes are optimized, the focus goes back to the design stage to improve product design. Then, industry efforts on sustainable manufacturing focus on material sourcing (extraction), supply chain, and eventually the 3Rs. The following issues were presented in the

workshop.

Manufacturing process analysis: John Sutherland shared lessons from his analysis of a machining process. He mentioned that a characterization of a manufacturing process is required to measure the environmental impact of the process. For example, different processing conditions and alloy types affect the environmental impact of a machining process. In addition, he recommended that not only energy consumption but also air quality during production must be investigated for the health and safety of workers.

Sustainable Design: Bert Bras, Karthik Ramani, and John Sutherland reiterated that sustainable design is critical because of its downstream impact on the environment. Karthik Ramani proposed how engineers can use an LCA tool in the conceptual design phase. Engineers want to estimate the environmental impacts of their conceptual designs. However, most previous tools for sustainable design failed to estimate the environmental impacts of a conceptual design because conceptual design data are neither complete nor detailed. Therefore, he proposed a way to estimate the environmental impacts of a conceptual design. Karthik Ramani used the environmental impact data of existing products. He analyzed the environmental impacts of existing products for their functions. Then, he estimated the environmental impacts of a conceptual design using the function-impact matrix. The function-impact matrix provides estimated impacts of functions and enables engineers to distribute the impacts to components of a conceptual design. His research resulted in identifying up to 70 % of conceptual design accounts for 70 % of the environmental impacts. Bert Bras and John Sutherland pointed out that sustainable design requires creativity and a service-oriented approach. Previous design approaches focused on redesign of components to use less material. However, the service-oriented approach, which involves selling services (e.g., printing services) rather than actual products, can be more sustainable than the previous approaches. Bert Bras showed the service-oriented approach example in the camera industry. He used an LCA example to show that providing services (printing services in wholesale) instead of products (PC printers in houses) can be better.

Supply chain analysis: John Sutherland pointed out that the growing priority of sustainability would have an impact on suppliers, facility location, size, and distribution. It requires determining the environmental impacts of a product by summing impacts of its components and materials across the supply chain. Then he raised issues such as modeling supply chain processes, information systems for data collection, interoperability, and the need for a compliance infrastructure for metrics, standards, and regulations.

Kincho Law addressed various issues about supply chain process modeling and implementation. He recommended an open standards approach. He proposed GreenSCOR, which is a framework for modeling supplying chain processes. In addition to performance metrics included in the Supply Chain Operations Reference (SCOR) framework[23], the GreenSCOR includes additional metrics for evaluating the environmental footprint. He also suggested using open standards such as Business Process Modeling Notation (BPMN)[24], Business Process Execution Language (BPEL)[25], Web Service Definition Language (WSDL)[26], and Simple Object Access Protocol (SOAP)[27] for supply chain process models and web services. Kincho demonstrated a prototype system -- called "SC Collaborator." The system provides user-interfaces to collect the environmental footprint of components from participants across the supply chain. Then, the system aggregates and calculates those data and reports the total environmental footprint of a product.

Reuse, Recovery, and Recycle: Reuse, recovery, and recycle processes must get more attention from researchers because these have considerable impacts on sustainability. According to Bert John Sutherland, recycling materials requires much less energy than refining raw materials. For example, while recycling aluminum requires 0.32 MJ/kg of energy, its refining process requires 240 MJ/kg. Thus, Bert Bras and John Sutherland emphasized that de-materialization should be a very high priority from an energy point of view.

Metrics: Research on sustainability metrics attracted considerable attention in the workshop. Most participants showed interest in the semantics of metrics[28], computation of metrics, and use of metrics for decision-making. Speakers in the university session addressed several of these issues.

Sustainability metrics described by speakers reflect the triple bottom line. Hong Zhang showed a list of ISO standards related to the triple bottom line, and briefly explained about the United

[23] Supply Chain Council, SCOR Frameworks, https://www.supply-chain.org, 2009
[24] Object Management Group, Business Process Model and Notation (BPMN), http://www.omg.org/spec/BPML/2.0, 2009
[25] Organization for the Advancement of Structured Information Standards, Web services business process execution language version 2.0 primer, http://docs.oasis-open.org/wsbpel/2.0/primer/wsbpel-v2.0-primer.pdf, May 2007.
[26] World Wide Web Consortium, Web services description language (WSDL) version 2.0, http://www.w3.org/TR/wsdl20-primer, June 2007
[27] World Wide Web Consortium, SOAP version 1.2 part1: messaging framework, second edition, W3C recommendation, April 2007.
[28] Metrics and indicators are used interchangeably here.

Nations Commission on Sustainable Development Framework (CSD)[29]." The framework provides a classification of sustainability metrics or indicators. It classifies indicators into four sustainability aspects such as social, environment, economic, and institutional aspects and classifies indicators further into sub-categories for each aspect.

Jawahir suggested that sustainability indicators should be classified according to the levels of measured objects such as product, process, enterprise, and supply chain. He applied the multi-level approach in classifying indicators developed by the Organization for Economic Co-operation and Development (OECD).

Sustainability index calculation methods and using metrics for decision support: I.S. Jawahir described a methodology for calculating a sustainability index. He used the weighted sum of scores between 0-10 for each influencing metrics. If a metric is measurable, and the minimum and the maximum of the metric are known, the metric can be converted into a score between 0-10. If a metric is not measurable, it can be scored between 0-10 based on designers' experience. Although sustainability metrics/indices for different materials/products/scenarios can be calculated, it may not be clear that one is better than other. For example, material 'A' may be good for the environment, but it may not be good when assessing the social/economic impacts. Meanwhile, material 'B' may not be good for the environment, but it may be good for assessing the social/economic impacts. However, there is neither a guideline nor an evaluation method to make a trade-off between environmental impacts and social/economic impacts. David Ervin and Hong Zhang addressed this issue in the workshop. Ervin proposed a monetized approach to calculate sustainability indices. The approach monetizes all metrics of the triple bottom line using the genuine savings concept, so that it resolves the summation difficulty of different metrics and allows substitution between natural capital and other forms. The Genuine Metrics is based on Genuine Savings[30], which focuses on analyzing the economic benefits and costs associated with development activities. Genuine Metrics is essentially a method for combining financial and environmental data.

Hong Zhang pointed out that current LCA techniques have limitations for making trade-offs

[29] The United Nations Commission on Sustainable Development (CSD) was established by the UN General Assembly in December 1992 to ensure effective follow-up of United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit. http://www.un.org/esa/dsd/index.shtml

[30] J.Ram Pillarisetti, The World Bank's 'genuine savings' measure and sustainability, Ecological Economics, Volume 55, Issue 4, 1 December 2005, Pages 599-609

between environmental protection and both social and economic concerns in the product life cycle. Since LCA traditionally does not take into account social and economic impacts, Hong Zhang proposed social and economic indicators for LCA. He presented a technique based on the principal component analysis (PCA) technique to aggregate sustainability indicators on a variety of scales.

Information systems: Most issues for sustainability information systems are coupled to the aforementioned issues. Typical information system issues are data/service interoperability and process/information modeling issues across the supply chain. Kincho Law proposed an open standards approach for developing an information system, which can collect data across the supply chain and report environmental footprints. He used the EU LCA dataset[31] to calculate footprints because it is open to the public and free.

