Symposium on Sustainability and Product Development
IIT, Chicago, August 7-8, 2008

Beyond the 3R's: 6R Concepts for Next Generation Manufacturing:

Recent Trends and Case Studies

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Presentation Outline

- Sustainability: General Background
- Total Product Life-cycle Consideration, including End-of-Life Options
- Sustainable Manufacturing: Definitions, Basic Elements and Most Common Terms
- Product Sustainability Assessment – A Summary
- Case Studies:
  - (a) Machining Processes: Sustainability Evaluation
  - (b) Consumer Electronic Products: Development of a Sustainability Scoring Method for Laser Printers
  - (c) Autobody Design and Manufacture: Total Life-cycle Analysis and Applications
- National and International Trends
- Scientific and Technological Challenges

Sustainability:
General Background

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Sustainability: Definitions

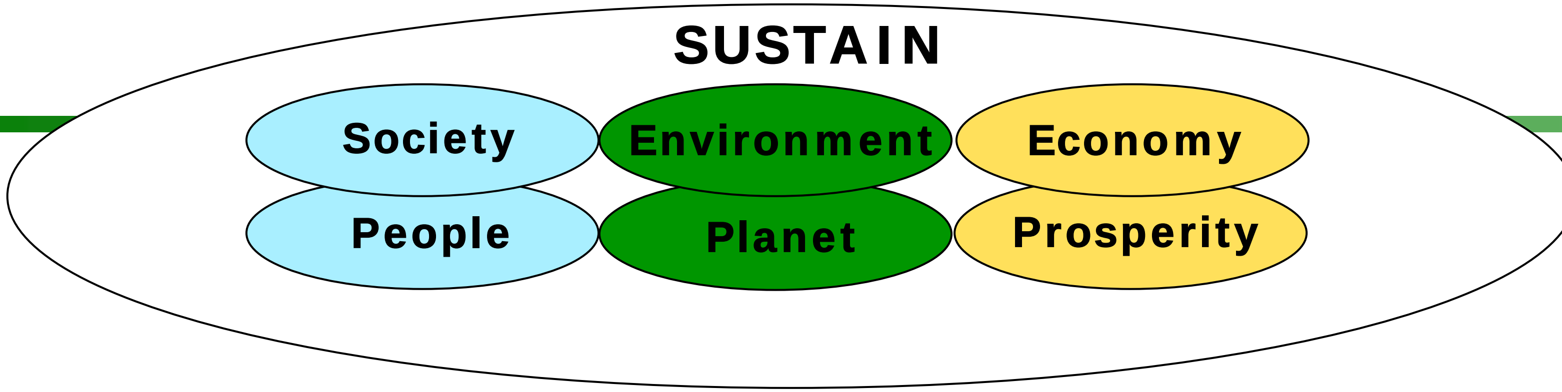
Dr. Gro Harlem Brundtland

- "**Sustainability**" means different things to different people
- There is no universally acceptable definition for the term "sustainability", but the most commonly known definition comes from the 1987 U.N. Brundtland Commission headed by Dr. Gro Harlem Bruntland:

" Meeting the needs of present without compromising the ability of future generations to meet their own needs"

- Some of the most commonly known sustainability terms are:
  (a) Environmental Sustainability
  (b) Economic Sustainability
  (c) Societal Sustainability

Similar Thoughts



OBJECTIVES

Society

- Improved Health
- Safety
- Enhanced Quality of life
- Ethics

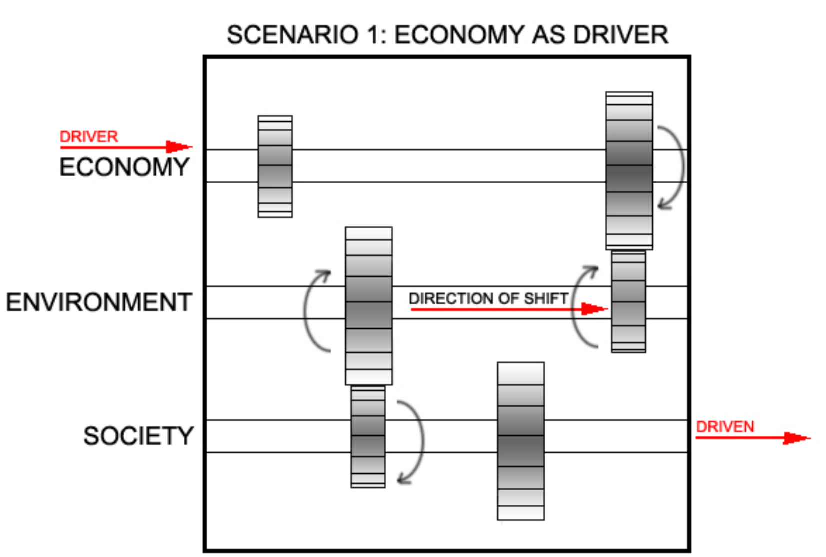
Environment

- Cleaner Air, Water and Soil (Lower Toxicity & Pollution)
- Eco-balance & Efficiency
- Greater Implementation of Regulations, Codes, etc. (Improved Logistics)

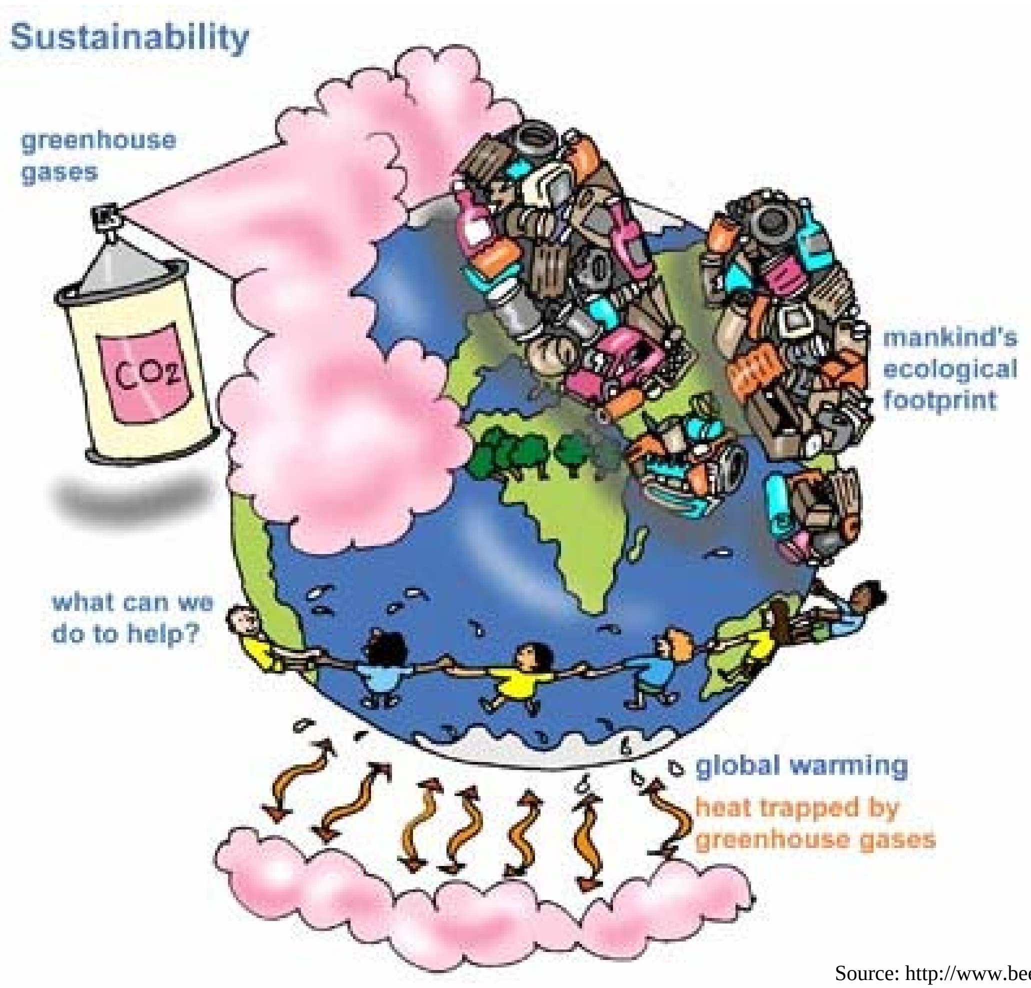
Economy

- New Employment
- Product and Process Innovation (Technological Advancement)
- Large-Scale new business opportunities (3 new "R"s)

Sustainability Drivers



Significance of Sustainability



Source: http://www.beechenhill.co.uk/sustainability.htm

How many Earths have we got ?

?

Can a single earth support the ever-increasing demands for resources ?

