Environmentally Benign Manufacturing: Status and Vision for the Future

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Lecture #27 (3/19/04) – Originally presented at NAMRC 31

Introduction

- The environment is an ever-increasing priority for corporations
- Adoption of Environmentally Benign Manufacturing (EBM) philosophy
  - Narrowly: Green manufacturing processes
  - Broadly: Corporate-wide environmental improvement
- NAMRI/SME involvement grew in 1990s
  - Formation of an EBM working group
  - NSF Workshop
  - Paper reports on workshop findings

Background

- **NSF-EBM global benchmarking study**
  - **1999-2000: visits by interdisciplinary panel**
  - **52 locations in the U.S., Europe, & Japan**

Example Sites Visited

U.S.	Europe	Japan
Caterpillar, Inc.	EC Dir. for Science	Fuji Xerox
DuPont	Hoogovens Steel	Kubota
Ford Motor Co.	Siemens AG	NEC Corporation
Interface Americas	TU Berlin	Toyota Motor Co.
GM	Volvo	Univ. of Tokyo

Background

- Why Europe and Japan?
  - Leadership in environmental issues
  - High population densities
  - High per capita GDP
- Focus
  - Entire manufacturing enterprise
- Emphasis: materials
  - Metals/polymer processing
- Emphasis: industries
  - Automotive and electronics

Background

- General information sought from visits to companies and research labs:
  - National level strategies being undertaken
  - Corporate level EBM motivational factors
  - Systems level problem solving or issues
  - Analytical tools for products/processes
  - Technology highlights
- Key finding:
  - Business needs and cultural/geographic differences influence environmental focus

Background

- Regional focus in EBM issues
  - United States (cost concern)
    - Avoiding fines and litigation
    - Non-haz materials and cleaner production
  - Northern Europe (societal concern)
    - Product end-of-life, recycling infrastructure
    - Elimination of hazardous materials
  - Japan (societal concern)
    - Incorporating EBM into business principles
    - Principal goal is resource conservation

Workshop

- Global Benchmarking Study – summarizes situation → where to go from here??
- NSF-sponsored NAMRI/SME workshop
  - September 2001 in Ypsilanti, Michigan
  - Goal: identify key EBM challenges and provide a vision for the future
  - Automotive/transportation industry
- Workshop subgroups
  - Metals Processing
  - Non-metals Processing
  - Product Design and Support
  - Enterprise and Factory Operations

