Sustainable Manufacturing – A Business Perspective

Summary Document

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Preface

This document is the third in a set of materials exploring the theme, *Sustainable Manufacturing – a Business Perspective*. The first document – the pre-read package - released in November 2014, prepared participants for a workshop by assuring a common understanding of the subject area. That workshop was held on November 13 and 14, 2014. The second document, a Technology Roadmap for Sustainable Manufacturing, presents the results of the workshop, plus post-workshop analysis, in detail. It is a substantive work. All practitioners of sustainable manufacturing, technical leaders, educators, and manufacturing managers are encouraged to read this document and to retain it for reference.

This summary document, the third document, completes the set. It is written for those who need "just the bottom line." It provides abbreviated introductory information and moves quickly to the results of the workshop and the presentation of the key findings. All these materials are available on the Institute for Sustainable Manufacturing website at http://www.ism.uky.edu/2014/11/21/sustainable-manufacturing-roadmap-workshop-documents/

It is important to note that the delivery of the document set is not the end of the effort, but the beginning. The Partnership for Research and Innovation in Sustainable Manufacturing (PRISM) is a consortium formed by the Institute for Sustainable Manufacturing of the University of Kentucky. The vision for PRISM is to create and manage a dynamic partnership that raises the awareness of sustainable manufacturing, earning a strong position for sustainability as an essential component of national advanced manufacturing activities and enabling the management and execution of a structured R&D project slate. The partnership will seek collaboration and leverage across the industrial and academic community to deliver science-based solutions to sustainable manufacturing challenges.

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1 Introduction

1.1 Background

In 2013, the University of Kentucky, Institute for Sustainable Manufacturing launched a new consortium called the Partnership for Research and Innovation in Sustainable Manufacturing (PRISM). The goals of PRISM are

> *To collaboratively study, identify and address significant technical challenges in implementing sustainable manufacturing at product, process and system levels, and to seek integrated solutions, to include the development of highly innovative, transformational technologies broadly deployable for diverse manufacturing applications.*

PRISM received funding from the National Institute of Standards and Technology (NIST) Advanced Manufacturing Technology Consortia (AMTech) program to support the development of a technology roadmap for Sustainable Manufacturing and to mature the PRISM consortium. The activities described in this document are supported by the AMTech award, with the goal of delivering a technology roadmap to guide PRISM efforts.

On November 13 and 14, 2014, 46 invited participants engaged in a facilitated workshop to produce the foundational materials for a technology roadmap. The theme for that workshop and the roadmap was *Sustainable Manufacturing – A Business Perspective*. In preparation for the workshop, a pre-read package was distributed to all participants to set the stage for effective participation. After the workshop, a technology roadmap was produced. Both the pre-read package and the complete roadmap are available on the ISM website: http://www.ism.uky.edu/2014/11/21/sustainable-manufacturing-roadmap-workshop-documents/.

This summary document offers highlights of the work at the executive level. It places sustainable manufacturing in a business context and presents a brief summary of sustainable products, processes, and systems. It concludes with a summary of the Imperatives--those needs workshop participants found most urgent and critical.

1.2 Sustainable Manufacturing

There are many definitions for sustainable manufacturing. They all address the goal of achieving development, production, support, and disposition of products that satisfy customer defined needs without present or future harm or threat. Although true sustainable manufacturing demands a balanced scorecard for business success, many definitions tend to focus on energy efficiency and environmental responsibility alone. PRISM moves beyond this limited view and asserts that sustainable manufacturing cannot reach its goal unless it is addressed from the perspective of a sustaining, profitable business. This business-based approach is well known as the triple bottom line, which addresses environmental, societal, and financial impacts. A balanced triple bottom line demands a systems approach. Hence, PRISM is dedicated to ***the systems-based design and production of innovative products that are optimized for best total lifecycle value in all aspects including affordability, producibility, and sustainability. Sustainable manufacturing does not seek to stand alone, but seeks a recognized position as a key enabler for the success of the manufacturing enterprise.***

Effective achievement of sustainable manufacturing demands that all aspects of the product realization lifecycle – from concept, to design, to manufactured product - through operation, and including lifecycle support and end-of-life management – be addressed as an integrated system. In the PRISM vision, sustainability is recognized and integrated into that system at all levels. The ideation and conceptualization of products and their design will address all business issues, including sustainability. Manufacturing processes and the resources utilized will be optimized for total value, including sustainability. The systems that support the enterprise will support the total success of that enterprise, accomplished through choices that support sustainability. All these aspects of the enterprise will be integrated in a single system. That product realization system will support the optimization of the component functions and of the total manufacturing enterprise. This key concept is illustrated in Figure 1.

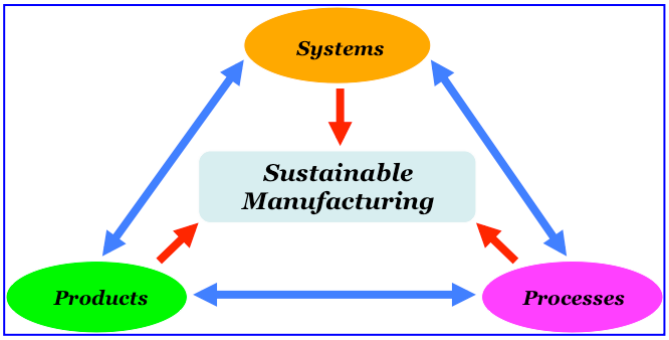


Figure 1: PRISM addresses three elements of sustainable manufacturing with the realization that these elements must be fully integrated.

1.3 The Business Imperative

Regulatory pressures can force change and are important in mandating minimum acceptable behaviors. However, market pressures and business opportunities create deeper, more effective, and longer lasting change. The following scenario illustrates the value of sustainable manufacturing, broadly defined, as an integral component of a corporate business strategy.

> *A sustainable enterprise makes money from everything it does. It does so in part by keeping costs low, using inexpensive raw materials and minimizing the amount consumed. It generates no wastes that are not profitable and none that cause detrimental external release - simply because it is good business to do so. It is efficient in all aspects, including energy use, and is constantly vigilant for improvement opportunities. Because of its efficiency, it has high return on all assets, and because of its responsibility, compliance is not an issue. Instead of being merely an end goal, compliance becomes a strong motivator for excellence beyond expectations. The products are uncompromising solid and their performance is consistent because all their aspects are understood, including risks and boundaries. Processes are optimized to meet product needs and controlled for real-time incident identification and response. The company's finances are solid and its reputation is strong, which enables agile response to any opportunity. Its employees set the industry standard for value from their employment package, yet their cost for value delivery is the lowest in the industry. Most of the company's innovation and success comes from the staff because the employees are engaged partners in the business of sustainable manufacturing – in commitment and in fact. They understand the corporate goals and the factors that impact sustainable manufacturing and why they are important, so everyone is engaged in finding innovative solutions. They are protective of corporate priorities, they understand the competitiveness equation, and they outperform their competitors. They understand "lean and green" and they understand "green" in the context of the corporate goals to which they are committed – not as a secondary,*

separate objective. Sustainable manufacturing is a corporate commitment, and everything that the corporation does supports that commitment.