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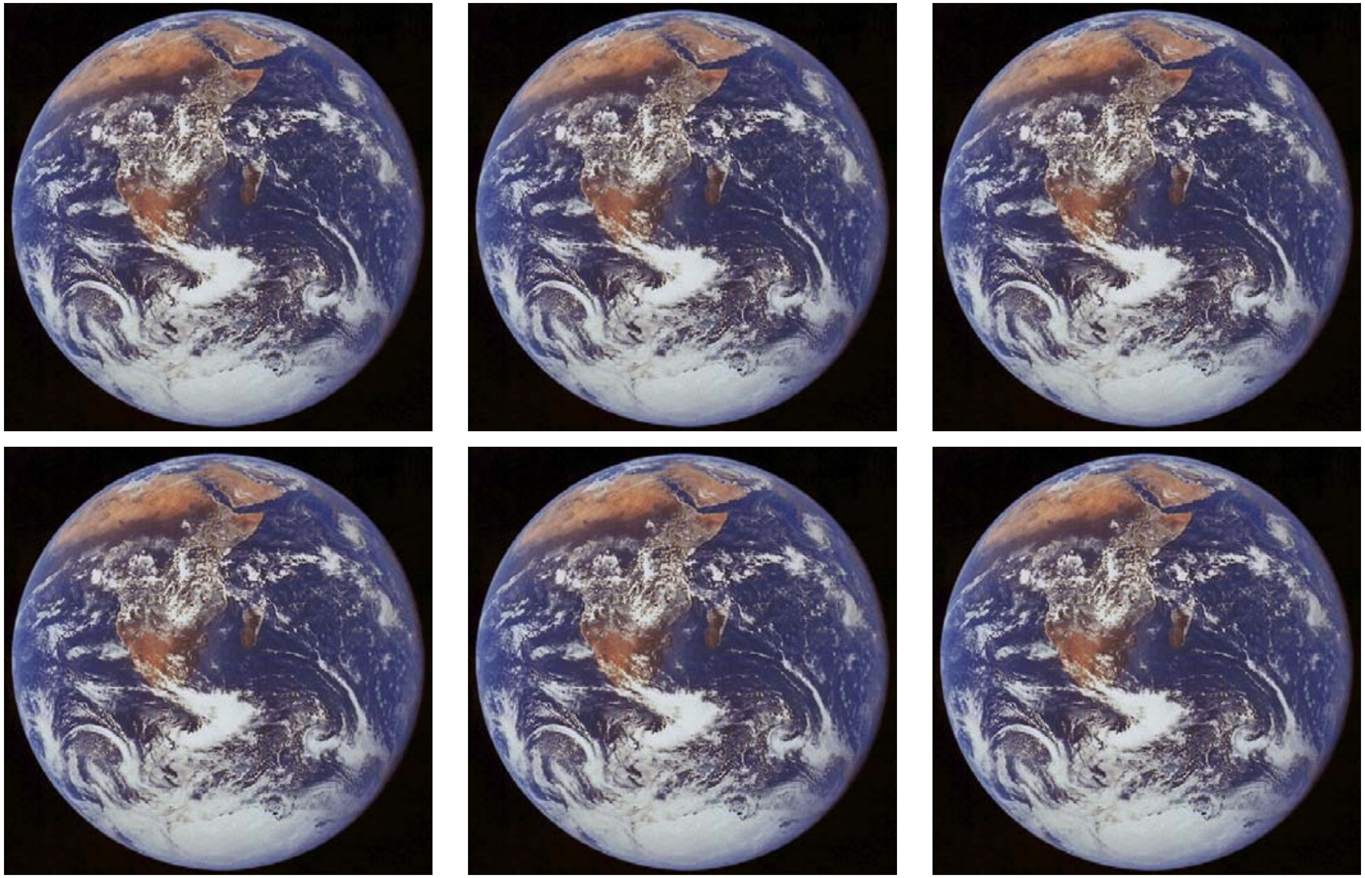
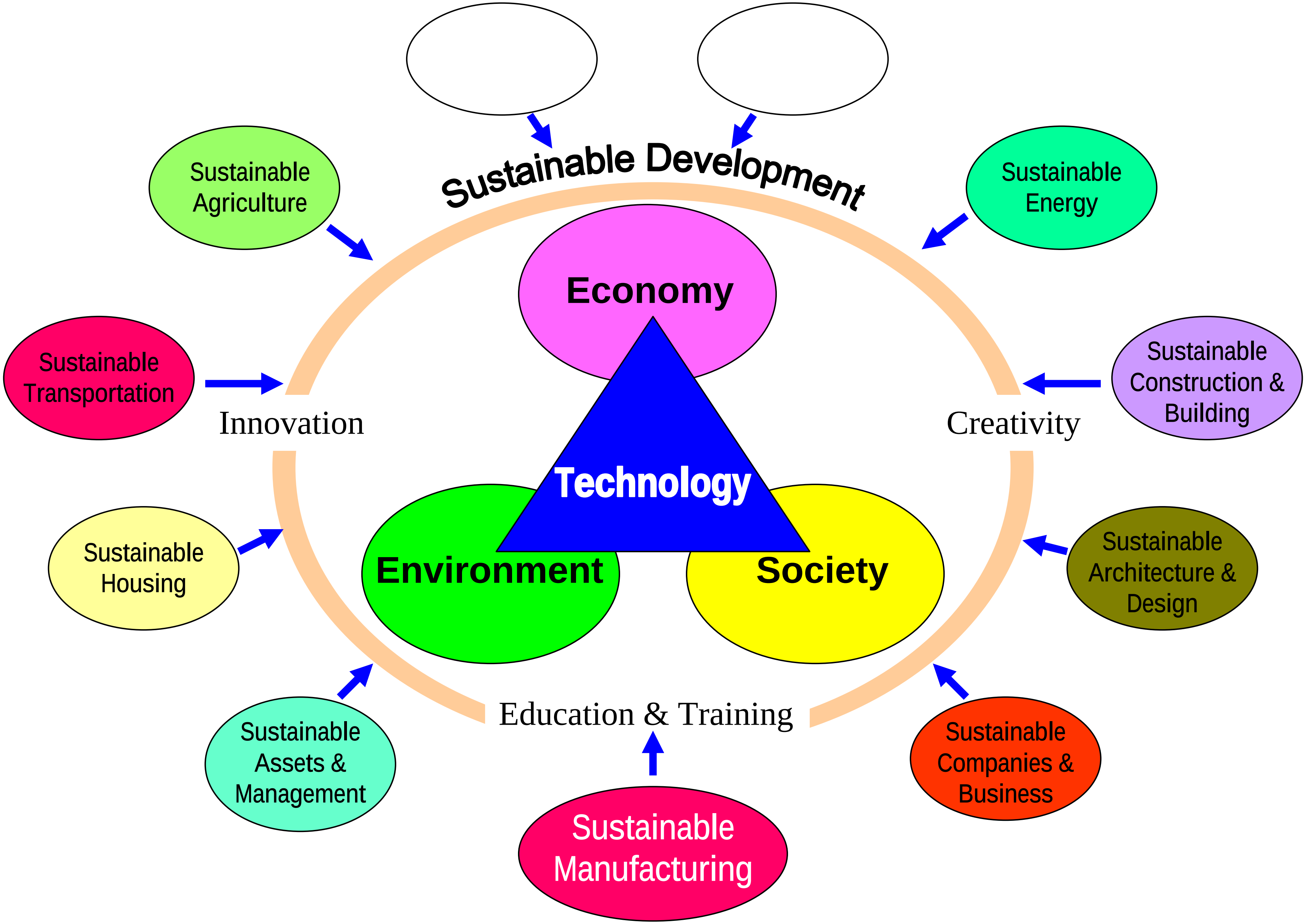
We will need six Earths for all countries to reach the U.S. level of consumption



