ENPM 692
MANUFACTURING AND AUTOMATION

SUSTAINABLE MANUFACTURING

Time: Wednesdays 7:00pm - 9:40pm
Location: JMP 2222

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Plan

- Part 1
  - Sustainable Manufacturing
    - Challenges, competencies and opportunities
  - Towards Sustainable Manufacturing
- Part 2
  - Life Cycle Thinking – Why its make sense?
- Part 3
  - Sustainable Production and Manufacturing
- Part 4
  - Discussion and Case Studies

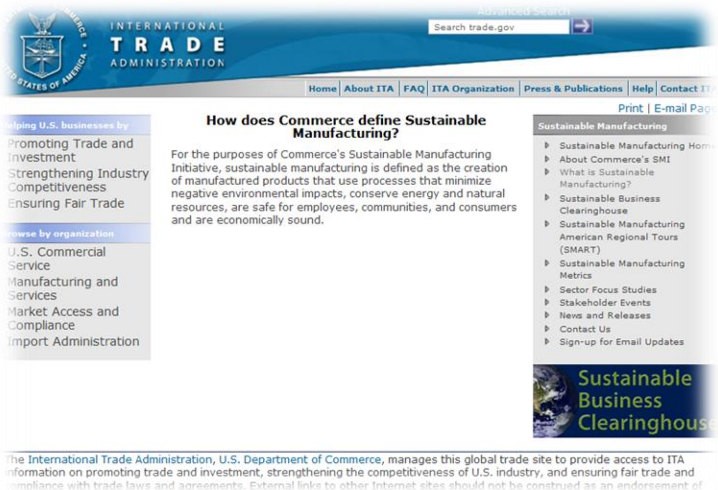
Outline

- Part 1
  - Sustainable Manufacturing
    - Challenges, competencies and opportunities
  - Towards Sustainable Manufacturing
    - Life Cycle thinking
    - Innovation

A Good Place to Start

The Report of the Brundtland commission defined sustainable development as **"meeting the needs of the present without compromising the ability of future generations to meet their own needs"**

"Sustainable manufacturing is defined as 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."



… with consideration of life cycle factors

- Commerce's Sustainable Manufacturing Initiative

Challenges, Competencies and Opportunities

STAGE 1
Viewing Compliance as Opportunity

CENTRAL CHALLENGE
To ensure that compliance with norms becomes an opportunity for innovation.

COMPETENCIES NEEDED
>> The ability to anticipate and shape regulations.

>> The skill to work with other companies, including rivals, to implement creative solutions.

INNOVATION OPPORTUNITY
>> Using compliance to induce the company and its partners to experiment with sustainable technologies, materials, and processes.

STAGE 2
Making Value Chains Sustainable

CENTRAL CHALLENGE
To increase efficiencies throughout the value chain.

COMPETENCIES NEEDED
>> Expertise in techniques such as carbon management and life-cycle assessment.

>> The ability to redesign operations to use less energy and water, produce fewer emissions, and generate less waste.

>> The capacity to ensure that suppliers and retailers make their operations eco-friendly.

INNOVATION OPPORTUNITIES
>> Developing sustainable sources of raw materials and components.

>> Increasing the use of clean energy sources such as wind and solar power.

>> Finding innovative uses for returned products.

STAGE 3
Designing Sustainable Products and Services

CENTRAL CHALLENGE
To develop sustainable offerings or redesign existing ones to become eco-friendly.

COMPETENCIES NEEDED
>> The skills to know which products or services are most unfriendly to the environment.

>> The ability to generate real public support for sustainable offerings and not be considered as “greenwashing.”

>> The management know-how to scale both supplies of green materials and the manufacture of products.

INNOVATION OPPORTUNITIES
>> Applying techniques such as biomimicry in product development.

>> Developing compact and eco-friendly packaging.

STAGE 4
Developing New Business Models

CENTRAL CHALLENGE
To find novel ways of delivering and capturing value, which will change the basis of competition.

COMPETENCIES NEEDED
>> The capacity to understand what consumers want and to figure out different ways to meet those demands.

>> The ability to understand how partners can enhance the value of offerings.

INNOVATION OPPORTUNITIES
>> Developing new delivery technologies that change value-chain relationships in significant ways.

>> Creating monetization models that relate to services rather than products.

>> Devising business models that combine digital and physical infrastructures.

STAGE 5
Creating Next-Practice Platforms

CENTRAL CHALLENGE
To question through the sustainability lens the dominant logic behind business today.

COMPETENCIES REQUIRED
>> Knowledge of how renewable and nonrenewable resources affect business ecosystems and industries.

>> The expertise to synthesize business models, technologies, and regulations in different industries.

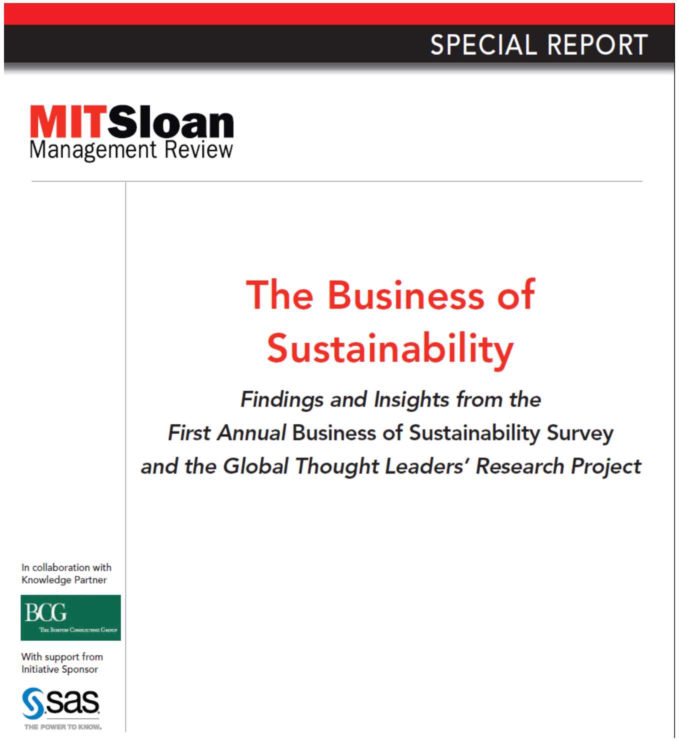
INNOVATION OPPORTUNITIES
>> Building business platforms that will enable customers and suppliers to manage energy in radically different ways.

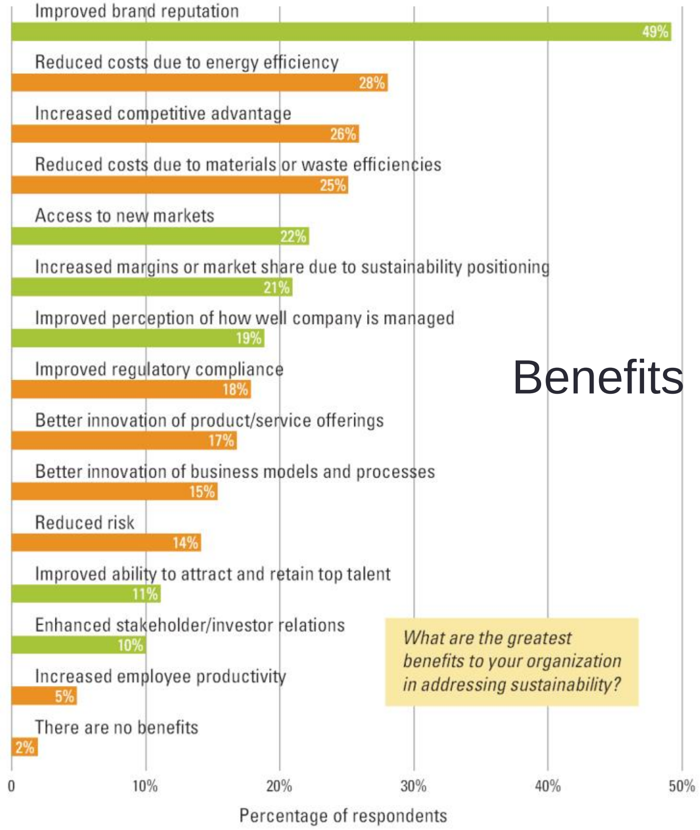
>> Developing products that won’t need water in categories traditionally associated with it, such as cleaning products.

>> Designing technologies that will allow industries to use the energy produced as a by-product.

Why Sustainability Is Now the Key Driver of Innovation, HBR

Industry Speaks….



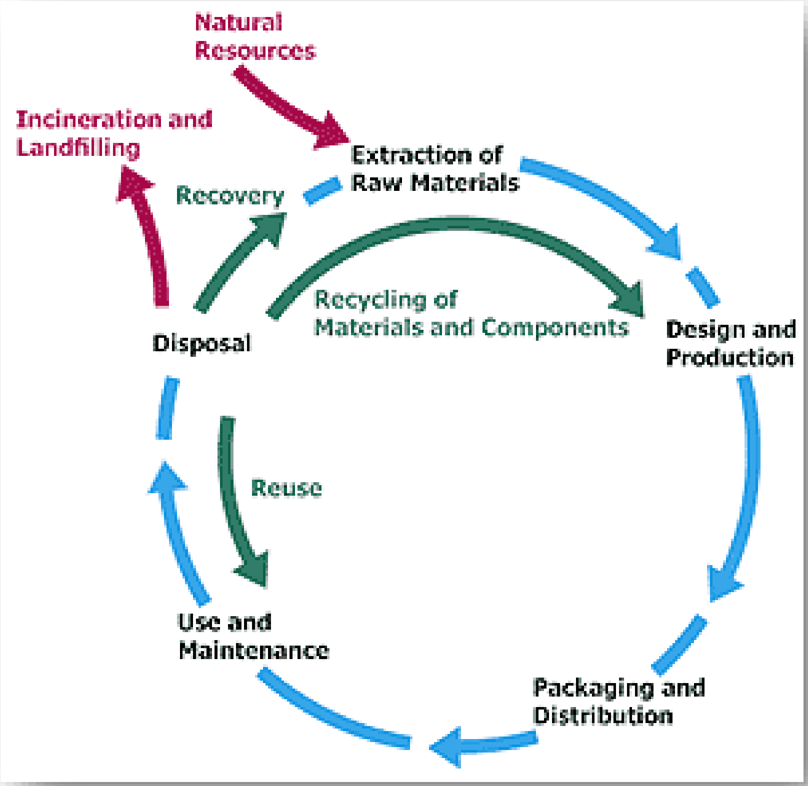


Benefits of Sustainability

There is a strong consensus that sustainability is having – and will continue to have -a material impact on how companies think and act .

