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Procedia Manufacturing 8 (2017) 20 – 27

Procedia MANUFACTURING

14th Global Conference on Sustainable Manufacturing, GCSM 3-5 October 2016, Stellenbosch, South Africa

Strategies for Value Creation through Sustainable Manufacturing

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Abstract

Making the business case and establishing strategic directions for sustainable manufacturing requires a collaborative effort. Strategic capabilities that can help create sustainable value for all stakeholders must be identified. Technologies and methodologies to provide these capabilities for implementation must then be developed, through public-private partnerships. This paper presents major business imperatives and strategic capabilities necessary to enable value creation through sustainable manufacturing identified based on extensive engagement with business leaders and industry professionals as well as academic experts and government agency representatives. The paper also presents a future vision for sustainable products, processes and systems that can be derived from such capabilities.

Peer-review under responsibility of the organizing committee of the 14th Global Conference on Sustainable Manufacturing

Keywords: Sustainable manufacturing; Roadmapping; Business case

1. Introduction

Many definitions have been presented for sustainable manufacturing in recent times. According to one of the most comprehensive definitions, sustainable manufacturing, 'at the product, process and systems levels must demonstrate reduced negative environmental impact, offer improved energy and resource efficiency, generate minimum quantity of wastes, provide operational safety and offer improved personnel health, while maintaining and/or improving the product and process quality with overall lifecycle cost benefits' [1]. Traditional manufacturing practices have focused primarily on the pre-manufacturing, manufacturing and use stages of product lifecycles, leading to excessive waste and landfill. While lean manufacturing practices focus on waste elimination (Reduce), green manufacturing emphasizes the use of 3Rs (Reduce, Reuse and Recycle). However, none of these strategies enable maximizing value recovery from end-of-life products. Implementing sustainable manufacturing practices using a 6R (Reduce, Reuse, Recycle, Recover, Redesign and Remanufacture) methodology enables closed-loop, total lifecycle-based material flow [2, 3], with a holistic consideration at the product, process and system levels [4]. This evolution of

Peer-review under responsibility of the organizing committee of the 14th Global Conference on Sustainable Manufacturing
doi:10.1016/j.promfg.2017.02.002

manufacturing strategies, for the entire lifecycle covering four lifecycle stages (Pre-manufacturing, Manufacturing, Use, Post-use), with value recovery through the various 'R's, as well as the corresponding gradual reduction in landfill through each strategy, is comprehensively illustrated in Fig. 1.