This scenario highlights the systems approach to sustainable manufacturing. The message can be captured in the concept of optimization of the "ilities." Six corporate objectives may capture the totality of the sustainable enterprise - to produce products optimized for

- Affordability – Not necessarily lowest cost, but demonstrably the best total value
- Marketability – Products attuned to the market and sellable
- Profitability – Risk management and efficiency assure profitability
- Producibility – Processes are matched to the product in conceptualization and design and proven effective in virtual and physical evaluation
- Manageability – All functions of the enterprise are understood and managed within acceptable risk envelopes with critical functions protected from potential changes
- Sustainability – All factors that support the triple bottom line are integrated without compromise into all functions of the enterprise

Attributes of the Business Case

The business case for sustainable manufacturing is well demonstrated in a presentation from Department of Commerce, International Trade Administration.[1] This and other works point to a consensus around the business value and incentives in sustainable manufacturing. The business case for sustainable manufacturing includes, but is not limited to

- **Resource and Production Cost Savings** – Substantial cost savings have been documented from the replacement of materials and processes with improved alternatives that are more cost effective while saving energy and reducing environmental impact.
- **Protection/Enhancement of Brand Value** – Increasingly, the consuming public is willing to make purchasing decisions based on both the reality and the perception of improved sustainability and corporate image.
- **Corporate Financial Strength and Risk Aversion** – Strong sustainable manufacturing practices reduce the risk of failure and its consequences, enabling confident commitment and investment.
- **Employee Loyalty and Engagement** – Studies strongly support the fact that employees prefer to work for companies viewed as good citizens; their loyalty and performance follow that preference.

1.4 Methodology and Functional Model

The foundational information for the PRISM technology roadmap was developed through a facilitated workshop. The 46 participants were divided into three groups: sustainable products, sustainable processes, and sustainable systems. Each of these elements was further divided into sub-elements. Crosscutting themes that apply to all elements were addressed by all three groups. This structure is

[1] Developed by the U.S. Department of Commerce, International Trade Administration, Manufacturing and Services December 6, 2011, accessed at http://www.trade.gov/green/sm-101-module.asp, click on The Business Case for Sustainable Manufacturing.

captured in the functional model of Figure 2. The functional model guided the workshop, and provides the foundation for the PRISM Technology Roadmap.

For the subelement and crosscutting themes, each small group addressed the **current state** and needs assessment, the **vision** for the future, and the **solutions** that are needed to resolve the deficiencies of the current state and to move to the envisioned future state. All workshop attendees participated in prioritization from which ten top solutions were identified, and project ideas were selected from the top ten solutions. After the workshop, careful analysis of the workshop results led to the identification of 12 Imperatives, highlighted later in this document.

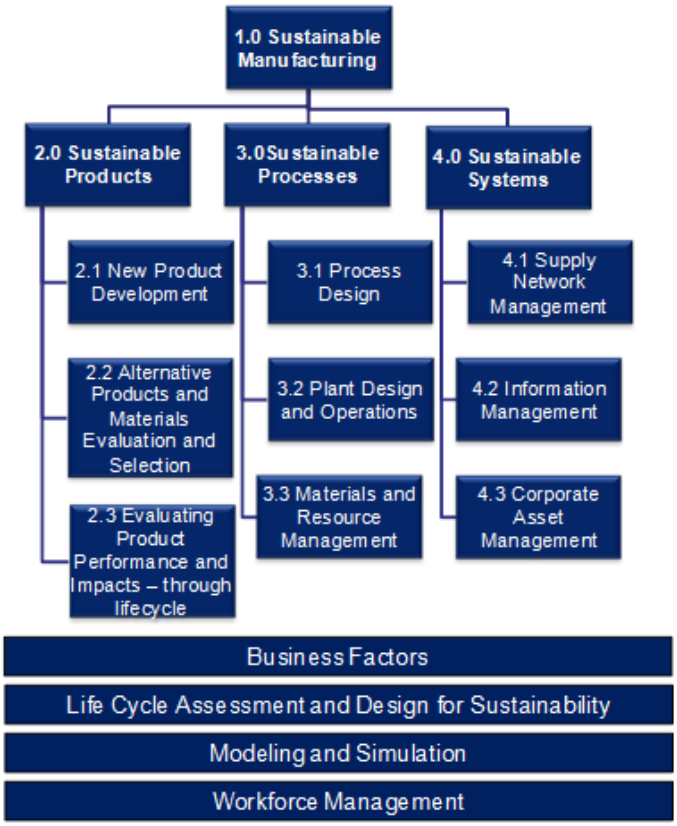


Figure 2: The functional model provides the structure for the development of the PRISM Technology Roadmap

2 Overview of the Elements of Sustainable Manufacturing

A consistent theme throughout the work of PRISM is a focus on sustainable products, processes, and systems. The PRISM Technology Roadmap addresses these elements in detail. Following are abstracts of the roadmap document.

2.1 Sustainable Products

Current State: There is an explosion of new and innovative products. Product performance continues to improve. The importance that consumers place on sustainability in product selection is increasing, and companies are responding. However, there is great diversity in the degree to which this emphasis influences corporate product decisions. The inability to accurately assess the risks,

cost, and performance in product decisions, and to foresee and avoid unintended consequences, limits the ability to quantitatively influence the product decision process.

Lifecycle Assessment (LCA) methods and tools are focused on evaluating the environmental impacts of products throughout the lifecycle – from cradle to grave. Product Lifecycle Management (PLM) toolsets build on the foundation of product design and product data and extend to other functions in managing the design and development of products and processes. Recent additions to the increasingly capable PLM toolsets include sustainable manufacturing modules. The extension of LCA from analysis to decision support and optimization, the maturation of PLM tools for total value optimization, and the integration of LCA and PLM capabilities offer compelling opportunities.

Vision: In the future, a comprehensive set of computer-based tools will guide the Integrated Project Team (IPT) through an evaluation of requirements and product possibilities and to optimized total value solutions. The alternative materials, configurations, and features will all be evaluated for cost, performance, risk, potential impacts, and total lifecycle value and the best total value decisions will be objectively made and documented. All potential problems and risks, even those that typically are not visible in the data or the final recommendations, will be flagged for human evaluation and interaction. A recommendation will be provided for each important decision point in product development, including quantification of risk and uncertainty. The design package for every product will include a quantified, total value recommendation of all product attributes in the integrated product/system with a data file documenting the decision process. The product development technical data package will follow and support the product through its lifecycle, including end-of-life management.

2.2 Sustainable Processes

Current State: Great improvement is occurring in the integration of manufacturing process considerations into product design and development. IPTs are working together for best solutions. New virtual tools are being applied to optimize plants and processes early in the concept and scenario stages. Lightweighting pressures and concern over material impacts are driving the selection of alternative materials and resources that provide improved performance. Visualization tools are being integrated with analysis systems to optimize plant, equipment, and process design before any physical commitment or operation. The ability to model integrated systems and processes, to monitor their performance, and to integrate the actual and expected performance in intelligent systems is a new reality for certain applications. Increasingly, sustainable processing is viewed as a business necessity.

Vision: In the future, product requirements will drive a virtual evaluation of all options, including materials, facilities, processes, and other resources, to produce the best alternatives for total value optimization. All sustainability factors will receive appropriate attention in the evaluation. Knowledge-based systems will support best alternative selection and will automate/augment the creation of the information needed to drive an intelligent manufacturing environment. LCA systems will move from compliance tools to valued decision support systems that enable the optimization environment. Manufacturing processes will be evaluated and optimized virtually, including integration of multiple processes and equipment, with first-and-every-product success the norm. Intelligent systems will assure continuous operation within acceptable control limits; all deviations

will be addressed in the most effective way, and products will be delivered with 100% assurance of in-process quality. This intelligent environment will optimize efficiency and sustainability.

2.3 Sustainable Systems

Current State: Systems engineering and related methodologies have raised awareness of the necessity of addressing challenges from a holistic view, including an awareness of the value of a sustainable approach to design and manufacturing. Companies are investing in sustainable supply networks that minimize risks and seek long-term stability and risk mitigation. However, there still exists a tension between short-term financial gain and prolonged sustainable investments. Progress is being made in making information available to all who need it across the supply network. Cyber security issues arguably present the greatest risk to the sustainable supply base, and most agree that there is no ready answer to this multi-faceted threat. The aging workforce and the lack of a technologically sound, sustainability aware, emerging workforce are crucial current state concerns.