Bert Bras shared his experiences about sustainability software development for manufacturing companies. He presented an extension to the activity-based costing (ABC) approach to assess environmental impacts, but he found that it was difficult to apply the ABC approach to the manufacturing company he worked with because the company had incompatible financial systems.

6. NGO Research

The Non-Government Organizations (NGO) Research section had participation from various NGOs and Standards Developing Organizations (SDOs), and industry consortia, focusing on various standards development efforts, harmonization of standards, and sustainability reporting mechanisms and standards. The speakers were asked to give an update on various standards development efforts and progress in implementing these standards in terms of accounting and reporting, verification and validation, and product labeling. Currently there are three competing standards related to sustainability:

1. PAS 2050[32], which is a specification for the assessment of the life cycle greenhouse gas emissions of goods and services
2. ISO 14000 series of standards, which are developed under ISO TC 207, apply to standardization in the field of environmental management systems and tools in support of sustainable development

[31] European commission's joint research centre, ELCD core database version II, http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm, 2009.
[32] The British Standards Institution, http://shop.bsigroup.com/en/Browse-by-Sector/Energy--Utilities/PAS-2050/

3. GHG Protocol-Product and Supply Chain Standard developed jointly by World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) to support the public reporting of product level GHG emission inventories for all products and services in all market sectors

The above standards need to be harmonized so that industry can implement them in an effective manner.

The session began with a keynote address by Dr. Mark Cohen**,** Vice President for Research, Resources for the Future, whose presentation was summarized in Section 2. This was followed by presentations by participants from various SDOs, NGOs, and industry consortia, including the American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM), World Resource Institute (WRI), National Center for Manufacturing Sciences (NCMS), National Council For Advanced Manufacturing (NACFAM), and Cadmus Group. The presentations covered standards development efforts, an overview of US standards development process, sustainability metrics, and progress in implementing these standards in terms of accounting and reporting, verification and validation, and product labeling.

Pankaj Bhatia, **World Resources Institute (WRI),** Director of GHG Protocol Initiative, gave an update on the product accounting and reporting standard and gave a brief overview on a new initiative called Greenhouse Gas Protocol Product and Supply Chain Initiative. The two published standards under this initiative are: 1) A Corporate Accounting and Reporting Standard (Corporate Standard), and 2) The GHG Protocol for Project Accounting. (These can be downloaded from the following URL: http://www.ghgprotocol.org/standards.) He also mentioned they are developing two new standards, namely, Scope 3 (Corporate Value Chain) Accounting and Reporting Standard and the Product Life Cycle Accounting and Reporting Standard (product carbon foot printing). The main objectives of the Product Life Cycle Accounting and Reporting Standard are to:

- Support the public reporting of product level GHG emission inventories for all products and services in all market sectors
- Support other uses of product GHG information, e.g., internal product reduction decisions, and tracking of emissions for internal purposes
- Help users of the standard reduce emissions by making informed decisions about the products they manufacture, buy, use, and sell.

Pankaj also stressed that there is a growing demand to compare similar products based on their

life cycle GHG emissions. However, there are many technical challenges in ensuring that such comparisons are valid. To do so, there is a need for methodological consistency at the product category rules (PCR) level. PCRs provide a mechanism for agreeing on specific rules in relationship to individual product categories. PCRs are established under ISO 14025:2006[33] with the aim of improving comparability. The environmental performance of products differs significantly according to the product categories (where a product category is defined as a group of products, which can fulfill equivalent user needs). Hence, it is critical to select a set of appropriate indicators and calculation rules. To achieve this objective, Product Category Rules (PCR), formerly called Product Specific Requirements (PSR), corresponding to the general EPD program requirements are defined. According to ISO 14025, PCR are a set of specific rules, requirements, and guidelines for developing Type III environmental declarations for one or more product categories. Three different types of environmental labels and declarations are currently in use. They include: Type I environmental labeling, Type II self-declared environmental claims, and Type III environmental declaration.

Further research work in product carbon foot printing is currently being undertaken. This underscores the widespread recognition of the limitations of the previous international standards and the need for consistency in the methods used. He also mentioned that the WRI/WBCSD announced in July 2008 that they would be collaborating on a product carbon foot-printing project, while the International Standards Organization voted in November 2008 to proceed with development of a new international standard on product carbon foot-printing (ISO 14067:2008).

Manish Mehta, **National Center for Manufacturing Sciences (NCMS),** Executive Director, Industry Forums & Technologies Research Corporation, , gave an overview of collaborative initiatives for sustainable products manufacturing at NCMS. Specifically, he highlighted the Sustainable Product Initiative (SPI), a six-year EPA sponsored program (2004-2010) for developing "best practices," design criteria, analytical tools, manufacturing capabilities and/or recovery techniques for future products, resulting in an enhanced level of environmental acceptability and sustainability than products that are currently available. The main target sectors are automotive, office furniture, and textiles. As part of this initiative, NCMS has developed a Sustainable Product Standards Guide, a collaboratively developed "How-to" document addressing multi-attribute standards development processes and pitfalls. NCMS has engaged leading organizations pursuing standards-related activities to confirm relevance and differentiation of the NCMS-led effort. NCMS is planning to release an advanced "draft" Guide

[33] http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=38131

by March 2010. A Wiki has been established to solicit broader input. (See http://spi.ncms.org/standards for details.) Manish also described some of the Life Cycle Assessment (LCA) projects at NCMS and showed details about Life Cycle Analysis of Volatile Organic Compounds (VOCs) in Paints & Coatings, called Coatings Counselor 2.0 LCA.

Gary Kushnier, **American National Standards Institute (ANSI),** Vice President of International Policy, gave an overview of the U.S. approach to standards and conformance, leading toward the goal of one standard, one test, one global acceptance and used the following notation (1:1:1) to emphasize this point. He pointed out that the main difference between the U.S. approach to standardization and that followed in other nations is that the U.S. uses the bottom-up approach where users drive standards and conformance activities. Whereas most nations follow a top-down approach, in which a centralized body drives standards and conformance activities. He also mentioned that the U.S. conformity assessment system, much like the standards system, evolved in a decentralized manner. Gray noted that the standards are just good ideas unless products, processes, systems, and personnel conform to them. Conformity assessment activities are not centrally organized and the approaches vary among sectors. He also gave a very brief overview of ANSI initiatives related to sustainability.

James D. Thayer, Cadmus Group, Senior Associate, and Professor, Portland State University, presented an idea of genuine metrics based on genuine savings. Genuine savings uses a firm's Property, Plant & Equipment (PP&E) as the baseline for its current sustainable base. Sustainability is calculated by adjusting this base for investments in, or depletion of, social capital and natural capital (resources). To translate the genuine savings model into an analytical framework for use at a corporate or operating level, the metrics are linked to the GRI sustainability indices. The last step adjusts the PP&E upwards and downwards by the appreciation and depreciation costs to find the net impact of sustainability activities. He explained the benefits of using genuine metrics.