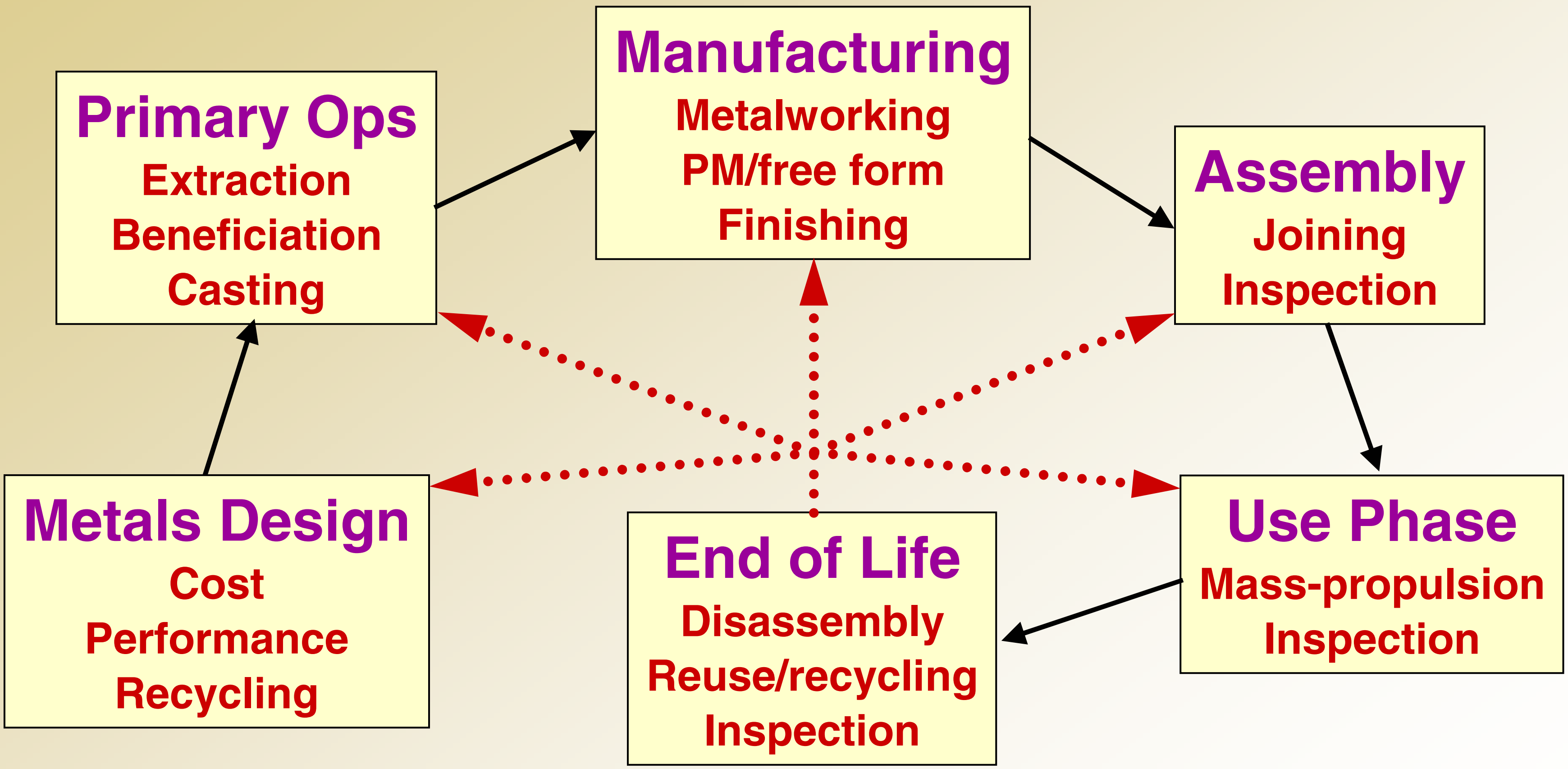
Organizing Committee

- Dr. Walter Olson, University of Toledo

- Dr. John Decaire, NCMS
- Dr. Richard Furness, Ford Motor
- Dr. Steven Liang, Georgia Tech
- Dr. Robert McCune, Ford Motor Comapny
- Mr. Richard Neal, IMTI
- Dr. Steve Skerlos, University of Michigan
- Dr. John Sutherland, Michigan Tech

Metals Processing

Life cycle stages considered



Metals Manufacturing

- Deepak Bhat
- Fred Cannon
- Paul Chalmer
- Jean Dasch
- Delcie Durham
- Ahmed ElSawy
- Robert McCune
- Tom Piwonka
- Steve Skerlos
- John Sutherland

General Research Priorities

- Casting
  - Net Shape Casting
  - More Environmentally Benign Casting
- Effluent Free Machining
- Life Cycle System Design
  - Material selection, manufacturing, recycling
  - Alloys designed based on ALL life-cycle stages
- Minimize Air Emissions and Energy in Joining
- Engineering Surfaces
  - Better understand role/need
  - Effluent Free Processes
- Facilitate End of Life Disassembly

Topics Discussed

- Metals Design, Selection, and Processing
- Metals Production and Casting
- Metalworking
- P/M and Free Form Manufacturing
- Surface Operations
- Joining and Assembly
- Inspection
- Cross-Cutting Issues

Metals Design, Selection, and Processing

- Traditional focus – usage stage of life-cycle: specialized alloys
- Encourage adoption of broader life-cycle view during material design/ selection
- Takes steps to promote recovery:
  - Identification, separation, & purification
- Move toward more universal alloys
  - True recycling rather than down cycling

Metals Production and Casting

- To reduce mining & beneficiation pollution: improve recycling & reuse rates
- Use of plastics waste in steel production (Japan)
- Net-shape casting to eliminate down-stream steps
  - Modeling
  - Sensing
  - New sand coatings, binders, foams
- Better energy management

Metalworking

- Priority: coolants & lubricants (MWFs)
  - Dryish machining
    - Corrosion control, chip management, dust, tool wear, thermal management
  - MWF needed
    - Volume reduction, MWF recycling, mist control, bio-contamination
- Process planning
  - Minimize engineered scrap & energy
- Reconfigurable machines and dies
- Tool-less forming & tailor welded sections
- Die Coatings