Vision: A holistic, systems-based approach to design, manufacturing, and lifecycle support will be the norm. The integrated product team will be equipped with an interactive toolset that supports objective evaluation of alternatives and the selection of the best total value solutions. They will define system requirements and will interactively play out various product scenarios with real-time, accurate assessment of the lifecycle cost, performance, and sustainability impact of all options. The evaluation will include sourcing alternatives and supply network design. All needed information will be available to the product team and the enterprise in an as-needed, yet secure environment. Corporate assets, including human assets, will be proactively managed, assuring that all needs, now and at any future time, are fully met. Partnerships between industry and the broad academic/training community will deliver a workforce perfectly prepared for specific tasks and for their role as strategic partners for corporate success. LCA will move from a tool that assures environmental responsibility to a system that interacts with other systems to optimize sustainability for the product lifecycle. Emerging hardware and software systems will mature to provide assured secure collaboration.

3 Imperatives

From the identification of 71 needed solutions, the workshop participants prioritized to define the ten top solutions. Subsequent to the workshop, the editorial team refined the results from the workshop to identify 12 Imperatives. While these Imperatives are important, the reader is cautioned not to ignore the wealth of information and knowledge that is captured in the full text of the roadmap.

The Imperatives are listed below, followed by one-page descriptions of each.

Imperative 1: Sustainable Manufacturing Education and Workforce Development

Imperative 2: Next Generation LCA and Decision Support Toolset

Imperative 3: Corporate Asset Management

Imperative 4: Risk, Uncertainty, and Unintended Consequences for Supply Networks

Imperative 5: Product Lifecycle Management (PLM) Capability for Process Planning

Imperative 6: Public-Private Partnership for Sustainable Manufacturing

Imperative 7: Lifecycle Cost Models

Imperative 8: 6R End-of-Life Management

Imperative 9: Flexible and Scalable Manufacturing Alternatives

Imperative 10: Sustainable Manufacturing Metrics

Imperative 11: Information - to Knowledge - to Intelligent Sustainable Manufacturing

Imperative 12: Secure Information Exchange and Collaboration

3.1.1 Imperative 1: Sustainable Manufacturing Education and Workforce Development

The Opportunity:

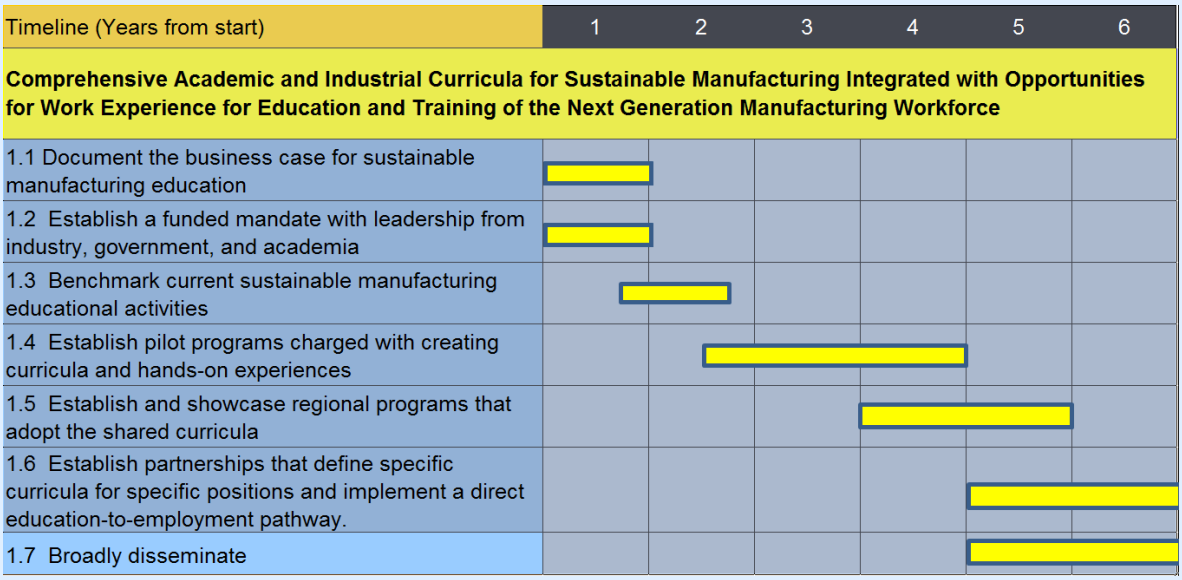
The emergence of advanced manufacturing as a technology enabled pathway to efficiency opens the door for sustainable manufacturing to take its place as an important factor in the optimization equation. First, a clear business case and plan for sustainable manufacturing education is required. Then, education across all levels of the academic and workforce spectrum will enable sustainable manufacturing to be broadly embraced as an important factor in lifecycle product management.

Business Case:

- An educated, sustainability aware workforce:
  - Enhances corporate knowledge and supports innovation
  - Enhances top-line brand equity
  - Delivers triple bottom line positive impact on the competitive position
  - Reduces the cost of compliance and risk of lack of compliance

Gaps and Challenges:

- The business case for sustainable manufacturing is not clearly established
- Sustainable manufacturing is not seen as an education priority. Leadership in industry and academia must be convinced that there is a compelling need
- The curriculum must be developed and broadly disseminated



3.1.2 Imperative 2: Next Generation LCA and Decision Support Toolset

The Opportunity:

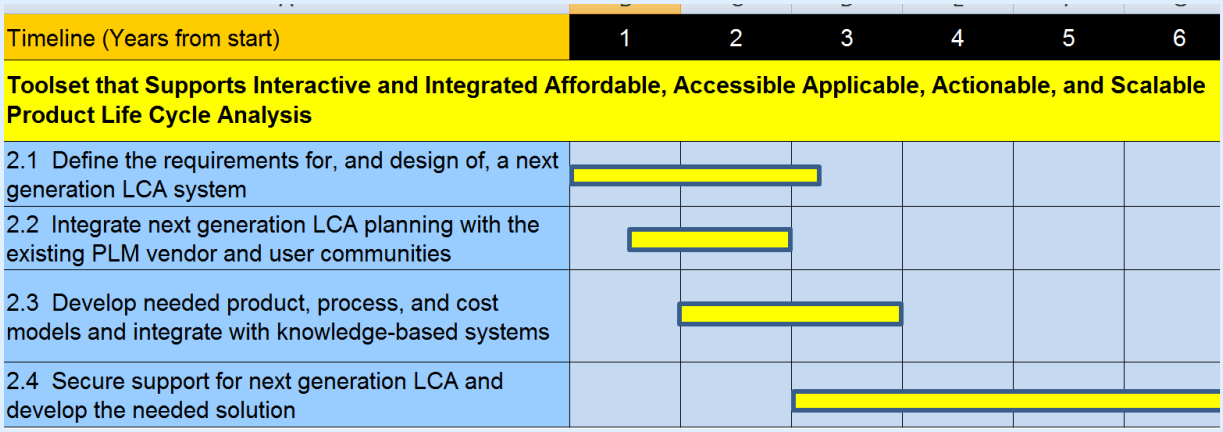
LCA delivers value when assessing the potential environmental and energy impacts, but it is often an isolated activity, not integrated with product and process development or providing decision support. There is a great opportunity to move sustainable manufacturing and LCA from a peripheral activity to a mainstream and integral component of a total value optimization environment.