Jeffrey Mittelstadt, **National Council for Advanced Manufacturing (NACFAM),** Vice President, Sustainable Manufacturing, gave an overview of NACFAM's Sustainability Framework Model. The main idea of this model is to develop and provide modeling for business decision-making with respect to sustainability. The model is based on existing financial and environmental metrics and is continuously enhanced through project applications. He also mentioned that NACFAM has established a Sustainable Manufacturing Council to advance U.S. manufacturers toward sustainable manufacturing.

Stephen Mawn, American Society for Testing and Materials (ASTM) International E60 Committee Staff Manager, gave an overview of ASTM and the current activities of E60[34]. Many ASTM International committees address sustainability, namely, infrastructure/built environment, water, agriculture, energy, products, waste, materials, and toxics. ASTM Committee E60 on sustainability was formed in 2008 and has more than 500 members. The technical subcommittees include the following: E60.01-Buildings and Construction, E60.02-Hospitality, and E60.80-General Sustainability Standards. The administrative subcommittee consists of the following E60.90-Executive, E60.91-Strategic Planning, and E60.95 Student Liaison and Affairs.

The E60 committee has so far published ten standards. Examples of these include ASTM E2432-Standard Guide for General Principles of Sustainability Relative to Buildings, and E2114-Terminology for Sustainability Relative to the Performance of Buildings Draft Standards. Stephen also mentioned that there are many sustainability standards under development: nine draft standards for sustainability in industry, and six draft standards related to sustainability in infrastructure/buildings are under preparation.

7. Software Solutions

The Software Solutions session predominantly focused on the need for tool support for sustainable manufacturing, in particular currently available tool support, and the standards compliance of the software applications. Companies are becoming increasingly interested in adhering to standards/directives such as RoHS and WEEE to compete globally. This calls for a systematic approach towards enabling these and other international standards at the institutional level as well as at the product level. Currently, there are several initiatives by individual software developers working closely with CAD companies to develop software support for environmental impact assessment of products, processes, and services. The software tools not only help companies assess the impacts of their products but also help them to determine if a product is compliant to a particular standard or not.

John Fox, **Parametric Technology Corporation (PTC)**,[35] Director, Product and Market Strategy, spoke on "Software Tools and Information Exchange Standards." He explained the importance of complying with sustainability-related product standards that will enable companies to be competitive in the global markets. He also explained how software could help companies assess the compliance of products by analyzing the life cycle of products, and all the

[34] http://www.astm.org/COMMIT/COMMITTEE/E60.htm
[35] http://www.ptc.com/

components that go inside the product. John Fox described PTC's 'Insight'[36] software, which could help designers assess whether a particular product is compliant to a certain standard or not. The software can process various kinds of data forms to create a database from suppliers, material database and legacy databases.

Michael J. Zepp, **Dassault Systemes**[37]**,** Director, Global Market Development Environmental Compliance and Sustainability, gave a presentation entitled "Innovation for Eco-Sustainability." He indicated that sustainable strategies create new usages and buying criteria for products and services. He also spoke about the importance of sustainable design using LCA and he expressed that software could be used to assess environmental impact and help designers design sustainable products. The importance of regulatory compliance and designing products for those compliant to various sustainability regulations could help us achieve eco- sustainability.

Laurie Jansen, Siemens[38], focused on Siemens strategy for incorporating sustainability in Siemens' PLM systems. She pointed out that developing sustainable products and processes require assessing the products to indicators that fall under environmental, social, and economical factors. Laurie called for an integrated approach towards LCA. According to her, sustainability could be achieved through the following tools and techniques: plan for sustainability, design for sustainability, practice sustainable manufacture, provide sustainable services, examine end of life, governance, compliance, and reporting.

Elena Arvanitis, **Siemens**, ended the session with her talk entitled "Sustainable Product Design and Manufacturing at Siemens: Sustainability Metrics and Environmentally Compatible Product Design." (Although her talk should have been a part of the industry session, it was included here due to scheduling constraints.) Sustainability is commonly measured as performance along a *triple bottom line*: environmental, social, and economical. Elena spoke about environmental performance and internal reporting, corporate responsibility, a corporate environmental protection program, and product-related environmental protection. Using examples, she explained how, by analyzing the life cycle of products, we could save energy and resources during product use and manufacturing.

8. Breakout Sessions

The plan and agenda for the breakout sessions were based on a structured brainstorming and

[36] http://www.ptc.com/appserver/wcms/events/series.jsp?&im_dbkey=89520
[37] http://www.3ds.com/
[38] http://www.usa.siemens.com/entry/en/

team-oriented problem solving process that has been applied successfully in prior NIST-led workshops. This process consists of the following two steps: 1) Problem/Opportunity Identification, and 2) Analysis and Planning. The Analysis and Planning step can be further broken down into: 2.1) Root cause analysis, 2.2) Recommendation Generation and 2.3) Action Planning.

A session facilitator helped to guide/mentor/facilitate the sessions --- but the content, ideas, analysis, and recommendations were the group's responsibility. Each session had a scribe to take notes and to prepare the material for the group report. The participants were separated into two breakout groups. On the first day (13 October, 2009) of the breakout session, all workshop participants contributed to identifying and grouping the "top attributes" pertaining to the workshop objectives, to be discussed at length by the breakout groups. On 14 October, 2009, the two groups spent most of the time dealing with the identified "top attributes," followed by recommendations. The identified breakout groups

1. *Critical factors driving sustainable manufacturing:* The themes discussed in this group were business case for sustainability, promoting eco-innovation, standards and metrics, tool support, promoting reduced energy consumption, and positioning of standards.
2. *Decision support system for sustainable manufacturing:* The themes discussed in this group were standards harmonization, science of sustainability, greening the supply chain, data availability, and needs.

The participants generated recommendations or conclusions by selecting the best ideas or combining ideas for the "top attributes" identified. The group completed one form (see below) for each recommendation. The group covered as many of the "top attributes" as possible.

Breakout Team ID	
Problem or Issue:	
Root Cause:	
Recommendation:	

Action Plan: *Possible steps towards the goal*	**Roles**
	Industry
	Government
	Academia
	NGO
	Software

NIST Workshop on Sustainable Manufacturing: Metrics, Standards, and Infrastructure, October 13-15 2009, NIST

Figure 2: Recommendation Template

- The Problem or Issue is a statement of what is wrong.
- The Root Cause is a statement of why the problem exists. Every "why" becomes another problem statement. Sometimes you have to ask "why" a number of times to try to get to the root cause. The root cause restates the observed problem in a way that lends itself more readily to "corrective action planning." This is like trying to get from the *symptoms* to a *disease* diagnosis.
- The Recommendation is a high-level plan or strategy to address the root cause of the problem. One form is completed for each recommendation. There may be more than one recommendation for the same problem, or a team may have time to consider more than one problem.
- The Action plan is a specific set of tasks with an identified set of "roles" and (if possible) time frame, to *implement* the recommendation.

Group 1: Critical factors driving sustainable manufacturing

Group 1 took up the following set of key issues and subtopics for further elaboration, starting with this set and identifying the most common themes.

