Editorial: Special Issue on: "Developing Sustainable Products, Processes and Services"

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1. Introduction

We are witnessing an increased interest to ensure that future generations have adequate resources to maintain a high standard of living. The World Commission on Environment and Development defines sustainable development as, "S*ustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs."* [1] 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*."[2] Others have argued that any definition of sustainability should include dynamic efficiency throughout the lifecycle 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 many definitions of sustainability suggested by various stakeholders, but

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

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

we generally agree with the following observation by Daniel Sitarz[3]:"*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. It is clear that the world is moving forward aggressively to achieve sustainable design and manufacturing with lifecycle 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.

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.

Ensuring a sustainable future requires a 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,

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[3] Sustainable America, America's environment, economy, and society in the 21st Century, Published in 1998, EarthPress.

because tackling any one of the issues in isolation could result in unintended consequences.

2. Global Efforts in Sustainable Manufacturing

There are many relevant research and technology development efforts reported across the globe. In particular, the European Union is very proactive and has mandated several key activities to alleviate greenhouse gas emissions[4]. Asia's posture in this arena is exemplified in a recent interview[5] where Mr. Katsuaki Watanabe, President of Toyota is quoted as saying "... in my vision for the future, the most important themes are the environment, energy, safety…." Hiroshi Komiyama explains Japan's "Vision 2050" report and steps taken by Japan in achieving a sustainable society. The essential points are:[6]

- realization of a recycling system of materials
- tripling energy efficiency
- doubling renewable energy

Japanese manufacturing enterprises have developed many ecological technologies related to energy, pollution, and recycling for the last fifty years in response to Japanese government's specific restrictions. The Japanese government has also initiated several initiatives mainly through Ministry of Economics, Trade and Industry to develop a strategic technology roadmap for sustainable manufacturing since 2005[7]. The characteristics of the roadmap are that sustainable manufacturing should be understood from broader social perspectives such as, declining birth rate, and aging Japanese population. The declining birthrate and an aging population constitute the greatest changes faced by Japan in its economic

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[4] For example, see http://www.eurotreaties.com/atkey.html

5 The HBR Interview, Harvard Business Review, October 2007

6 Fourth International Symposium on Environmentally Conscious Design and Inverse Manufacturing, 2005, Eco Design 2005, 12-14 Dec. 2005, page(s): 2- 4

7 http://www.meti.go.jp/policy/economy/gijutsu_kakushin/kenkyu_kaihatu/str2009.html

and social structures, which create restrictions on domestic management resources such as labor and capital.

Many organizations in the US have addressed energy or environmental issues individually. The National Academy of Sciences has produced many studies on climate change[8]. Recently, companies in the United States Climate Action Partnership (USCAP)—businesses including GE, Alcoa, DuPont, and PG&E—announced their call for federal standards on greenhouse gas emissions[9]. In their report, they call for "*Mandatory approaches to reduce greenhouse gas emissions from the major emitting sectors including emissions from large stationary sources, transportation, and energy use in commercial and residential buildings that could be phased in over time, with attention to near, mid and long-term time horizons."* The Pew Center issued a report that states, "*all survey respondents believe that government involvement is necessary to address climate change.*"[10] The Green Supplier Network[11] is a joint effort of Environment Protection Agency (EPA), NIST/Manufacturing Extension Partnership (MEP), major manufacturers and their suppliers. They provide independent assessments of manufacturing sites and offer suggestions for "lean and clean" manufacturing improvements. Other EPA programs include WasteWise[12] designed to reduce municipal solid waste and industrial wastes. In the Climate Leaders[13] program in which companies

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8 For example, see "Understanding and Responding to Climate Change – Highlights of National Academies Reports," 2006.