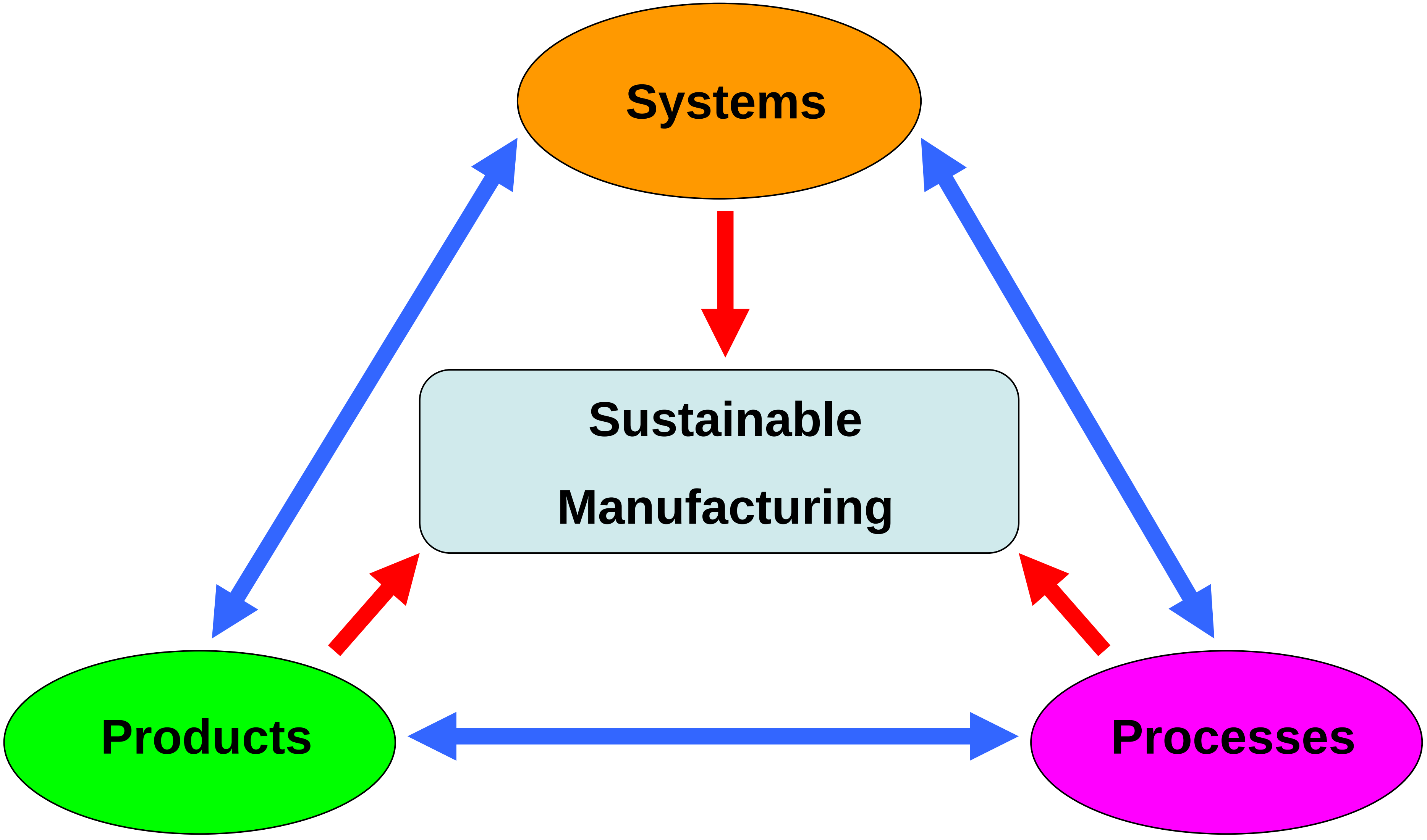
Sustainable Growth

Balances economic, environmental and societal needs

Source: che.chonbuk.ac.kr/data/ BASF%20-%20SH%20Lee%20lecture.ppt



Sustainable Development
Sustainable Agriculture
Sustainable Energy
Economy
Sustainable Transportation
Sustainable Construction & Building
Innovation
Creativity
Technology
Sustainable Housing
Environment
Society
Sustainable Architecture & Design
Sustainable Assets & Management
Education & Training
Sustainable Companies & Business
Sustainable Manufacturing

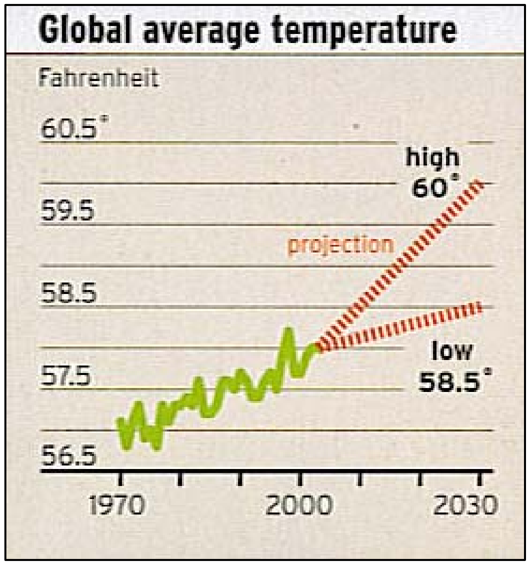


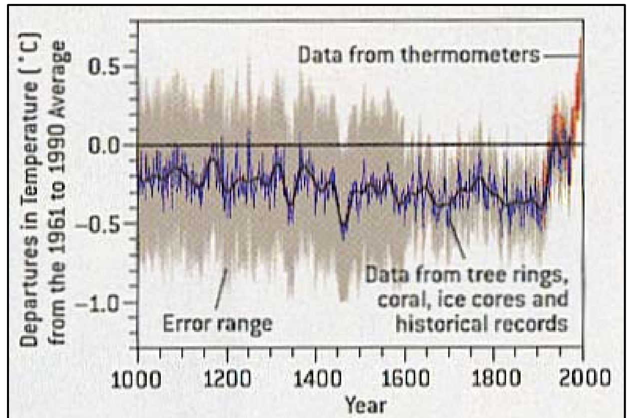
Systems
Sustainable
Manufacturing
Products
Processes

Ever-increasing Traffic Flow and Pollution

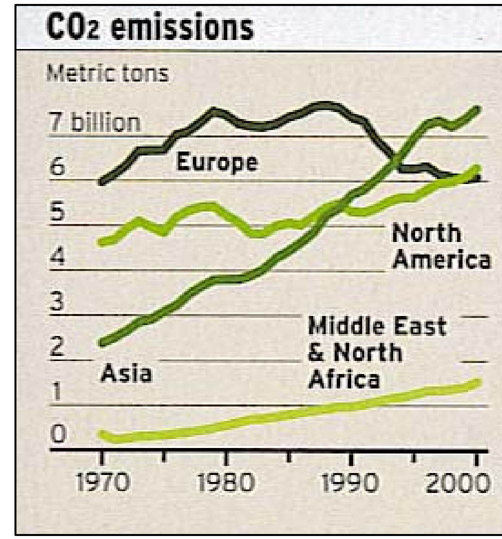
A traffic jam idles motorists in Bangkok; carbon emissions from gasoline-burning cars are one of the causes of global worming
(*Source:* TIME Global Warming, 2007)

Global Warming



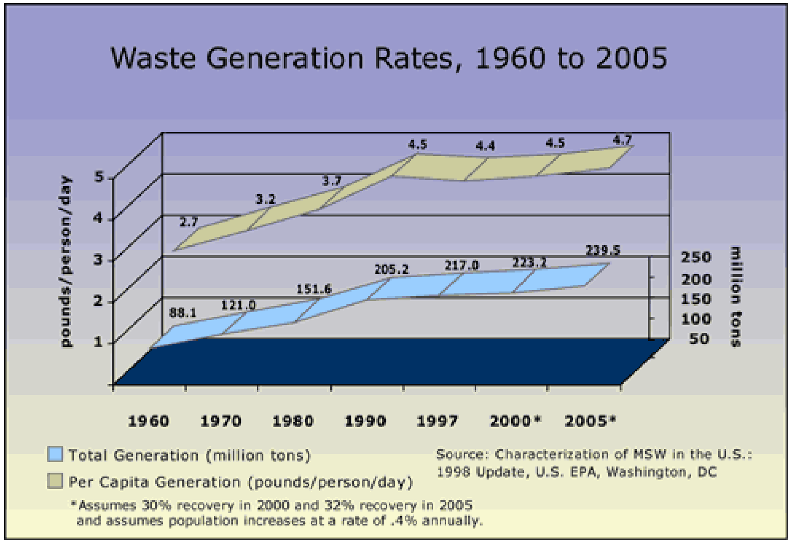


"HOCKEY STICK" graph shows a 20th-century upturn in temperature in the Northern Hemisphere. The error range is greater in the past because the data are sparser.



Source: US News & World Report, July 2004

US Waste Generation Rates and Landfill



PLASTIC SODA BOTTLES.........FOREVER

GLASS BOTTLES..........1 MILLION YEARS

BATTERIES.........100 YEARS

ALUMINUM + TIN CANS.........50 to 100 YEARS

PLASTIC BAGS.........10 to 20 YEARS

PLASTIC-COATED MILK CARTONS.........5 YEARS

ORANGE PEELS.........6 MONTHS

PAPER.........2 to 5 MONTHS

How Long Does It Take for Some Commonly Used Products to Biodegrade ?

Source: http://www.zerowasteamerica.org/images/6-1.gif

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Automotive and Consumer Products

Source: http://www.inmagine.com/pdv031/pdv031027-photo

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World's Annual Material Waste

Source: Office of Technology Assessment, Managing Industrial Solid Wastes from manufacturing, mining, oil, and gas production, and utility coal combustion *(OTA-BP-O-82), February 1992, p. 10.*

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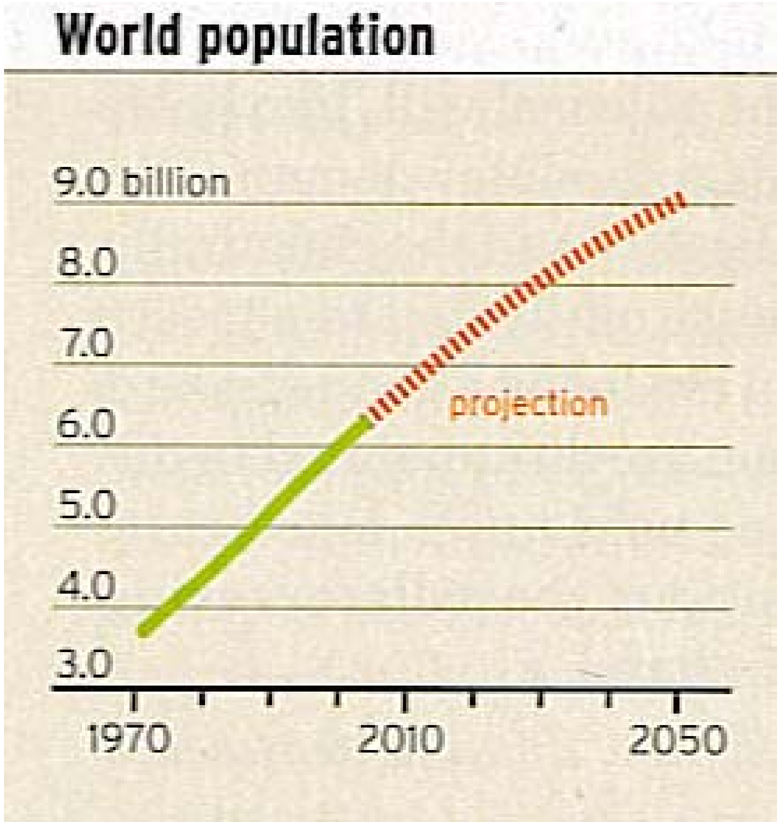
Projected World Population by 2050



Sources: Conservation International; Intergovernmental Panel on Climate Change; International Energy Agency; National Snow and Ice Data Center, University of Colorado–Boulder; Pacific Institute for Studies in Development, Environment, and Security; U.S. Census Bureau; World Resources Institute's EarthTrends and Global Forest Watch; WWF-World Wide Fund for Nature