Powder Metallurgy and Free Form Manufacturing

- Expanded use of Powder Metallurgy & Free Form Manufacturing
- P/M: eliminate barriers
  - Complexity vs. Part Size
  - Surface properties & strength
- Environmental issues unknown
- Thixo-forming
- Production rate a challenge

Surface Operations

- Heat treatment, cleaning, plating, rinsing, etc. – among the most polluting manufacturing activities
- Improved understanding of tribology
- Integrated processing/use coatings
- Low energy processes needed:
  - Avoid bulk treating
  - Selective treating, e.g., lasers and microwaves
- Improved recovery of toxics/metals in aqueous waste

Joining and Assembly

- Net shape – less need for these
- Welding processes identified as principal concern
- Fluxes, fumes, energy consumption, & safety
- Welding: in conflict with notion of reversibility of joints for recycling
- Use modeling/optimization and sensing to minimize welds and waste

Inspection

- Improved inspection
  - Short term increased scrapped product
  - Facilitate discovery of root-cause problems
- Avoid toxics penetrants in surface integrity assessment – new technology
- Product-integrated sensors
  - Inspection
  - In-use product evaluation – extend use phase of product

Cross-Cutting Issues

- National Environmental Agenda
- Energy
- Life cycle design tools & data – integration into the design process
- Process consolidation, hybridization, & elimination
- Supply chain issues
- Education

Metals Processing – Summary

- Metal design/selection
  - Evaluate manufacturability, recyclability, and total life cycle cost of engineered alloys
- Primary processing and casting
  - Improve recycling and net shape casting
- Metalworking
  - Reduce/eliminate metalworking fluid
  - Minimize scrap and energy consumption
- P/M and free form manufacturing
  - Improve speed of production and material properties

Metals Processing – Summary

- Finishing operations
  - Eliminate bulk heat treatment
  - Reduce solvent use
  - Implement closed-loop finishing
- Joining and assembly
  - Reduce welding fumes, fluxes, and energy
  - Examine reversibility of permanent joints
- Inspection
  - Enhance inspection methods, to avoid traditional problems (e.g., acoustics, laser)
  - Develop product-integrated sensors

Metals Processing – Summary

- Cross-cutting issues
  - A national environmental strategy
  - Life cycle design tools and supporting data
  - Manufacturing process consolidation/ hybridization
  - Analysis of increasingly decentralized supply chain relationships in the automotive/transportation industry
- Give environment a greater priority in engineering education

Non-Metals Processing

Non-metals in the transportation industry

Non-metal materials

Current practice and use
Material selection and design
Materials reduction

Processing non-metals

Current practice
Assembly and disassembly
Design and manufacturing

Identification/ definition of research needs

Research needed to reach EBM objectives

Non - Metals Manufacturing

- Jim Anderson
- Gary Gruver
- Esin Gulari
- Barbara Karn
- Helen Lou
- Sam McSpadden
- Kesh Narayanan
- Richard Paul
- Pat Ponticel
- Sara Jordan

Vision for All Materials

- Decisions on materials to use will be made on the basis of whole life cycle assessment and environmental Total Accounting Cost.
- There will be greater use of recycled materials in manufacturing, maintaining the original quality of the materials after recycling.
- Materials will be environmentally friendly (for instance, will automatically absorb odors, pollutants) and use of hazardous materials will be eliminated.
- Our understanding of materials and their properties will enable predictable processing with minimal energy requirement.
- We will be able to create the final product in fewer steps, for example near net-shaping for polymers.
- Fewer different materials will be required to create a given product.
- Smart materials will have self-contained information about their status, indicating when failure is imminent and repairing flaws in some cases.
- Materials and products will be miniaturized where there is no adverse effect; materials will need special qualities to support this (e.g. super strength, smart materials, thermally functioning, etc.)
- Materials will be lighter (and therefore energy efficient) but will retain their strength and ability to absorb shocks, impacts without loss of original performance.
- Materials will allow their individual components to be easily separable in the recycling stage.

Needs for All Materials

- Materials with wide spectrum of performance features, amenable to less processing to create final product.
- Materials that can automatically sense their properties and performance status
- Decisions on material use based on thorough scientific knowledge and including concerns for high value materials and all the environmental costs of using a particular material throughout the life cycle
- New materials development program to suggest alternative innovative production strategies meeting production requirements, to overcome resistance to change and introduce new technology.
- Material/process design assistance systems (e.g. for transportation systems) which include environmental issues and full life cycle assessment
- Standardized set of information on materials that can integrate with processes to meet the desired product specifications.
- Requirement to address environmental issues in all industrial sectors and their roadmaps.
- Quantified, specific goals to be achieved in a set amount of time in terms of environmental costs.

