Editorial

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According to one of the widely used definitions for sustainable manufacturing, it involves "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound" (US Department of Commerce, 2007). This is further extended in NACFAM (2009) to indicate that sustainable manufacturing includes both the manufacturing of 'sustainable' products as well as the sustainable manufacturing of all products.

While these and other numerous definitions of sustainable manufacturing have been put forward in recent years, most are inadequate; each addresses one or a few aspects that must be covered in different domains to promote sustainable manufacturing but none comprehensively cover all integral aspects. First and foremost, sustainable manufacturing should consider the economic, environmental, and societal impacts, usually referred to as the triple bottom line (TBL). The impacts on the sustainability of a manufactured product and its manufacturing processes also need to take its entire life-cycle into consideration, which, when looked at very broadly, includes four different stages: pre-manufacturing, manufacturing, use, and post-use. An important consideration when promoting sustainability across these four life-cycle stages is a focus on closed-loop material flow, to recover value remaining in products at end-of-life for re-channelling back into the subsequent life-cycles of the same, or different, products. To enable this cradle-to-cradle approach (McDonough and Braungart, 2002) at the product level, a holistic framework, such as that put forward through the 6R methodology (Jawahir, 2008) must be followed. The innovation-based 6R (*reduce*, *reuse*, *recycle*, *recover*, *redesign*, and *remanufacture*) approach allows for a transformation from the cradle-to-grave concept to multiple life-cycle consideration for a specific product (Jayal et al., 2010). Such an approach can enable minimising the use of virgin materials as well as other resources expended to extract and convert virgin materials to make such products. At the process (manufacturing as well as business processes) level optimised improvements to ensure more efficient resource (material and energy) utilisation, reduced emissions (solid, liquid and gaseous) as well as improved safety and health are needed.

Building on the prior definitions to incorporate total life-cycle considerations, Jawahir et al. (2013) refined the definition of sustainable manufacturing to indicate practices that demonstrate reduced negative environmental impact, offer improved energy and resource efficiency, generate minimum quantity of wastes, provides operational safety and offers improved personal health.

One area that has been overlooked by many but extremely important to ensure product and process sustainability is the system (i.e., the plant, enterprise and the entire supply chain) within which these products and processes exist. At the manufacturing systems (or plant) level, which essentially involves the integration of numerous individual processes to transform raw materials into finished products, a systems-based approach to implementing TBL performance improvements must be adopted to optimise trade-offs inherent to all sustainability interventions. At the supply chain level, unless processes the designed, planned and managed to enable the closed-loop flow, the goal of producing more sustainable products will not be feasible.

This indicates the need to, first, explicitly consider the post-use life-cycle stage (which, conventionally, has been an afterthought for many companies) to implement reverse logistics operations in a scale that is much broader than in the customary sense where the focus has been on channelling back unsold goods; companies must now expand the reverse logistics operations to actively enable implementing the 6R's for closed-loop flow. Figure 1 illustrates this integrated emphasis necessary in sustainable supply chains through the application of the 6R's across all four life-cycle stages to promote sustainable manufacturing. Also important to note is that, while the product-process-systems emphasis is essential to promoting sustainable manufacturing, recognition of the interconnectivity between the these elements is even more vital to produce functionally superior, more sustainable products using sustainable technologies and advanced manufacturing methods (Jayal et al., 2010). The need for product-process-system emphasis in sustainable manufacturing is reiterated by Jayal et al. (2010).