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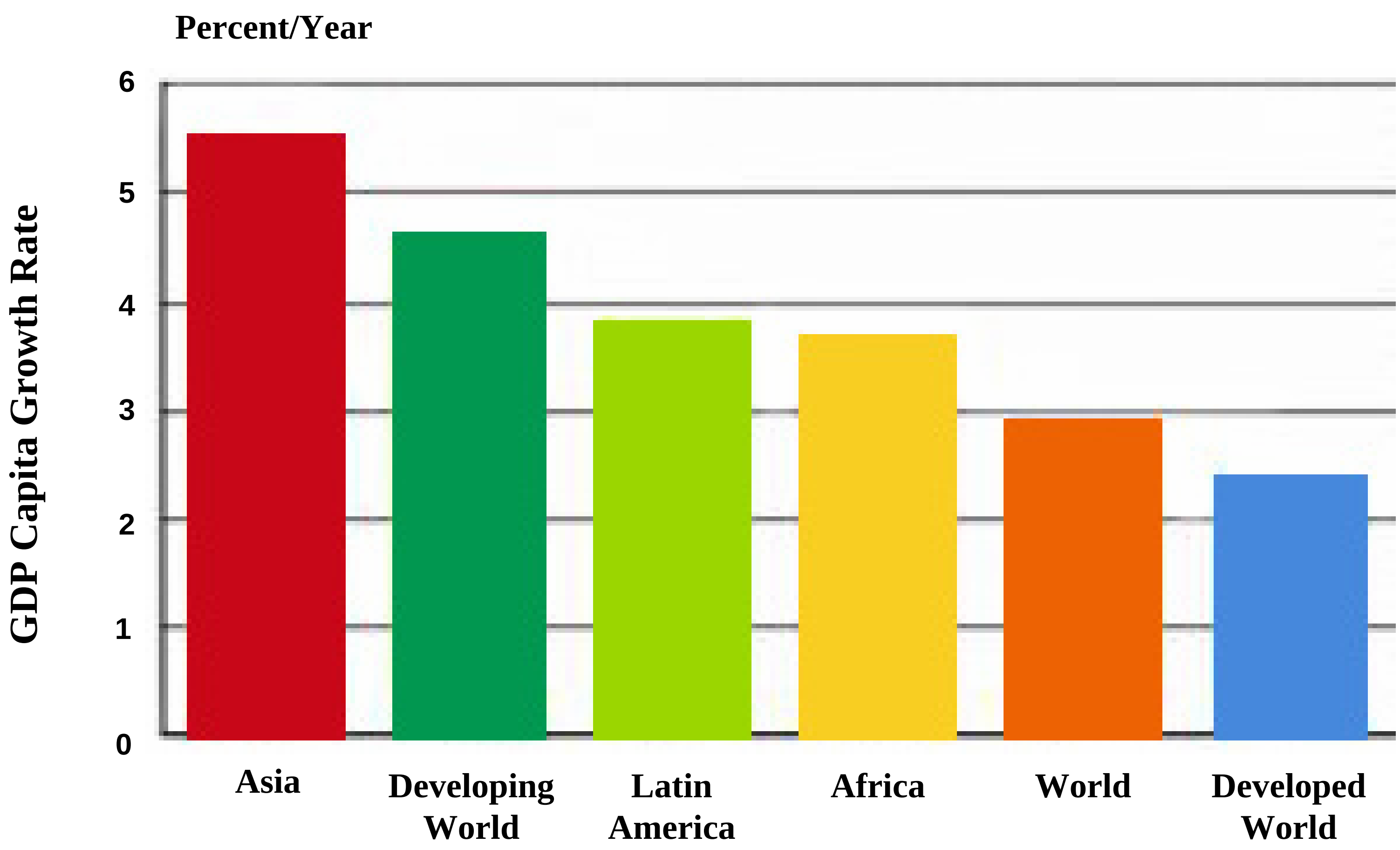
GDP Growth Rate



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Most Common E-waste Components

- Printed circuit boards
- Cathode ray tubes
- Wires and cables
- Mercury switches
- Batteries
- Light generators (e.g., lamps)
- Capacitors and resistors
- Sensors and connectors

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Electronic Waste

- Computer equipment is a complicated assembly of *more than 1,000 components,* many of which are *hazardous and toxic.*

- A major culprit in the hazardous waste areas is the computer monitor and television *cathode ray tube (CRT),* which contains *five to eight pounds of lead.*

- The non-biodegradable refuse from e-waste and other sources often ends up in land-fills or incinerators where toxic substances such as *residues of lead, cadmium, lethal mercury, carcinogenic asbestos, tin plates, arsenic, PVC and plastic waste, lead and cadmium batteries etc.* contaminate the land, water and air, posing serious health hazards and affecting the environment.

Source:
http://www.tribuneindia.com/2004/20040322/login/main1.htm

Legislative Drivers

- Waste Electrical & Electronic Equipment (WEEE) Directive
- Restriction of Hazard Substances (RoHS) Directive
- End of Life Vehicles (EoL)
- Eco-design of End Use Equipment (EuP) Directive

Electronic Waste Covered by the WEEE Legislation















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Ten Categories of Electronic Wastes Covered by the WEEE Legislation

1. **Large Household Appliances** - washing machines, fridge/freezers, microwaves, fans, radiators, large appliances for heating rooms/beds/seating furniture
2. **Small Household Appliances** - vacuum cleaners, irons, electric knives, clocks, scales
3. **IT and Telecom.-** computers, calculators, phones
4. **Consumer Equipment** - radios, TVs, VCRs
5. **Lighting Equipment** - luminaires (excluding household), straight/compact fluorescent lamps, otherlighting of equipment for spreading or controlling light (excluding filament bulbs)
6. **Electrical/Electronic Tools** (excluding large scale stationary industrial tools) - drills, sewing machines, sprayer/spreaders, lawn mowers
7. **Toys & Leisure/Sports Equipment** - train sets, video games, cycle computers
8. **Medical Devices** (excluding implanted and infected devices) (Excluded from RoHS) - dialysis, nuclear medicine, freezers
9. **Monitoring & Control Instruments** (Excluded from RoHS) - smoke detectors, thermostats, measuring/weighing appliances
10. **Automatic Dispensers** – coffee/drinks machines, ATMs.

Total Life-cycle Considerations and End-of-life Options

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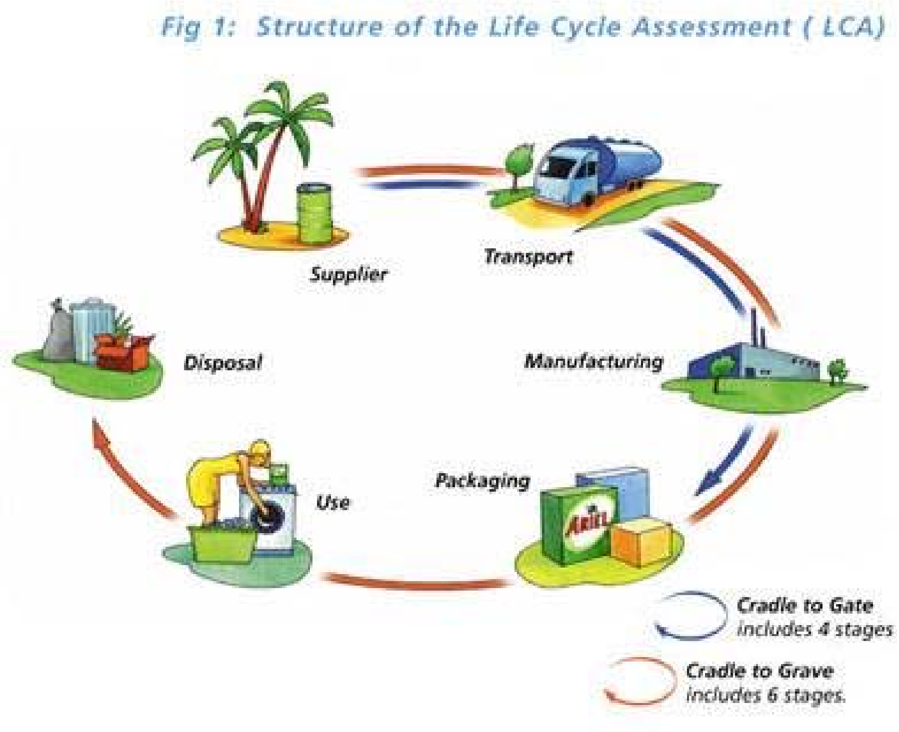
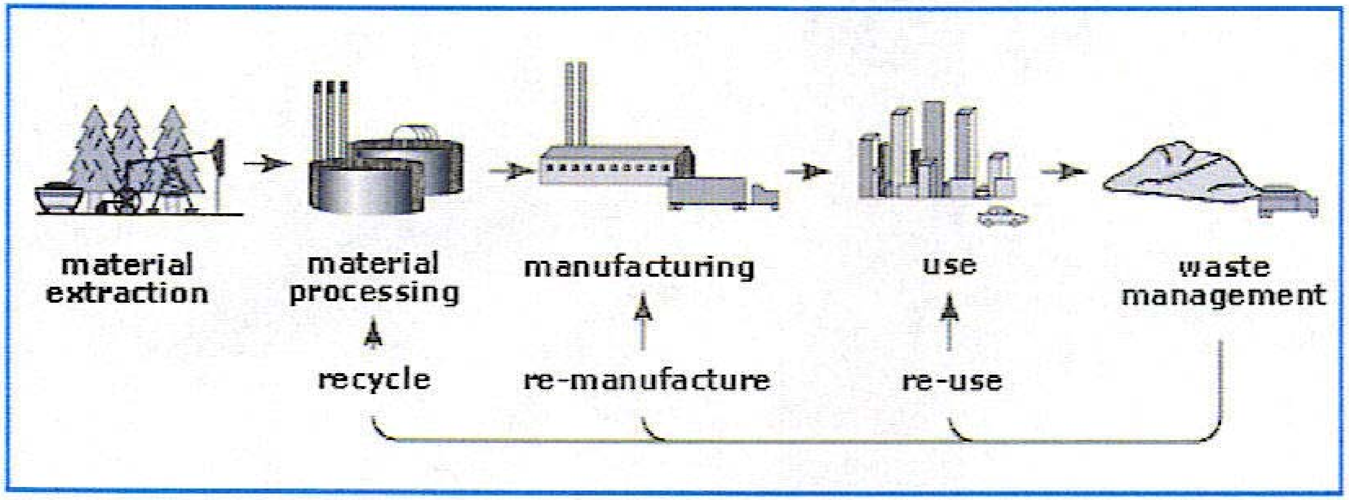
Changing Faces of Life-cycle Progression