Polymers & Composites Vision

- Polymers and composites will be easier and cheaper to manufacture with low environmental impact.
- In order to create greater compatibility for material recycling, there will be smaller variety of materials used in products.
- Components will be engineered to have very long use period, maintaining their original quality and functional integrity.
- There will be an active market for reused/ remanufactured parts, similar to the metallic market today.
- We will have alternatives to environmentally troublesome components such as tires and glass.

Polymers & Composites Needs

- **New polymers and composites with improved properties. Research Topics:**
  - Evaluation of the materials used in the manufacture of brakes of automobiles and design newer methods of braking.
  - Alternative polymers and composites for improved function over longer life cycle (e.g. tires whose tread doesn't wear out or separate)
  - New structural materials/foams that are lightweight and also have many desirable properties like ability to conduct away heat from the surface.
  - Materials with resistance to damage from UV rays, additives and chemicals.
  - Materials programmed to biodegrade at the end of use cycle.
- **Use environmentally benign catalysts. Research Topics:**
  - Resins that react more predictably and reliably.
  - New catalysts that don't have VOCs, HAPs, heavy metals.
- **Technology and Infrastructure to reprocess materials/parts to put them back in the Use Phase. Research Topics:**
  - Ability to automatically sense and sort components at end-of-life, for recycling/reprocessing
  - Ability to crack polymers into monomers and reusing them.

Glass & Ceramics Vision

- We will have strong, transparent, and lightweight materials (alternative to glass) that are not susceptible to fogging, ice, or shattering, and are strong enough to bear loads.
- New alternatives to glass windshields and windows will keep themselves clean and will sense temperature/light and invoke ventilation/darkness control.
- Ceramics will be easier and more efficient to fabricate/machine, less susceptible to flaws, with a long life and improved mechanical properties.
- Glass and ceramics will be easier to recycle back into same quality products.

Glass & Ceramics Needs

- Improved predictability and structural properties in ceramics, with ability to process to near net shape. Research Topics:
  - Ceramic technology to create new materials with resistance to flaws and improved mechanical properties (such as better ductility and absorption of vibration, under higher temperatures).
  - Ceramic fabrication processes to allow easier finishing, fabrication of features (including small holes) and near net shape capability.
- Improved functional properties of glass or alternative transparent material. Research Topics:
  - Transparent material with strength to support loads and resistance to shattering.
  - Glass or alternative transparent material with ability to sense temperature and invoke ventilation capability, and to darken in presence of strong light.
- Recycling technology to remove undesirable materials from the material being recycled. Research Topics:
  - Ability to recycle and reprocess vehicular glass even when other substances (e.g. adhesives, antennas, coatings) have been applied.
- Long term need of eliminating undesirable materials.

Biomaterials Vision

- Renewable resources will be used in increasing number of applications, for functional enhancement or reduced cost or environmental impact, thus lessening dependence on fossil fuels.
- Natural polymers will be enhanced, or bioengineering will create needed molecular structures to develop new materials with desired properties and accelerated production cycles.
- Smart biomaterials will incorporate self-healing to flaws and will automatically adapt to varying operating conditions

Biomaterials Needs

- **Ability to cost-effectively produce polymers with enhanced functionality from Biomass. Research Topics:**
  - **Investigation and use of bio-mimicry to create materials according to a plan or pattern**
  - **Bioengineering techniques to speed up production cycles and incorporate self-adaptive functionality.**
- **Development of alternative technologies that aren't dependent on fossil fuels. Research Topics:**
  - **Reduce the energy intensiveness of producing fuel or other materials from biomass**

Lubricants Vision & Needs

- **Lubricants: Antifreeze, hydraulic fluids, cutting fluids**
- **Vision:**
  - **Future transportation systems will have minimal need for lubricants and other environmentally hazardous fluids.**
- **Needs:**
  - **Engines and mechanisms that require less lubricant to operate effectively and prevent wear.**
- **Research Topics:**
  - **Materials that have low coefficient of friction and excellent wear characteristics to reduce usage of lubricants**

Processes Vision

- Processes will be fewer, simpler, robust, clean, energy-efficient, concurrent, self-optimizing and energy efficient.
- We will develop substantially different and environmentally less troublesome processes as well as refine existing ones, ensuring that environmental concerns are prominently considered.
- We will use modeling & simulation to facilitate understanding, design and testing of the processes.
- Processes will be modularized into standardized process steps to enable easier assembly and disassembly.
- Processes will allow for more automation and higher utilization of equipment.
- Processes will reduce usage of hazardous materials and output of hazardous wastes, and will drastically reduce consumption and waste of water.