1. *Business:* how do the following diverse factors affect the business case: compliance, economic models, profit, case studies, and new sustainable products?
2. *Eco-innovation:* How to promote eco-innovation?
3. *Metrics:* How to develop metrics based on solid models, cases, and good data for model validation?
4. *Tools:* What are the gaps and problems with a methodology such as LCA? What is the business case for tools?
5. *Energy:* How to reduce energy consumption for sustainable growth?
6. *Standards:* How should standards be posed so that the positive incentive side drives them?

Multiple factors affecting sustainable products: Businesses need to make decisions based on a diverse range of factors when it comes to sustainable manufacturing. To make sound decisions, they must consider compliance, economic models, profit, and case studies.

Problem or issue:

- How to make sound business decisions when confronted with a variety of sustainability factors?

Root cause:

- Businesses are mainly concerned with profit, sales, and market share. It is difficult to compare these factors among different diverse companies and industries.

Recommendation:

- Develop a better understanding of the drivers and relationships among these factors.

Action plans:

- Reduce costs by analyzing the life cycle of products, establishing a link between sustainability and financial performance.
- Develop measurable indices, which can be represented in monetary terms. This must assist decision making by comparing profits with cost of being sustainable. Much of the responsibility to investigate the science behind these indices and establish a methodology for their measurement lies with academia.
- Anticipate regulations and clearly identify the minimum requirements that satisfy compliance. NGOs have the responsibility to educate the industry and society at large about standards and publish business cases illustrating them.

- Towards this end, we expect the industry to be transparent and encourage sharing and co-operation. Governments must provide a level playing field for all businesses.

Promoting eco-innovation: Eco-innovation is the innovative design of products and processes that are sustainable or contribute to sustainable development. The quest for sustainable products has provided an opportunity to come up with innovative designs for the future. However, such designs have so far been risky and under-funded.

Problem or issue:

- How to promote eco-innovation?

Root cause:

- There is a lack of funding for fundamental research in the design of sustainable products. Research in this area requires a high amount of resources, and has a high uncertainty.

Recommendation:

- Be open minded, and learn from previous experiences in Europe.

Action plans:

- Learn a lot about eco-innovation from Europe, where a number of innovative designs have been developed in recent years for green and sustainable products.
- Encourage open-mindedness. Develop new business cases for innovative designs, and facilitate their acceptance.
- Increase industry-academia interaction and find avenues for funding for eco-innovation.

Metrics, data models, and validation: There is a need for simple and high level metrics, and these need to be supported by good data models. Previous attempts have led to metrics that are difficult to estimate, and for which data is not readily available.

Problem or issue:

- How to develop metrics based on well-defined data models, and where can we get good data to validate them?

Root Cause:

- There is no standard single unit for comparing metrics, making them difficult to compare and analyze.

Recommendation:

- Develop simple high-level metrics.

Action plans:

- We must have a multi-level approach, leading to simple metrics at the highest level.

- Ensure that it is easy to compare the metrics to standards.
- Metrics must be normalized with respect to production.

Methodologies in practical use: The focus here is on the use of methodologies such as LCA (life cycle assessment) when applied to the supply chain. The typical problem is that not all the companies in the supply chain can afford to apply the methodologies to their products. For example, LCA requires substantial product and process information across the supply chain, and small companies in the supply chain may not have enough information or an efficient way to access the information. They may not have enough power to control their original equipment manufacturers or sub-tier suppliers to get information.

Problem or issue:

- What are gaps and problems with a methodology such as LCA?

Root Cause:

- Not all the companies, especially small companies, in the supply chain can apply the methodologies to their products.
  - They may not have enough information.
  - They may not have an efficient way to access information.
  - They may not have enough power to control their sub-tier suppliers to get information.

Recommendation:

- Develop a simple and transparent methodology for small companies to go through it in a short time and less cost.
- Create a new business model for companies to conduct the methodology voluntarily in pursuit of their profits.

Action plans:

For Academia

- Develop transparent methodologies which:
  - Can compute sustainability without exposing critical technology of the companies.
  - Can build different levels of information and process models in supply chain.
  - Includes a role of auditing and validating.
- Develop clear metrics for the methodology.

For industry

- Create a new business model.

Necessities for reducing energy consumption: Companies hesitate to invest money for improved energy efficiency of their manufacturing process (e.g., investment on energy-efficient

facilities for replacing legacy facilities). The government needs to have a proper carrot and stick approach that encourages companies' investment. Current methods to evaluate energy consumption and the lack of decision-support tools for this were addressed. The evaluation methods and decision-support tools are critical for companies to decide their investment. The evaluation methods should be able to calculate the environmental impacts, and these evaluation methods should consider the energy life cycle and source types. Additionally, there is a need for developing energy simulation models and analysis tools for a trade-off analysis between investment and environmental impacts.

Problem or issue:

- How to recognize and promote reducing energy consumption for sustainable growth?
- Why do companies struggle to make a decision to invest money to reduce energy consumption?

Root Cause:

- Current evaluation methods for energy consumption are not sufficient to measure environmental impacts.
- Decision-support tools are necessary for companies to make their decision to invest money to reduce energy consumption.

Recommendation:

- Develop a carrot and stick approach, which encourages a company to invest money to reduce the amount of energy consumed.[39]
- Create eco-labeling for manufacturing machines.

Action plans:

- Develop evaluation methods for energy consumption which consider:
  - Source types of energy.
  - Life cycle of energy.
  - Depreciation of assets over time with respect to energy spent.
  - Develop decision-support tools that can simulate systems that use energy.
  - Evaluate the trade-off between investment and environmental impacts.
- Develop best-practices in industry to
  - Reduce resource consumption.
  - Recycle energy.

Standards: Simple and credible metrics are essential for sustainability standards to hold a strong

[39] Added by editors

market position. If a standard includes simple and representative metrics, it will be used by more companies (refer to the metrics category in this breakout session summary). In addition to the simple metrics issue, sustainability standards need to have brands of conformity associated with them. The brand quality of the standards should be maintained. A branded sustainability standard can be a positive driver of the market. If the brand is well known in the market, companies will invest money to get a certification or award of the standard.

Problem or issue:

- How should standards be posed in the market so that the positive incentive side drives them?

Root Cause:

- Metrics in the standards are too complex for companies to use.
- Current sustainability standards may not have strong effects on market share.

Recommendation:

- (See the recommendation about metrics.)
- Create brand values of sustainability standards.

Action plans:

- (See the action plans in the metrics category.)
- Create brand values of sustainability standards
  - Associate awards or certifications of the standards to sustainable products.
- Maintain the brand values of sustainability standards.

A summary of the group deliberations was presented by Karthik Ramani and are provided below (the slides can be found on the workshop website given below)
http://www.nist.gov/mel/msid/sustainable_workshop.cfm).

Group 2: Decision support system for sustainable manufacturing

Group 2 considered the following areas: Alignment of sustainability initiatives between US/EU/World, at local, state, and federal levels; sustainability product labeling and grading; standards, metrics, indicators, and standards' landscape for the enterprise; greening the supply chain; information modeling, semantic technologies, tools to support a systems approach; data availability and needs; education and outreach; cost of compliance and reporting; mathematical models and science of sustainability; and making a business case for sustainability. In the final deliberations, Group 2 focused on the following themes: 1. Harmonization of standards, 2. Mathematical models and science of sustainability, 3. Greening the supply chain, and 4. Data

availability and needs.

