

Sustainable Manufacturing: *The Driving Force for Innovative Products, Processes and Systems for Next Generation Manufacturing*

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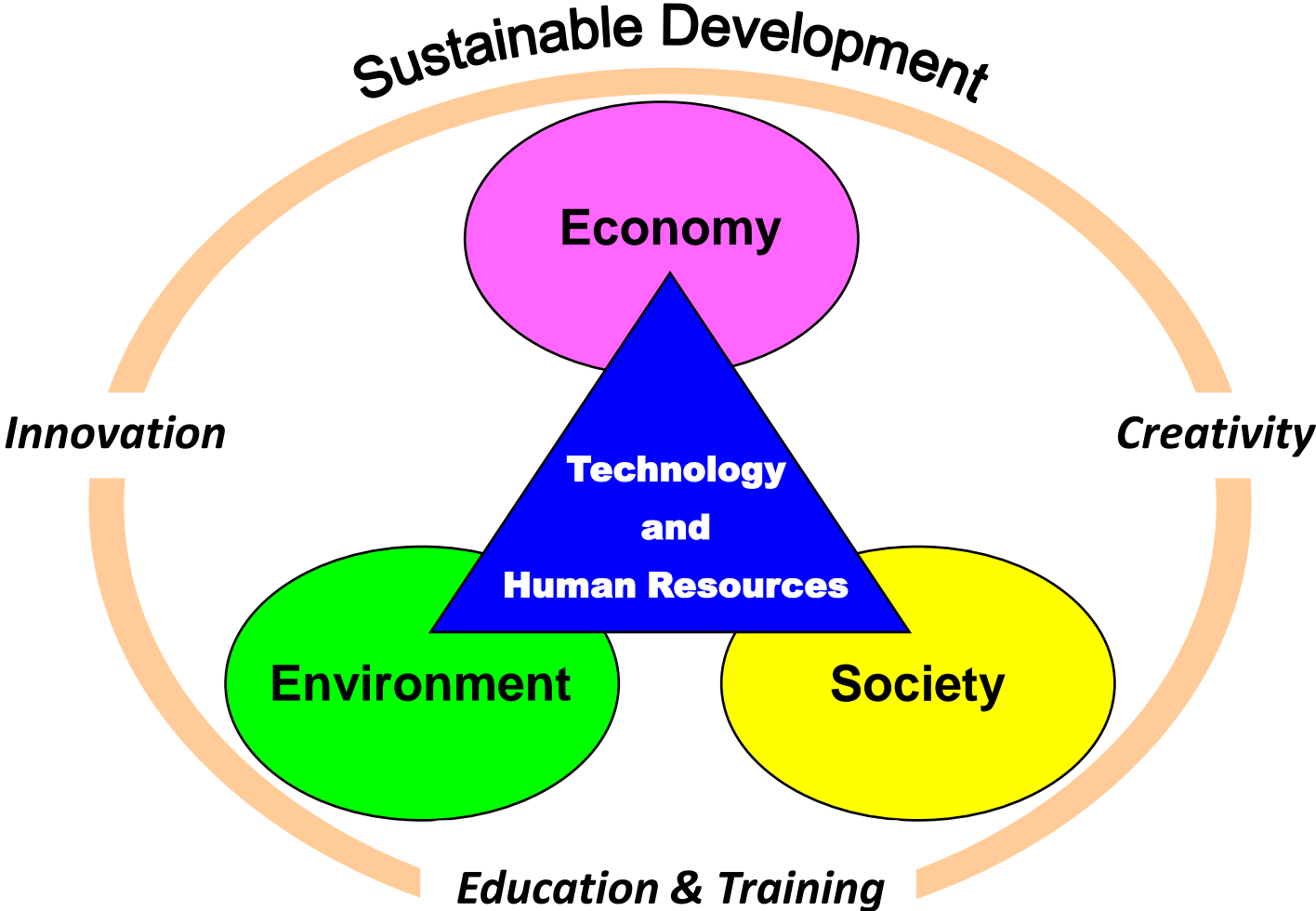
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Sustainable Growth: Example of a Tree Planted



The Foundation of Sustainable Development



Sustainable Manufacturing: Definition

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, 2009)

Sustainable manufacturing includes:

- (a) manufacturing of “sustainable” products, and
- (b) sustainable manufacturing of all products.