Processes Needs

- Enhanced process control and goal of continuous production instead of batch production.
- Processes that are safer and less repetitive for humans and the environment.
- Better Modeling and Simulation of processes and their inputs, to enable analysis and improvement, reducing processing to only that which adds value to the product.
- Fully instrumented processes, to reveal details of performance and Processes need to self-monitor and note/report/self-adapt when going out of tolerance.
- Maximized/optimized tolerances provided by the processes, according to product requirements.
- Simpler manufacturing processes that are capable of being performed by workforce without high technical skills.
- Parallel development of and training for execution of new processes.
- Specific management of different types of waste from manufacturing facility in most environmentally and cost effective way.

Non-Metals Processing Comments

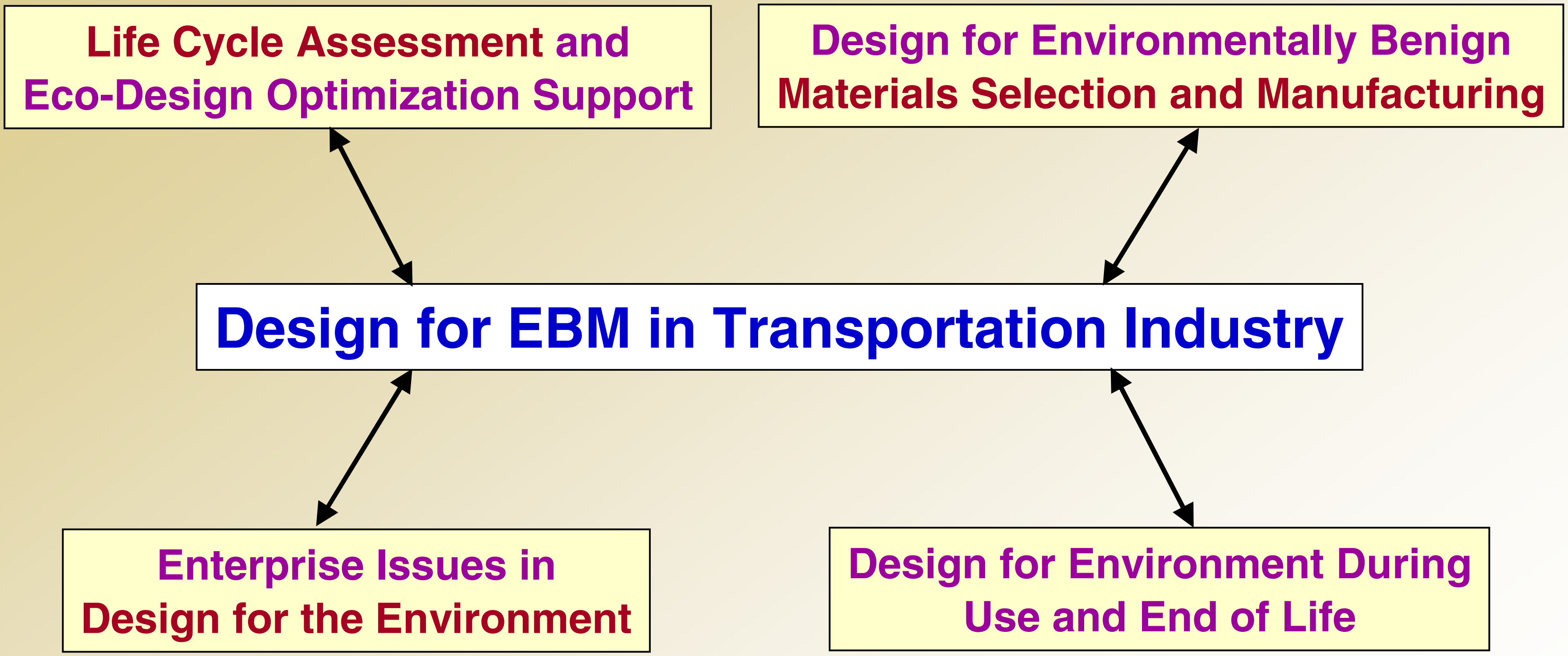
- **Materials**
  - Wider spectrum of properties needed
  - Optimize use, reuse, and recycling
  - Increase use of bio-materials
  - Reduce material type variety within a product