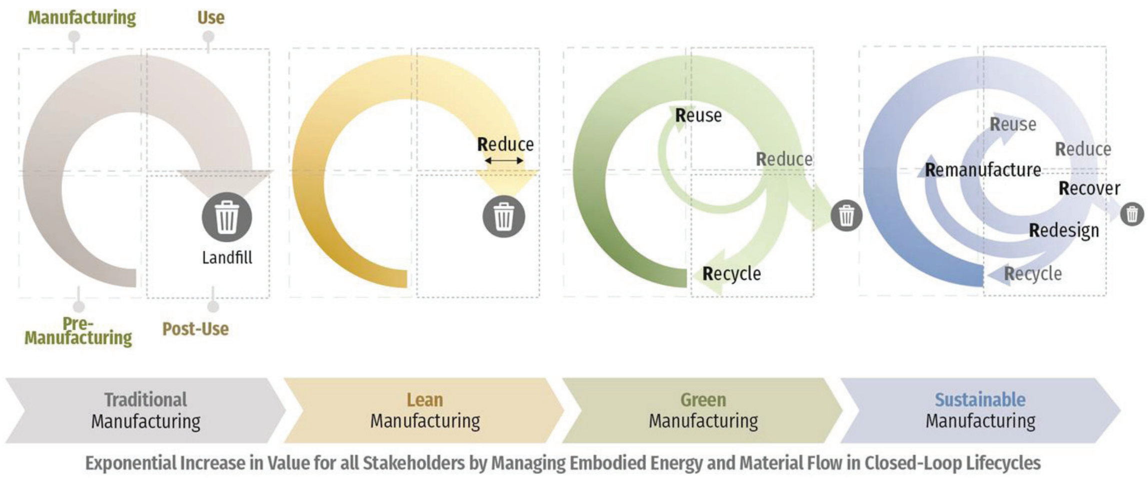


Fig. 1 Evolution of Manufacturing Strategies

Progressive companies who understand the strategic importance of sustainable manufacturing practices are already taking steps to implement initiatives for more resource-efficient and socially-responsible business. However, according to some other reports, novices and slow adopters of sustainability initiatives claimed to see less financial benefits [6]. Therefore, if the broader industrial community is to be more engaged to embrace sustainable manufacturing practices, the economic and competitive issues of implementing such efforts must be identified and methods to address those concerns must be developed. This requires a business-focused view of describing sustainable manufacturing as an 'enabler for the total success of the manufacturing enterprise, and it requires the integration and optimization of products and processes in a systems environment' [6] in order to exemplify the potential benefits of sustainable manufacturing. Hence, sustainable manufacturing must be addressed from a business perspective while integrating the total performance of the enterprise, and relevant strategies for value creation in manufacturing must be identified.

This paper presents major challenges faced by manufacturing organizations as they attempt implementing sustainable manufacturing practices, as well as strategies/capabilities that must be developed to address those challenges to enable value creation through sustainable manufacturing. The findings are based on extensive interactions with business leaders and industry professionals from all major industry sectors, including automotive, aerospace, consumer products manufacturing, as well as academic experts and government/agency representatives through a few dedicated workshops in the U.S. under a major grant from the National Institute of Standards and Technology (NIST), including a Sustainable Manufacturing Roadmapping Workshop held at the University of Kentucky (Lexington, KY, USA) in November 2014 on establishing the business imperatives and strategic directions [7]. The vision for the future state of sustainable manufacturing that will be feasible through the development and implementation of these strategic capabilities is also presented in this paper.

2. Key strategies to enable value creation through sustainable manufacturing

In manufacturing, value is generated through activities and interactions between suppliers, manufacturers, customers and other stakeholders [8]. However, when it comes to sustainable value creation, the economic, environmental as well as societal (the triple bottom line or TBL) impacts on all stakeholders must also be considered. According to Lazlo [9], in a business context, sustainable value is created when value is generated for shareholders as well as all other stakeholders simultaneously. As such, manufacturing organizations must balance the trade-offs between TBL perspectives and conflicting goals of different stakeholder groups when pursuing sustainable manufacturing practices. In order to achieve this, a variety of challenges must be overcome to develop innovative strategies for sustainable value creation in manufacturing. Some of the key strategic capabilities identified by industry experts to enable broader and rapid implementation of sustainable manufacturing practices [7] are discussed in the sections below.

2.1. Sustainable manufacturing education and workforce development

Implementing sustainable manufacturing practices can help enhance TBL value to all stakeholders. However, too often, the pursuit of sustainability in manufacturing is relegated to a superficial level to include only the environmental effects and energy-efficiency in product and process development. The major reason for this is that sustainable manufacturing is not considered as an educational priority. As a result, the present curriculum, across engineering colleges, other university departments, community colleges/trade schools, and K-12 programs often do not emphasize sustainable manufacturing. An educated and sustainability-aware workforce will enhance corporate knowledge and support innovation, a key requirement for sustainability. Therefore, to enable innovation and technology development, education and workforce development efforts must focus on the 3Rs of the education lifecycle (Recruit, Reeducate and Retrain - see Fig. 2) of personnel to meet the knowledge and skills requirements. Such a lifecycle-based approach to education and workforce development can help develop a continuously employable (through retraining and reeducating) and sustainability-aware workforce.

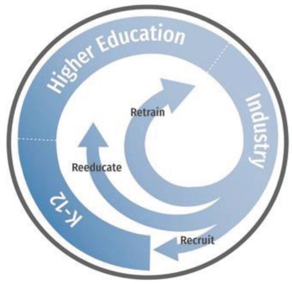


Fig. 2 Education 'Lifecycle' to Promote Sustainable Manufacturing

2.2. Next generation decision support toolset

While Lifecycle Assessment (LCA) delivers value in assessing the potential environmental and energy impacts, it is often an isolated activity, not integrated with product and process development or to provide any decision support. There is a great opportunity to move sustainable manufacturing and LCA from a peripheral activity to a mainstream and integral component for total value creation and optimization by integrating them with other decision support toolsets. The challenge for industry is that many decision support toolsets are contained in disparate systems and they lack interoperability. There is also limited access to lifecycle data. Therefore, to optimally assess sustainability gains in relation to affordability, producibility and various other *'ilities'*, there is a need for interoperable decision support toolsets for total lifecycle sustainability assessment early in the product development cycle. For example, the use of integrated decision support tools that integrate innovations at the product, process and system levels, providing access to data from all lifecycle stages (such as illustrated in Fig. 3), can help evaluate the total lifecycle sustainability effects; and will allow decision making through what-if analyses on economic, environmental and societal costs benefits of using different materials, manufacturing processes and supply chain strategies.