The former includes:

manufacturing of renewable energy, energy efficiency, green building, and other “green” & social equity-related products,

and, the latter emphasizes:

sustainable manufacturing of all products taking into account the full sustainability/total life-cycle issues related to the products manufactured

(National Council for Advanced Manufacturing (NACFAM), 2009)

Innovation-based Sustainable Manufacturing

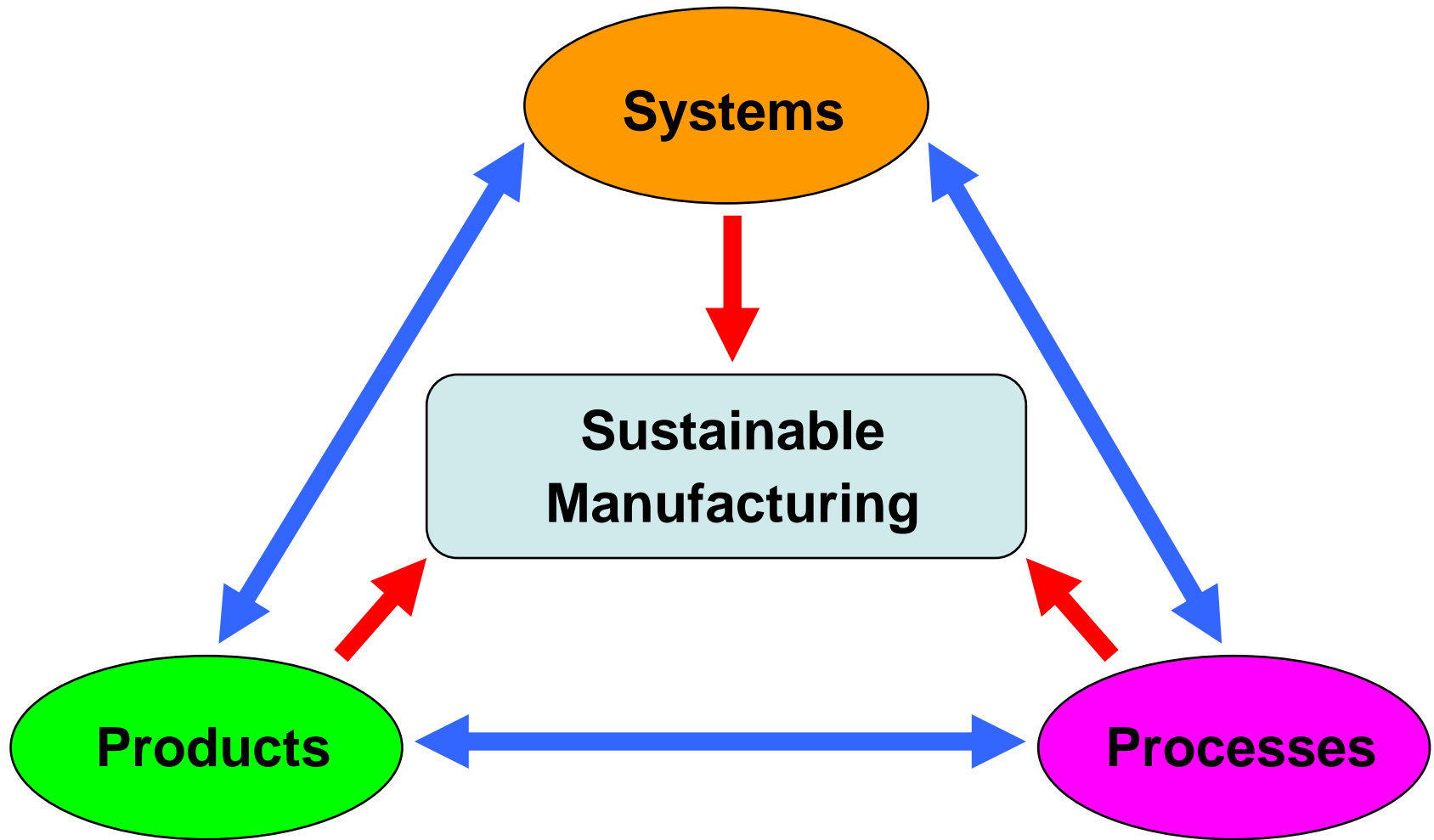
Sustainability is the driver for **innovation**

Innovation promotes accelerated growth in **manufacturing**

Manufacturing is the engine for **wealth generation** and **societal well-being**