- **Processing**
  - Lower environmental impact
  - Ease assembly, disassembly, and recycling
  - Near-net-shape processing (e.g., ceramics)
  - Miniaturization and micro-manufacturing

Non-Metals Processing Comments

- **Research needs**
  - Base use decision on complete LCA
  - Develop smart materials and processes
  - Develop comprehensive databases
  - Minimally tweak present procedures
  - Facilitate maximum material segregation
  - Increase instrumentation/automation
  - Develop better simulation methods
  - Investigate and use bio-mimicry to create new materials according to a plan/pattern

Product Design and Support: PDS



Product/Process Design and Support

- Ross Good
- Laura Armstrong
- Greg Keoleian
- Rolf Steinhilper
- Venkat Allada
- Earl Beaver
- David He
- Julie Ann Stuart
- Li Lin
- Richard Mazur
- Bhavik Bakshi
- Helen Lou
- Reggie Caudill
- Richard Neal

Some Major Issues

- Selling the message that Environmental sustainability is a profitable strategy and can be a competitive advantage
- The “triple bottom line” versus profit only
- Focusing research on the real needs for EBM
- Bridging the gap between academic research and industrial implementation
- The business case: sustainability is not environmental philanthropy

Product/Process Design and Support

- Product/ Process Systems Design
- Life-Cycle Analysis
- Design for Sustainability
- Communication

- Product Life-Cycle Support
- Product Tracking
- Product/ Material Recycle & Recovery

Life-Cycle Analysis

Vision:

Life Cycle techniques will be incorporated in product and process system design and management decisions delivering sustainable products and systems. Total Cost will be minimized and total life benefit will be maximized

Life-Cycle Analysis

Key Needs:

- ❖ Integrated, shared databases that are accessible, controlled for proper access, complete, and accurate
- ❖ Streamlined LCA tools for level of need and level of cost applications, scalable across the extended enterprise
- ❖ Systematic performance evaluation indicators for inclusion in life cycle systems
- ❖ Prognostic guidance in design, based on best knowledge

Design for Sustainability

Vision:

Revolutionary and evolutionary products, processes, and services that provide the highest triple bottom line value throughout the product lifecycle.

Design for Sustainability

Key Needs:

- **Understand the correlation between product sustainability, customer needs, and functional requirements to align trade-off analysis and identify research requirements**
- **Understand ways to exploit sustainability as a corporate competitive advantage**
- **Develop mechanisms to influence consumers to place value on sustainability in buying decisions**
- **Design for total value (integrated "X")**

Communication

Vision:

- **Integrated product/process design policy that incorporates economic, social, and ecological impacts and ubiquitously communicates this philosophy and practice throughout the extended enterprise**

Communications

Key Needs:

Improved information systems for sharing sustainability information:

- **With appropriate value placed on all aspects of product lifecycle**
- **Vertically and horizontally communicated across the extended enterprise**
- **With an open, practical, and secure communications infrastructure**

Product Tracking

Vision:

Multiple, optimized product / module / material life cycles making money at each stage and adding value at each new cycle

Tracking, planning, and support for Multiple lives for every component

Product Tracking

Key Needs:

- **Documentation of all materials in a product and assistance in best use assurance for end of life handling**
- **Proper responsibility for end of life issues**

- **Note: Much discussion about legal issues related to non-oem add-ons**

Product/Material Recycle and Recovery

Vision:

Products and processes designed for sustainability throughout a cradle to grave lifecycle, through the enablement of every step of the reuse, recycle, and recovery

Product/Material Recycle and Recovery

Key Needs:

- Tools to support the highest form of recovery and reuse
- Maximize development and utilization of renewable/sustainable materials and products

Observation: There seems to be more emphasis on minimizing detrimental use than creating new alternatives

Summary

Overarching themes in product and process design and support:

- **Design for sustainability**
- **Integration of design requirements and optimizing tools**
- **Lifecycle management of products, components, and materials**
- **Optimized use in multiple lives and multiple products**