9 A call for action- Consensus Principles and Recommendations from the U.S. Climate Action Partnership: A Business and NGO Partnership, www.us-cap.org

10 Getting Ahead of the Curve: Corporate Strategies that Address Climate Change, by A. Hoffman, prepared for the Pew Center on Global Climate Change, University of Michigan, October 2006

11 www.greensuppliers.gov

12 http://www.epa.gov/wastewise

13 http://www.epa.gov/climateleaders/partners

primarily manufacturers, pledge to meet specific greenhouse emission reduction goals. DOE has in place a wide spectrum of energy efficiency programs[14].

The lesson is that the world is moving forward aggressively to achieve sustainable manufacturing. However, the critical issue is we need a consistent and traceable information and metrology infrastructure in the area of sustainable manufacturing – an infrastructure that supports *all* sectors of manufacturing and one that is globally compatible through the development and adoption of international standards.

The future dominance of issues surrounding energy production, environmental impact, and most recently, greenhouse gases is hard to overstate. The recently released report by McKinsey & Company [15] entitled "Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?" observes in its opening remarks that "Sustainability, which includes meeting the challenge of greenhouse gas emissions (GHG) and other aspects of environmental preservation, is rapidly becoming a priority for American business and for public policy." Global investments in sustainable energy (including wind, solar, and water power) more than doubled from 2004 to 2006, to $70.9 billion, according to a 2007 report by the United Nations Environment Program.

Recent directives from the EU like RoHS (Restriction of Hazardous Substances), REACH (Registration, Evaluation and Authorization of Chemicals), WEEE (Waste Electrical and Electronic Equipment) and ELV (End of Life Vehicles) regarding hazardous and toxic materials have substantially impacted many manufacturing industries. For example, The RoHS directive cost the electronics industry billions of dollars to

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14 http://www.eere.energy.gov

[15] http://www.mckinsey.com/clientservice/ccsi/pdf/US_ ghg_final_report.pdf.

comply[16], yet it only phased out six classes of substances. REACH (often called "RoHS on steroids") will have a much wider application than RoHS. The greenhouse gas emissions trading mechanism has resulted in the European Union Emission Trading Scheme (EU ETS). In 2006, the EU ETS market traded 1,101 MtCO2e (Millions of tons of carbon dioxide equivalent). The carbon market grew in value to an estimated US $30 billion in 2006 (€23 billion), three times greater than the previous year.[17] It seems likely that some form of carbon emission trading system will be put in place in the U.S., creating a marketplace valued at $80B - $250B. On a positive note, however, some corporate leaders are looking at sustainable manufacturing as an opportunity rather than an impediment. Recently John Fleming[18], President and CEO of Ford Europe said "*Sustainability is the pre-condition for continuing business and will finally turn into an opportunity."*

A recent Harvard Business Review article declared, "*There is no alternative to sustainable development"*[19]. A similar but more extensive study by Massachusetts Institute of technology (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."[20] 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.

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[16] Electronic News, March 2006, http://www.edn.com/index.asp?layout=article&articleid=CA6310931

[17] State and trends of the carbon market 2007, World Bank. Report, World Bank Carbon Finance Unit,

[18] Ford Product Sustainability Index (PSI), http://media.ford.com/pdf/Ford_PSI.pdf

[19] Why sustainability is now the key driver of innovation, Harvard Business Review, Sept. 2009, pp. 56-64.

[20] The business of sustainability, MIT Sloan Management Review Special Report, 2009.

The MANUFUTURE Technology Platform in the EU[21] and the Intelligent Manufacturing Systems (IMS)[22] program has sustainable manufacturing as a top priority in their agenda.

Many international conferences and workshops on sustainable manufacturing have been organized in the past couple of years to understand issues and concerns about sustainable manufacturing. Notably, at a recent Sustainable Manufacturing Initiative summit organized by the US Department of Commerce, representatives of a broad spectrum of U.S. industries expressed

- frustration over a vast number of inadequately defined measures of sustainability
- difficulties with collecting and exchanging sustainability information
- difficulties with working across enterprise supply chains to ensure meaningful improvements in sustainability and conformance to regulations.