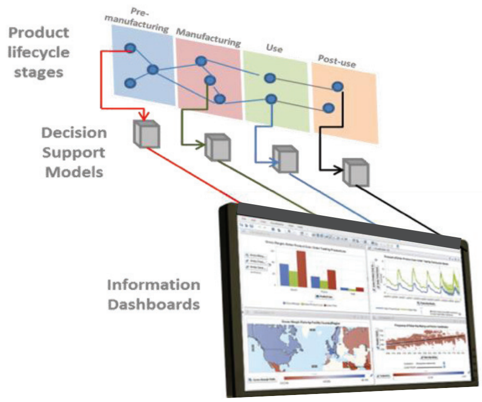


Fig. 3 Decision Support Tool Sets Supported by Lifecycle Data

2.3. Risk, uncertainty and unintended consequences for supply networks

Literature shows that most companies experience at least one supply chain incident per year, leading to immediate loss of productivity and revenue, as well as increased shareholder concern damaging a company's reputation [10, 11]. Even more damaging is that such events can lead to an instant loss of benefits from prolonged efforts to promote sustainability. Thus, the increasing complexity of global supply networks and the consequences of unexpected failures present an opportunity and a demand for improved risk assessment, avoidance, and mitigation capabilities. The ability to establish safe operating envelopes, well within the bounds of acceptable performance, and to operate within those boundaries, assures safe, energy-efficient, environmentally-responsible, and sustainable operation. The present risk models do not address all factors or the aggregation of factors. Current risk models also lack visibility, often too simplistic, and present a 'rear view mirror' approach to risks based on past events. Therefore, to enhance value creation through sustainable manufacturing and increase resilience against catastrophic events, risk models with real-time visibility and intelligence for risk identification, assessment, avoidance and mitigation are necessary. By establishing continuous visibility of supply chain risk areas and implementing mitigation measures, companies can meet customer requirements, and achieve profitability and sustainability.

2.4. Product Lifecycle Management (PLM) capability for process planning

Existing process planning practices are limited in emphasis to the manufacturing stage of the product lifecycle. Extending process planning capabilities to assess impacts of product design on impacts in other lifecycle stages, by integrating with Product Lifecycle Management (PLM) can enable more value generation. Thus, there is a need to move from process planning, as driven by the singular necessity to produce specific product features and outcomes, to the selection of optimized processes that are integrated with the product design function to facilitate ease of end-of-life processing, including reuse, remanufacturing or recycling. Such an approach will allow exploration of all alternatives to meet process requirements for holistic optimization, including a sustainability focus in all processes and optimized planning for all 6R processes. Evaluating all process alternatives demands the full characterization of materials/processes, and access to data and models, the provision of which is a major challenge. While advanced process planning is knowledge-intensive, developing such expanded PLM capability for process planning will reduce the need for iterative process development and will contribute to increased sustainable value creation.

2.5. Lifecycle cost models

Better lifecycle cost models would enable more accurate prediction of costs and optimization of product and process attributes for creating the total lifecycle value; it can also deliver better products at lower costs. The ability to evaluate alternatives and determine the best total product and process value demands the detailed understanding of all cost factors early in the development process. However, the conventional pathway to obtain cost knowledge is through the analysis of historical data. This approach limits the exploration to what we know and understand, and it discourages innovation. Instead, an enriched understanding of the foundational cost elements is needed (based on requirements) from which accurate cost models can be constructed for all product alternatives being evaluated. Better cost models, that incorporate data from all four product lifecycle stages (Fig. 4), will permit more accurate cost assessment early in the development process to reduce product cost. It will also enable developing product designs that allow for better end-of-life management (reuse, remanufacturing or recycling) to promote increased value recovery. Further, total lifecycle cost models will also provide business value by reducing the risk of unanticipated cost escalation, particularly relevant in cases when there is extended producer responsibility for products.