PDS Comments

- Life cycle assessment
  - Life cycle scope and procedure
    - Develop guidelines for streamlining LCA
    - Compare outcomes of full and streamlined LCA
  - Data quality and availability
    - Improve data quality; fill data gaps
    - Verify LCA data repeatability
    - Quantify uncertainties and risks
  - Environmental priorities and optimization
    - How to weight environmental impacts
    - Develop trade-off analysis; achieve eco-design

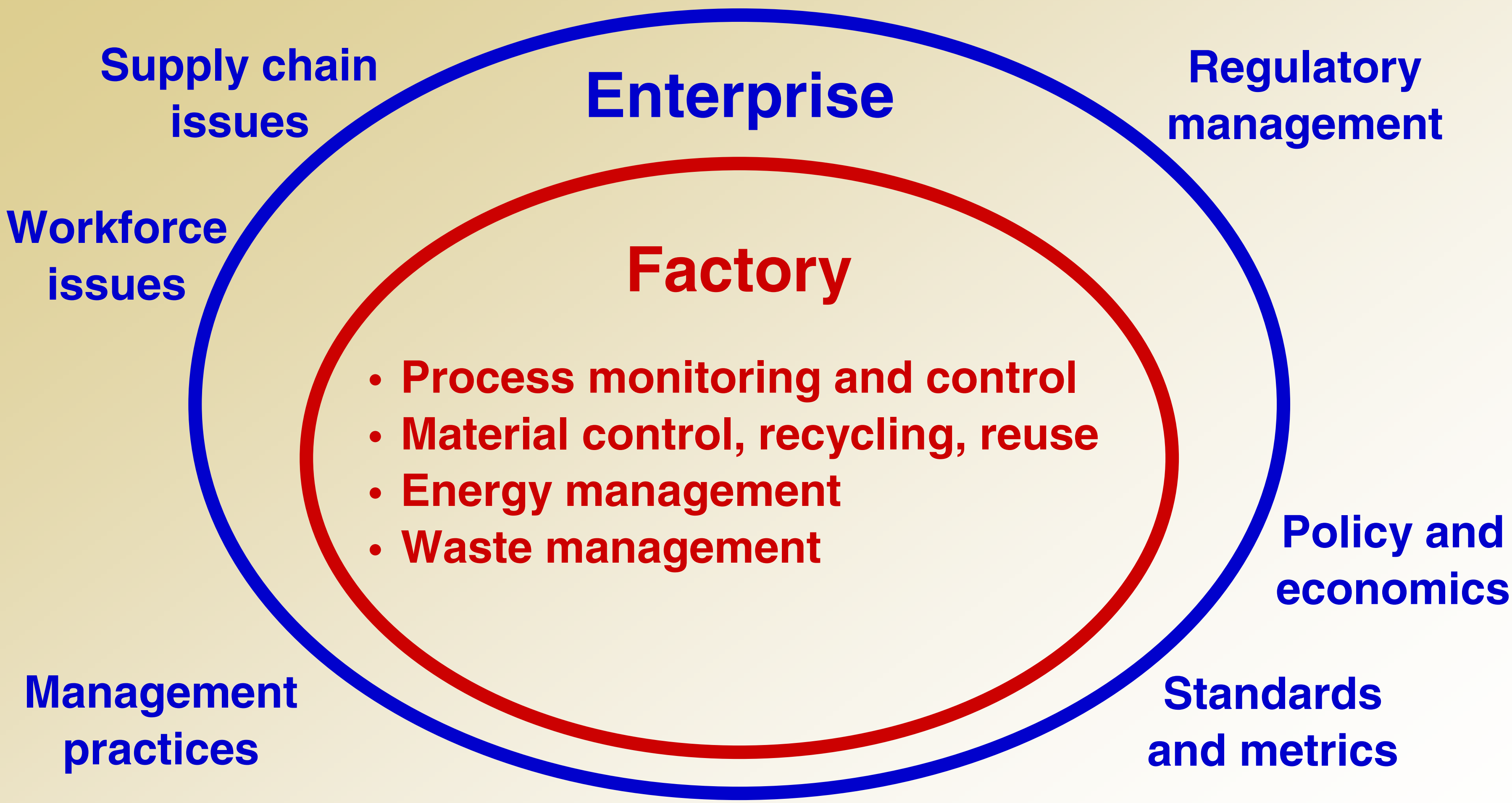
PDS Comments

- ❖ **Materials and manufacturing**
  - ➢ **Materials selection**
    - Material data, especially for recycled materials
    - Engg. design curricula includes the use of novel, recycled, & recovered environmentally benign materials
  - ➢ **Process selection**
    - Quantify process inputs and outputs
    - Spatial and temporal environmental impacts in manufacturing → for use by designers
    - Develop/modify manufacturing to achieve EBM