Life Cycle Thinking

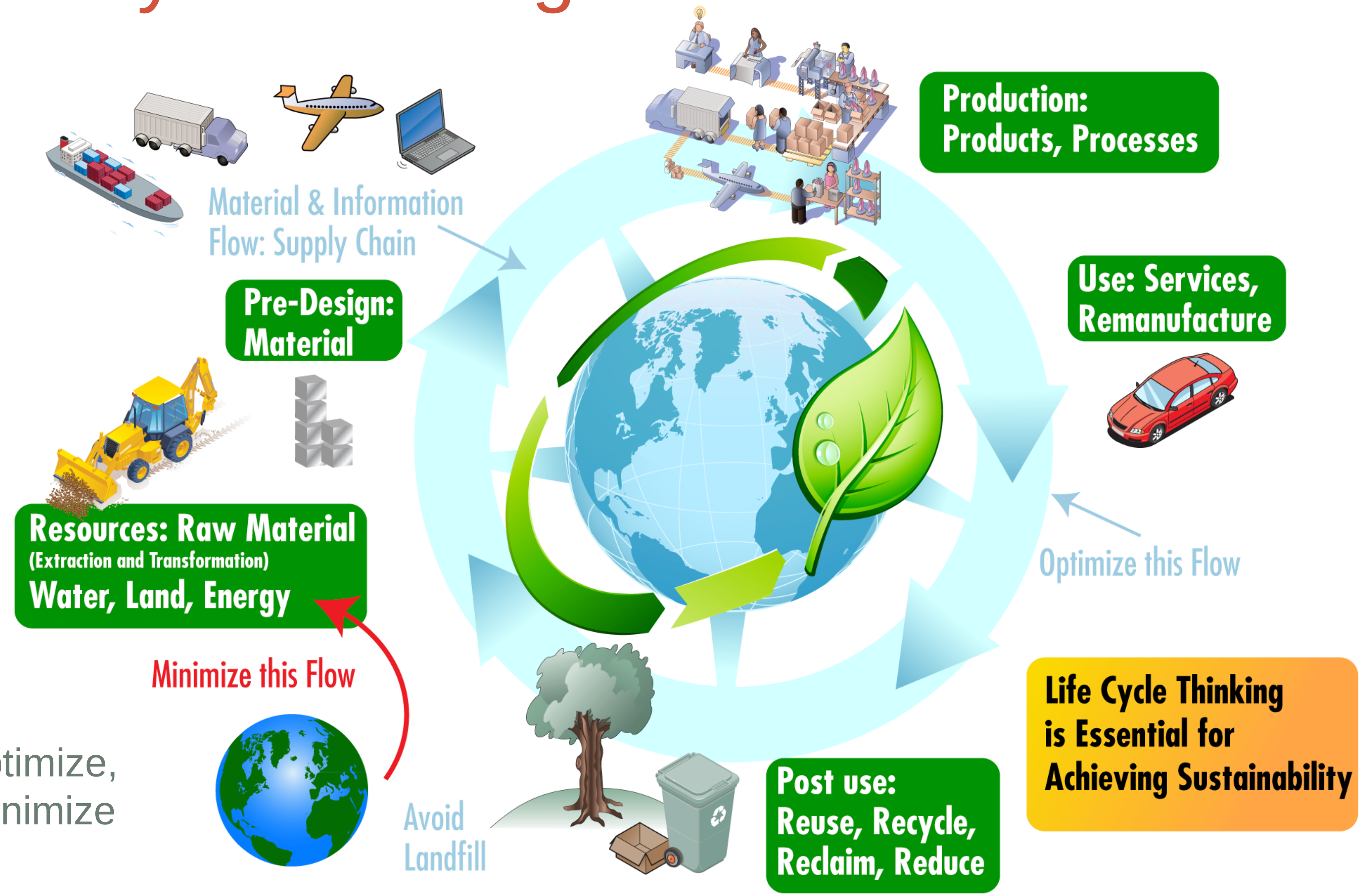
Life cycle thinking expands the traditional focus on manufacturing processes to incorporate various aspects associated with a product over its entire life cycle.



The producer becomes responsible for the products from cradle to grave

Re	**- think**
Re	**- duce**
Re	**- place**
Re	**- cycle**
Re	**- use**
Re	**- pair**

Life Cycle Thinking is Core



Flows to optimize,
Flows to minimize

“ **Sustainability means living on nature's income rather than its capital.**”
— **Murray Gell-Mann** 1969 Nobel Prize in physics

Innovation: Key to Sustainability

- **sustainability** is the new key driver of innovation

Plan

- Part 2
  - Life Cycle Thinking – Why its make sense?
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PART 2

Life Cycle Thinking – Why its make sense?

Class exercise

Correlate

Sustainability	Life Cycle Thinking
Life Cycle Management	Life Cycle Assessment
Life Cycle Costing	Continuous Improvement

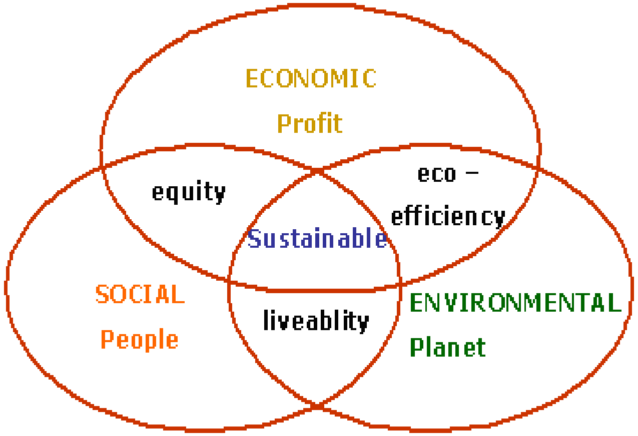
What is the Circular Economy?

https://www.nist.gov/video/what-circular-economy

Reflections?

Sustainability	Life Cycle Thinking	Life Cycle Management
Life Cycle Assessment	Life Cycle Costing	Continuous Improvement

Sustainability



Sustainable development
"meet present needs without compromising the ability of future generations to meet their needs"

(WCED, 1987. UN conference)

In the business community sustainability is coined **"the triple bottom line",** expressing that industry has to expand the traditional economic aspects to include environmental and social dimensions - to create a more "sustainable business"**.**

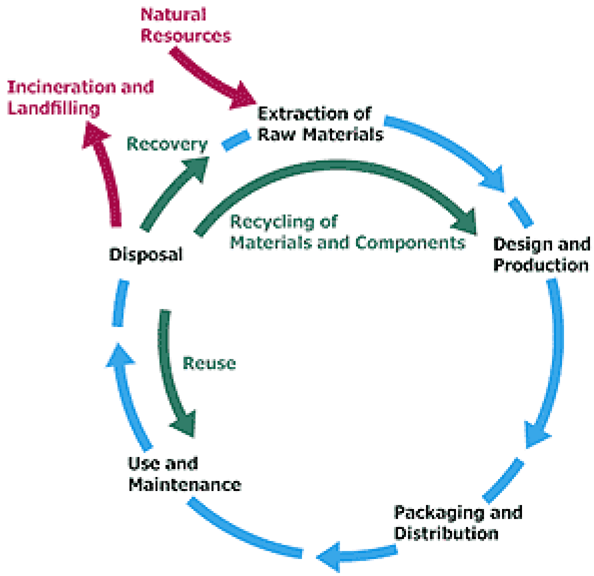
-- Elkington 1997

Life Cycle Thinking

Life Cycle Thinking

Life cycle thinking expands the traditional focus on manufacturing processes to incorporate various aspects associated with a product over its entire life cycle.

The producer becomes responsible for the products from cradle to grave and has, for instance, to develop products with improved performance in all phases of the product life cycle



6 RE philosophy

Re - think
Re - duce
Re - place
Re - cycle
Re - use
Re - pair

Reference: Lifecycle thinking
Source: https://www.lifecycleinitiative.org/wp-content/uploads/2013/09/UNEP_Background_document_LCM_2006_Febr.pdf

Life Cycle Management

LCM is the *application of life cycle thinking* to modern business practice with the aim *to manage the total life cycle* of an organization's products and services towards more sustainable consumption and production

LCM is *systematic integration of sustainability*, e.g. in company strategy and planning, product design and development, purchasing decisions and communication programs

LCM is not a single tool or methodology but a flexible *integrated management framework of concepts, techniques and procedures* incorporating environmental, economic, and social aspects of products, processes and organizations

LCM is a dynamic process; organizations may begin with small goals and objectives with the resources they have and get more ambitious over time.

[Hunkeler et al. 2004]

LCM Approach

Phase	Approach to LCM implementation
Plan	1. Set policies – set goals and determine the ambition level 2. Organize – get engagement and participation 3. Survey – make an overview of where the organization is and where it wants to be 4. Set goals – select an area/s where the efforts will be directed, determine goal (s) and make an action plan
Do	5. Make environmental improvements – put the plan into action 6. Report – document the efforts and their results
Check	7. Evaluate and revise – evaluate the experience and revise policies and organizational structures as needed
Act/Adjust	8. Survey again, define more goals, etc.

The Deming (PDCA) Cycle

play
stop
step
rew

LCM Objectives

Management Level

	Social dimension	Environmental dimension	Economical dimension
Objective	SUSTAINABILITY		
Concept	LIFE CYCLE THINKING		
Strategies	LIFE CYCLE MANAGEMENT		
	Corporate social responsibility	Pollution Prevention	Product- and supply chain management
Systems	OHSAS 18001	ISO 14001 & POEMS	ISO 9001, TQM, EFQM
Tools	Work place assessment	Cleaner Production, LCA, EcoDesign,	EMA & LCC

Explanations: OHSAS = Occupational Health And Safety, POEMS = Product Oriented Environmental Management System, TQM = Total Quality Management, EFQM = European Foundation for Quality Management, LCA = Life Cycle Assessment, EMA = Environmental Management Accounting, LCC = Life Cycle Cost Analysis.