Ref: http://www.scienceinthebox.com/en_UK/sustainability/lifecycleassessment_en.html

Cradle to Cradle Approach

Figure 1: The life cycle of a product



(Life-cycle Thinking – http://www.ami.ac.uk/courses/topics/0109_lct/)

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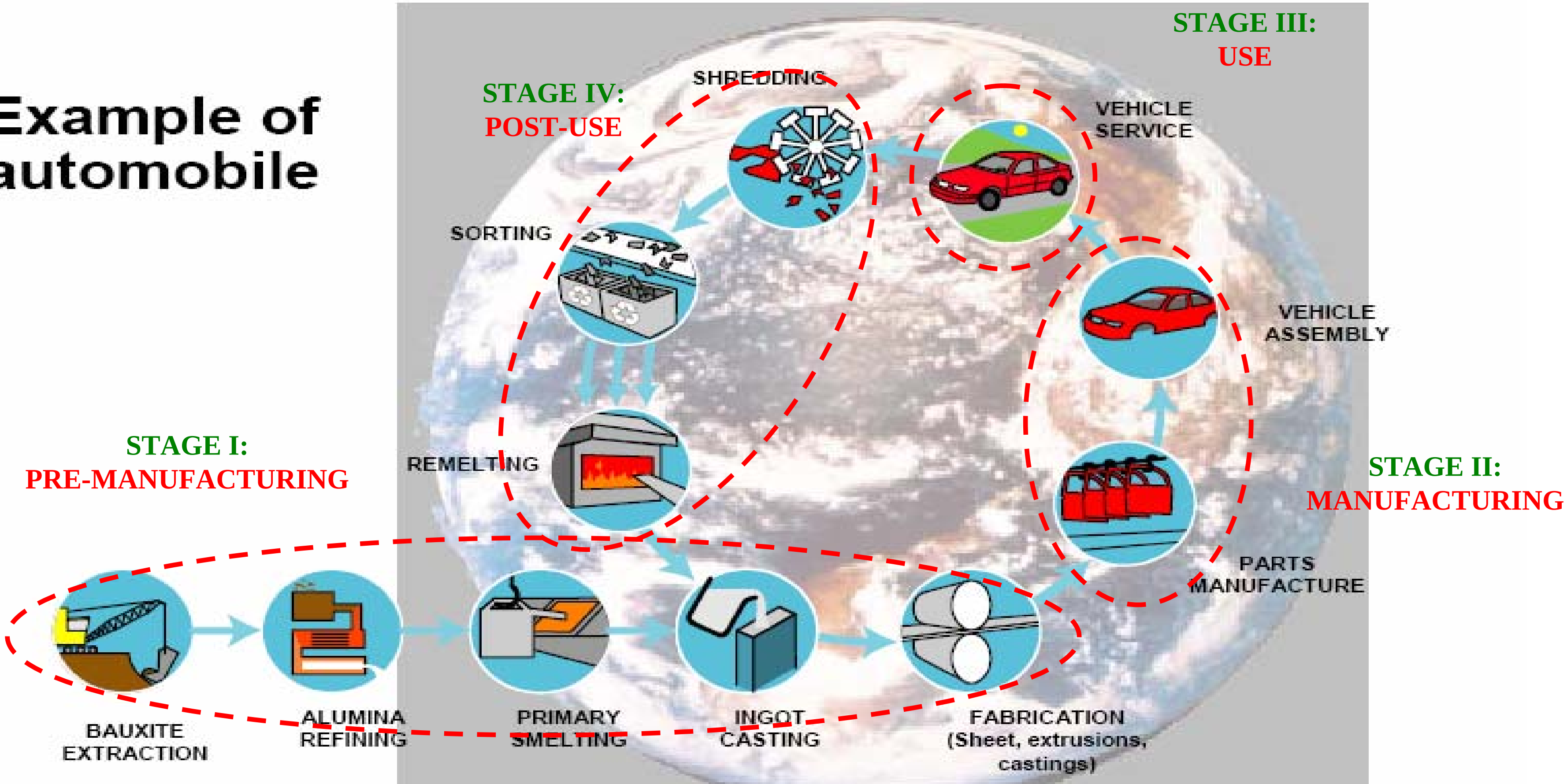
Life-Cycle Stages of a Manufactured Product

Example of automobile



Source: ALCAN: Life Cycle Management in the aluminum industry

Take It Back!

Extended Producer Responsibility (EPR) Laws

- Require companies to take back products after their useful life
- The goal is to induce manufacturers to
  - # eliminate unnecessary parts
  - # forgo unneeded packaging
  - # design products that can easily be **disassembled**, **recycled**, **remanufactured**, or **reused**

Source: http://www.globalchange.umich.edu/gctext/Leo%20Wiegman/Moving%20Toward%20aonomy%20Jan05.ppt

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Take It Back! *(Contd.)*

- Several countries in Europe, Asia, and Latin America have implemented EPR legislation for a wide range of products, including:
  - packaging
  - electric and electronic equipment
  - vehicles
  - tires
  - batteries
  - office machinery

Source: http://www.globalchange.umich.edu/gctext/Leo%20Wiegman/Moving%20Toward%20aonomy%20Jan05.ppt

products processes RISE systems
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Sustainable Manufacturing:
Definitions, Basic Elements and Most Common Terms

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Sustainable Manufacturing: *Terms and Definitions*

- Environmentally-responsible manufacturing
- Environmentally benign manufacturing
- Cleaner processes (Green manufacturing)
- Economically advantageous manufacturing (Lean manufacturing)
- Energy-efficient manufacturing
- Manufacturing using renewable source of energy

Sustainable Manufacturing: *Basic Elements*

Expectations:

- Reducing energy consumption
- Reducing waste
- Reducing material utilization
- Enhancing product durability
- Increasing operational safety
- Reducing toxic dispersion
- Reducing health hazards/Improving health conditions
- Consistently improving manufacturing quality
- Improving recycling, reuse and remanufacturing
- Maximizing sustainable sources of renewable energy

Sustainable Manufacturing: *Design Objectives*

- Designing for Repair, Reuse and Recycling
- Designing for Waste Minimization
- Designing for Product Disassembly
- Designing for Energy Efficiency
- Designing for Product Demanufacturing
- Designing for Remanufacturing
- Designing for Serviceability
- Designing for Reduced Materials Use
- Design and Manufacture for Reduced Costs
- Sustainable Design and Manufacture (Designing for Sustainability)