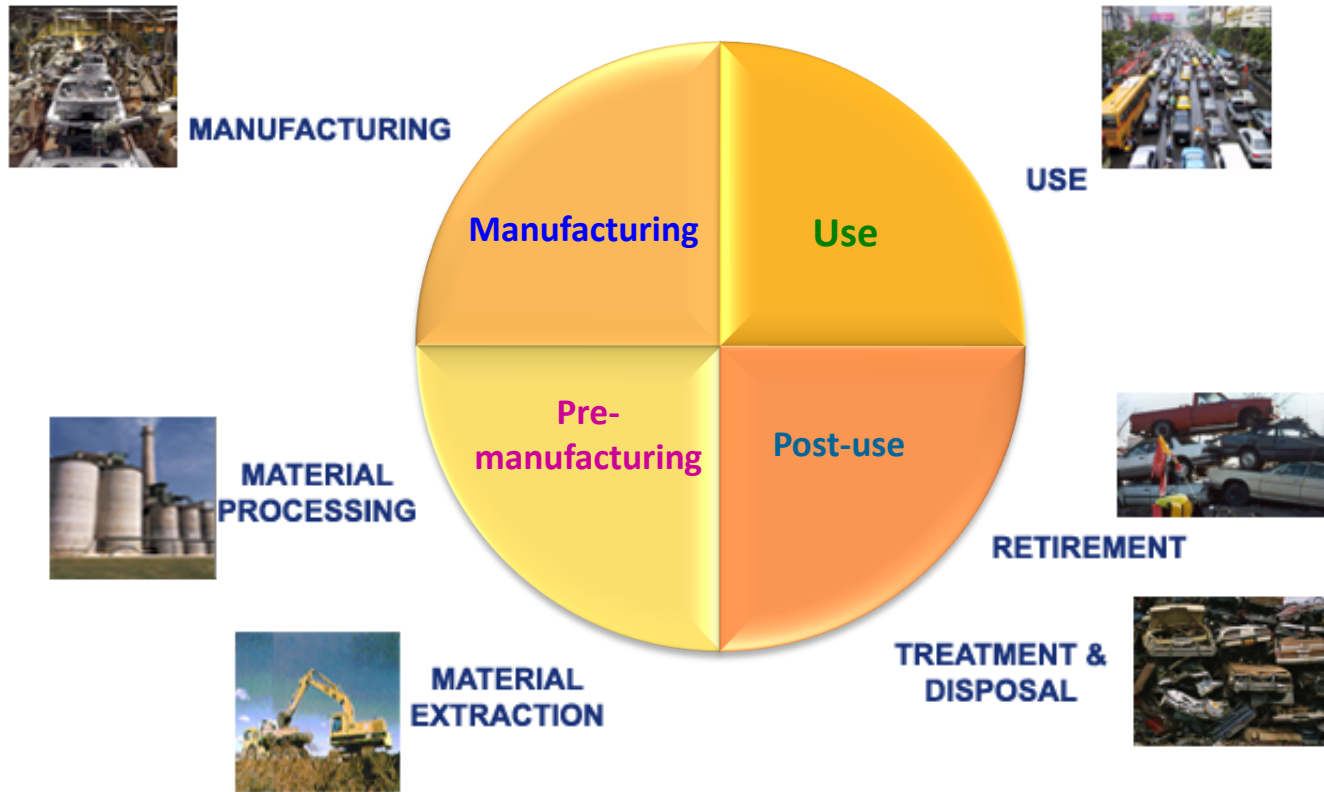
Societal well-being and **economic growth** heavily depend on the level and quality of **education and training**