Adopted/ modified: LCM Slide Show 2005

LCM Challenges

Policies / Strategies	Sustainable Development, Triple Bottom line, Integrated Product Policy (IPP), Dematerialization (Factor 4-10), Cleaner Production, Industrial Ecology, Eco-efficiency, Sustainable Asset Management, etc.
Systems / Processes	Integrated and Environmental Management Systems (ie. ISO 9000/ 14000, EMAS, EFQM), Extended Producer Responsibility (EPR), Product Development Process (PDP), Certification, Environmental Communication, Value Chain Management, etc.
Concepts / Programs	Product stewardship, Design for Environment, Supply Chain Management, Public Green Procurement, Stakeholder Engagement, Corporate Social Responsibility, Green Accounting, Supplier Evaluation, etc.
Tools / Techniques	Analytical: LCA, MFA, SFA, I/O, ERA, CBA, LCC, TCO etc. Procedural: Audits, Checklists, Labeling, EIA, etc. Supportive: Weighting, Uncertainty, Sensitivity/Dominance, Scenarios, Back casting, Standards, Voluntary Agreements, etc.
Data / Information / Models	Data: Databases, Data Warehousing, Controlling Information: Best Practice Benchmarks, References, etc. Models: Indicators, Fate, Dose-response, Monte Carlo etc.

LCA
LCC

Adopted/ modified: LCM Slide Show 2005

Life Cycle Management

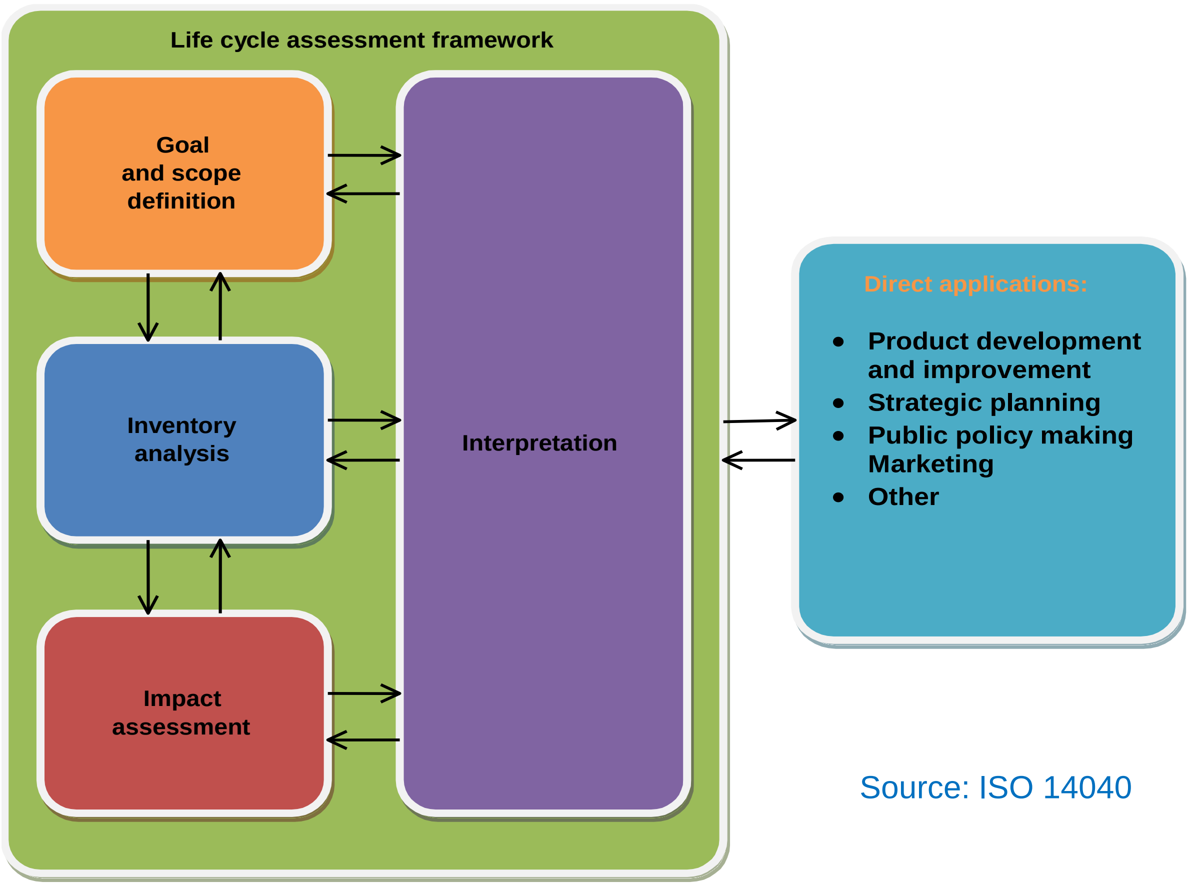
Life Cycle Assessment

Life Cycle Assessment (LCA) process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements.

LCA is a method that *considers energy and raw material consumption*, different types of *emissions* and other important factors related to a specific *product's entire life cycle* from an *environmental point of view*.

Reference: ISO 14040

LCA Framework



Step 1: Goal Definition & Scope
ISO 14040

Step 2: Inventory Analysis
ISO 14041

Step 3: Impact Assessment
ISO 14042

Step 4: Improvement Assessment / Interpretation
ISO 14043

Source: ISO 14040

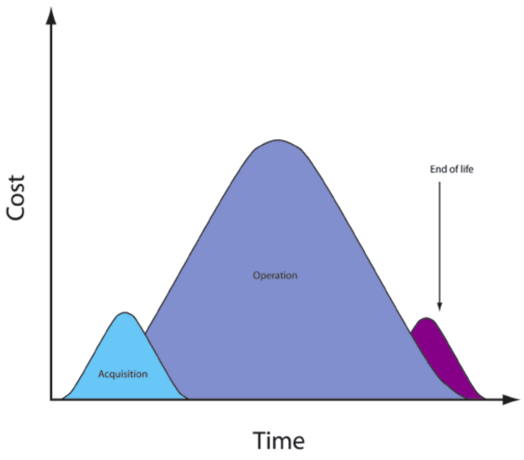
Life Cycle Assessment

Life Cycle Costing

Life Cycle Costing (LCC) is as an assessment of **all costs associated with the life cycle of a product that are directly covered by any one or more of the actors in the product life cycle** (supplier, producer, user/consumer, EOL-actor), with complimentary inclusion of **externalities that are anticipated to be internalized** in the decision-relevant future.

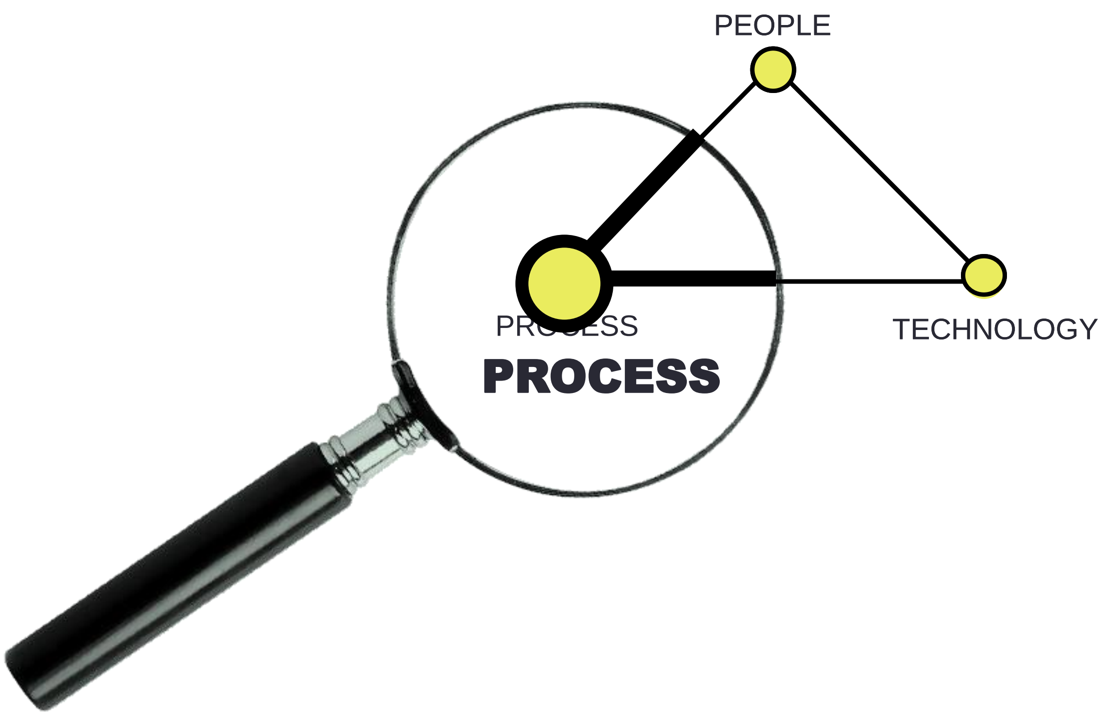
Rebitzer, G 2003,

- Optimize product and process planning & development (R&D), purchasing decisions, etc
- Exploitation for sales and marketing (integrate use and end-of-life performance of products and services)
- To identify trade-offs and economic-environmental win-win situations
- To support internal decision-making in corporate context



Maturity Models-Continuous Improvement

A reference model of mature practices in a specified discipline, used to assess a group's capability to perform that discipline.



"The quality of a product is largely determined by the quality of the process that is used to develop and maintain it."