Harmonization of standards: The current state of the art in sustainability standards is that there are too many standards out there, and there is no proper organization or association between them. It is difficult for businesses to make sense of the large number of standards, identifying which ones are relevant to them, or handle overlapping concerns between different standards. Some guidance is needed in choosing the right standards that are of common concern to the industry.

Problem or issue:

- How can we harmonize different standards? How can we identify the most important standards?

Root Cause:

- There are too many standards, metrics, and definitions for sustainability.

Recommendation:

- Several recommendations were made, including the following:
    - Allow the market to decide – let businesses choose what standards they follow.
    - The government could choose a set of standards that all businesses must follow.
    - The original equipment manufacturers (OEMs) might follow the strictest standards. In most cases, this would entail conformance to less demanding standards.

Action Plans:

- The participants of Group 2 agreed that this is a difficult issue to address, and there can be no definitive action plan at this stage. Some recommendations were made, and various market factors will affect the outcome.

Mathematical models and science of sustainability: Strong mathematical models must support decision support systems for sustainable development. The science behind sustainability metrics and recommendations must be strongly grounded.

Problem or issue:

- How can we develop strong mathematical models and scientific studies for sustainability?

Root Cause:

- Need for strong mathematical models for sustainability.

Recommendation:

- Develop open source models that are generic, extensible, and easy to build and share.

Action plans:

- Stimulate open source models from research institutions. Industries can play a collaborative role by providing test cases.
- Recognize data exchange problems and create exchange protocols. NIST could play the role of a central repository for data exchange protocols, and the definition of a data exchange specification.
- Separate modeling into various levels of detail.

Data availability and needs: One of the main hindrances to activities such as LCA is the lack of readily available data. Several methodologies related to sustainability suffer from a shortage of data. It is difficult to conduct research and develop new methodologies without access to data.

Problem or issue:

- What are the data needs and how can they be satisfied?

Root Cause:

- It is hard to get data due to companies' privacy policies, and the available data is usually inaccurate and error prone.

Recommendation:

- Create global data repositories.
- Address aggregation and disaggregation of data.

Action plans:

- Identify the stakeholders to address data aggregation and disaggregation problems.
- Address data needs for conformance assessment.
- Collect activity based data (such as water, energy).
- Collect data globally and use global repositories.

Greening the supply chain: A commonly faced problem throughout the industry is sustainability analysis and compliance management in the supply chain. Most OEMs find that their supply chains are unaware of sustainability standards or do not have any data for compliance management. Often, their contracts mention nothing related to sustainability and require no action by the supplier to be compliant. This is changing slowly with initiatives by businesses such as Wal-Mart.

Problem or issue:

- How can we ensure that the supply chain is compliant?

Root Cause:

- Supply chains have no sustainability concerns.
- Small and medium companies lack supplier information.

Recommendation:

- Develop reporting standards for suppliers.
- Industry must drive suppliers to be compliant.

Action plans:

- Provide education and training to suppliers in simple terms, stressing on the importance of compliance.
- Develop standards for suppliers to report data to OEMs. OEMs can prioritize the scope of the data in conformance with standards.
- Industry must drive the suppliers to be conformant with sustainability standards.
- Develop a database of commonly available information on material content, processes etc.

A summary of the group deliberations was presented by Sudarsan Rachuri. The slides can be found on the workshop website[40]. The following section summarizes the overall outcomes and recommendations from the workshop participants.

9. Summary

The primary objective of the workshop was to bring together experts and various stakeholders to identify and discuss measurement and standards enablers that positively affect the social, economic, environmental, and technological aspects of designing sustainable production processes and products. The workshop was well attended with thirty presentations organized into five sessions: 1) Government Initiatives; 2) Industry Perspectives; 3) University Research; 4) Non-Government Organizations (NGOs) research; and 5) Solution Providers' Views.

The workshop participants identified several challenges faced by the manufacturing industry in its pursuit of sustainability goals and provided a set of key recommendations. The major challenges identified were as follows:

1. Industry is unable to measure economic, social, and environmental consequences of their activities and products accurately during the entire life cycle and across their supply chain. One of the main reasons for this is the lack of data traceable to a neutral organization. Even if the data were available, industry is finding it difficult to aggregate and disaggregate data to compute sustainability metrics.

[40] http://www.mel.nist.gov/msid/conferences/Agenda_SMW.htm

2. Full life cycle analysis or assessment of products requires new methods to analyze, integrate, and aggregate information across hierarchical levels, organizational entities, and supply chain participants.
3. Industry lacks neutral and trusted standards and programs to demonstrate, deploy, and accredit new sustainable manufacturing practices, guidelines, and methods.
4. There are too many metrics; they need consolidation and harmonization. Also, they need to be 'monetized' as appropriate.
5. Regulations need to be supported by industry standards (e.g., RoHS and IPC-1752). These regulations and standards should be harmonized.
6. Information standards are necessary to enable interoperability among engineering tools, business enterprise tools and Life Cycle Assessment tools for an integrated systems approach.

Key recommendations from the workshop participants follow, in no particular order.

Metrics (or indicators)*:*

- Pursue a multi-level approach for metrics, with simple metrics at the highest level.
- Consolidate and harmonize the diverse set of existing metrics.
- Monetize metrics as appropriate.

Standards*:*

- Support regulations (e.g., RoHS) with industry standards (such as IPC-1752).
- Develop a strategy for the harmonization of many standards and directives that currently exist for sustainability.
- Create brand values for sustainability standards and maintain the brand values.

Infrastructure*:*

- Create a software infrastructure for gathering, analyzing, exchanging, and aggregating information for sustainability, including support for global data repositories.
- Develop a simple and transparent methodology for life cycle assessment calculation.
- Develop a science of sustainability, including open source models that are generic, extensible, verifiable, and easy to build and share.

Best Practices:

- Create a new business model for companies to apply the methodology developed for LCA voluntarily, which maximizes profits while minimizing costs.
- Develop best practices for eco-innovation, i.e., design of products and processes that are sustainable or contribute to sustainable development.
- Create eco-labeling for manufacturing processes and machines.

- Develop sustainability reporting standards for suppliers, and provide education and training to suppliers in simple terms, stressing the importance of compliance.
- Develop traceable life cycle inventory data to enable life cycle analysis of products, processes, and services and to enable verification and validation of life cycle impact measurements and benchmarking.

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Appendix A. Panel on Industrial Perspective on Sustainable Manufacturing and Standards[41]

Gahl Berkooz, Moderator

Panelists: Robert Bechtold (HARBEC Plastics), Korhan Sevenler (Xerox), Kathi Futornick (URS), Jeff Mittelstadt (NACFAM), Margaret Lindeman (Lockheed Martin), Stephan Biller (GM), Denise Van Valkenburg (MASCO Retail Group), John Sutherland (Purdue University)

Berkooz: *Vijay Srinivasan of NIST said sustainability is where quality was 25 years ago. We addressed quality at Ford with change in culture, training, etc, more than a business driver. How is it in your company?*

Bechtold: People are becoming more receptive, it is getting into the culture. Originally, it was my pipe dream, but now it is companywide as we are getting more and more suggestions and ideas from my employees and our customers are asking.