The bilateral Indo-US Workshop on Designing Sustainable Products, Services and Manufacturing Systems, held at IISc Bangalore during August 2009 provided the following set of recommendations:

- benchmark and develop suitable measures for sustainability
- develop a repository of suitable methods for use to improve sustainability
- prepare training material using the above results for educating students to be ‘sustainable designers’, use this training material to solve a series of realistic problems situated in India and USA in joint teams with researchers from India and the USA to test and

[21] http://www.manufuture.org/platform.html

[22] http://www.ims.org

demonstrate the efficacy of the research results and training material

- develop an annotated repository of methods for use in various stages of product development for various applications
- conduct a series of case studies demonstrating how various sustainability methods are used in solving real design problems, and a set of solutions to the real design problems used in these case studies

Similar issues and concerns were echoed with greater technical depth and clarity in a Sustainable Manufacturing workshop hosted by NIST soon afterwards. Based on the NIST Sustainable Manufacturing Workshop, the major challenges faced by the manufacturing industry in their pursuit of sustainability goals can be summarized as follows:

1. they are unable to accurately measure economic, societal, and environmental impacts and costs of their products during the entire life cycle and across their supply chain.
2. full life cycle analysis (LCA) of products requires new methods to analyze, integrate, and aggregate information across hierarchical levels, organizational entities, and supply chain participants.
3. they lack neutral and trusted programs to demonstrate, deploy, and accredit new sustainable manufacturing practices, guidelines and methods.

What all this means is that the sustainable manufacturing issue is front and center in the minds of manufacturers today. Is sustainability an opportunity or cost? There was a general agreement that there is no choice but to treat it as an opportunity.

3. Systems Approach to Sustainable Manufacturing

The primary goal of a systems approach is to capture and formalize descriptions of these processes and interactions. Because of the complexity of these systems, simulation and modeling will also play an important role in understanding the overall impact of changes in any one subsystem. To achieve sustainability, it is important to address these issues holistically by bringing together multidisciplinary knowledge from research scientists, engineers, and practitioners working in different research areas.

The systems approach of sustainability requires life cycle thinking. The life cycle of a product starts with raw material extraction, continues with the pre-design and fabrication of the relevant semi-finished products, includes manufacturing and assembling of the final product as well as its 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 extracting material from the Earth and putting waste back into the Earth. We would like to minimize this flow and in particular, we want to achieve zero landfill. The second cycle includes pre-design, production, use, and post-use stages of the product lifecycle. 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 use feedback into the design and manufacturing to improve the design.

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), maximizes the use of renewable resources, eliminates toxic substances,

and produces zero waste that in effect reduces carbon (including carbon equivalent) intensity across the entire lifecycle of products and services.

For recyclable products such as aluminum products, a life cycle can be modeled "cradle-to-cradle" by a product system where the recycled material can substitute primary material. Only the material that is lost at the different stages of the life cycle needs to be replaced by primary material as illustrated in the figure below.

Life cycle thinking is an approach to address and analyze all these activities concerning risks, opportunities, and value creation to find the best overall solutions. It involves internal decision-makers from R&D, production, marketing, or management, as well as external stakeholders such as suppliers, retailers, customers, consumers, and the public.