-Software Engineering Institute

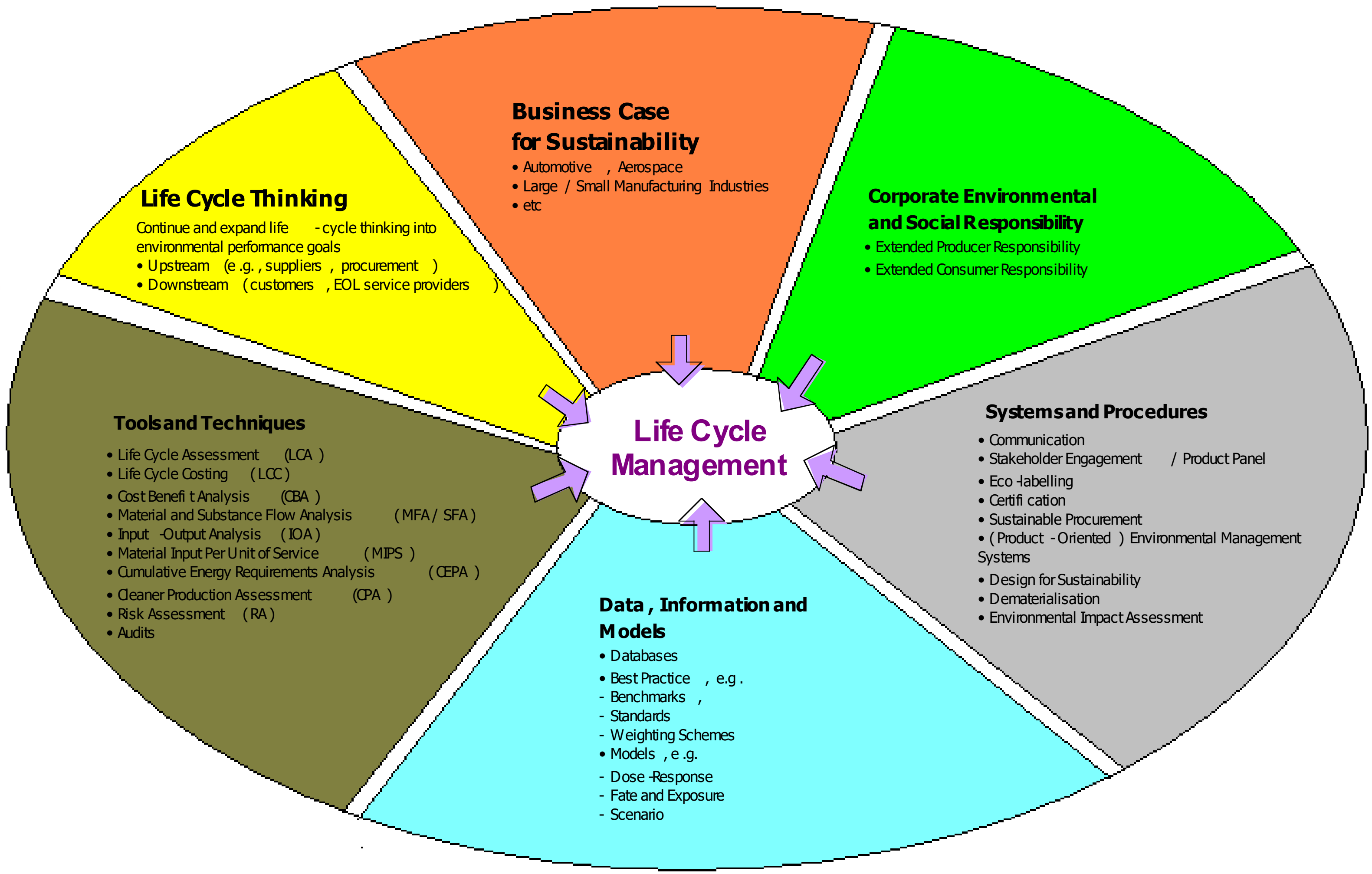
Parent of 'maturity models' – Philip Crosby

Wrote "Quality is Free" in 1979

Related Process Improvements

- improved schedule and budget predictability
- improved cycle time
- increased productivity
- improved quality (as measured by defects)
- increased customer satisfaction
- improved employee morale
- increased return on investment
- decreased cost of quality
- **Innovation for Sustainability**

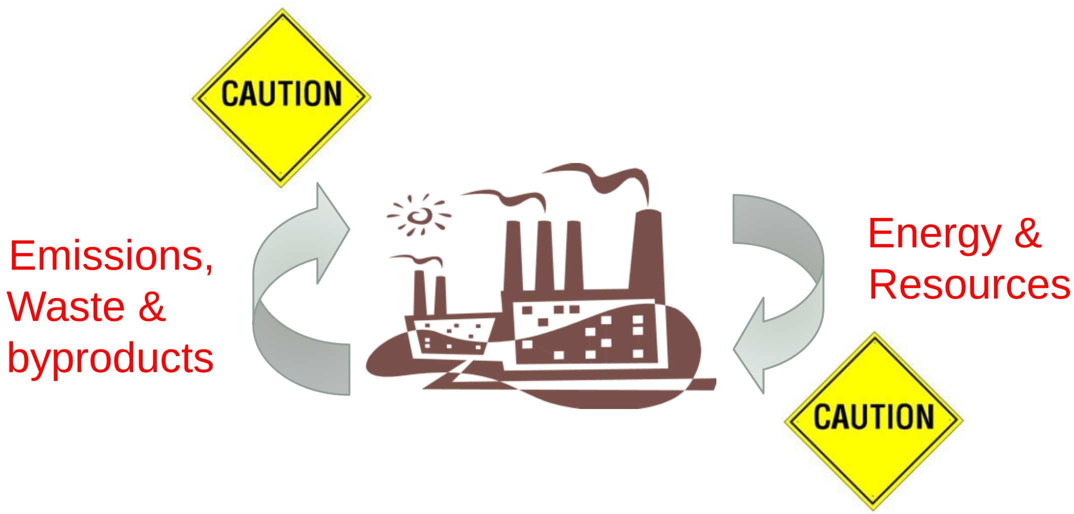
Life Cycle Management: Connecting Various Operational Concepts and Tools



PART 3

Sustainable Production and Manufacturing

Sustainable Manufacturing



Sustainable **M**anufacturing

Technologies applied to transform materials with reduced energy consumption, reduced emissions, reduced generation of waste products, and reduced use of non renewable or toxic materials.

Develop technologies to transform materials with controlled emission of greenhouse gases, use of non-renewable materials or generation of waste.

For Sustainable Manufacturing

Solution-enabling measurement science activities are defined by the following thrust areas:

- **Methodologies for sustainable processes and resources -** to characterize unit manufacturing and assembly processes, including supplier capabilities, enabling industry level manufacturing assessments to improve production efficiency.
- **Integration infrastructure for Sustainable Manufacturing -** enables the systematic and functional integration of unit manufacturing systems and subsystems to perform as a holistic sustainable system for improved production efficiency while being economically competitive. This includes tracking and optimization for material and energy efficiency.

Unit Manufacturing Processes

Manufacturing a product or component usually requires the integration of a number of processes. "Unit processes", are those individual operations (e.g. casting, machining, and surface treatment) required to produce finished goods by transforming raw material and adding value to the work piece as it becomes a finished product.

Enabling technologies

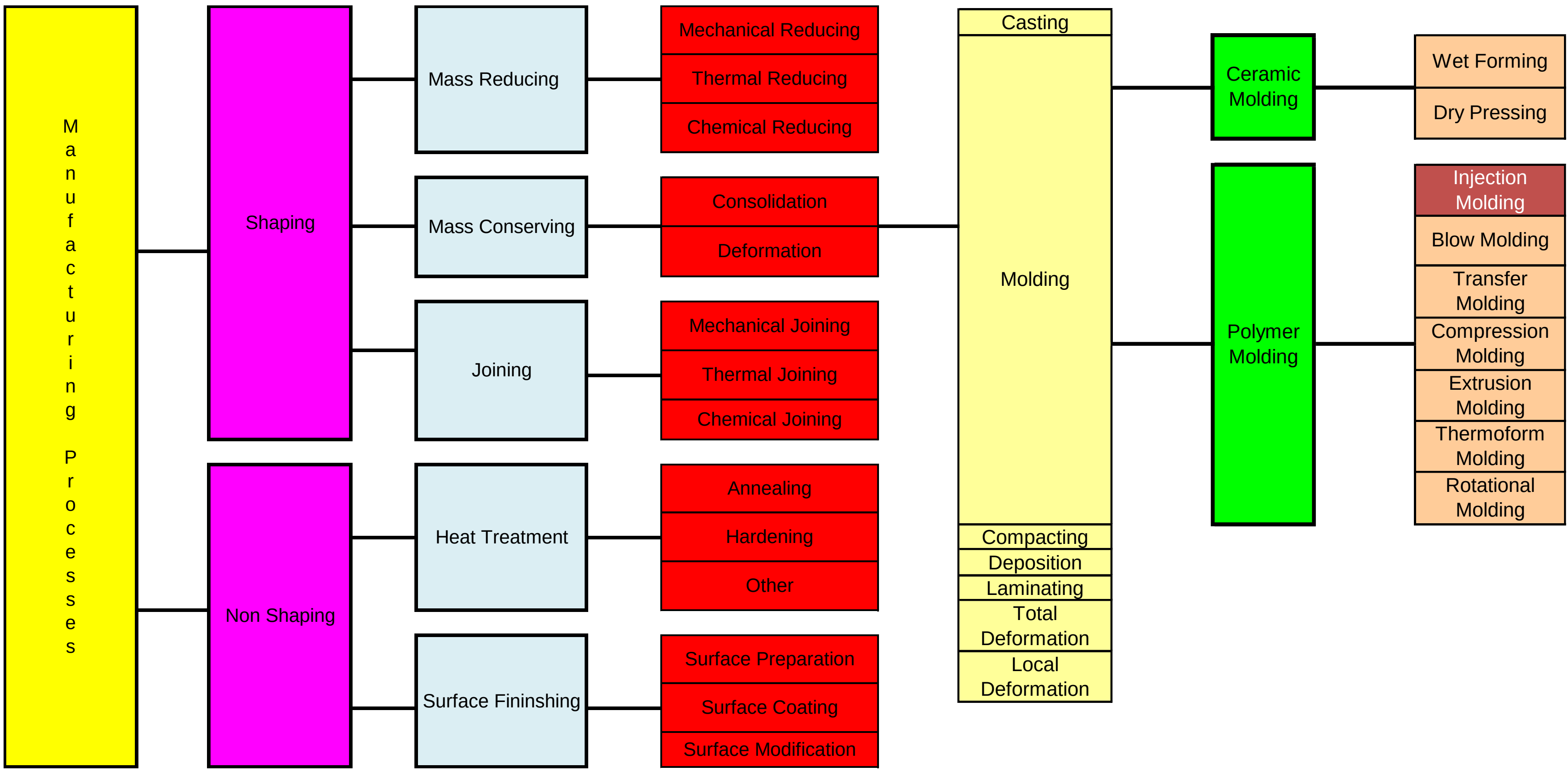
- material behavior
- simulation and modeling
- sensors
- process control
- process precision and metrology
- equipment design

Contribute to the long-term competitiveness

Research in these enabling technologies must be connected to the basic physics of processes, and the results verified through experiments on specific unit processes.

Reference: National Research Council

Unit Manufacturing Processes



Efforts by Wichita State University: uplci

Reference: Todd, H.R., Alen, K.D., (1994) Manufacturing Processes Reference Guide, Industrial Press Inc.