Integral Elements of Sustainable Manufacturing

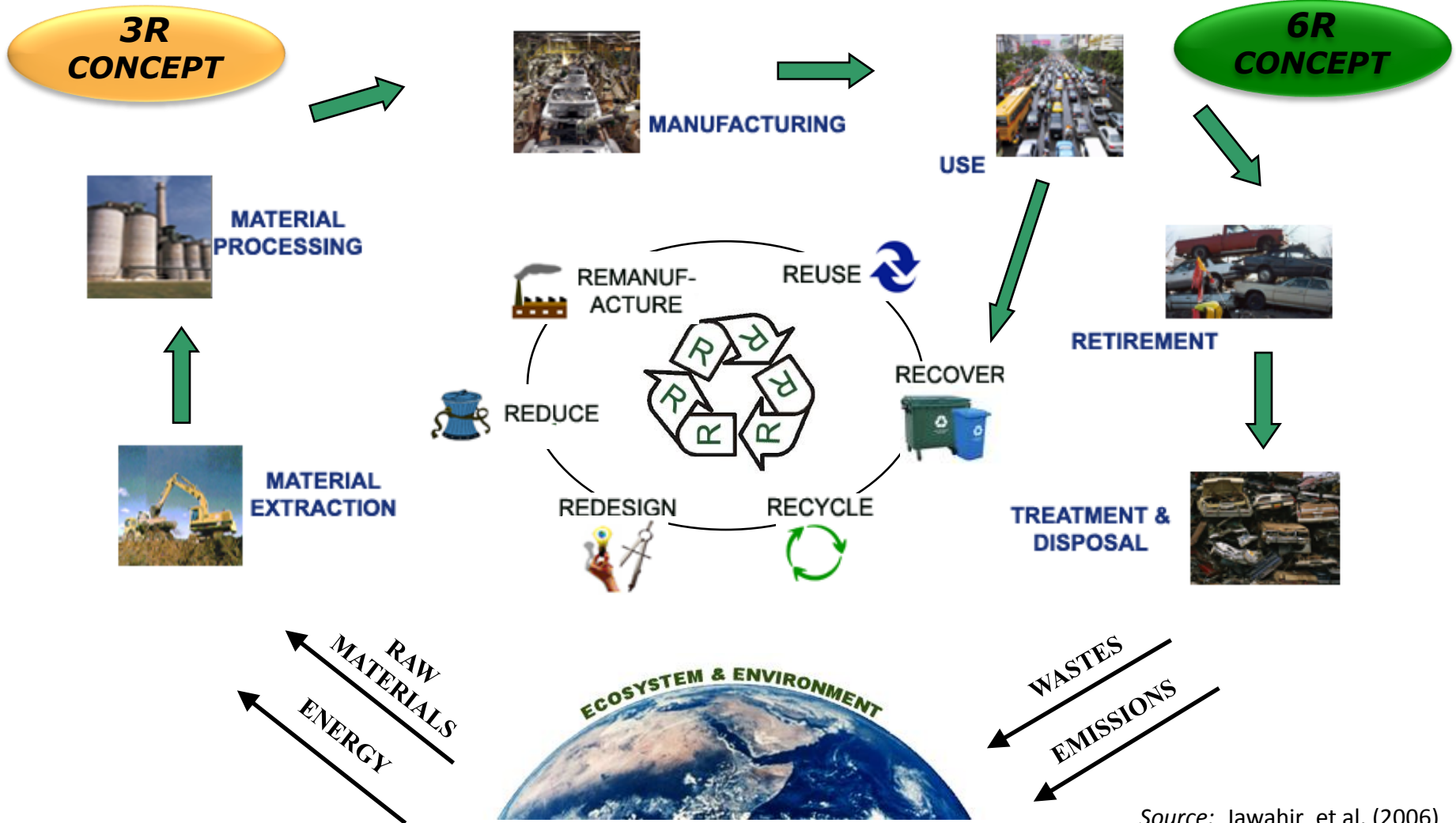


Holistic and Total Life-cycle Approach

Emphasis on all four product life-cycle stages