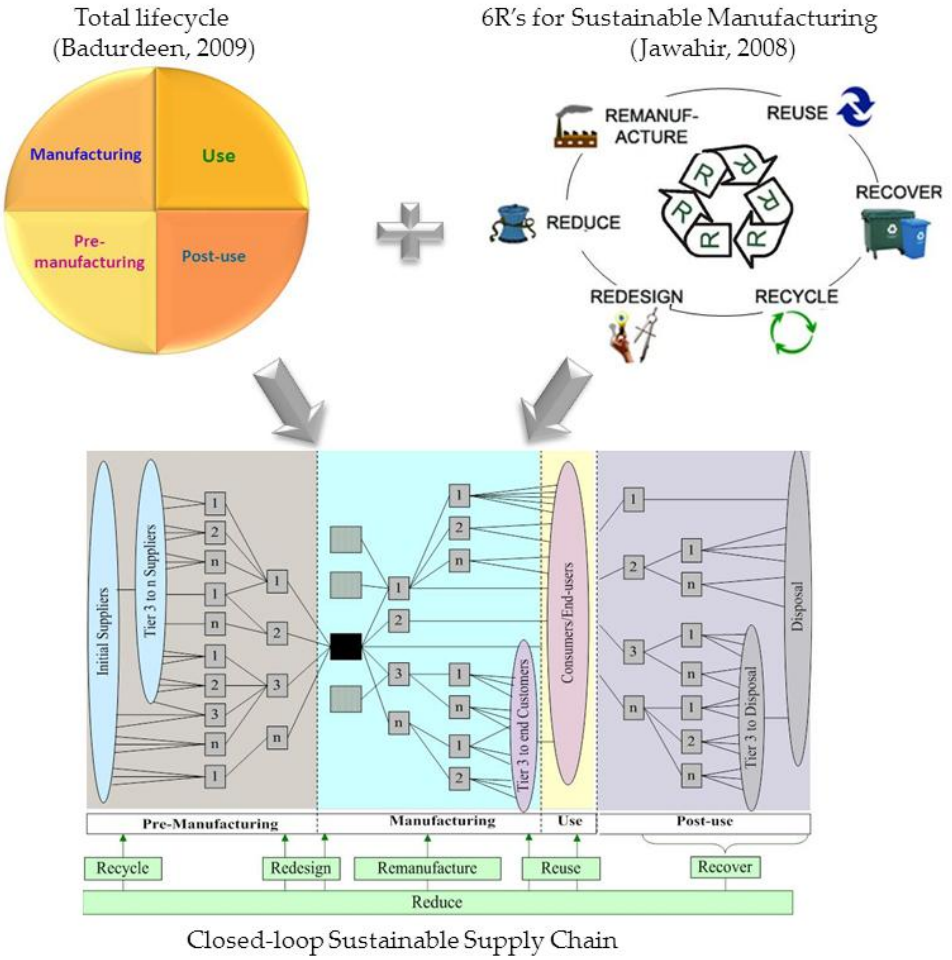
Haapala et al. (2013) present a comprehensive review of research in various domains related to sustainable manufacturing. Implications of producer, consumer and environmental interactions when creating sustainable value, in manufacturing and at a much broader scale, are examined by Ueda et al. (2009). Brammer et al. (2011) provide a thorough review of the body of knowledge on sustainable supply chains. While these and other contemporary literature highlight the recent advances in research in different domains to promote sustainable manufacturing, all these and many other recent studies and joint industry-academic workshop reports (Badurdeen, 2011; SMART, 2013; ASME, 2013) examine the numerous gaps and further research necessary to advance sustainable manufacturing. In the systems domain, these efforts reiterate the planning, design, management and integration efforts necessary at the manufacturing systems and supply chain level to promote sustainable manufacturing.

The collection of papers included in this special issue on sustainable manufacturing address various aspects pertaining to the manufacturing systems and supply chain domain. The papers present some recent developments in methods and techniques to address challenges – at the plant, enterprise and supply chain levels – brought about due to system complexity as a result of interdependence between system aspects and the products manufactured and processes used, difficulties in collaborating and communication between various stakeholders in the system and problems with quantifying and improving performance along economic, environmental and societal perspectives as well as assessing trade-offs involved.

Improving energy efficiency in manufacturing plants and across the supply chain has become a concern due not only to increasing energy costs but also because of the negative environmental consequences of fossil fuel-based energy consumption. Poller, Hopf, Krones and Müller present the concept for a learning environment on energy

efficiency termed the 'centre of energy competence – logistics and factory planning'. They discuss the approach followed to developing and implementing the concept, a useful framework for organisations focused on developing an energy-efficient factory. While the primary emphasis of their paper is the plant/enterprise level, the approach can be extended to improve energy efficiency at the supply chain level and achieve better environmental performance.

Figure 1 Integrated framework for sustainable supply chains (see online version for colours)



Source: Badurdeen et al. (2009)

Manufacturing enterprises and supply chains represent complex systems whose interdependent performance must be optimally designed and managed to minimise trade-offs when improving economic, environmental and societal performance is the goal. Adopting systems thinking practices can help understand how various factors in this domain are intrinsically linked to each other and how improving performance in one area could potentially affect another. In their paper, Zhang, Calvo-Amodio and Haapala define a unified theoretical framework by providing operational definitions for sustainable

manufacturing assessment through the application of systems thinking methods. They conduct a content analysis to gather operational definitions and provide a discussion of how systems thinking can be integrated for sustainable manufacturing assessment.

Making the business case continues to be one of the challenges to increased corporate engagement in sustainable manufacturing efforts. In their paper, Van der Spiegel, Linke, Stauder and Buchholz report a study conducted to review the sustainability goals and strategies at the corporate, business and operational levels of organisations to assess how the various goals are prioritised and implemented. They present a web-based case study using information from 100 companies to investigate the most widely pursued goals and how awareness of goals is promoted.

The approach presented in the paper by Bilge, Badurdeen, Seliger and Jawahir could prove useful for organisations when making the business case for sustainability initiatives. They address value creation at the systems level – at the plant, enterprise and supply chain – by considering the supply chain as a value creation network with various value creation modules. The total life-cycle perspective is covered and different attributes that the value creating modules must possess, in order to create sustainable value from economic, environmental and societal perspectives, are identified; the potential interactions between different value creation factors are also described. Their approach presents a framework to quantify sustainable value creation which can then be compared with organisational strategic alignment to assist with long-term decision making.

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