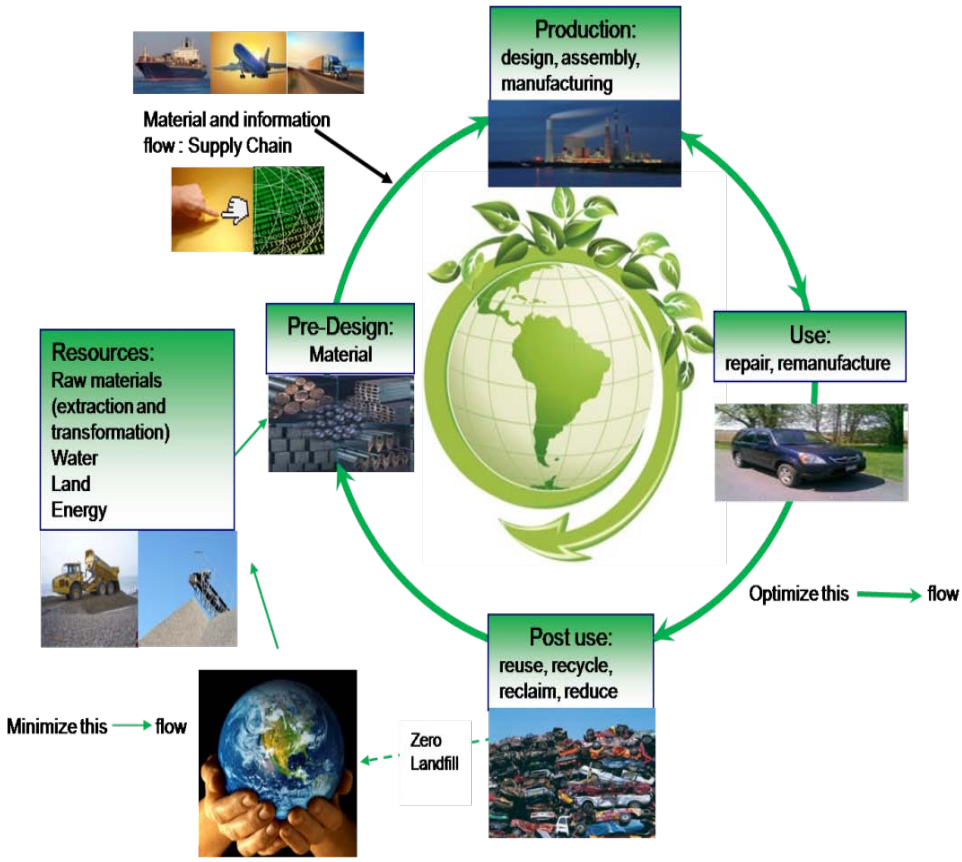

Figure 1: Sustainable Manufacturing - A closed loop view

4. Contribution of this Special Issue

We will now relate the contribution of the papers in this special issue to the framework laid out in the foregoing remarks.

Pre-Design: Material and Production

Life Cycle Assessment (LCA) for products made of composite materials is very rare and one of the main reasons for this is data availability. The paper by Jayaraman and Xu describes the importance of undertaking

LCA of products made of composite material as it is getting used extensively from automobiles to aircraft. The paper outlines data availability for the products used in the packaging, automobiles, and construction industries.

Production

Bert Bras discusses issues and challenges of sustainability. The Life cycle thinking approach is discussed extensively in this paper. The paper identifies key concepts that need to be considered regarding sustainability. In particular, lifecycle assessment, closed loop material flows, user behavior, and systems modeling are highlighted as key issues. Using a transportation system the paper explains the potential of applying available modeling tools from the PLM community to sustainability.

Material/Information Flow : Supply Chain

In a recent Harvard Business Review article, many business executives bemoaned, "*you are only as green as your supply chain.*"[23] The paper 'Extending Total Life-cycle thinking to Sustainable Supply Chain Design' introduces a total life-cycle based approach to sustainable supply chain management. The paper aims to develop a framework to incorporate sustainability factors across the extended networked enterprises. The paper attempts to include sustainability factors into the Global Supply Chain Forum (GSCF) framework.

Use: repair, remanufacture

[23] http://www.hbrgreen.org/

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The concept of remanufacturing is gaining momentum. During remanufacturing the products are disassembled and the parts are cleaned, repaired or replaced and finally reassembled to specified working condition. There are several issues relating to remanufacturing including product recertification, quality and warranty. The paper by Shafiee, Saidi-Mehrabad and Jalali Naini deals with remanufacturing of product. The paper establishes a cost optimization model to determine optimal levels of remanufacturing for used items sold with failure free warranty.

To understand and improve product design and performance it may be critical to collect product-use data from the field. The paper 'Function performance evaluation and its application for design modification based on product usage data' by Shin et al., expresses the importance of data used to design products to improve the beginning-of-life (pre-design) and middle-of-life (usage) phases of these products. The central idea of this paper is the feedback of the product-use field data to improve product design and performance.