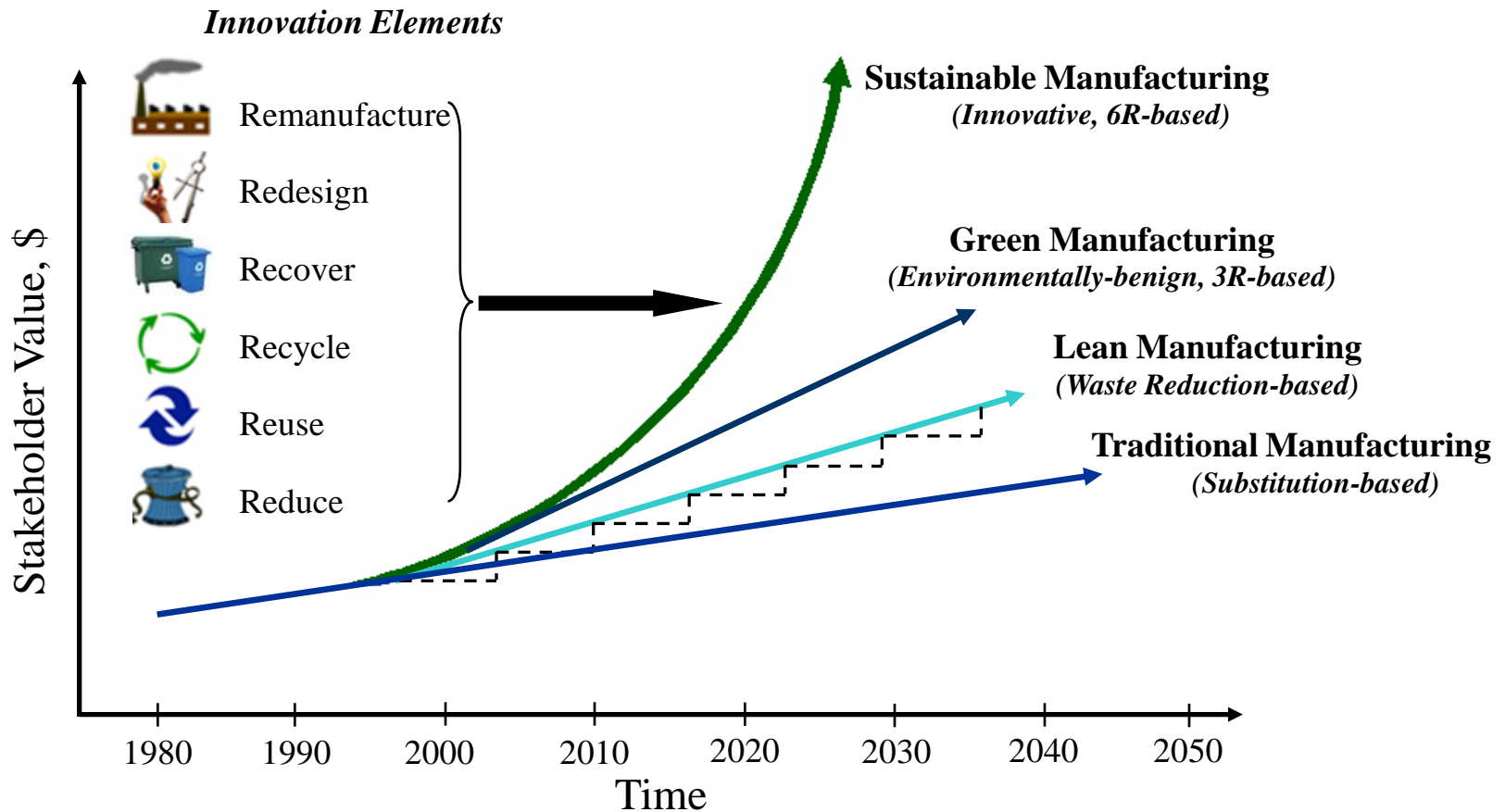


Closed-loop Material Flow – The 6R Approach

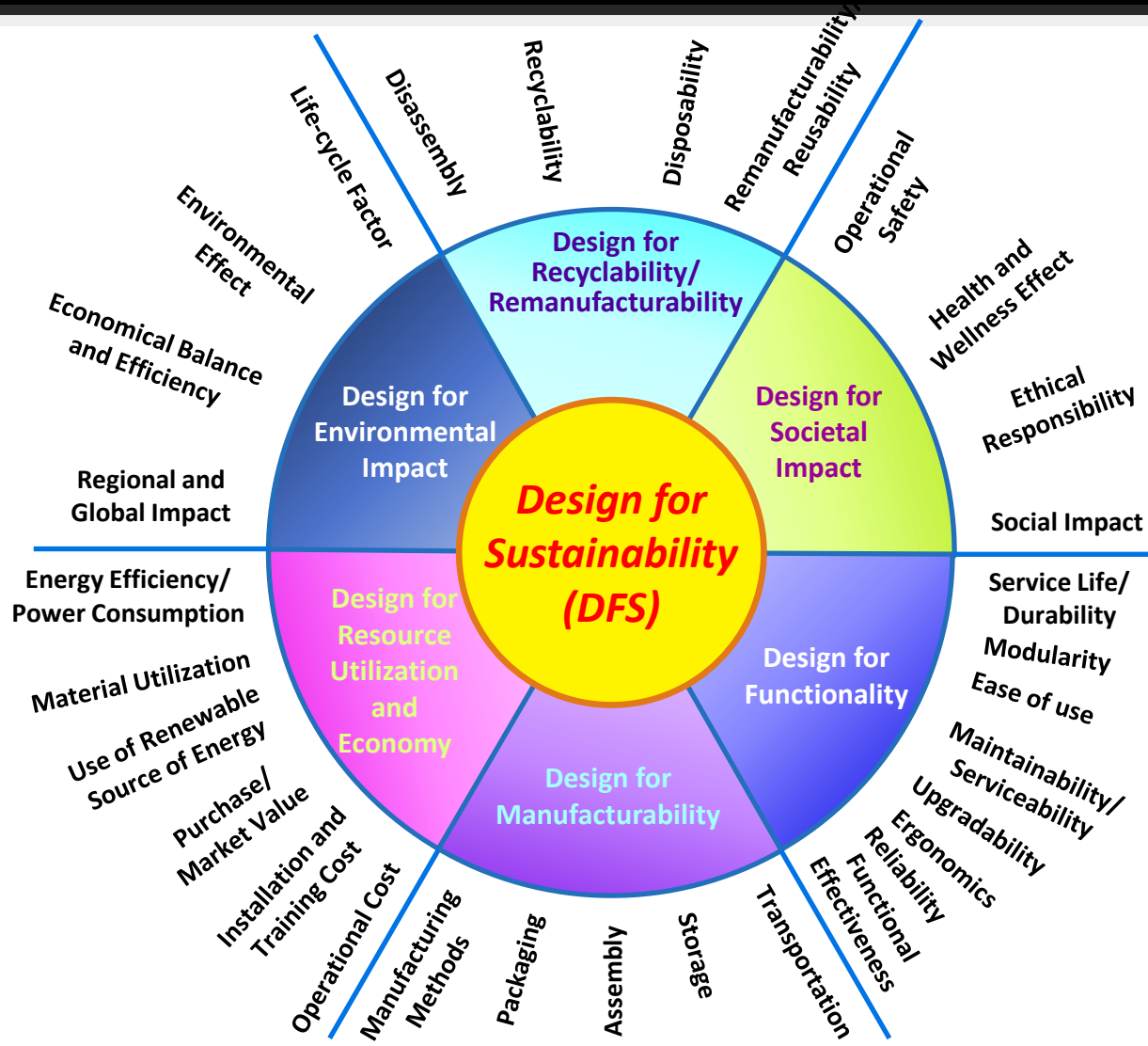


Source: Jawahir et al. (2006)