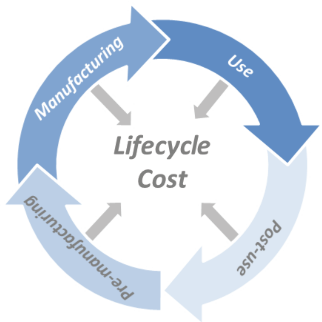


Fig. 4 Lifecycle Cost Models to Enable Cost Assessment

2.6. 6R-focused end-of-life management

Improved and pervasive end-of-life (EOL) planning offers the opportunity to reduce environmental impact, save energy, and maximize the total lifecycle value of the product. By including end-of-life considerations in the conceptualization and design process, the best disposition plans can be built into the products and can be conveyed in the information that accompanies the products. The 6R concept offers a great foundation for instilling end-of-life planning in the development process. When all combinations of 6Rs are engaged and optimized, lifecycle management plans will result. End-of-life management strategy deployment must also be approached by focusing on higher value recovery options such as reuse and remanufacturing prior to recycling, which results in destroying most of the embodied energy in the products (see Fig. 5). There are gaps in the culture, the businesses processes, and the technology toolsets available to achieve this vision. The most stringent end-of-life activities are enforced by regulatory statues, for example, in the European Union. While they may be effective, a compelling business case as a driver is preferable as enhanced end-of-life management will create new revenue streams, helping companies enhance brand value and market share.

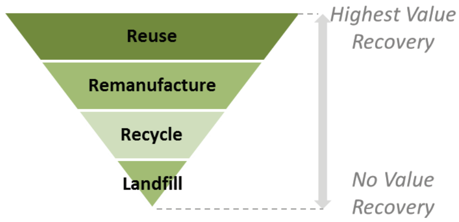
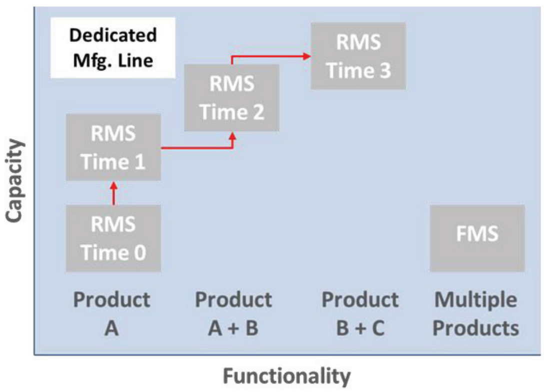


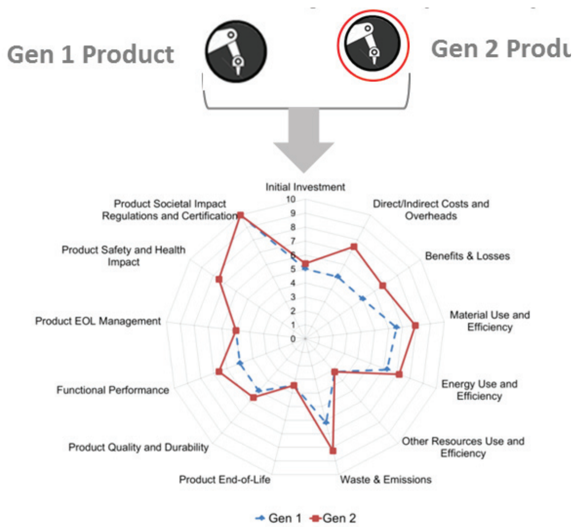
Fig. 5 End-of-life Value Recovery Options

2.7. Flexible and scalable manufacturing alternatives

Manufacturing operations have evolved over the last few years to embrace integrated supply networks. To enhance sustainability performance, the next level of evolution for manufacturing must be flexible and scalable systems that produce products at the most beneficial location, utilizing the best available resources, methods and equipment to provide dramatic cost reduction, increased productivity, and sustainability advantages. Existing infrastructure and methods often cannot support such flexible and scalable manufacturing; the systems are not adaptable to provide total sustainability value in a flexible manner. Implementing flexible and scalable manufacturing practices, such as through the integration of Reconfigurable Manufacturing Systems [12] capabilities to enable 6R-based closed-loop material flow, will allow companies to reduce risk and meet quality when meeting customer needs (see Fig. 6a). Transportation costs, and related sustainability issues, can also be reduced by strategies such as flexible and scalable point-of-use manufacturing. All this can help reduce cost, and increase profitability, while also enhancing sustainability, thus making for good business practice.