Sutherland: We need the leaders to start, and then everyone else will follow eventually.

Lindeman: Agree culture is important and takes a lot of time. Initially we were led by the Environmental Health and Safety, but still have a long way to go to think about design and its influence, so we have a long way to go. It is a journey.

Mittelstadt: Motivated employees will come up with very creative things. If you empower the employees at every single level, and empower them to come up with solutions on their own, they will wow you. I believe there is room for a cultural shift to broaden the employee's ability to provide information on a broader level.

Futornick: A lot of potential for cultural shift, but siloed, including my terminology, e.g., lean is different from green, etc.

[41] The panel discussion is presented in a narrative style to capture all the discussions that happened during the panel session. The panel discussion session was not recorded. This report of the panel discussion is a transcription from the note takers and hence may not fully reflect the actual statements by the participants completely; however, those referenced in the Appendix reviewed and approved the content.

Berkooz: *Question to Lockheed: How do you see training for proposal writing for sustainability? How do you train your contract writers to write on something like carbon footprint?*

Lindeman: Contracts did not ask for sustainability. We (our quality engineers) are starting to have discussions with customers and suppliers. We are training our quality engineers them on how to write contracts. Initially the drive came internally, but now the reporting and need for information from customers is coming outside in.

Van Valkenburg: We need to get away from the silos and make decisions to all the information we have. We must take cultural issues with everyone involved rather than separately

Berkooz: *Question to Xerox. How are you responding to regulations, and how did standards fit in? How much was business pull? In addition, how much was regulation push? To what extent do you employ standards to integrate, the opportunities?*

Sevenler: Almost 100 % restrictions are coming from regulations. We do have some standards, but no real benchmark, and no real way of assessing. I can share details on standards later. Answering to a previous question, to make sustainability a priority we need to make consequences clear, to facilitate cultural shift.

Audience (Rachuri): How much was the alignment between engineering and regulations at Xerox Corporation?

Sevenler: We were not very aligned, taken somewhat by surprise, given engineering schedule, to comply with RoHS. Japanese colleagues, e.g., at Fujitsu, were much more prepared.

Berkooz: *My next question is to GM. You present a compelling vision for activity-based allocation. That is a lot of work, what is the incentive?*

Biller: The real question is who is going to pay for this? However, even GM does not have that much leverage over suppliers. Our experience with giving requirements to PLM providers is not very good. We do not have enough muscle to influence our requirements into their products. They will not do it if the rest of the market is not asking. R&D needs to build the prototypes and give IP to vendors. That is the only thing that worked with UGS.

Audience (Rachuri): Is it not the right time to standardize the protocol for sustainability related

information from CAD/PLM systems? Perhaps it should be projected as enabling middleware solutions and creating a new market for the solution providers. End users need to ask for standards.

Biller: Totally agree.

Lindeman: We have always had to customize our tools.

Thayer: Companies are extremely interested in good branding, e.g., in European market. It is possible to motivate with branding as well as regulation.

Lindeman: That works for commercial products, what about others?

Thayer: Intel Inside is branding, even though it is not direct consumable.

Jansen: Trying to sort out priorities and understand needs of the market place. Better sustainability support needs better PLM support. We will present this tomorrow.

Fox: I agree that better sustainability support needs better PLM support and it is number one priority for us. From work with Motorola, we found it is hard to modify the big package systems to aggregate data. Our strategy is to integrate with those systems to pull data together. Currently focused on materials and restricted substances. Regulatory cost is in duplication, and we need standards to address this problem.

Brown: Most capability needed already available in PLM systems, but can only deliver the last 10-15 % with demand.

Audience (Srini): It is important to note that only PLM vendors are here. ERP systems are accounting-oriented, and are equally important in sustainability reporting, but are not represented here.

Berkooz: *Question to URS. How does the complexity of sustainability regulations compare to previous ones? You presented a lot of complexity within your company to get your hands around compliance and reporting. How do you think it will take a medium-sized company to comply, particularly with the supply chain?*

Futornick: Twenty years ago, companies were just barely complying. It is hard to get them to consider these issues in the product design. Today many of those companies are still struggling. An example of an SME providing to a Northern European car manufacturer, the SME was not aware of other than US requirements. They were not aware of any of the EU or Chinese requirements. We introduced an Environment Management System (EMS) on steroids rather rapidly. Unlike in the past, the client had no alternative due to competition. They are beginning to see the opportunities of designing and selling new products. It has become a highly competitive market for SMEs, and some are now realizing the competitive advantage to know and work with the regulations and compliance. They are introducing new product lines, changes to manufacturing, and seeing the opportunity.

Van Valkenburg: We do not really have a choice in turning it into an opportunity.

Berkooz*: Question to Masco. You mentioned coming into an audit deadline. How did you handle this?*

Van Valkenburg: The key was focusing attention on integrating regulation into their existing system, not force fitting regulation. With Environment Management System (EMS), we have just added some additional goals, modified functions, but did not completely overhaul it. For example, they already had a red cross visual symbol for safety indicators; we just added a green globe for sustainability indicators.

Audience (Law): How to we work with China, India, etc, on compliance?

Futornick: No answer yet, but we handhold suppliers through whole process, and with Chinese government through consortia. We must make it simple. We take the global requirement and synthesize it. We have been working with China for four years, and have not rolled anything out yet.

Bechtold: We are advocating the idea of new opportunities, e.g., bringing technology geographically closer to consumption. As a small company, we believe true sustainability will regain our US manufacturing competitiveness. Merely the transportation costs associated with global suppliers is not sustainable

Berkooz: The requirement is that all the Ford's suppliers need to be ISO 14000 compliant.

Sutherland: We require plants to adhere to local rules, but this does not necessarily achieve sustainability.

Lindeman: We are drafting global requirements currently.

Mittelstadt: Dow has found that bringing overseas plants to US standards makes them more efficient. There is a book written about it recently.

Audience (Rachuri): NIST wants to know how government, academics, and industry can interact, and what you want from government.

Biller: Government could play a huge role, e.g., identifying regulations and subsidies and their timelines to reduce the large cost to companies in tracking all of it. The government can provide mechanisms for translating a regulation into an ontology or standardized form. We are currently driven more by not knowing what we do not know. We apply the most restrictive rules we could find globally. Government could also provide data. Government could help provide better data sources, make the data available, and increase collaboration across the agencies.

Mittelstadt: DOC has information about the subsidies, state-by-state, and see http://www.dsireusa.org/.

Lindeman: NIST closely work with academia, which is an important resource for addressing difficult problems.

Sevenler: This workshop has helped me a lot and it will increase the motivation at Xerox. There are many focus areas and I suggest trying even smaller breakouts. For example, one might be validation of academic models.

Audience (Zhang): If US data were available, would industry use it?

Biller: Depends on industry. Our commercial customers only care about the fuel consumption, whereas military cares about tonnage capacity.

Berkooz: Government can look at incentives for industry if they utilize alternative energy sources.