Business Case:

- Most of the costs are locked in during the early phases of product development. Including sustainability in a total lifecycle value assessment, early in the development cycle, can lead to significant cost savings.
- The risks of product and process failure are great, and the consequences can be catastrophic. Early assessment and risk mitigation will protect corporate viability.

Gaps and Challenges:

- Sustainability lacks equal status with affordability and producibility in an optimization equation
- LCA is not integrated with the product lifecycle management toolset
- Effective outcome prediction requires the integration of LCA with M&S tools and knowledge-based systems



3.1.3 Imperative 3: Corporate Asset Management

The Opportunity:

Corporate asset management is a broad topic ranging from management of a specific piece of equipment to design and operation of a plant or a corporation - including human resources and sourcing decisions. Corporate asset management is often viewed as a tactical process with of separate individual decisions. Embracing corporate assets as a system offers the opportunity for optimization, stability in operations, and sustainability of the enterprise.

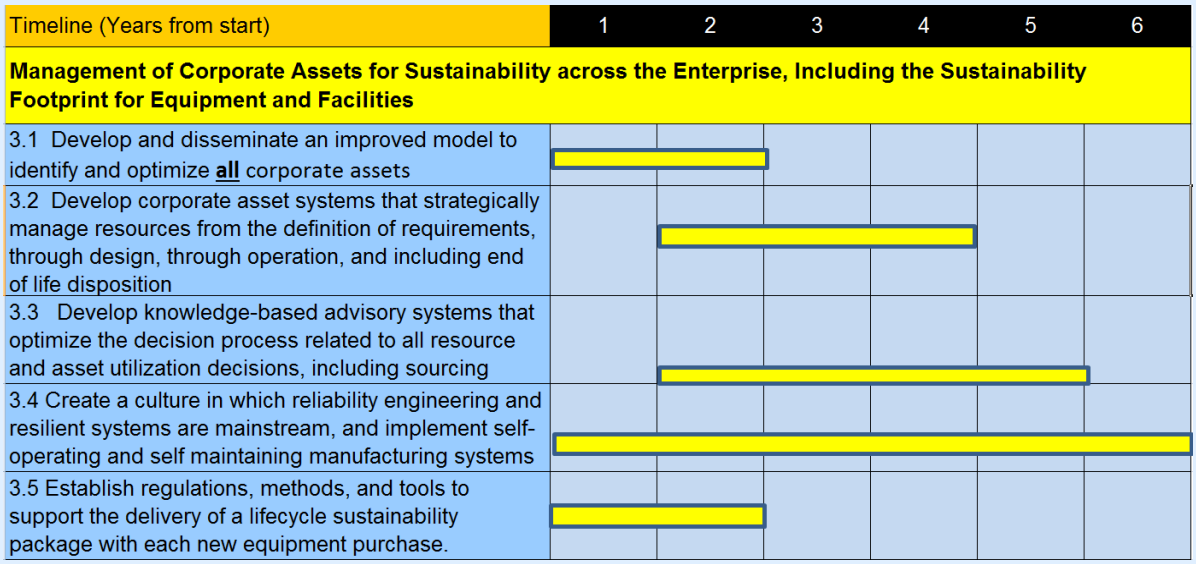
Business Case:

A holistic view of asset management assures 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
- Improved corporate image and business position

Gaps and Challenges:

Corporate assets are distributed among siloed functional organizations; an awareness of the need for a systems approach is rare. The first challenge is to create a clear awareness and business case for integrated asset management – breaking organizational walls. The second challenge is to build and deploy a toolset that manages these assets for best total corporate value.



3.1.4 Imperative 4: Risk, Uncertainty, and Unintended Consequence Analysis for Supply Networks

The Opportunity:

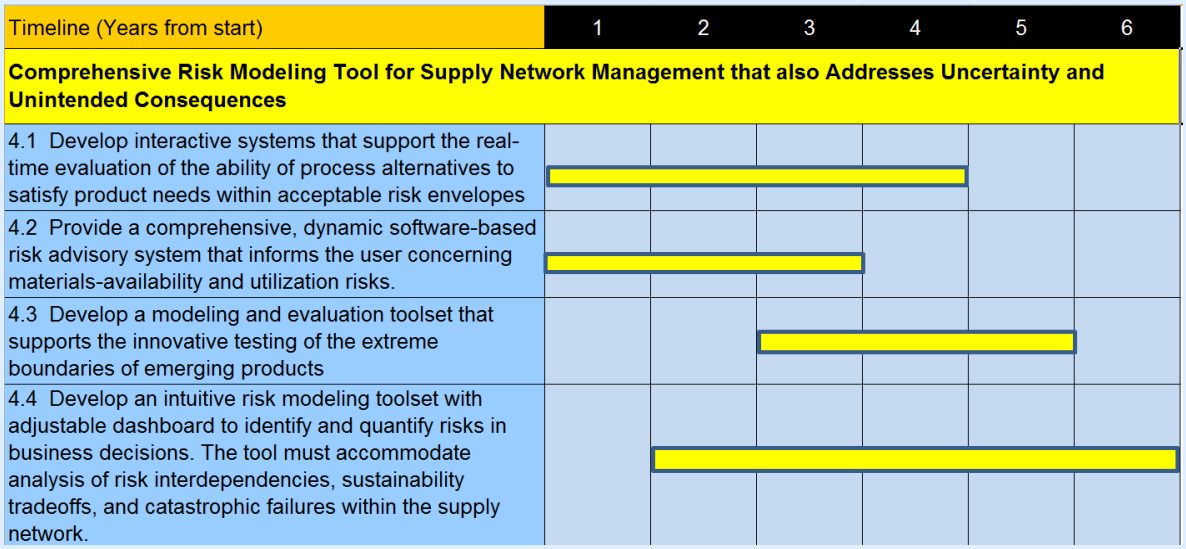
The increasing complexity of the global supply networks and the consequences of interruption of supply present an opportunity and a demand for improved risk assessment, avoidance, and mitigation capabilities. The ability to establish safe operating envelopes, well within the bounds of acceptable performance, and to operate within those boundaries, assures safe, energy efficient, environmentally responsible, and sustained operation.

Business Case:

- Protection of the company from loss or supply disruption
- Confidence in the ability to produce product and meet requirements
- Aggressive and informed engagement
- Customer confidence, demonstrated in preferential selection

Gaps and Challenges:

The present risk models do not address all factors or the aggregation of factors and are particularly deficient in addressing uncertainty and unintended consequences. Better management of uncertainly and more extensive evaluation of obscure modes of supply network failure are critical need areas. Better and more intuitive user interfaces that facilitate innovative exploration of failure modes are needed. Real-time monitoring and dynamic model updating are areas of challenge.



3.1.5 Imperative 5: Product Lifecycle Management (PLM) Capability for Process Planning

The Opportunity:

The chance to shift from process planning driven by the need for specific product outcomes to the selection of optimized processes integrated with the product design for best total value. This approach provides a way to explore alternatives for holistic optimization, including a sustainability focus in all processes and optimized planning for each of the 6-r end-of-life processes.