The paper 'Management of Residual life cycle costs for sustainability in Middle of Life phase' proposes a decision support system to manage the middle of life phase to obtain data which may impact on the whole value chain. The paper focuses on two different scenarios: 1) the optimization of the maintenance service for truck fleets and 2) for machine tools through the application of an innovative strategy based on a predictive maintenance approach. The result is the realization of the proper intervention and the optimal timing for the substitution of the product components.

The paper titled 'The role of AIDC technologies in product recovery – an Information Quality perspective,' examined several solutions for providing product recovery decision-makers information associated with discarded products. These systems offer the ability not only to make

product information available to the recoverer, but also to improve the quality of available information.

The paper ‘Sustainability in the auto-repair industry: a life cycle assessment approach’ proposes a model to support the auto repair industry in the development of a network with the aim to reduce environmental impacts and energy consumption. A model based on an LCA approach to help auto-repair industry to measure, monitor, and improve their performances to get economical, environmental, and competitive advantages is discussed. An empirical application in a body repair workshop is implemented to validate the proposed model and to verify its applicability and significance.

Post-Use: Disposable/recycling

The paper titled ‘Visualization of LCA Environmental Impacts of Electrical and Electronic Products using Multidimensional Scaling,’ states that growing amounts of waste electrical and electronic equipment cause serious damage to the environment and have adverse effects on human health. The aim of this paper is to illustrate the wide-ranging applicability of the concept of environmental performance applied to a variety of household appliances, using Multidimensional Scaling (MDS) to compare them and visualize their positioning.

The paper by Parlikad and McFarlane discusses product recovery and End-of-life analysis. It provides an overview of different emerging technologies and systems that could help in improving the information available to recoveries. The paper discusses a model for the product recovery process using a decision-theoretic approach. The paper also informs about strategies to ascertain the reusability of the end-of life cycle phase of products.

Apart from these papers, there is also a review paper by Arena et al. The paper titled ‘A State-of-the-art of Industrial Sustainability: Definitions, Tools, Metrics’ reviews and synthesizes literature on sustainability from an operational point of view. The paper has extensive literature research and analysis on generic notion of sustainability. The paper titled ‘Life cycle thinking and sustainable food production,’ captures the use of LCA in sustainable food production. The central idea of this paper is to come out with some recommendations for the proper use of LCA for real world applications such as global food production. The paper contains four general recommendations.

5. Conclusions

The papers in this special issue may not encompass the entire domain of Sustainable Products, Processes, and Services, however these papers provides considerable amount of research contributions in this field. Sustainable manufacturing is a very broad area of research but we believe this special issue does provide a sampling of efforts in the field.

It is clear from this special issue and similar efforts that there is a growing need for:

- A standardized terminology of terms and concepts, harmonized and extended sustainable metrics, uncertainty models for carbon footprint analysis, and models for data accuracy, traceability, precision, and uncertainty for life cycle data developed in collaboration with industrial consortia and software providers.
- Clearly defined sustainability metrics and merging with product life cycle information models
- Quantifying the sustainability performance of advanced materials, chemical and manufacturing processes, and products and systems over their life cycle

- Accounting for economic, environmental, and societal impacts of a design to enable optimization of cost, quality, and sustainability in the design stage
- Standardized information exchange protocols between life cycle analysis tools and decision support tools
- An ontological framework that will relate manufacturing attributes to existing and developing regulations
- Information models and tools to facilitate the development of specifications of environmental performance measures that quantifiably evaluate the impact of a product or manufacturing process on the environment

Our hope is that this issue will create a dialogue among various stakeholders to solicit the state-of-the-art approaches and suggested methods that address issues outlined above, especially focusing on design of sustainable products, processes and services, and sustainable manufacturing.

The editors would like to thank all the authors for their excellent contributions and the reviewers for their comments and suggestions to improve the overall quality of the papers. The editors also wish to acknowledge the authors for their understanding and patience in finalizing this special issue.