Appendix B. Workshop Analysis by Vijay Srinivasan, NIST

After surveying thirty large corporations, a recent article in the Harvard Business Review declared, "there is no alternative to sustainable development"[42]. A parallel, more extensive study by MIT found that "there is a strong consensus that sustainability is having – and will continue to have – a material impact on how companies think and act"[43]. These dramatic developments owe to the fact that the manufacturing sector, represented by these companies, has a significant impact on the economy, society, and the environment around the world. Close to home, the U.S. manufacturing sector contributes 11 % of the Gross Domestic Product (GDP) and provides 10 % of the nation's workforce with high-paying jobs. It is also the largest consumer of energy (45 %), the second largest consumer of mined materials (21 %), a major producer of solid waste (10 trillion kg per year), and a significant user of hazardous materials – all of which are implicated in a growing number of environmental problems. These facts are not lost on the U.S. government. The U.S. Department of Commerce (DOC) recently named sustainable manufacturing as one of its key performance goals and called upon NIST to provide national assistance to realize this goal.

Recognizing the environmental impact of manufacturing and the products they produce, many countries and regions have introduced regulations such as RoHS (Restriction of Hazardous Substances), REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) and WEEE (Waste Electrical and Electronic Equipment) that restrict the sale of products containing hazardous or prohibited substances. Additionally, many companies have introduced consumer-oriented labeling to indicate various aspects of sustainability in their products, including Energy Star and labels for recycled content and recyclability of products. Some of these labeling are mandated by governmental regulations. Even if many of these regulations are local, their implications on the manufacturing sector are global – for example, the U.S. manufacturers are scrambling to comply with the European regulations because they do not want to be locked out of that lucrative market.

As the U.S. manufacturing sector sells globally, it also sources globally. It manages a global supply chain in all four major phases of a typical product's life cycle: raw material selection,

[42] "Why sustainability is now the key driver of innovation," Harvard Business Review, Sept. 2009, pp. 56-64
[43] The business of sustainability, MIT Sloan Management Review Special Report, 2009

product realization, customer use, and material recovery. As the U.S. manufacturers and their global suppliers struggle with sustainability issues in the product life cycle, they are discovering that they need to measure, control, and manage sustainability in a complex mix of temporal (life cycle) and spatial (global supply chain) dimensions. Additionally, they have to respond to the impact of their actions on economical, social, and environmental issues in this complex space-time domain. Business executives often bemoan, "You are only as green as your supply chain"[44], and compare the global sustainability challenges of today to the 'total quality management' (TQM) challenges they faced nearly a quarter century ago[45]. They are also concerned about the dwindling supply of raw materials and resources (e.g., energy, water), and the sometime unfriendly sources of material supply.

At a recent summit organized by the DOC Sustainable Manufacturing Initiative, representatives from a broad spectrum of U.S. industries expressed their frustration over a vast number of inadequately defined measures of sustainability, the difficulties with collecting and exchanging sustainability information, and difficulties with working across enterprise supply chains to ensure meaningful improvements in sustainability and conformance to regulations.

These concerns were echoed with greater technical depth and clarity in a Sustainable Manufacturing workshop hosted by NIST soon afterwards. The NIST workshop attracted participants from large and small companies in the U.S. manufacturing sector (GM, Ford, GE, Xerox, Lockheed Martin, Rockwell Automation, P&G, Siemens, Harbec Plastics, Masco, URS), software vendors (Dassault Systems, Siemens PLM, PTC), government (DOC, NIST, NASA, NSF), non-governmental organizations (WRI, NCMS, CAMDUS, ANSI, NACFAM, ASTM), and academia (Stanford, Purdue, Georgia Tech, Rochester Institute of Technology, University of Kentucky, Portland State University, Texas Tech University).

Most of the industrial concerns and lessons learned were summarized in the industrial panel convened by the NIST Sustainable Manufacturing Workshop. Some of the messages were:

- Sustainability should start with leaders at the top. In addition, bottom-up solutions are very useful and powerful (because people want to be part of the solution to an important problem).
- Educating suppliers on sustainability is important and is a challenge.
- Regulations drive a lot of engineering action – often non-compliance is the fear that drives these actions.

[44] http://www.hbrgreen.org/
[45] "The green conversation", Harvard Business Review, Sept. 2008, pp: 58-62

- Branding[46] is very important for business. Many companies are positioning themselves at the forefront of sustainability movement to protect and/or enhance their brands.
- Is sustainability an opportunity or cost? There was a general agreement that there is no choice but to treat it as an opportunity.

In the NIST Sustainable Manufacturing Workshop we found evidence that the more experienced manufacturing firms see opportunities in sustainability beyond mere compliance with regulations – in fact, they view this as a driver of innovation. They find that by adopting lean manufacturing practices they can reduce waste (a sustainability goal) while saving associated costs. They also see new market opportunities if they can introduce innovative materials, processes, and products to meet the global economic, societal, and environmental sustainability needs.

In the meantime, several non-governmental and standards development organizations are actively engaged in proposing and issuing guidelines, standards, and regulations. It was clear at the NIST workshop that they need some urgent coordination. Several academics have studied these problems and are trying to bring some order and understanding to various sustainability practices. It is encouraging to see that the academic community that studies these problems includes economists, who are proposing methods to monetize many of the sustainability metrics.

Based on the NIST Sustainable Manufacturing Workshop, the major lessons we learned from the U.S. manufacturing industry in their pursuit of sustainability goals can be summarized as follows:

- **Metrics**: There are too many metrics; they need consolidation and harmonization. In addition, they need to be 'monetized' as appropriate.
- **Standards**: Regulations need to be supported by industry standards (e.g., RoHS and IPC-1752).
- **Infrastructure**: Software infrastructure is critically needed – and is just emerging – for gathering, analyzing, exchanging, and aggregating information for sustainability.

[46] The American Marketing Association (AMA) defines a brand as a *"name, term, sign, symbol or design, or a combination of them intended to identify the goods and services of one seller or group of sellers and to differentiate them from those of other sellers"*. Branding also means that a particular entity or organization is the only one that provides an effective solution to a particular problem.

Appendix C. AGENDA

(The web links to the available presentations are underlined)

DAY	Title	Name	Affiliation
OCTOBER 13 2009	Conf. Registration		
Session Coordinator: Howard Harary	Welcome Remarks	Howard Harary	Acting Director, Manufacturing Engineering Laboratory (MEL/NIST)
	Opening Remarks	Patrick Gallagher	Director, National Institute of Standards and Technology (NIST)
	Introductory Remarks	Vijay Srinivasan	Chief, Manufacturing Systems Integration Division (MSID/NIST)
	Workshop Introduction	Sudarsan Rachuri	Workshop Chair
	Break for Tea/Coffee	Break for Tea/Coffee	Break for Tea/Coffee
Government Initiatives: Session Chair: Vijay Srinivasan	**Keynote talk 1: The International Trade Administration's Sustainable Manufacturing Initiative**	**Mary Saunders**	**Assistant Secretary Manufacturing and Services, International Trade Administration (ITA)**
	Thoughts on Manufacturing for Sustainability	George Hazelrigg	National Science Foundation (NSF)
	Standards and Conformity Assessment	Gordon Gillerman	Chief of the Standards Services Division
	Sustainable and Life cycle Information-based Manufacturing (SLIM)	Ram Sriram	Group (DPG/NIST) Leader Design Process Group
	NASA Manufacturing Supply Chain Sustainability Issues	Kevin Watson	National Aeronautics and Space Administration (NASA)
	General Discussion		
	LUNCH	LUNCH	LUNCH