Business Case:

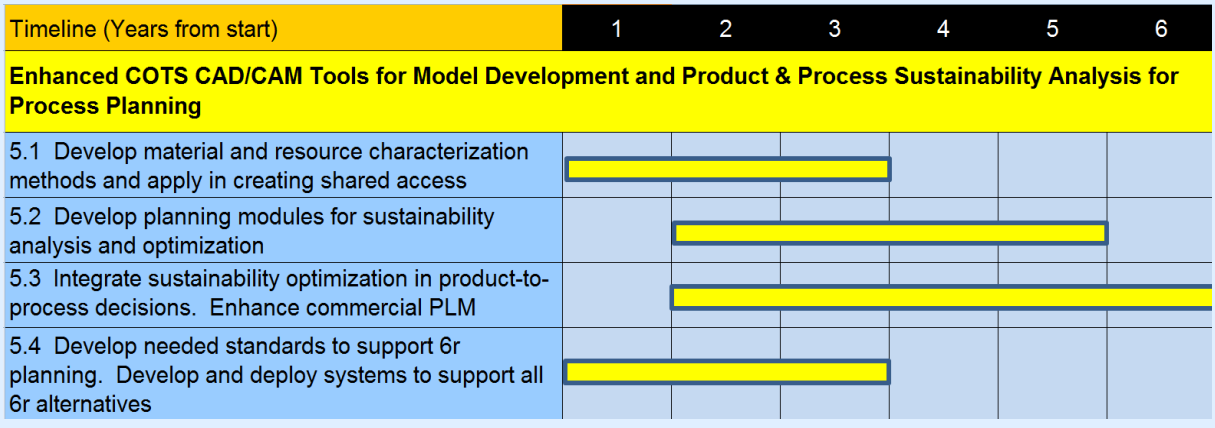
- Saves money and time by reducing iterative process development
- Provides insight into the true costs
- Eliminates unintended consequences from optimization of single processes and parameters
- Supports new value streams by optimizing 6R value
- Enables confident application of better process alternatives

Gaps and Challenges:

Open exploration of process alternatives requires the full characterization of materials and processes and access to data and models – provision of which is a major challenge.

Process planning is caught in between PLM, Manufacturing Execution Systems and Enterprise Resource Planning. "As planned" has never been given the importance of "as designed" or "as built."

Advanced process planning is knowledge intensive. Knowledge capture and application is weak across most manufacturing systems.



3.1.6 Imperative 6: Public-Private Partnership for Sustainable Manufacturing

The Opportunity:

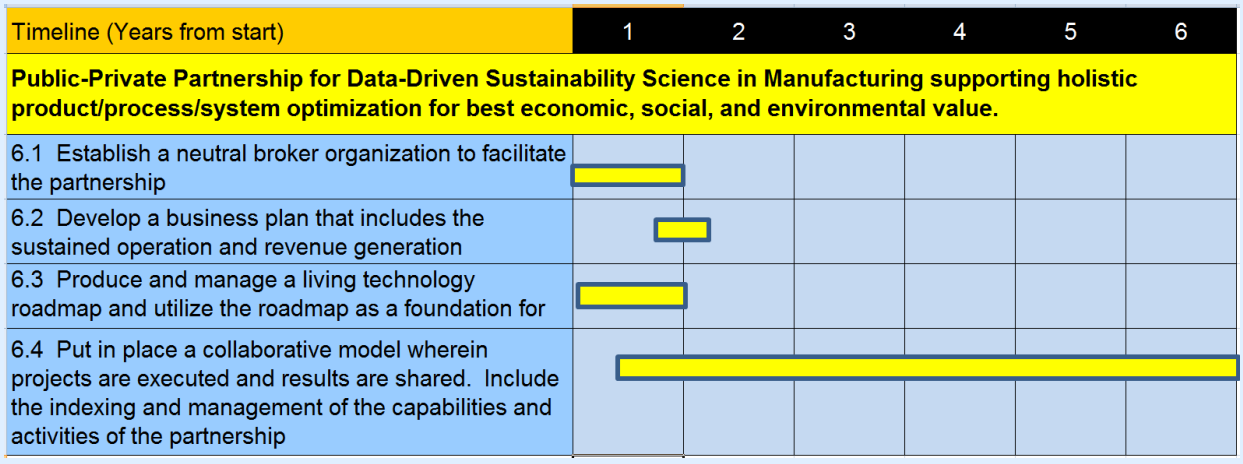
Effective definition of goals and focused collaboration can move sustainable manufacturing from an isolated topic of interest to a strong component within an integrated, holistic pursuit of total lifecycle product value. Present mechanisms for collaboration in sustainable manufacturing are limited, and the current stress on advanced manufacturing has not yet embraced sustainable manufacturing as a key topic. By coming together with a common purpose in an industry driven alliance, instilling a methodology for business-focused project selection, and working together to deliver value, the sustainable manufacturing community can contribute to the resurgence of manufacturing in the United States.

Business Case:

- Assures a strong "voice of industry"
- Provides a link from validated industry need to government funding sources
- Provides a methodology to assure that investments are focused
- Provides awareness of related activities, eliminating wasteful duplication

Gaps and Challenges:

- Determining roles and establishing governance in a broad alliance
- Gaining broad acceptance of the necessity for triple bottom line responsibility
- Effectively partnering with industry; avoiding competition for the same funding sources
- Providing shared access to needed data, information, models, and knowledge



3.1.7 Imperative 7: Lifecycle Cost Models

The Opportunity:

Better products can be delivered at lower cost by accurately predicting costs and optimizing product and process attributes for total lifecycle value. The ability to evaluate alternatives and determine the best total product and process value requires the detailed understanding of cost factors – early in the development process. The conventional pathway to accurate cost knowledge is by analysis of historical data. This approach limits exploration to what we currently understand and discourages innovation. A rich understanding of the foundational cost elements is needed, based on requirements, from which accurate cost models can be constructed. Cost analysis should include all of the components of sustainable manufacturing.

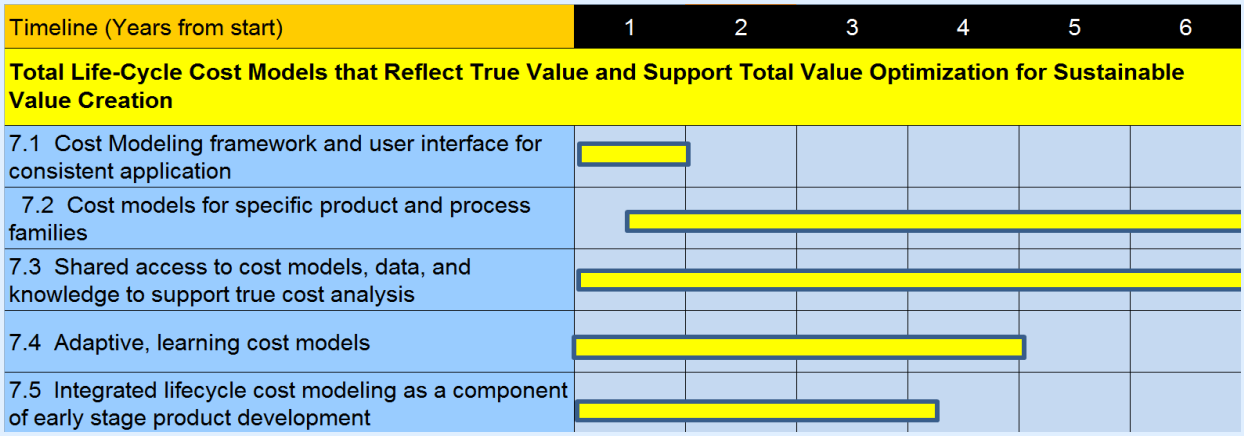
Business Case:

Accurate cost assessment early in the development process:

- Reduces product cost
- Reduces the risk of unanticipated cost escalation
- Enables cost optimization based on an accurate evaluation of all options
- Supports a full evaluation of total lifecycle costs and includes sustainability

Gaps and Challenges:

The ultimate achievement of true cost analysis early in the development process requires access to data, information, and knowledge from which mathematical relationships can be developed. To support broad applicability of the cost models, the captured knowledge and relationships must cross the boundaries of domains to support multiple applications. Establishing a common framework for cost modeling, capturing the required knowledge, and building true lifecycle cost analysis into the product development toolset is a formidable challenge.



