2011 EL Project Title and Number: Sustainability Metrics for Manufacturing

Program Title: Sustainable Manufacturing

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Summary: Manufacturing enterprises need flexibility with respect to material and energy requirements in order to respond quickly to fluctuations in the availability of these resources. Tracking of material and energy is a first step in their management. Material and energy needs assessments are hampered by a lack of scientific methods to measure the material and energy requirements of various design alternatives and to track between what is required and what is actually used. New standards are emerging to address these needs; however, these standards are relatively immature and test methods for their application are undeveloped. Furthermore, an information modeling infrastructure is also needed to include energy and material data in a product design. The infrastructure will support sustainability analysis of designs and provide inputs to other projects in the program. The sustainability metrics for this project will

- develop methods to validate material and energy tracking standards and their use,
- develop the infrastructure to incorporate this information into product designs,
- develop methods to use the information in energy and material use assessments in both the design and process planning phase of manufacturing, and
- engage industry in promoting these methods.

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Objective: To provide the measurement science necessary to assess and analyze energy and material use in a product design in order to track progress toward specified sustainable manufacturing goals and to demonstrate the viability of testing and validation methods in end-user applications.

What is the new technical idea? Flexible manufacturing processes need to respond to variability in material and energy resources while still accounting for cost, efficiency, quality, and other sustainability goals. Metrics for material and energy consumption of manufacturing systems need to be available to assess the sustainability of the manufacturing processes. However, much of the information needed to assess sustainability (both at the product and process level) has not been collected historically, much less integrated into product design specifications which are the basis for manufacturing planning. Energy and material measurements rely on an accurate association of this new data with complex designs and validation that this data is being correctly and meaningfully conveyed across the manufacturing system. In addition, it is critical that credible energy and material information is visible across the supply network. Standards for life cycle assessment (LCA), such as, ISO 14025, are used to substantiate the energy and material information of finished products in the supply network.

The capability to generate standards-based specifications of this information as designs evolve enables seamless information flow from design specification to manufacturing plans and eventually to life cycle analysis. Designing at the material and energy levels requires (1) additional accessibility and visibility of complex product data,(2) understanding of additional scientific disciplines, and (3) availability of appropriate information models for standards specification.

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

1. **Unified reference model for energy and material information**
   Develop a generic model of product structure that includes information required for tracking energy and material consumption that goes beyond the traditional bill-of-materials (BOM) to the notion of Sustainable BOM (SBOM) and work closely with other projects of the program to formulate trade-off analysis of various design choices for manufacturability.
2. **Methodology for sustainability assessment for manufacturability**
   Enable data aggregation and assessment methodology through standards that will work with manufacturing process characterization (using manufacturing and assembly unit processes) to enable the computation of the product level metrics including uncertainty quantification.

3. **Testbed and Industry Deployment**

Develop and demonstrate test methods and metrics for testing material and energy information that will enable the computation of energy efficiency and material usage metrics across the supply chain.

What is the research plan?

Design for sustainable manufacturability (Design for Sustainable Manufacturing-DSM) includes capturing information related to resource (energy, material, and water) efficiency during product design. The information is encapsulated in a model of Generalized Product Structure (GPS) making it available for downstream manufacturing processes. The feedback information from those processes will be further used to refine[1] the GPS to enable better tracking and aggregation of resource efficiency across the distributed manufacturing system. The GPS will also provide required information for the computation of sustainability metrics, such as, resource intensity[2].

The project will define sustainability related interfaces, which include sustainability objectives, for other projects in the program. These objectives enable the optimization of unit, assembly, production, and production network supplier processes. These interfaces will include GPS for energy and material tracking, product declarations for metrics calculations, and, closed-loop system parameters (product, process) for simulation and optimization.

The long-term vision for DSM is to expand the scope from the GPS to a closed-loop, design optimization framework that provides the analytics needed for decision support and, eventually, to total lifecycle system analysis for the design, production, usage, and disposal of manufactured goods. This project addresses the initial phase of that vision and will focus on the creation and validation of the GPS and related standards for material and energy tracking. The research needed in this project includes the following:

Identify stakeholders, their critical needs, and metrics (energy and material efficiency, and manufacturing resiliency - adaptability to variation in material and energy availability) and leverage global research efforts.

- Organize industries led workshop on product characteristics for defining energy and material impacts for sustainable manufacturing and understand industry needs
- Work across the projects to develop unified sustainability taxonomy and definitions and analyze information requirements for design stage computation for product manufacturability.
- Develop GPS and SBOM to enable trade-off analysis of various design choices for manufacturability.
- Work with ASTM E60 committee to establish a working group (WG) to specifically address standards related to energy and material tracking for sustainable manufacturing. Work through this WG to liaison with ISO TC 207 and TC 242 for 1402x, 50001 standards and IPC 175x standards.

[1] Information such as manufacturing resources (equipment), materials used during production, harmful by-products, bill-of-restricted materials etc.

[2] Resource intensity is a measure of the resources (e.g. water, energy, materials) needed for the production, processing and disposal of a unit of good or service, or for the completion of a process or activity; it is therefore a measure of the efficiency of resource use.

Develop metrics, models, and methodology for energy and material use assessment for manufacturability.

- Survey and study existing standards and metrics for energy and materials specification and incorporate workshop recommendations.
- Incorporate industry inputs into standards related to energy and material tracking.
- Define models for data aggregation through standards that will work with manufacturing process characterization (using the definition of manufacturing and assembly processes) for analysis and synthesis along with uncertainty quantification.
- Define a simplified initial methodology for computing the metrics for energy, material requirements and efficiency needs at the design stage with inputs from other projects.

Test, validate, and deploy standards and methods for inter-comparison studies and develop the technical basis for standards.

- Develop and demonstrate test methods and metrics for testing material and other related standards. Demonstrate using critical standards
- Investigate the information requirements of material standards and other engineering standards and work towards harmonization.
- Investigate manufacturing best practices to develop assessment methodology for energy and material use and study the industry need for defining sustainability readiness level (SRL) in a manner similar to the manufacturing readiness level (MRL).
- Extend the generic model of product structure to address food manufacturing sector, furniture manufacturing sector, plastic manufacturing sector, and primary metal manufacturing sector.
- Analyze the integration of management system standards (MSS) ISO 14000 (Environment), 9000 (Quality), 50000 (Energy)

Major accomplishments: Recent Results: Sustainability Standards Portal, Workshops, and leadership roles for a family of standards for material data exchange between supply chain participants (IPC 175x).

Standards and Codes: Work with standards committee/consortia specifically addressing sustainable manufacturing standards (ISO TC 207, ISO TC 242, ASTM E60, IEEE, IPC).Contribute to testing program for critical standards, and recommendations for harmonization with other relevant standards (OAGi, ASTM, IEEE, ASME, ISO, and others).