Evolution of Sustainable Manufacturing



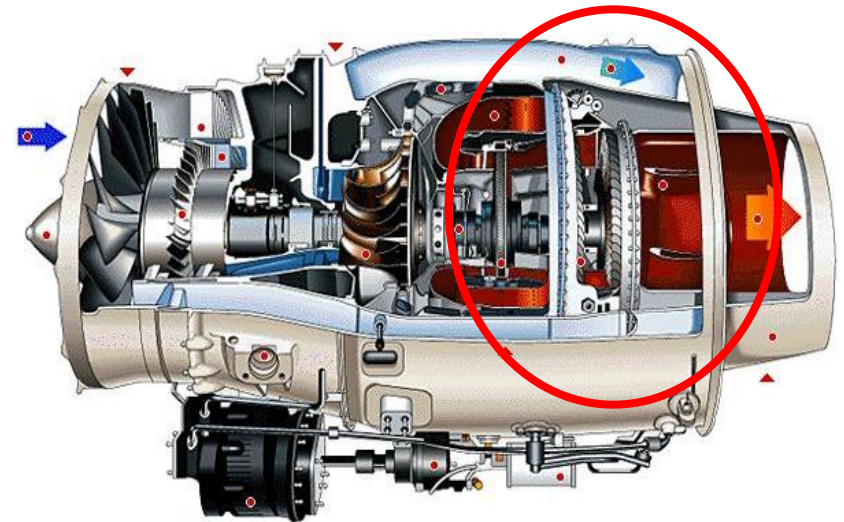
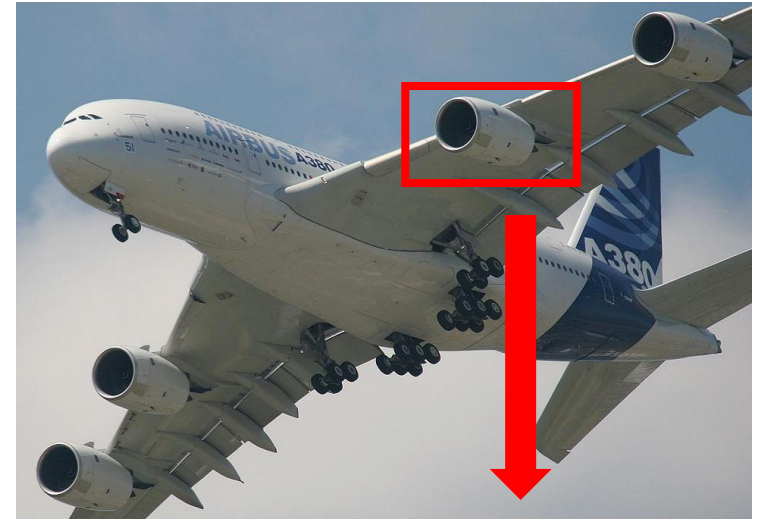
Product Design for Sustainability