3.1.8 Imperative 8: 6R-focused End-of-Life Management

The Opportunity:

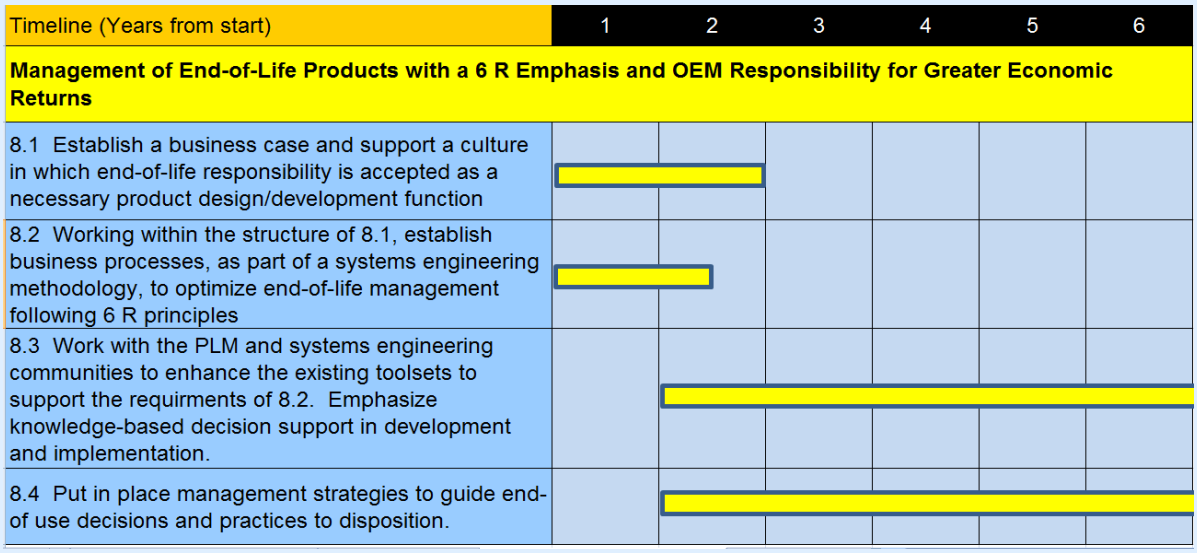
Improved and pervasive end-of-life planning offers the opportunity to reduce environmental impact, save energy, and maximize the total lifecycle value of the product. Including end-of-life considerations in the conceptualization and design process means the best disposition plans can be built into the products and conveyed in the accompanying product information. The 6R concept offers an excellent foundation for instilling end-of-life planning in the development process.

Business Case:

- Triple bottom line responsibility enhances brand value and wins market share
- End-of-life management creates new revenue streams and new jobs
- Recycling saves energy and lowers the cost of new products
- Lifecycle management avoids costly environmental damage and brand damage
- The evaluation/utilization of all 6R alternatives optimizes total product value

Gaps and Challenges:

Gaps exist in the culture, the businesses processes, and the technology toolsets. The most stringent end-of-life activities are enforced by regulatory statues. While they may be effective, a compelling business case is preferable as a driver. Business processes need to be changed to embrace end-of-life responsibility. Tools are needed to support the full evaluation (including true cost) of 6R alternatives and the selection of and planning for the most effective end-of-life alternatives.



3.1.9 Imperative 9: Flexible and Scalable Manufacturing Alternatives

The Opportunity:

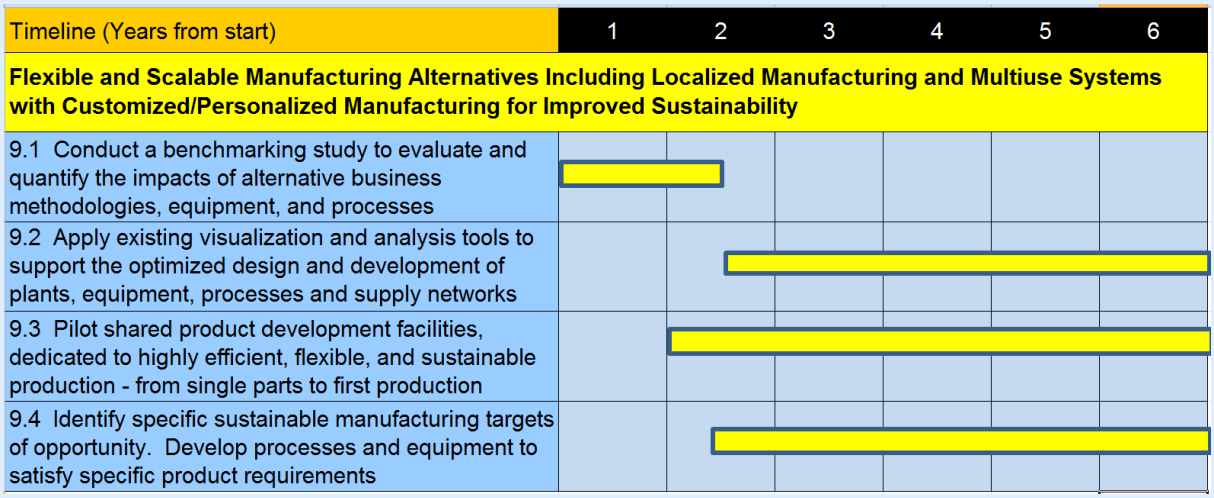
Current developments in manufacturing present the opportunity to rethink basic concepts about manufacturing plants and equipment. Stand-alone manufacturing plants have become components of integrated supply networks. Manufacturing companies have become systems integrators. The next evolution envisions flexible and scalable systems that produce products at the most beneficial location, utilizing the best available resources, and applying best methods and equipment that offer dramatic cost, productivity, and sustainability advantages.

Business Case:

- Spare parts inventories and warehousing costs are slashed
- Alternative processes produce better products with reduced negative impacts
- Risk and quality issues related to supply networks are mitigated
- Transportation costs are reduced through point-of-use manufacturing
- Multi-purpose manufacturing equipment consolidates processes, reducing cost

Gaps and Challenges:

- The concepts are postulated – not proven – evidence must be presented
- Entrenched infrastructures and methods support continuation of the norm
- Building a reliable clientele for shared facilities may be difficult
- Alternative manufacturing processes and equipment are expensive, and the processes are often slow, relegating their use to high value custom products
- Standardization enabling operation from standard data packages is essential



3.1.10 Imperative 10: Sustainable Manufacturing Metrics

The Opportunity:

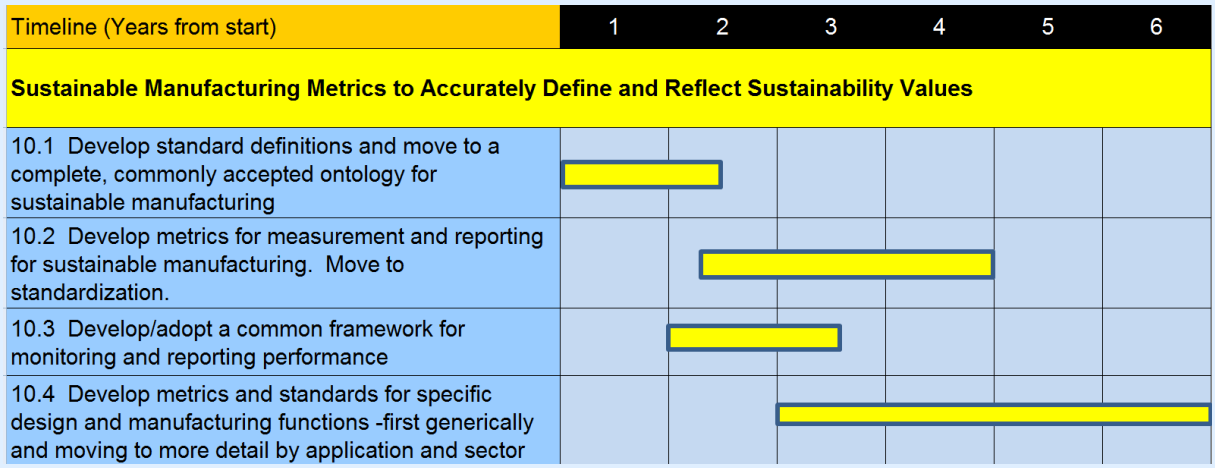
No standard method for measuring achievement of the triple bottom line currently exists. The provision of such a method would enable performance evaluation of strategies and companies. It would support goal setting and enable accurate determination of progress toward the goals. It would provide a measure of sustainability in products and processes across international boundaries and cultures. Standard metrics would support the determination of rewards and incentives that would lead to optimized lifecycle performance