Challenge: Manufacturing Processes

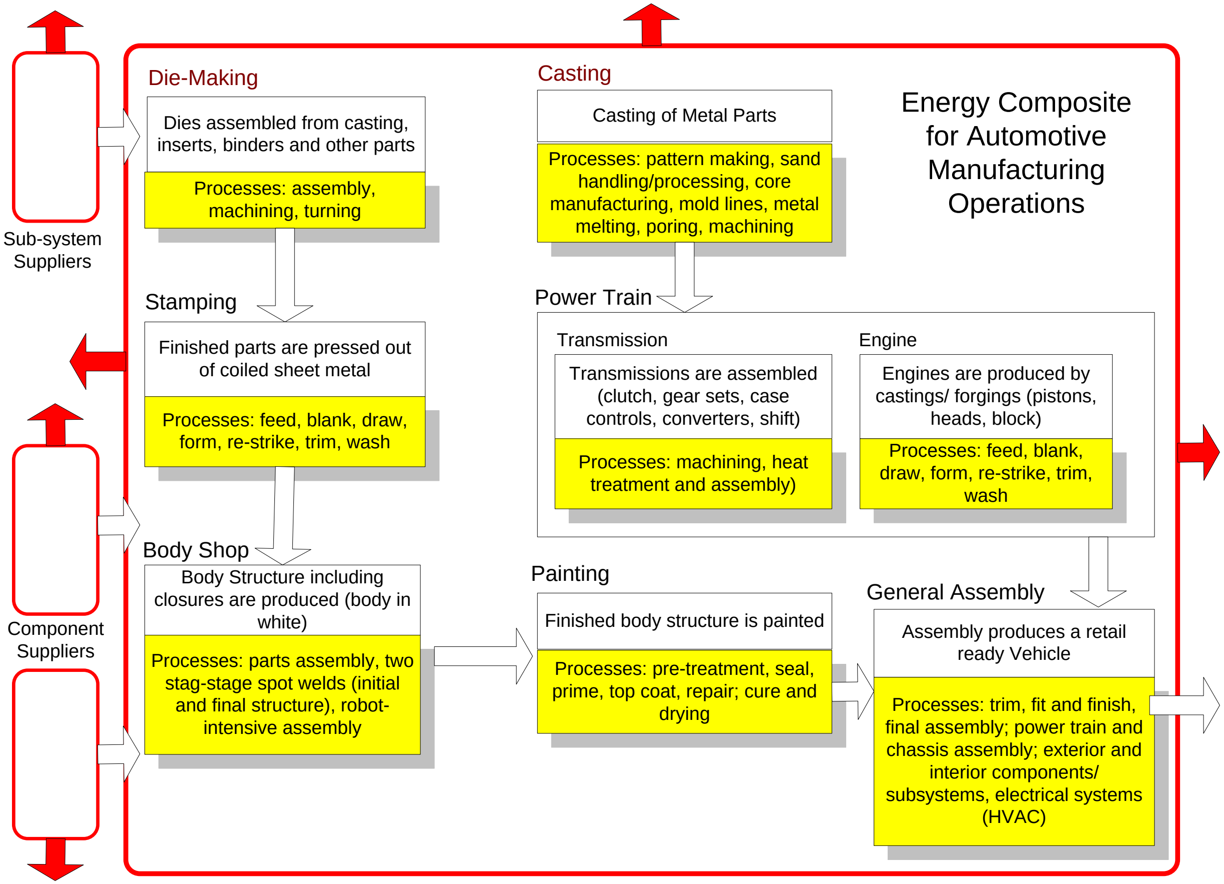
Analytical simulation and modeling of unit manufacturing processes based on knowledge of the underlying process physics and validated by experimental results is becoming a powerful tool to advance the optimization of unit processes. In this context, simulation is defined as the "representation or model of the operation of a system on a digital computer”.

Reference: Unit Manufacturing Process Research Committee, NRC, 1988

Future simulation tools should **incorporate both knowledge-based engineering systems and analytical techniques**. Preliminary design typically draws extensively on previous design experience. If a knowledge-based engineering system supporting sustainability were available, the following important areas could be addressed interactively during preliminary design:

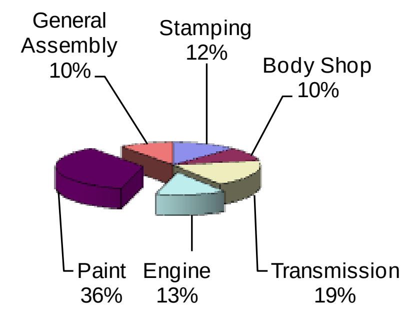
- selection of suitable unit processes
- optimum sequencing of the unit processes
- preliminary estimation of the unit process operational parameters
- operational parameter and performance indicator selection
- preliminary tooling design for each unit process

Why is It Important in Production?



Adopted & modified from USCAR Workshop Report

In-plant process energy distribution

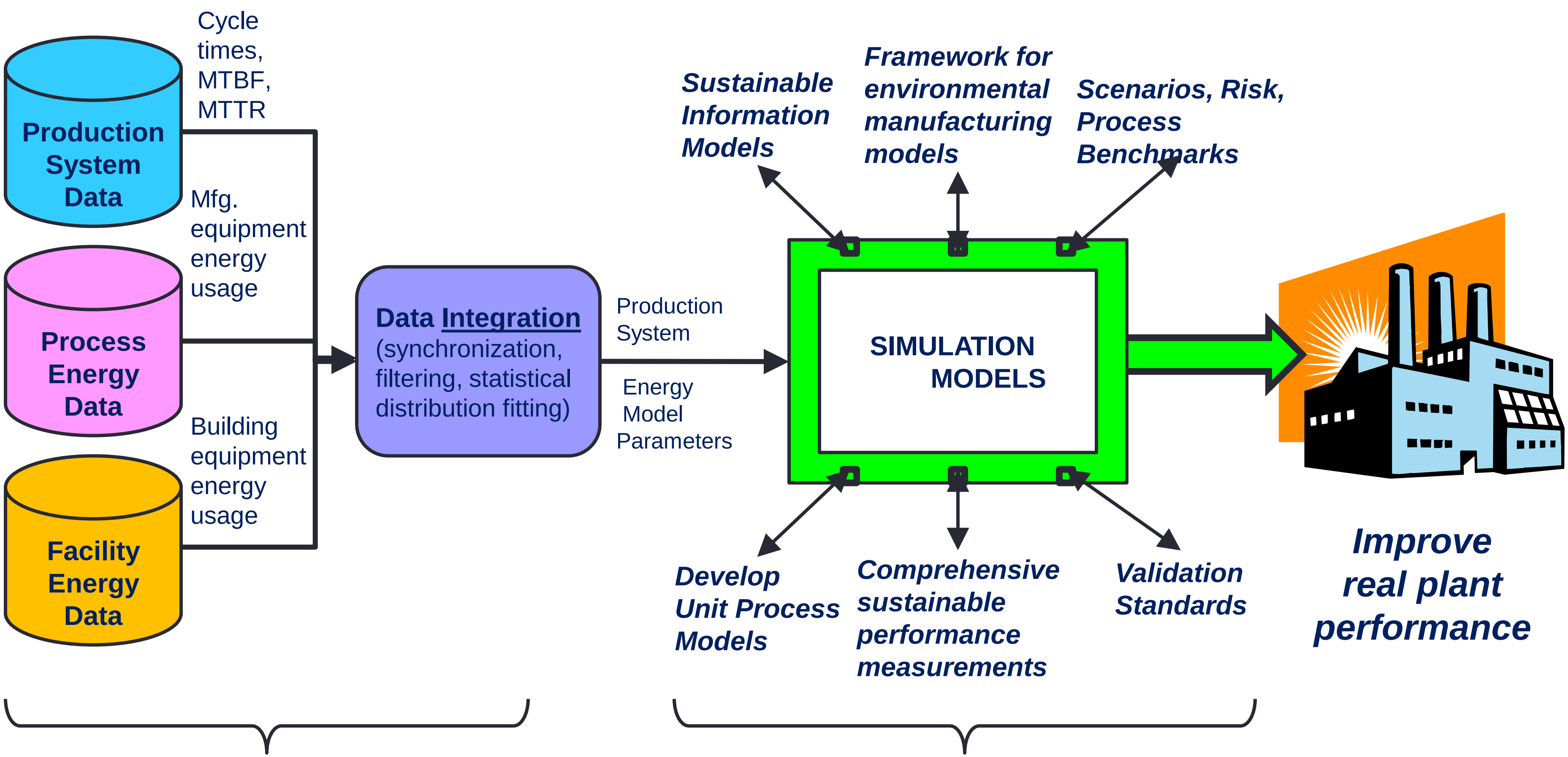


Energy Composite for Automotive Manufacturing Operations

Performance of Unit Processes

- It is energy efficient?
- Does it offer the potential to be cost-effective?
- Does it provide a unique way to cost-effectively exploit the physical properties of an advanced material?
- Can it shorten the time to move a product technology from the research stage to commercialization?
- Does it provide a method of processing that is fundamentally environmentally friendly?
- Is it applicable to a diverse range of materials?