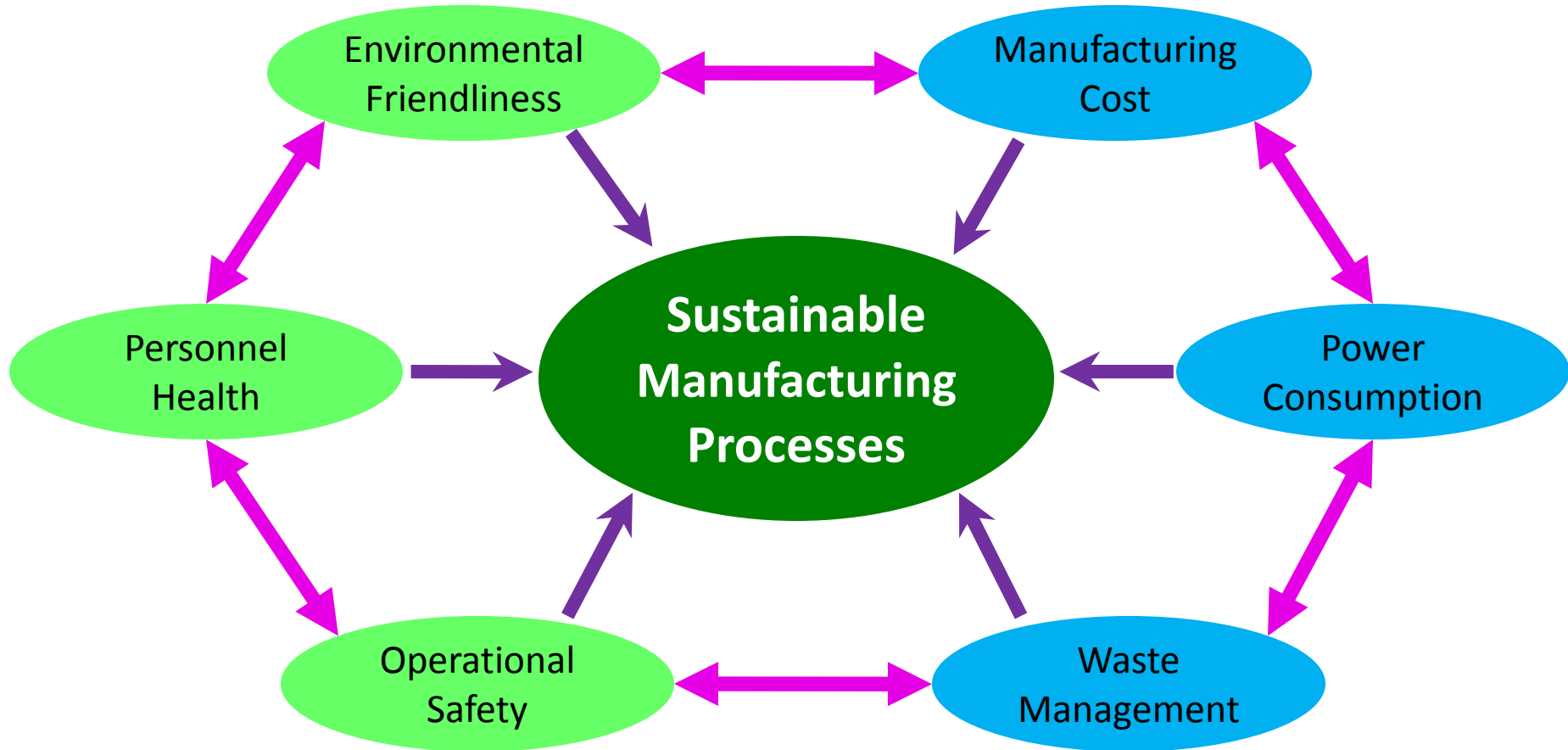
Product Reuse in Sustainable Manufacturing

Aerospace industry:

- 50 wt% of aero-engine alloys are nickel-based alloys – continuous efforts to *substitute materials*.
- Stationary and rotating components in the hot end of jet engines (e.g., turbine disk) – Predictability of cracks comes from the study of *sustainability science* - allows *reuse options* at a *cost advantage of 16 times!!*
- The reused disks are as safe as, or even safer than newly machined ones.