(a) Reconfigurable Manufacturing Systems [12]



(b) Product Sustainability Comparison using *ProdSI* [13]

Fig. 6 Examples for flexible/scalable manufacturing alternatives and sustainable manufacturing

2.8. Sustainable manufacturing metrics

Currently, there is no standard method for measuring triple bottom line (TBL) achievement or comparison. The provision of such methods would enable the common-scale and consistent evaluation of performance; it would provide a measure of sustainability in products and processes across international boundaries, cultures and manufacturing/trade practices. Standard metrics would also support the determination of rewards and incentives that would lead to achieving optimized lifecycle performance and improved product/process sustainability. Much of the current work on standardization of measurement in sustainability has been initiated and/or implemented in Europe (e.g., the Global Reporting Initiative). Better sustainable manufacturing metrics and measurement frameworks will enable a more definitive assessment of the impact of sustainability initiatives on competitive position and identification of areas of focus. Metrics can also help evaluate long-term vs. short-term benefits of sustainability initiatives to help make decisions that will be of strategic importance to create business and sustainable value.

For example, one of the recent efforts involves a comprehensive framework and metrics for assessing sustainable manufacturing performance at the product and process levels [13, 14]. Such methods can help companies assess the performance of alternate product designs (see Fig. 6b) or different manufacturing processes to assess their relative sustainable manufacturing performance in comparison to a baseline. The ability to evaluate performance along the core aspects (identified as clusters and sub-clusters in [13], [14]) will enable better decision making considering TBL performance.

2.9. Other strategies

In addition to the strategies discussed in the above sections, several other areas in need of strategic capability development for value creation through sustainable manufacturing were also identified [7]. In current systems, knowledge capture is often not systematized, nor does it cover the entire product realization spectrum of the total lifecycle, necessary for intelligent and sustainable design and manufacturing. Real-time information driven decision making will help companies make better decisions and reduce costs; it will also provide insight to protect the company from unintended consequences and mitigate risks. Better visibility and information availability will help eliminate wasteful and inefficient operations, promote sustainability and increase profits to increase overall business value. This is another strategic need in order to enable increased value creation through sustainable manufacturing. Cyber attacks cause harm globally every day, and the risk of supply networks suffering catastrophic damage is significant. While protection from an attack is imperative, it is equally important that the supply network be able to confidently exchange needed information without fear and within acceptable risk boundaries. Providing an open, shared and secure environment is the motivation for this imperative. Thus, secure collaboration platforms are needed and will enable confident sharing of needed information across the supply network, avoiding such costs.

By coming together in public-private partnerships with a common purpose, and working together to deliver value, the manufacturing community can address challenges that are too large for any single entity to undertake. Such partnerships can provide a link for validated industry needs to funding sources to initiate research activities, assuring industrial value of deliverables. One such recent initiative in the United States, for example, is the National Network for Manufacturing Innovation (NNMI) [15]. The NNMI institutes are established as public-private partnerships to develop high-impact transformative technologies that cannot be undertaken by any individual university or industry partner. A number of NNMI institutes in spanning various manufacturing technologies have already been established and the initiative to establish a new NNMI institute for sustainable manufacturing that will focus on technology development for reducing material, energy and other resource consumption, as well as emissions, is currently underway.

The opportunity to embrace corporate assets as a system to be strategically managed offers the opportunity for optimized decision making, stability in operations, and sustainability of the enterprise. The various elements that comprise the corporate assets are represented by functional departments in organizations, and there is seldom an awareness of the need for a systems approach to asset management. However, there is a strategic need to adopt a more holistic view of asset management to assure that all needed resources will be available when needed, enabling cost savings through reliability engineering, more confident business development, risk mitigation and protection against disruption, as well as improved corporate image and business position.

3. Vision for sustainable products, processes and systems

The vision formulated by industry leaders [7] in sustainable manufacturing provides an indication of the ideal state desired to make sustainable manufacturing an enabler for value creation and the success of the entire business enterprise. In that envisioned state, the design of more sustainable products will be a virtual process facilitated by a comprehensive set of computer-based tools that will allow performing an evaluation of all requirements for sustainability and alternative product possibilities. Further, knowledge-rich advisory systems will guide the selection of best alternatives for all sub-assemblies and materials.