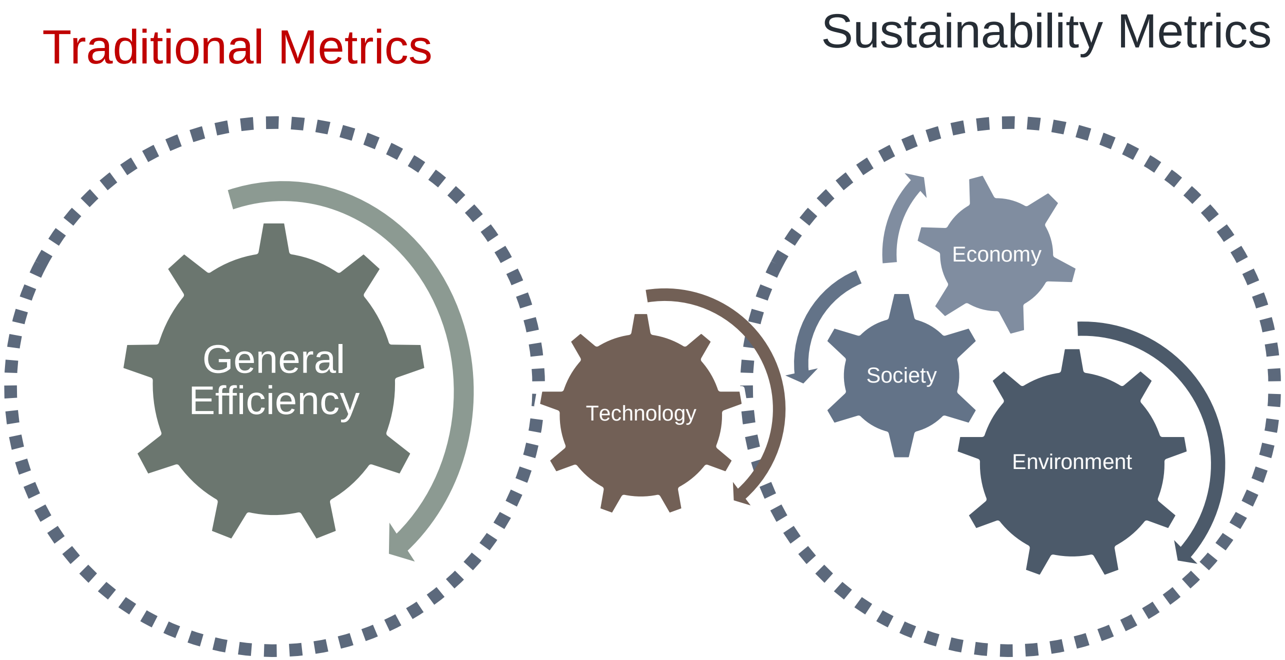
Bigger Picture: Sustainability Performance



Understand issues related to integrating diverse system data.

Simultaneously develop methodology and a system model

Traditional VS Sustainable Metrics



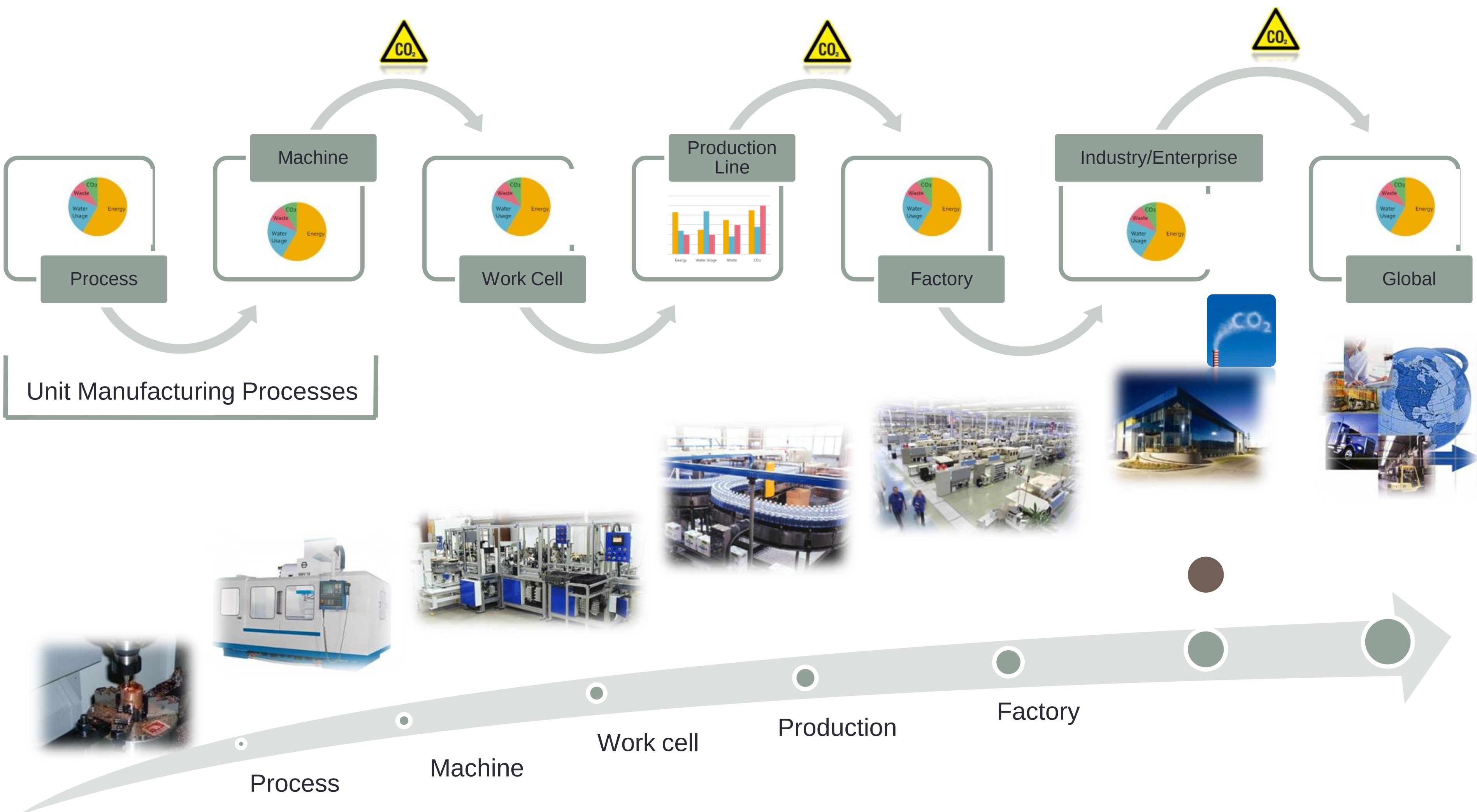
Traditional VS Sustainable Metrics

Traditional Metrics	Sustainability Metrics
• jobs produced per unit of time • job flow, cycle, or manufacturing lead time • make span of a set of jobs • job queuing time • queue lengths • job transfer time • worker and equipment utilization • equipment downtime due to breakage, blockage or starvation • machine utilization • balance of equipment utilization • overall plant capacity utilization • time to market • job lateness • number of jobs tardy • proportion of jobs tardy • order lead times • travel distance for products and components • inventory turns • work-in-process • scrap and rework measures • Costs and returns • cost of carrying raw materials and work-in-progress inventories • machine cost per unit time • material handling/transportation costs • labor cost • energy cost per unit time • total job completion cost • payback periods • return on investment in plant and equipment	• % of energy use that is renewable • energy use per unit of product made • energy cost per product unit • energy cost as % of total expenses • plant heating and cooling energy efficiency measures • Pollution • emissions per unit of product output • effluents that are captured and treated • greenhouse gases that are captured and treated • cost of fines and charges due to pollution • carbon footprint of products and processes • noise level measures • Material usage • % recycled/recyclable materials used • % environmentally-friendly materials used • output per unit of material used • output per units of water used • lifetime of materials used • environmentally-friendly packaging measures • paper process management measures • Waste • quantity of waste produced per unit output • percentage of waste materials recovered • waste water recovery measure • costs to recover (and dispose or reuse) discarded product, if regulations impose so • Worker health and safety • work-related accidents and injuries • ergonomics issues consideration in material handling and processing • healthcare costs due to occupational accidents • compensation costs due to work related injuries and suffering • worker job repetitiveness, satisfaction level, morale factors • lost work days due to injuries • lost production due to injuries • Community impact • land usage, green space, etc. • traffic impact on local roads • use of public transportation by employees

General Efficiency Focus

Focus on Energy, environment, society, economy, technology

Metrics and Maturity



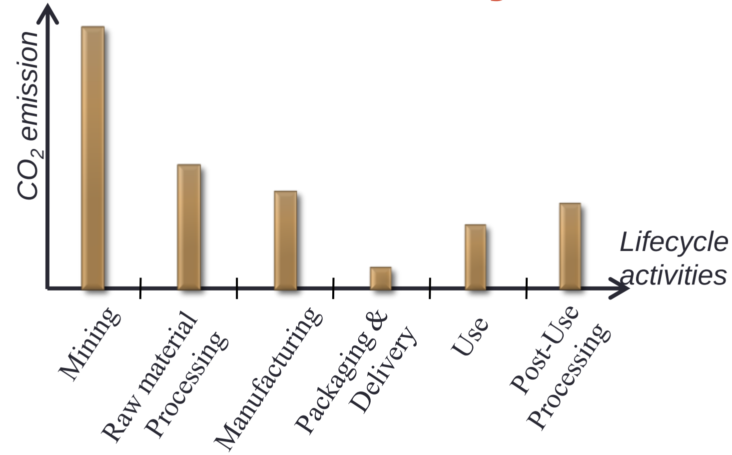
Indicator Categories(Overall)

- **Sustainability**
  - **Environmental Stewardship**
    - Emission
      - Water Effluent
      - Solid Waste
      - Air Emission
    - Resource
      - Material
      - Energy
      - Water Use
      - Land Use
    - (Ambient) Ecosystem
      - Biodiversity
      - Habitat
  - **Economic Growth**
    - Financial Performance
      - Costs
      - Saving
      - Profits
      - Productivity
    - Investment
      - General
      - Green
    - Impacts
      - Investors
      - Employees
      - Government
      - Community
  - **Social Well-being**
    - Employee
      - Health & Safety
      - Development
      - Satisfaction
    - Customer
      - Health & Safety
      - Customer Rights
      - Customer Satisfaction
    - Community
      - Health & Safety
      - Justice
      - Development
  - **Technological Advancement**
    - R&D Staff
    - R&D expenditure
    - Technology imports
    - Scientific papers
    - Patents
    - Technology exports
    - High tech products
  - **Performance Management**
    - Policy & Program
    - Conformance
    - Financial performance
    - Community relations