Business Case:

- Improved and better informed purchasing decisions
- Definitive assessment of competitive position and need areas
- Improved contracting methods, including incentives
- More confidence in purchasing
- Enhanced brand value

Gaps and Challenges:

- Much of the work on standardization in sustainability has been led by/done in Europe (e.g. the Global Reporting Initiative). Using this work as a baseline, U.S. cultural and business practice differences need to be addressed
- There is limited international consensus for sustainable manufacturing metrics (present focus is on the broader qualitative view of sustainability)
- Securing effective industry engagement in such activities is difficult



3.1.11 Imperative 11: Information - to Knowledge – to Intelligent Sustainable Manufacturing

The Opportunity:

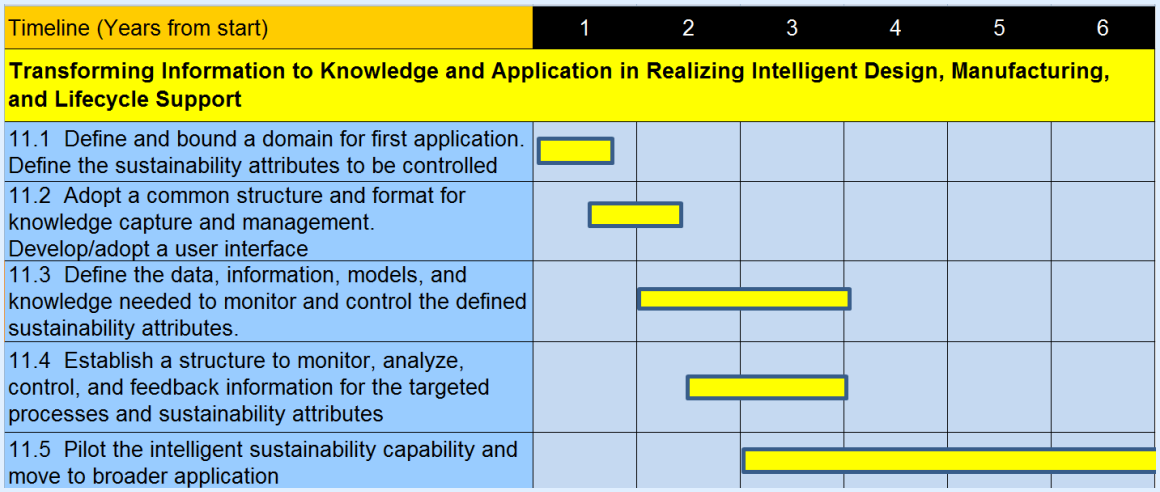
Smart or intelligent manufacturing is an opportunity to integrate data, information and analytical tools with **knowledge** to assure that the best decisions are made and that manufacturing processes are correctly executed. In an intelligent environment, products and processes designs are optimized and processes are monitored and controlled for 100% compliance within acceptable operating envelopes, yielding product quality assurance in real time. Further, the lifecycle performance of the product can be monitored and managed for best total value. Sustainable manufacturing provides an ideal basis for developing intelligent modules and piloting intelligent design and manufacturing.

Business Case:

- Slashes the cost associated with product, process, and equipment failure
- Protects against unintended consequences and mitigates risk
- Eliminates wasteful and inefficient operations
- Assures reliable operation and provides 100% assurance of quality product

Gaps and Challenges:

- Decision support requires a rich knowledge set, usually captured by domain
- Standardized methods for knowledge capture and application are lacking
- Intelligence across the product realization spectrum is required for complete intelligent design and manufacturing – a formidable task
- Fully characterizing and establishing intelligent control for complex equipment and processes is a challenging task
- Full achievement demands model-based development and control



3.1.12 Imperative 12: Secure Information Exchange and Collaboration

The Opportunity:

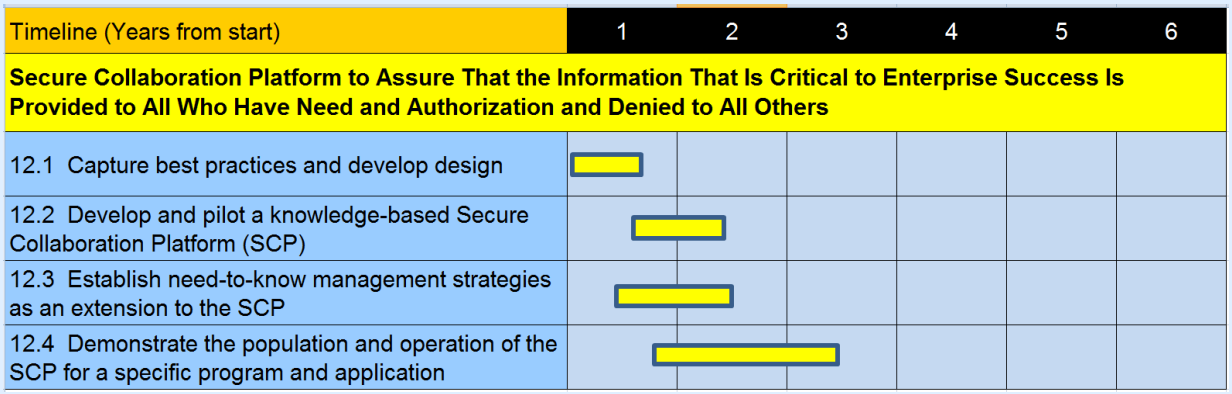
Cyber attacks cause harm globally every day, and the risk of US supply networks suffering catastrophic damage is significant. The threat of cyber intrusions impacts every aspect of the U.S. economy, including the nation's manufacturing infrastructure. While protection from attack is imperative, it is equally important that the supply network be able to confidently exchange needed information without fear and within acceptable risk boundaries. Providing an open, shared secure environment is the motivation for this imperative.