For enhanced value creation, manufacturing of products in the future will be supported by an evaluation of all alternatives, including processes, and other resources needed to produce the best alternatives for total value creation and optimization, including sustainability, supported by knowledge-based systems. Materials and process interactions will be fully characterized based on scientific principles. The analysis of material selection and process interaction, including cost, time, and impacts will be feasible. In the future, the status of materials, resources, wastes, and emissions will be continually visible, in real-time. There will be a rich modeling and simulation capability, for individual processes, and will be integrated across processes, and the new knowledge acquired will guide evaluation.

For increased sustainable value creation, in the envisioned scenario a holistic, systems-based approach to design, manufacturing, and lifecycle support will be the norm. All needed information will be available to the product team and the enterprise in an as-needed, yet secure, environment. A virtual environment will enable the user to easily and accurately evaluate all factors to balance cost, performance, sustainability, and risks for all supply options, conduct trade-offs, and select the most advantageous alternatives based on defined performance metrics. These envisioned capabilities for enhanced sustainable value creation at the product, process and systems levels to enable a closed-loop material flow-based approach to sustainable manufacturing is illustrated in Fig. 7.

4. Conclusions and future work

More widespread implementation of sustainable manufacturing practices require establishing the business case. This is necessary for companies to appreciate the financial, as well as TBL, benefits of implementing sustainable manufacturing initiatives. This paper presents a number of areas where capability gaps exist in enabling such a TBL-based approach to sustainable manufacturing. The capabilities and strategies that must be developed in the product, process and systems domains to enable increased value creation through sustainable manufacturing, identified based on extensive engagement with industry representatives, are presented in this paper. Finally, the envisioned state of

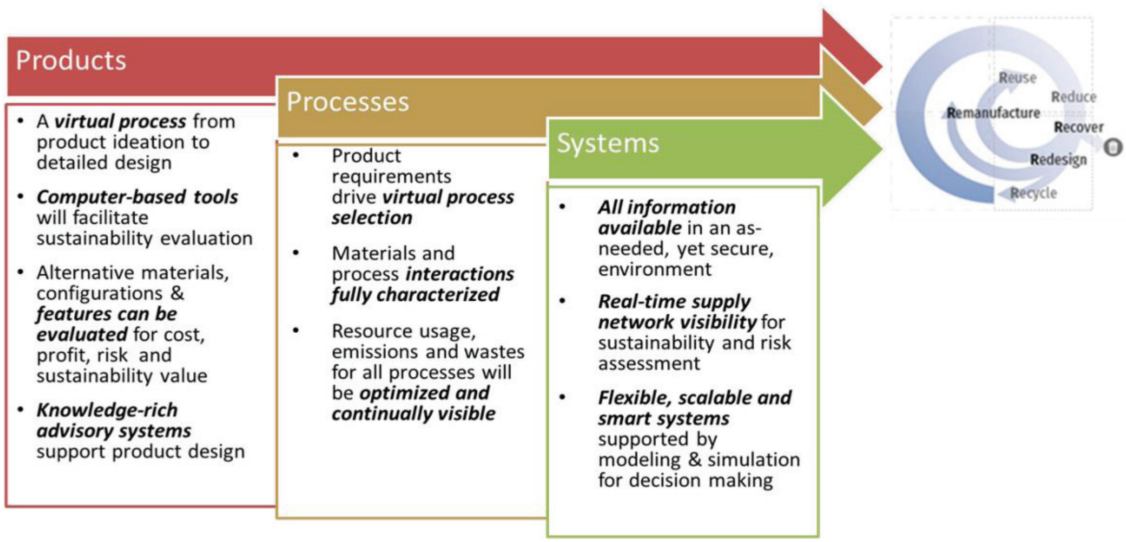


Fig.7 Vision for Sustainable Products, Processes and Systems

sustainable manufacturing in terms of how products will be designed, processes will be identified and the entire system and supply chain will be managed is also discussed.

Acknowledgements

The authors gratefully acknowledge the project funding from the National Institute of Science and Technology (NIST) Award No. 70NANB14H042 for the project titled 'Partnership for Research and Innovation in Sustainable Manufacturing (PRISM): Product, Process and System Integration' and the National Science Foundation CBET Award No. 1548385 titled 'Value Creation through Sustainable Manufacturing; September 24 and 25, 2015; Lexington, KY' that helped support the work presented in this paper.

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