Industry Perspectives: Session Chair: Al Jones	**Keynote talk 2: The Economic Opportunities of Sustainable Manufacturing**	**Robert Bechtold**	**Harbec Plastics**
	Lockheed Martin Go Green Program Overview	Margaret Lindeman	Lockheed Martin
	Compliance Management in Xerox	Korhan Sevenler	Xerox
	Energy Challenges in Automotive Manufacturing	Stephan Biller	General Motors R&D
	Sustainable Production at Rockwell Automation	Mary Burgoon	Rockwell Automation
	Overview of the Procter & Gamble Sustainability Program (PDF file not available for public release)	Robert Crawford	Procter and Gamble (P&G)
	GE Aviation Perspectives on Sustainability	Todd Rockstroh	General Electric (GE) Aviation
	Industrial Regulations and Standards - Metrics for Sustainable Performance	Kathi Futornick	URS Corporation
	Standards Opportunity in Sustainable Product Development and Manufacturing	Gahl Berkooz	Ford Motor Company
	Integrating Sustainability into Manufacturing Systems	Denise Van Valkenburg	Masco Retail Cabinet Group
	Tea/Coffee	Tea/Coffee	Tea/Coffee
	Breakout Session Planning	Sudarsan Rachuri	
OCTOBER 14 2009			
University Research: Session Chair: Nabil Nasr	Sustainable Production (PDF pending)	Nabil Nasr	Rochester Institute of Technology
	Sustainability: Challenges for the Manufacturing Enterprise	John Sutherland	Purdue University
	Assessment of Product and Process Sustainability: Towards Developing Metrics for Sustainable Manufacturing	Ibrahim S Jawahir	University of Kentucky
	Adapting Open Standards for Sustainable Engineering Supply Chain	Kincho Law	Stanford University
	Sustainable Design and Manufacturing Research at Multiple Levels	Bert Brass	Georgia Institute of Technology

	Sustainable Manufacturing Metrics and Standards: Guiding Theory	David Ervin	Portland State University
	Sustainable Early Design Methods	Karthik Ramani	Purdue University
	Why Measure Sustainability? -A Comprehensive Review and Future Applications	Hong C. Zhang	Texas Tech University
	Panel 1: Industrial Perspective on Sustainable Manufacturing and Standards	Gahl Berkooz (Panel Moderator)	
	LUNCH	LUNCH	LUNCH
NGO Research: Session Chair (s): Jeff Mittelstadt, Jae Lee	**Keynote talk 3: The Global Standard for Sustainability Reporting**	**Mark Cohen**	**Resources for the Future (RSFRF)**
	Developing International Standard on Product Life Cycle and Scope 3 Carbon Footprint Management - An Overview of the GHG Protocol Product and Supply Chain Standards	Pankaj Bhatia	World Resource Institute (WRI)
	Collaborative Initiatives for Sustainable Products Manufacturing	Manish Mehta	National Center for Manufacturing Sciences (NCMS)
	Overview of the United States Standards System	Gary W. Kushnier	American National Standards Institute (ANSI)
	Genuine Metrics	Jim Thayer	Cadmus Group
	NACFAM Sustainability Framework Model: Making Business Decisions for Sustainable Manufacturing (PDF pending)	Jeff Mittelstadt	National Council For Advanced Manufacturing (NACFAM)
	ASTM Committee E60 on Sustainability	Steve Mawn	American Society for Testing and Materials (ASTM)
	Tea/Coffee	Tea/Coffee	Tea/Coffee
	Break-out Discussion	David, Shaw	Sudarsan, Anantha
OCTOBER 15 2009			

Software Solutions: Session Chair (s): Kevin Lyons, Prabir Sarkar	Software Tools and Information Exchange Standards	John Fox	Parametric Technology Corporation (PTC)
	Innovation for Eco-Sustainability	Michael Zepp	Digital Enterprise Lean Manufacturing Interactive Application (DELMIA)
	Design for Sustainability in Product Life Cycle Management	Laurie Jansen	Siemens PLM Solutions
	Sustainability Metrics and Environmentally Compatible Product Design	Candemir Toklu, Elena Arvanitis	Siemens R&D
	Tea/Coffee	Tea/Coffee	Tea/Coffee
	Summary from Breakout Sessions		
Sudarsan Rachuri	Closing Discussion		
Ram Sriram	Valedictory sessions		

Appendix D. LIST OF ACRONYMS

ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
BPEL	Business Process Execution Language
BPMN	Business Process Modeling Notation
CAD	Computer Aided Design
CEO	Chief Executive Officer
CEQ	Council on Environmental Quality
CHP	Combined Heat and Power
DELMIA	Digital Enterprise Lean Manufacturing Interactive Application
DfE	Design for the Environment
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOJ	Department of Justice
DOL	Department of Labor
EMS	Environment Management System
EPA	Environmental Protection Agency
EU	European Union
GDP	Gross Domestic Product
GE	General Electric
GM	General Motors
GHG	Green House Gas
GRI	Global Reporting Initiative
ICT	Information and Communication Technologies
IPC	Institute for Printed Circuits
ISO	International Organization for Standardization
ITA	International Trade Administration
IT	Information Technology
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
LM	Lockheed Martin
MAS	Manufacturing and Services
MEL	Manufacturing Engineering Laboratory
MIT	Massachusetts Institute of Technology

MRCG	Masco Retail Cabinet Group
MSID	Manufacturing System Integration Division
NACFAM	National Council For Advanced Manufacturing
NASA	National Aeronautics and Space Administration
NCMS	National Center for Manufacturing Sciences
NGO	Non-Government Organization
NIST	National Institute of Standards and Technology
NSB	National Science Board
NSF	National Science Foundation
OECD	Organization for Economic Cooperation and Development
OEE	Overall Equipment Efficiency
OMB	Office of Management and Budget
OMG	Object Management Group
P&G	Procter & Gamble
PCR	Product Category Rules
PLM	Product Life cycle Management
PP&E	Property, Plant And Equipment
PTC	Parametric Technology Corporation
REACH	Registration, Evaluation, Authorisation and restriction of Chemicals
RoHS	Restriction of Hazardous Substances
RFF	Resources for the Future
SBA	Small Business Administration
SCOR	Supply Chain Operations Reference
SDO	Standards Developing Organizations
SLIM	Sustainable and Life cycle Information-based Manufacturing
SMARTs	Sustainable Manufacturing American Regional Tours
SMEs	Small and Medium-sized Enterprises
SMI	Sustainable Manufacturing Initiative
SOAP	Simple Object Access Protocol
SPI	Sustainable Product Initiative
SSD	Standards Services Division
STEP	STandard for the Exchange of Product model data
TC (ISO)	Technical Committee
TQM	Total Quality Management
VA	Department of Veterans Affairs
VOC	Voice Of Customers

W3C	World Wide Web Consortium
WBCSD	World Business Council for Sustainable Development
WEEE	Waste Electrical and Electronic Equipment
WRI	World Resources Institute
WSDL	Web Service Definition Language