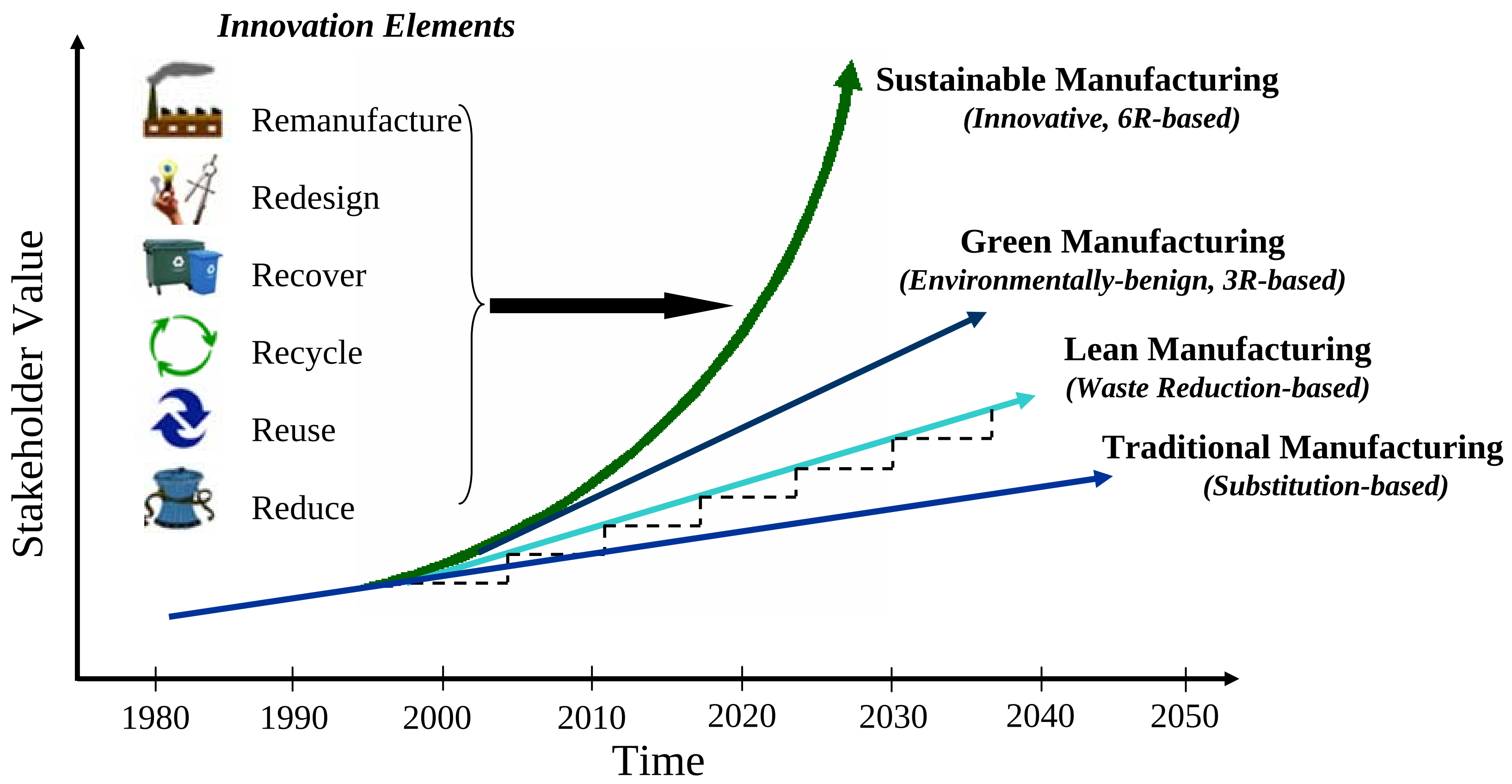
Sustainable Manufacturing: *The Paradigm "E"*

- Ecology
- Environment
- Energy
- Economy
- Employment
- Empowerment
- Education
- Excellence

Sustainable Manufacturing: *Definition*

Design and manufacture of high quality/performance products with improved/enhanced functionality using energy-efficient, toxic-free, hazardless, safe and secure technologies and manufacturing methods utilizing optimal resources and energy by producing minimum wastes and emissions, and providing maximum recovery, recyclability, reusability, remanufacturability, with redesign features, and all aimed at enhanced societal benefits and economic impact.

Evolution of Sustainable Manufacturing



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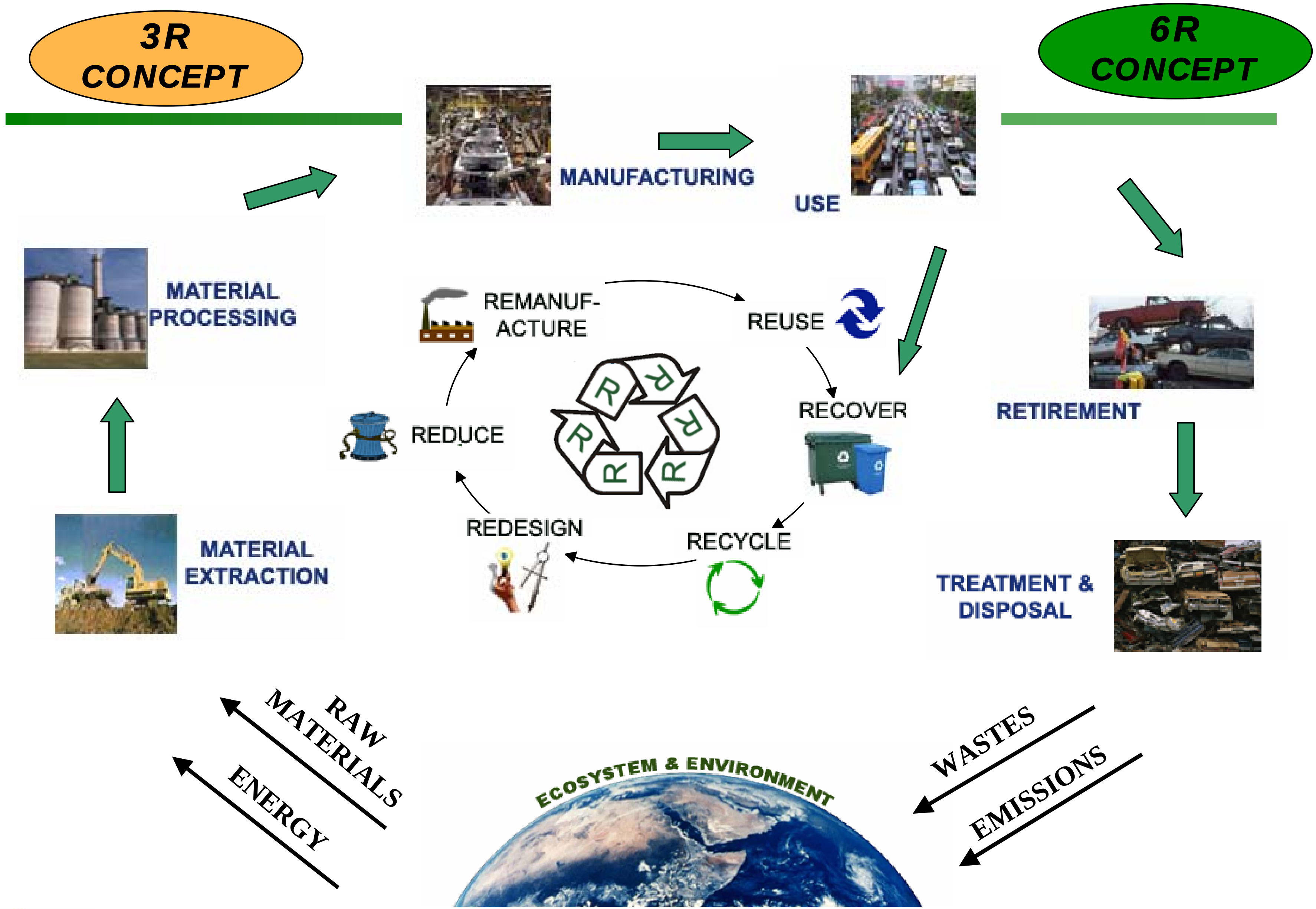

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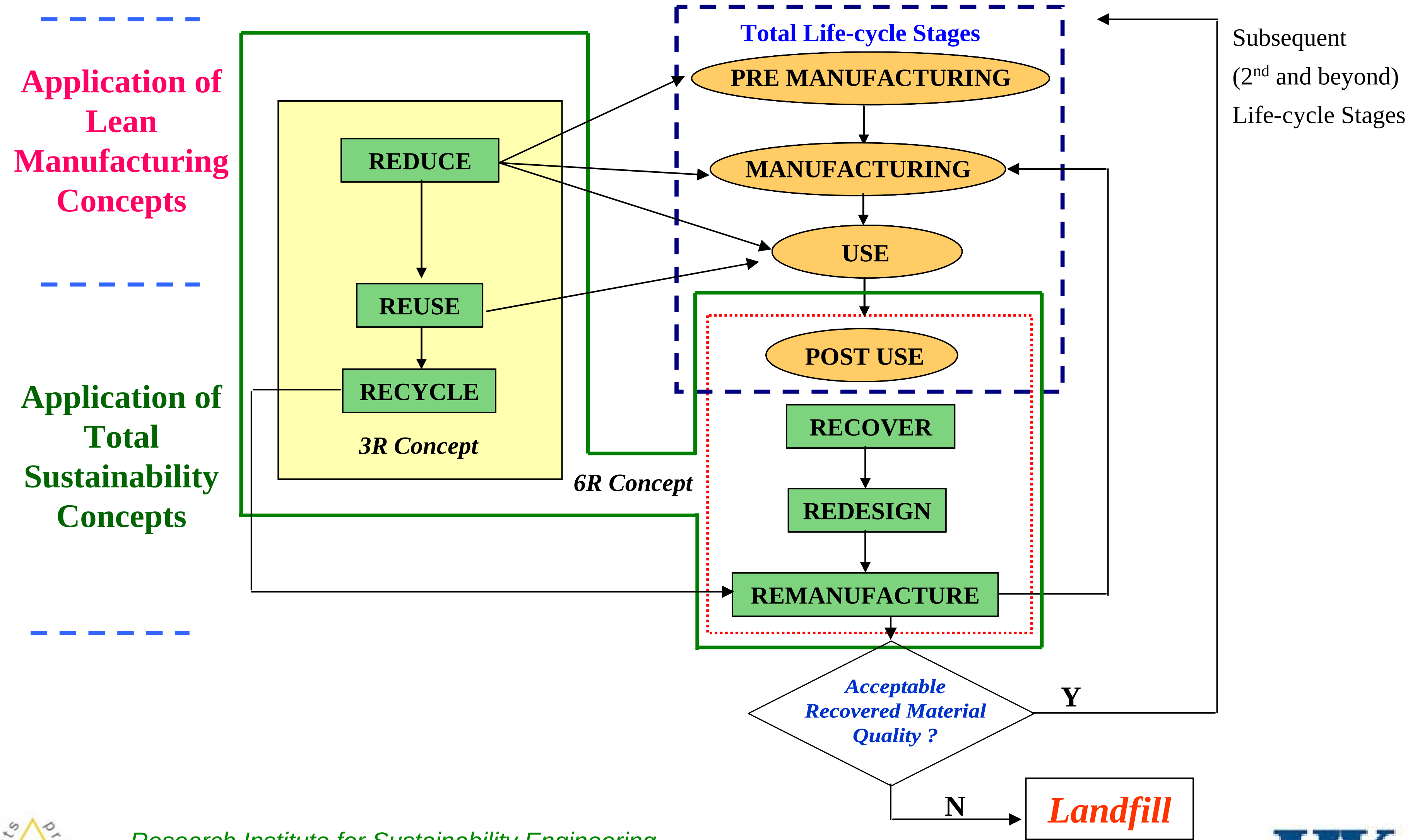
Material flow and its Interaction with 6Rs