Business Case:

- The cost of lost proprietary data and information, intellectual property, and technical design data is estimated to exceed $300B annually
- Secure collaboration enables confident sharing of needed information across the supply network
- A risk of compromise, sabotage, or failure is unacceptable

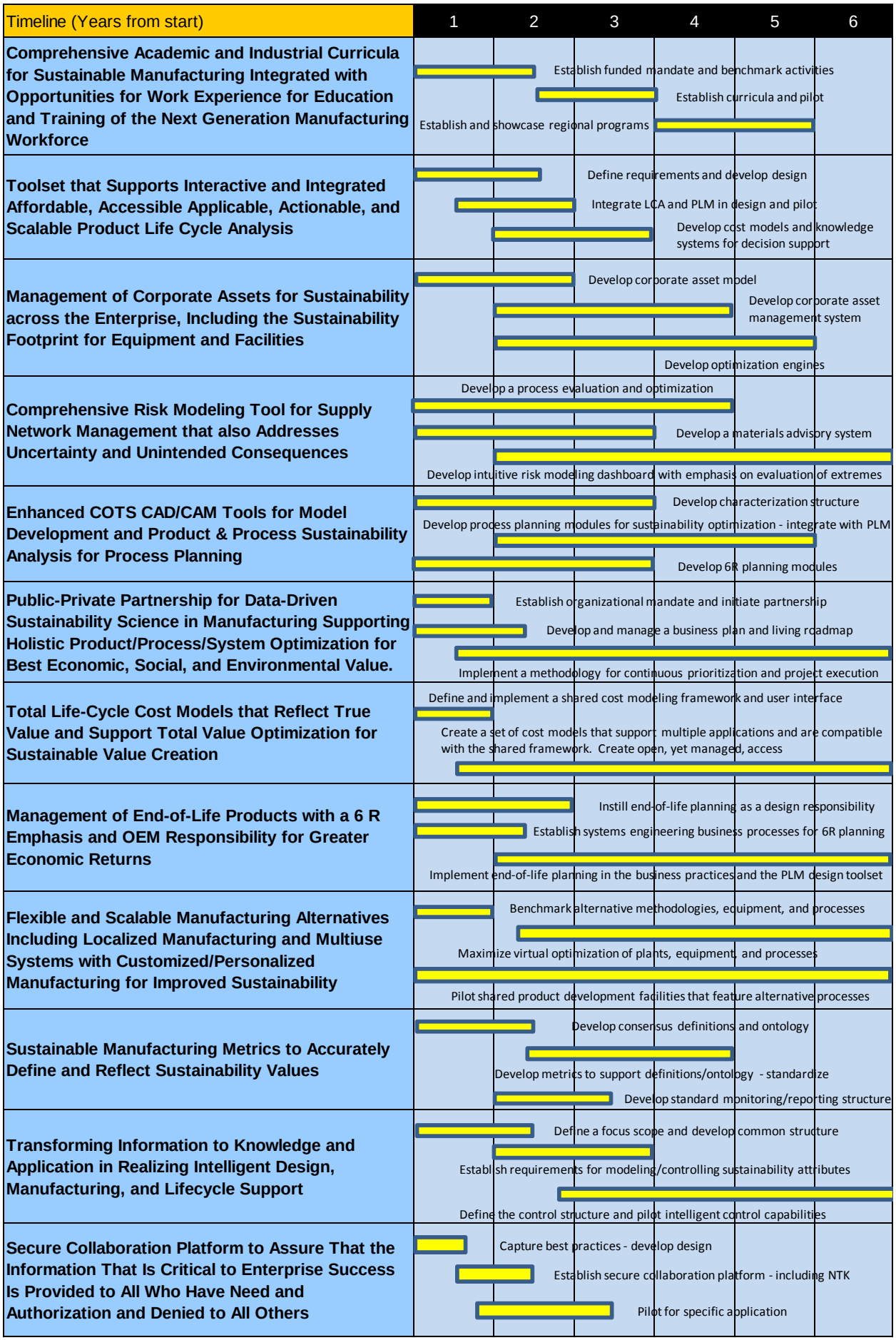
Gaps and Challenges:

- Prevailing practice is for each organization to be responsible for its own information security, with little harmonization or standardization between firms
- Specific vendors are introducing collaboration management systems with proprietary practices and protocols, making common standards difficult
- There is a delicate balance in establishing a framework for open collaboration while assuring the security of the content
- Establishing agreement on shared/standard structures will be difficult



4 Technology Roadmap

Three levels of technology roadmaps are presented. The one-page Imperatives present an abbreviated version of the more in-depth topical roadmaps presented in Appendix A of the PRISM Technology Roadmap. In this summary document, we present an even more abbreviated roadmap. The reader is cautioned that the wording and structure, and the points of emphasis, change with the level of detail presented. Therefore, the timelines do not roll-up from the detailed roadmaps to the abstracted versions. With maturity, that will come.


Timeline (Years from start)
1
2
3
4
5
6
Comprehensive Academic and Industrial Curricula for Sustainable Manufacturing Integrated with Opportunities for Work Experience for Education and Training of the Next Generation Manufacturing Workforce
Establish funded mandate and benchmark activities
Establish curricula and pilot
Establish and showcase regional programs
Toolset that Supports Interactive and Integrated Affordable, Accessible Applicable, Actionable, and Scalable Product Life Cycle Analysis
Define requirements and develop design
Integrate LCA and PLM in design and pilot
Develop cost models and knowledge systems for decision support
Management of Corporate Assets for Sustainability across the Enterprise, Including the Sustainability Footprint for Equipment and Facilities
Develop corporate asset model
Develop corporate asset management system
Develop optimization engines
Comprehensive Risk Modeling Tool for Supply Network Management that also Addresses Uncertainty and Unintended Consequences
Develop a process evaluation and optimization
Develop a materials advisory system
Develop intuitive risk modeling dashboard with emphasis on evaluation of extremes
Enhanced COTS CAD/CAM Tools for Model Development and Product & Process Sustainability Analysis for Process Planning
Develop characterization structure
Develop process planning modules for sustainability optimization - integrate with PLM
Develop 6R planning modules
Public-Private Partnership for Data-Driven Sustainability Science in Manufacturing Supporting Holistic Product/Process/System Optimization for Best Economic, Social, and Environmental Value.
Establish organizational mandate and initiate partnership
Develop and manage a business plan and living roadmap
Implement a methodology for continuous prioritization and project execution
Total Life-Cycle Cost Models that Reflect True Value and Support Total Value Optimization for Sustainable Value Creation
Define and implement a shared cost modeling framework and user interface
Create a set of cost models that support multiple applications and are compatible with the shared framework. Create open, yet managed, access
Management of End-of-Life Products with a 6 R Emphasis and OEM Responsibility for Greater Economic Returns
Instill end-of-life planning as a design responsibility
Establish systems engineering business processes for 6R planning
Implement end-of-life planning in the business practices and the PLM design toolset
Flexible and Scalable Manufacturing Alternatives Including Localized Manufacturing and Multiuse Systems with Customized/Personalized Manufacturing for Improved Sustainability
Benchmark alternative methodologies, equipment, and processes
Maximize virtual optimization of plants, equipment, and processes
Pilot shared product development facilities that feature alternative processes
Sustainable Manufacturing Metrics to Accurately Define and Reflect Sustainability Values
Develop consensus definitions and ontology
Develop metrics to support definitions/ontology - standardize
Develop standard monitoring/reporting structure
Transforming Information to Knowledge and Application in Realizing Intelligent Design, Manufacturing, and Lifecycle Support
Define a focus scope and develop common structure
Establish requirements for modeling/controlling sustainability attributes
Define the control structure and pilot intelligent control capabilities
Secure Collaboration Platform to Assure That the Information That Is Critical to Enterprise Success Is Provided to All Who Have Need and Authorization and Denied to All Others
Capture best practices - develop design
Establish secure collaboration platform - including NTK
Pilot for specific application

5 Next Steps

The Technology Roadmap provides a foundation for the PRISM activities. The Imperatives present rallying points around which industry, government, and academia can come together to address the larger issues of sustainable manufacturing. PRISM seeks to facilitate that coming together. On April 20 and 21in Ann Arbor, Michigan, the National Center for Manufacturing Sciences (NCMS) will lead a workshop, in concert with the University of Kentucky and PRISM, at which the specific needs and interests of the automotive/ground transportation sector will be explored. In the fall, tentatively set for Huntsville, Alabama, a similar event will seek alignment with the sustainable manufacturing needs of the aerospace sector. In parallel with these events, PRISM has begun work on the creation of a continuing forum and dialogue in which the sustainable manufacturing community can seek a clearer definition and a stronger constituency.