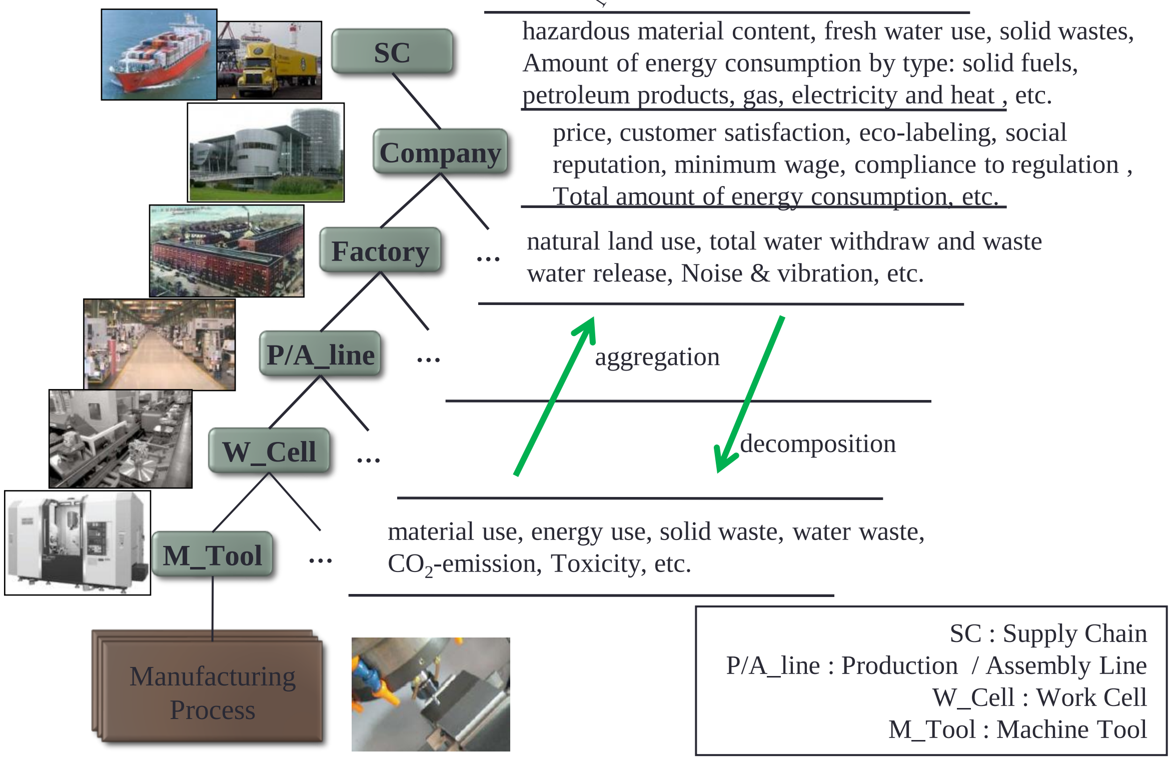
Source: Shaw C. Feng and Che B. Joung, "An Overview of a Proposed Measurement Infrastructure for Sustainable Manufacturing," Proceedings of the 7th Global Conference on Sustainable Manufacturing, Chennai, India, 2010.

Applying Throughout Product Lifecycle

- Indicators applied in a product's Life Cycle.



- Indicators applied at appropriate levels of an organization.



Aggregation Approach

It is an enormous and ineffective undertaking to create a generic sustainability production process model due to complexity of capturing various manufacturing processes across the enterprise and production network, along with life cycle factors.

Building blocks

A more practical and realizable approach is for industry to “compose” production models that are unique for their use yet are built using standardized building blocks.

PART 4

Discussion: Towards Sustainable Manufacturing

Towards Sustainable Manufacturing

Efforts directed at **identifying energy efficient alternatives** that provide opportunities for industries to improve energy efficiency of manufacturing operations executed during various manufacturing processes.

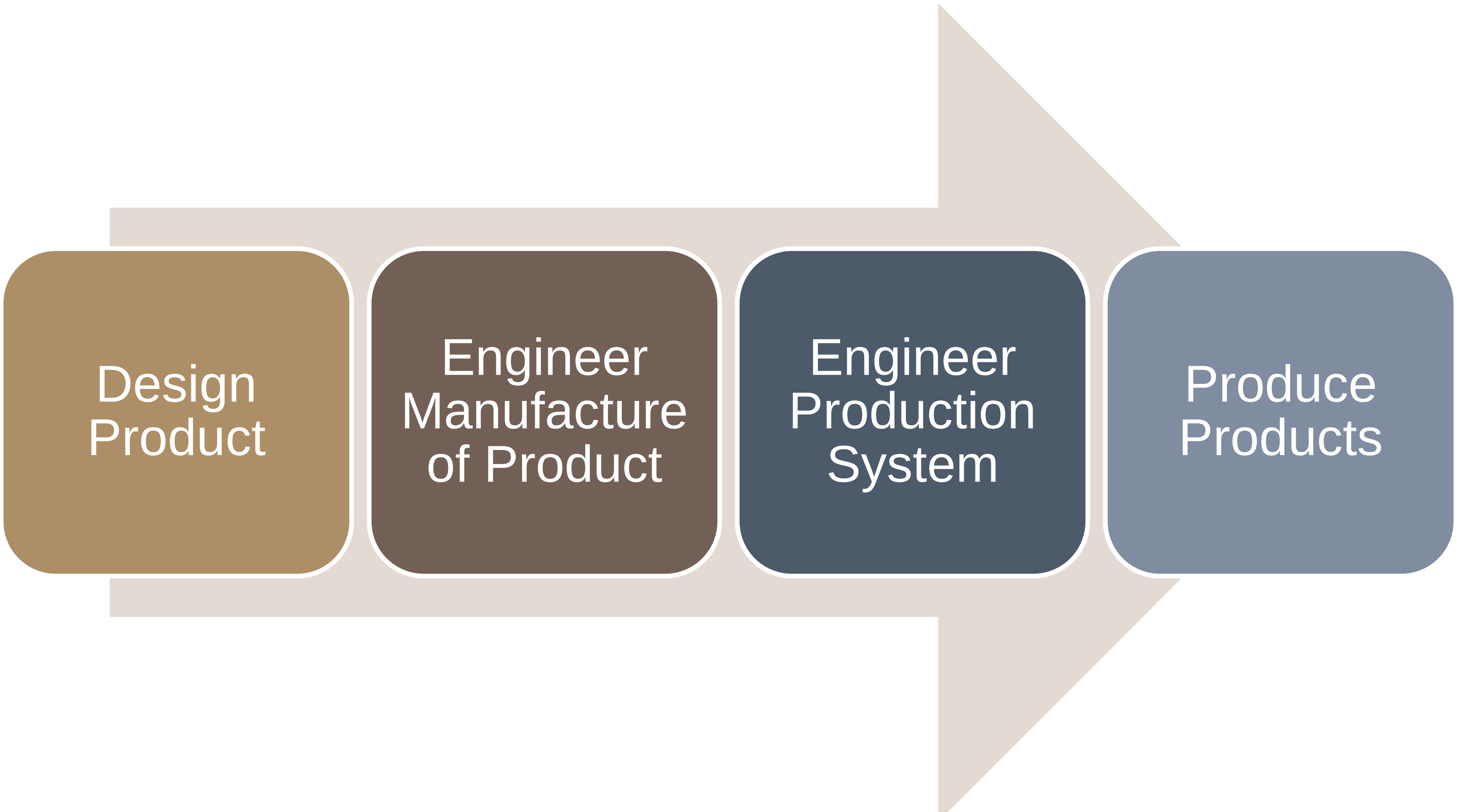
Where do we start?

A vision to the future use of **better planning, modeling and analysis tools** that support sustainable manufacturing and that is based on changes to case studies, metrics, software tools, interface standards, and data sets.

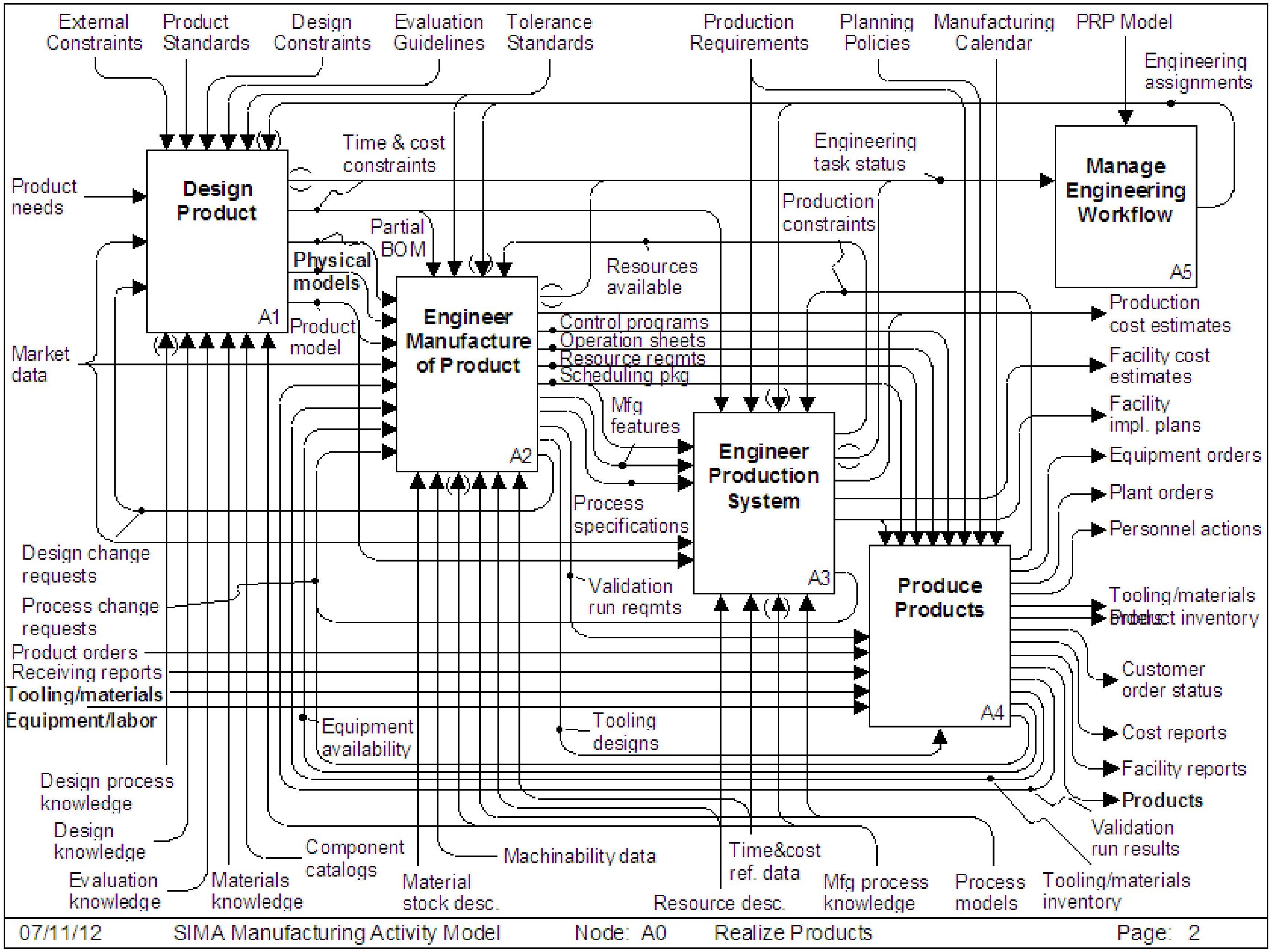
Promote novel ways of planning, modeling and simulation into manufacturing that takes into account sustainability factors such as energy use, wastes generated, pollution, carbon footprint, etc.