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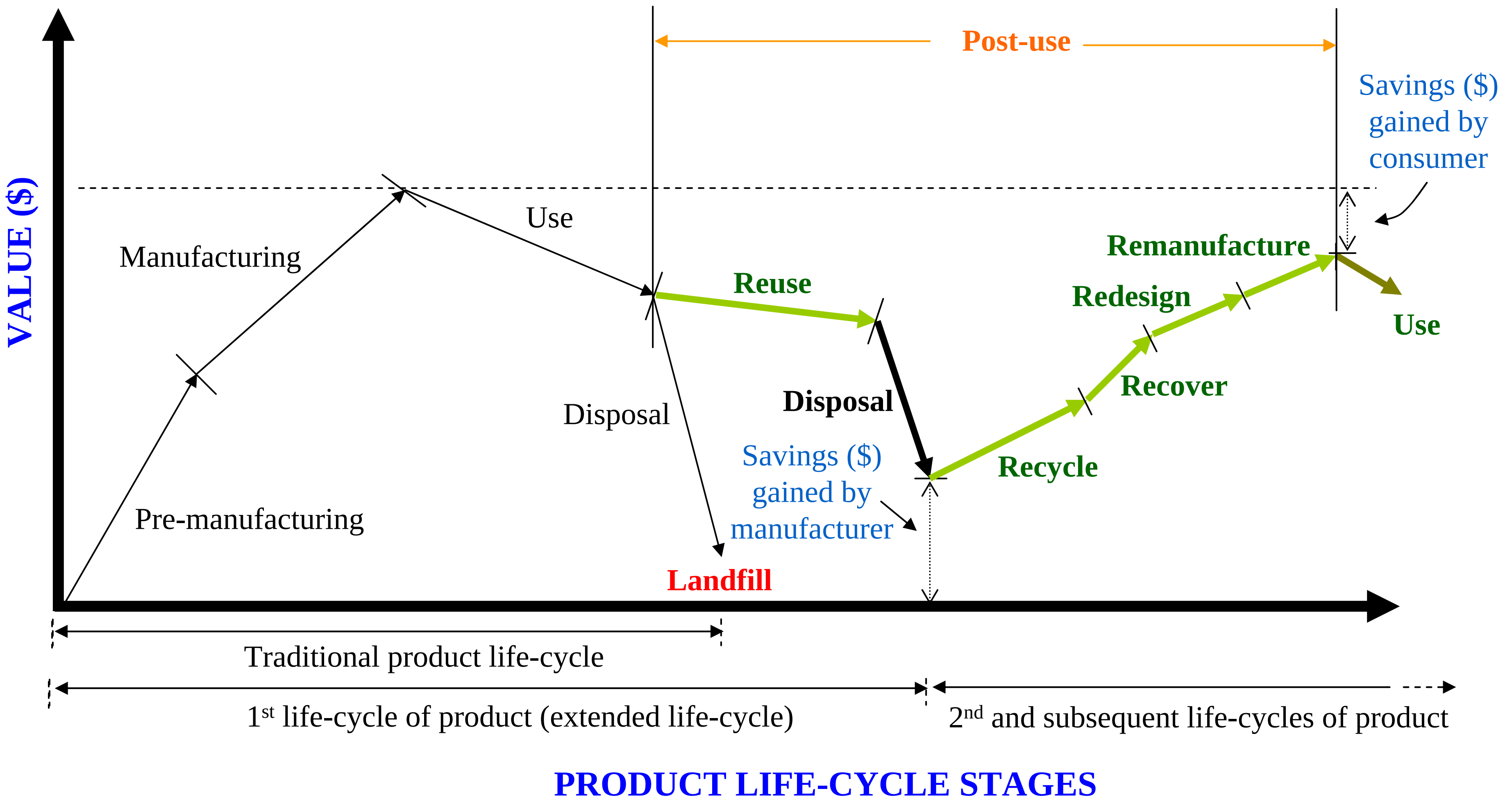
Product Value Gained from 6Rs



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Product Sustainability Assessment: *A Summary*

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Selected Eco-labels and Products Standards

Product Specific Standards

- Forest Stewardship Council Certified Wood
- Clean Vehicles
- Certified Green-e Program
- US Green Building Council LEED Rating System
- Cleaner and Greener Certification

Overall Standards

- Natural Step System Conditions
- Nordic Swan Eco-label
- Green Seal Product Standards
- Life Cycle Assessment (LCA)
- European Union Eco-label
- Energy Star Eco-label
- Sustainable Textile Standard

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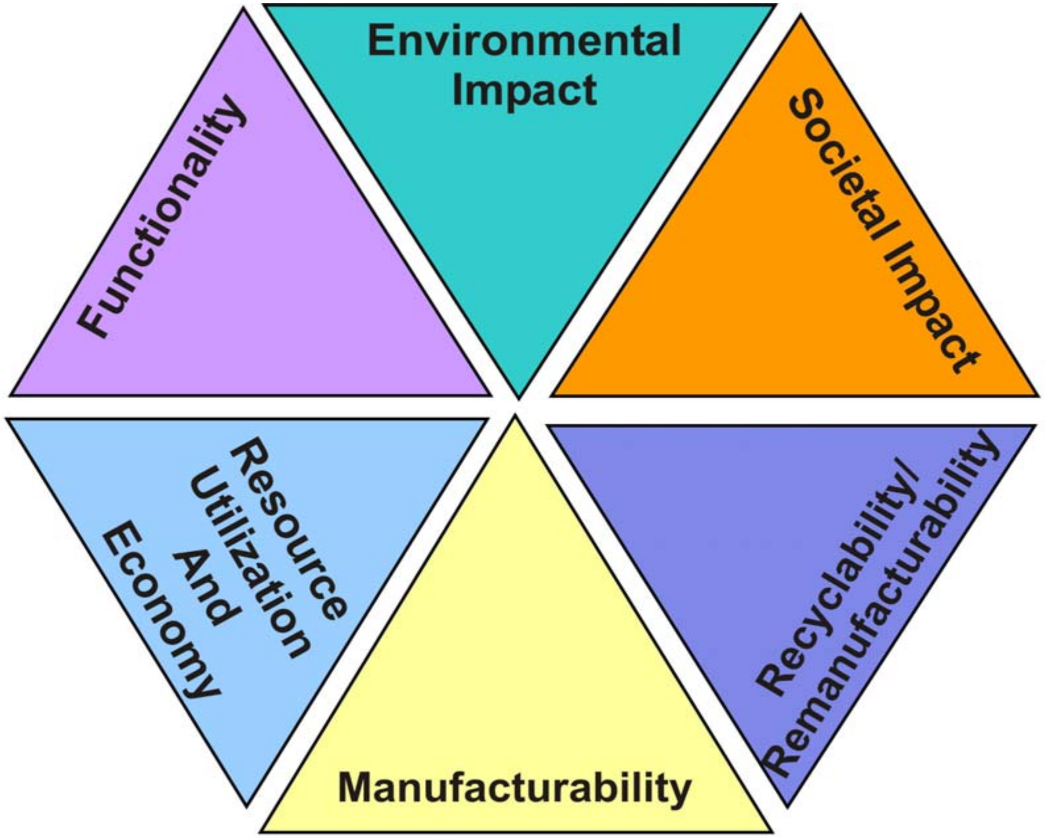
Factors Affecting Product Sustainability



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Integral Elements of Design for Sustainability (DFS)