PDS Comments

- Design for environment
  - Modular design
  - Design for post-use
  - Supply chain changes
    - Develop end-of-life inventory management
    - Use of information technology for tracking
- System issues
  - Communication – information technology
  - Technology diffusion – standard practice
  - Eco-drivers – marketplace advantages

Enterprise and Factory Operations



Enterprise and Facility Operations

- John Armstrong
- Clint Andrews
- Carol Carmichael
- John DeCaire
- Tom Graedel
- Tim Gutowski
- Steve Melnyk
- Cindy Murphy
- Monica Prokopyshen
- Joe Sarkis
- Jan Twomey
- Ron Williams

Process Used

- Create a rough vision of a future state that is desired for the enterprise

- Identify one or more major accomplishments that would move the enterprise toward the desired future state

- List the research needs to help achieve these major accomplishments

Future State

- **A competitive and socially responsible enterprise in the transportation industry that satisfies its stakeholder expectations for mobility using environmentally benign manufacturing processes. These processes have arisen from management practices that integrate environmental aspects in ways that are visible, credible, and feasible.**

Major Accomplishments

- Government policy is aligned with enterprise goals
- EBM improves profit margin of the enterprise
- Improved environmental performance is reflected by an understandable metrics scorecard
- The new workforce stimulates higher environmental performance because they understand EBM and bring innovative processes

Major Accomplishments

- Manufacturing executive of the year selected for energizing the workforce to implement EBM and exceed performance goals
- The paradox of waste has been solved: waste is designed out, not disposed of
- EBM feedback control has been installed on all company X manufacturing lines
- Year 2xxx was the first year the auto industry no longer purchased virgin metal, glass, rubber, or plastics. CEOs declare sustainable material inventory is already n the road.

Selected Research Programs

- Determine whether society needs more than the market and the ballot box for linking the customer voice to obtaining feedback and pull for EBM
- Determine the dynamic engineering and science based impacts of the automobile to understand resource application and prioritization of second order effects of these impacts, and to determine how technology and environment and social interactions at one level relate to impacts at another level. (global-regional-local)

Selected Research Programs

- Develop models of sectors and technological systems that assess, understand, and predict impacts on social, economic, and environmental systems

EFO: Comments

- Enterprise level operations
  - Regulations, policy, and economics
  - Standards, metrics, and management
  - Workforce and supply chain issues
  - Areas of research needed
    - Streamlined, standardized, and science-based regulations
    - Institutionalization of EBM strategy
      - Purchasing decisions & management practices
      - Standard software, metrics, and databases
      - Organizational information networks

EFO: Comments

- **Factory level operations**
  - **Process monitoring and control**
  - **Material control, recycling, and reuse**
  - **Waste and energy management**
  - **Areas of research needed**
    - **Develop models for social, economic, and environmental impacts**
    - **Prioritize improvement efforts; understand resource demands and environmental impacts**
    - **EBM and bottom line performance relationship**
    - **Integrate EBM into engineering/business curricula and company training programs**

Summary

- Four workshop subgroups
  - Metals Processing
  - Non-Metals Processing
  - Product Design and Support
  - Enterprise and Factory Operations
- Total life cycle analysis must be incorporated into the practice of design and manufacturing to improve the triple bottom line (social, economic, and environmental performance)

Conclusions

- U.S. industry must work competitively to gain a foothold in terms of global EBM
- Increasing use of metals and non-metals warrants research toward improving material use and reuse, and use of bio-materials
- Production and processing improvements are necessary to facilitate EBM strategies
- Organization and education initiatives must be cultivated for institutionalization of EBM

Acknowledgements

- Special thanks to all workshop participants (late Sept. 2001)
  - 60 industry/university/govt. experts
- Thanks to the National Science Foundation for financial support
- NSF-EBM workshop organizers
  - J. Decaire, R. Furness, S. Liang, R. McCune, R. Neal, W. Olson, S. Skerlos, and J. Sutherland