Discussion 1

- Product Realization

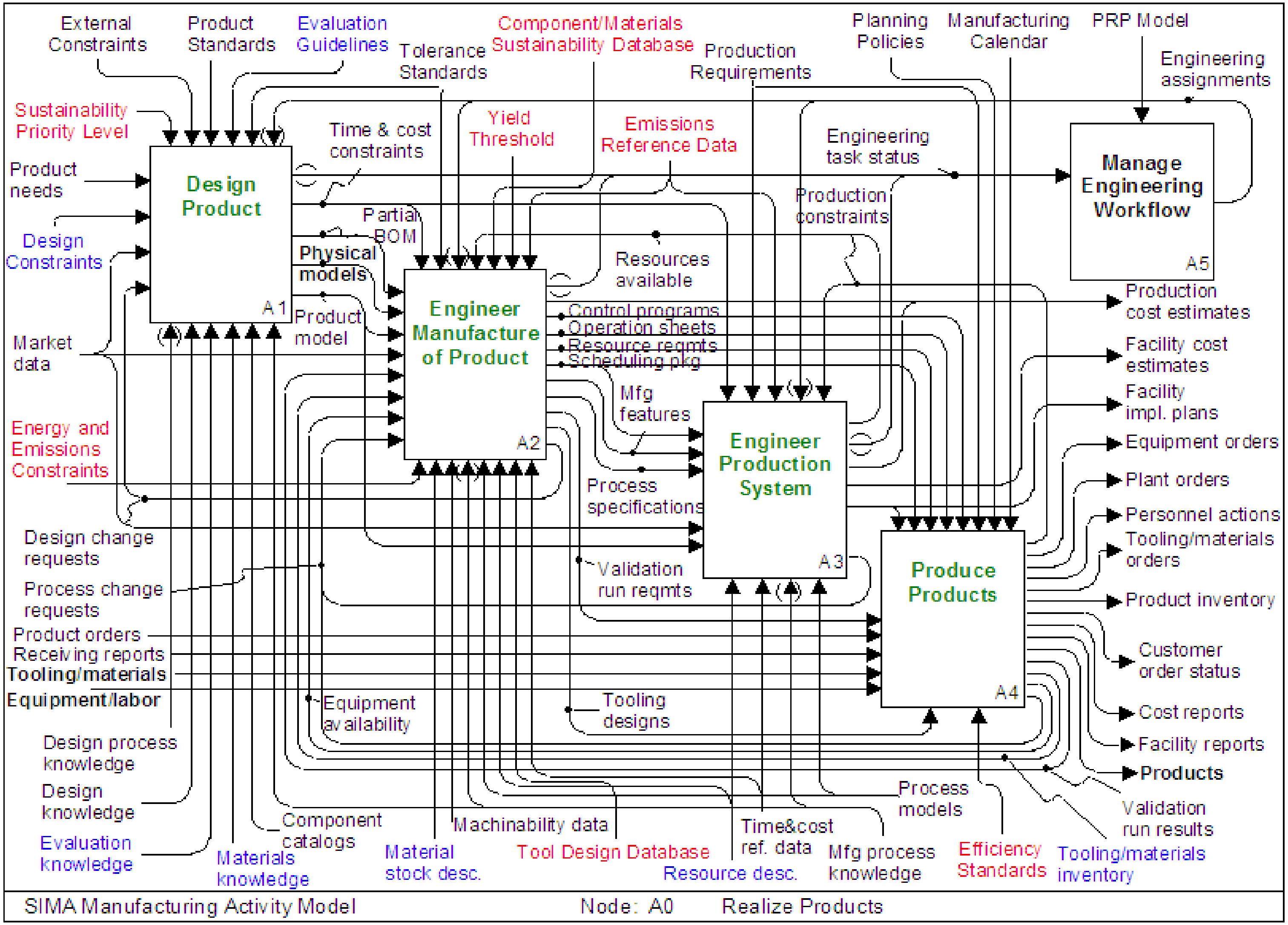


SIMA Architecture



Christopher, Neil, et al. SIMA Reference Architecture Part I. Ed. Edward Barkmeyer. NISTIR 5939

GreenSIMA



https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=915662

Discussion 2

- Introducing sustainability early into manufacturing process planning

How can we or can we introduce sustainability indices to complement cost, quality and time to arrive at alternative sustainable plans in identified manufacturing processes?

Can we obtain reliable manufacturing and energy related data?

Multi-Level Planning Analysis and Simulation

T
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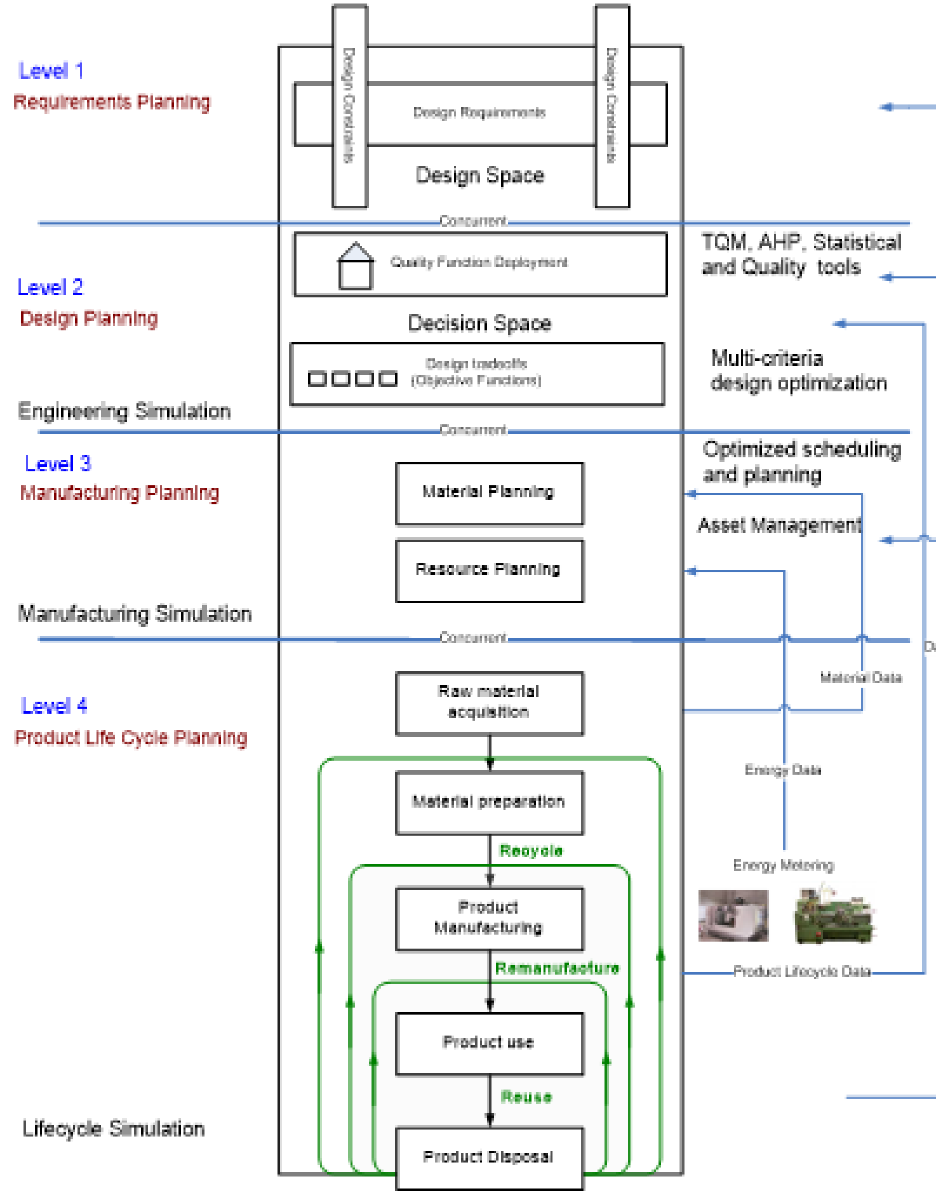
W
A
R
D
S

Integrated Planning and Simulation



Discussion 3

- Energy Monitoring and Mapping

Energy Monitoring and Mapping

Energy Meter Reading

Usefulness

Energy Efficiency trends	Green Manufacturing
Patterns of Performance	Benchmarking
Machine Monitoring	Process Optimization
Preventive Maintenance	Decision Support
Asset Management	
Efficient planning	

Figure: Usefulness of Energy monitoring

Energy/machine/cycle, Energy/machine/batch or Energy/machine/part.

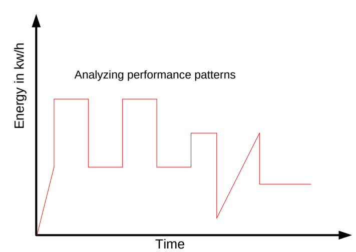


Figure: Energy vs. Time

Example:

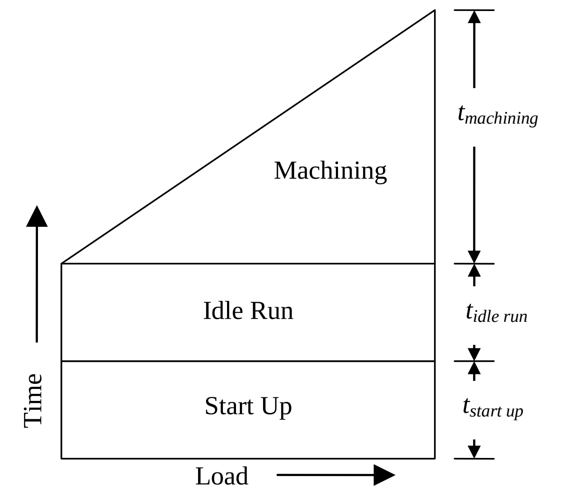


Figure: Load and time variation with respect to the three phases of machining operation

Correlate the type of machining operation/s performed, the material removed, the number of parts machined, and the amount of energy used

Discussion 4

- Additive Manufacturing for Sustainability
- Conventional Manufacturing VS Additive Manufacturing

Quiz time