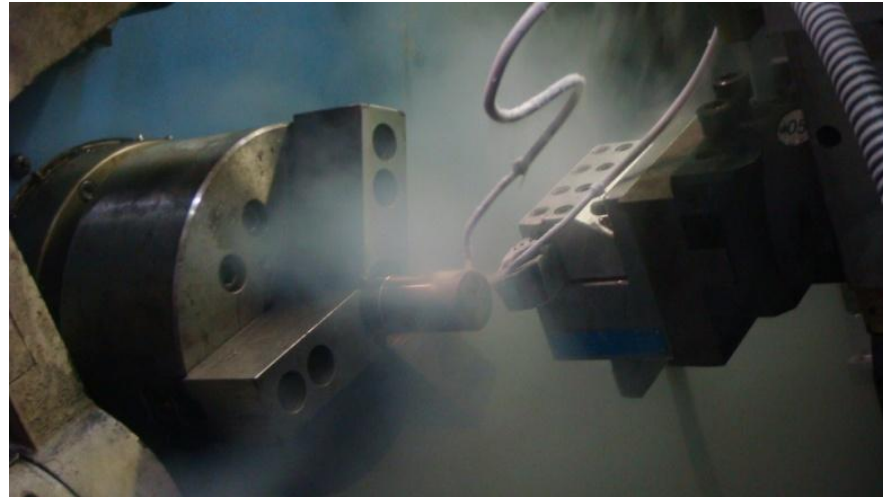
Sustainability Elements of Manufacturing Processes



Cryogenic Machining

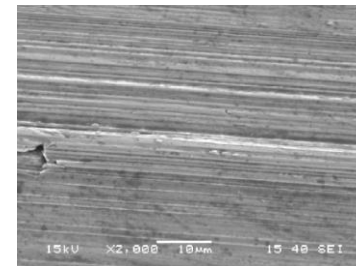
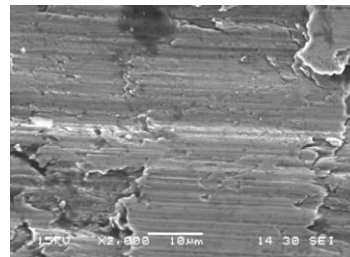
- Environmentally-friendly and safe coolant

- Increased productivity



- Better part surface quality

- Cost-effective



Extracts from the IMTI Benchmarking New Technology Workshop (February 2010)

- Make *innovation a continuous process for new and advanced products and processes*
- Integrate *digital product and process models* throughout the *product life cycle* to ensure the success of *the model based enterprise (MBE)*.
- Embrace and work to create *interoperability* throughout the manufacturing enterprise.
- Develop and implement successful processes for *information management and ownership*, including *intellectual property (IP)* issues.
- Work to develop *resilient supply chains* that can accommodate natural disasters and changes in players.

Technological Challenges and Opportunities for Sustainable Manufacturing

- **New materials technologies for sustainable products**

Molecular, microstructural and metallurgical transformation of materials; self-healing materials and memory alloys

- **Product innovation for sustainable manufacturing**

Product sustainability metrics; product design for sustainability including 1R – 3R – 6R transformations

- **Process innovation for sustainable manufacturing**

Environmentally benign/responsible manufacturing process development – toxic-free, hazardless, safe and secure technologies; minimal use of energy, water, including metal working fluids, chemicals, and other resources

- **Innovation and creativity in supply/value chain operations**

Integrated manufacturing systems for sustainability; sustainable supply chain operations; sustainable quality systems for manufacturing

Technological Challenges and Opportunities for Sustainable Manufacturing (Cont'd)

- **Compliance with regulations (REACH, WEEE, RoHS, EuP, ELV, etc.)**
- **Economic analysis and business case for sustainable manufacturing**
Marketing strategies and business economics for sustainable products and processes
- **Safety, health, public policy and regulatory issues in sustainable manufacturing**
Societal Impact studies; legislative and administrative issues; policy implementation; product and process liability; ethics
- **Education and training issues**

New Employment Opportunities

- **Sustainable manufacturing offers uniquely new kind of employment opportunities:**
 - *Innovative 6R applications*
 - *Total life-cycle consideration*
 - *Sustainable manufacturing processes*
- **Universities and colleges are well-positioned to provide educational and training programs**
 - *Undergraduate and graduate education*
 - *Non-credit professional continuing educational programs*
- **Incentives must be provided to academic institutions and manufacturing companies to *educate, train and develop the workforce for next generation manufacturing, and for conducting relevant fundamental and applied research.***

Acknowledgments

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- Professor O.W. Dillon, Jr., University of Kentucky

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