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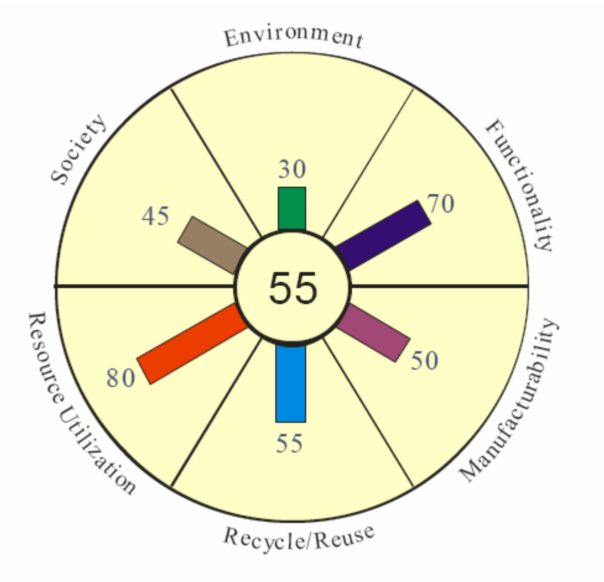
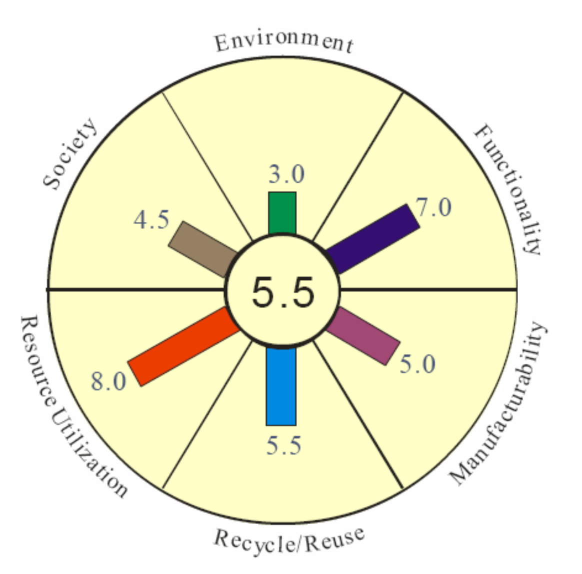
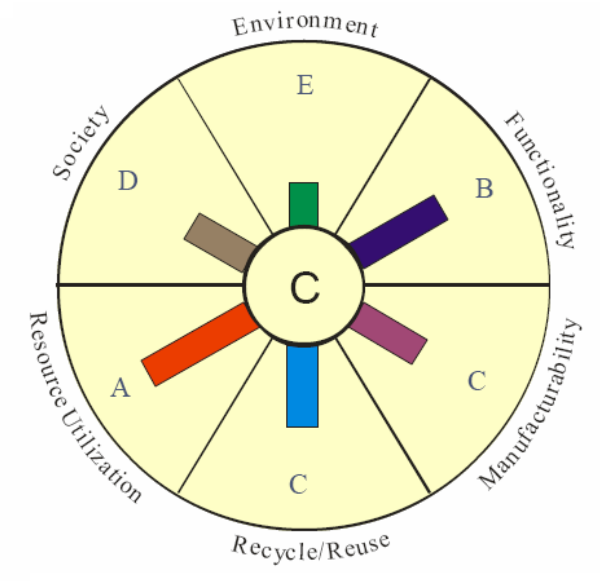
Product Sustainability Assessment







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Methodology for Calculating Product Sustainability Index (PSI)

A new 3 step methodology is introduced.

Step 1:

- The product developers need to identify potential influencing factors based on national/international regulations, federal and state laws, to be important factors from their own perspective.
- Focus on all three components of sustainability.
- Focus on all four life-cycle stages.

Step 2:

- A 3x4 matrix that represents all components of sustainability and all four life-cycle stages.
- Allocate a score/rating between 0-10 for each influencing factor.
- Weighting can be applied to the influencing factors based importance.
- Non-quantifiable factors can be scored based on designers' experience and judgment.

Analytical Foundation of Product Design for Sustainability

Step 3:
Methodology for Calculating PSI

$$PSI_{(en\_pm)} = \{[\sum_{i=1}^{n} IF_{(en\_pm)_i}]/(n*10)\}*100\%$$

$PSI_{(en\_pm)}$	=	Product Sustainability Index for Environment component of Pre-manufacturing stage
$IF_{(en\_pm)}$	=	Influencing Factor rated on a scale of 0-10 for the Environment component of Pre-manufacturing stage
n	=	Number of influencing factors considered

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Analytical Foundation of Product Design for Sustainability (contd.)

$$PSI_{en} = [PSI_{(en\_pm)} + PSI_{(en\_m)} + PSI_{(en\_u)} + PSI_{(en\_pu)}]/4$$

where,

$PSI_{(en\_pm)}$	=	Product Sustainability Index for Environment component of Pre-manufacturing stage
$PSI_{(en\_m)}$	=	Product Sustainability Index for Environment component of Manufacturing stage
$PSI_{(en\_u)}$	=	Product Sustainability Index for Environment component of Use stage
$PSI_{(en\_pu)}$	=	Product Sustainability Index for Environment component of Post-use stage

The overall product sustainability index (PSI_{TLC}) for a product over its total life-cycle

$$PSI_{TLC} = PSI_{so} + PSI_{en} + PSI_{ec}$$

PSI_{so}	=	PSI for Society Component
PSI_{en}	=	PSI for Environment Component
PSI_{ec}	=	PSI for Economy Component

A Framework for Comprehensive Total Life-cycle Evaluation Matrix for Product Sustainability

Sustainability Components		Pre-manufacturing	Score out of 10	Manufacturing	Score out of 10	Use	Score out of 10	Post-use	Score out of 10		
		Influencing Factors in the Product Life-cycle Stages									
	Environment	Material Extraction	7	Production Energy Used	7	Emissions	9	Recyclability	7		
		Design for Environment	8	Hazardous Waste Produced	9	Functionality	8	Remanufacturability	8		
		Material Processing	6	Renewable Energy Used	8	Hazardous Waste Generated	9	Redesign	7	(%) PSI_{en} =	77.29
								Landfill Contribution	7		
		(%) $PSI_{(en\_pm)}$ =	70	(%) $PSI_{(en\_m)}$ =	80	(%) $PSI_{(en\_u)}$ =	86.67	(%) $PSI_{(en\_pu)}$ =	72.5		
	Society	Worker Health	8	Work Ethics	7	Product Pricing	7	Take-back Options	7		
		Work Safety	8	Ergonomics	7	Human Safety	9	Re-use	6		
		Ergonomics	7	Work Safety	8	Upgradeablility	7	Recovery	7	(%) PSI_{so} =	73.54
						Complaints	8				
		(%) $PSI_{(so\_pm)}$ =	76.67	(%) $PSI_{(so\_m)}$ =	73.33	(%) $PSI_{(so\_u)}$ =	77.5	(%) $PSI_{(so\_pu)}$ =	66.67		
	Economy	Raw Material Cost	6	Production Cost	6	Maintenance Cost	7	Recycling Cost	7		
		Labor Cost	3	Packaging Cost	7	Repair Cost	6	Disassembly Cost	8		
				Energy Cost	8	Consumer Injury Cost	8	Disposal Cost	4	(%) PSI_{ec} =	61.25
				Transportation Cost	5	Consumer Warranty Cost	7	Remanufacturing Cost	7		
		(%) $PSI_{(ec\_pm)}$ =	45	(%) $PSI_{(ec\_m)}$ =	65	(%) $PSI_{(ec\_u)}$ =	70	(%) $PSI_{(ec\_pu)}$ =	65		
		(%) PSI_{pm} =	63.89	**(%) PSI_{m} =**	72.78	**(%) PSI_{u} =**	78.06	**(%) PSI_{pu} =**	68.06	**(%) PSI_{TLC} =**	70.69

Symbol				
Score	Excellent 85-90%	Good 70-84%	Average 50-69%	Poor < 50%

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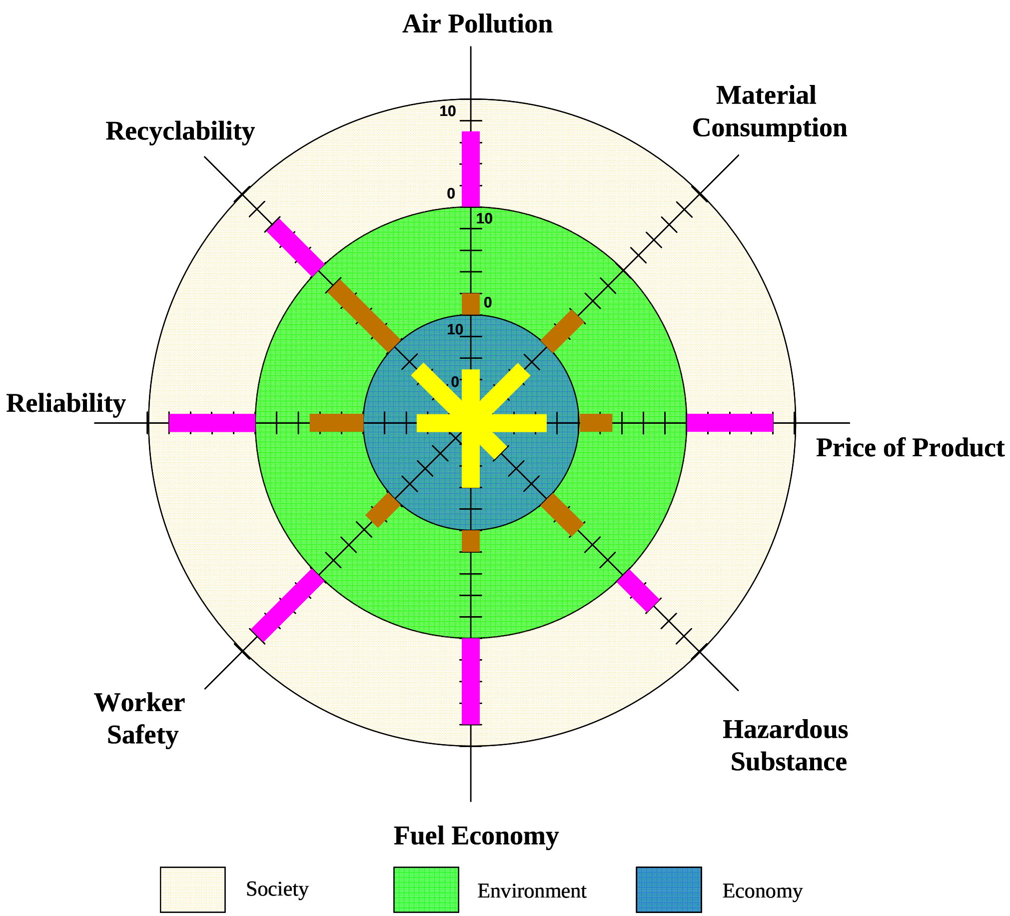
Generic Product Sustainability Score



A Generic product sustainability score showing the influence of various factors on society, environment and economy and their sustainability ratings

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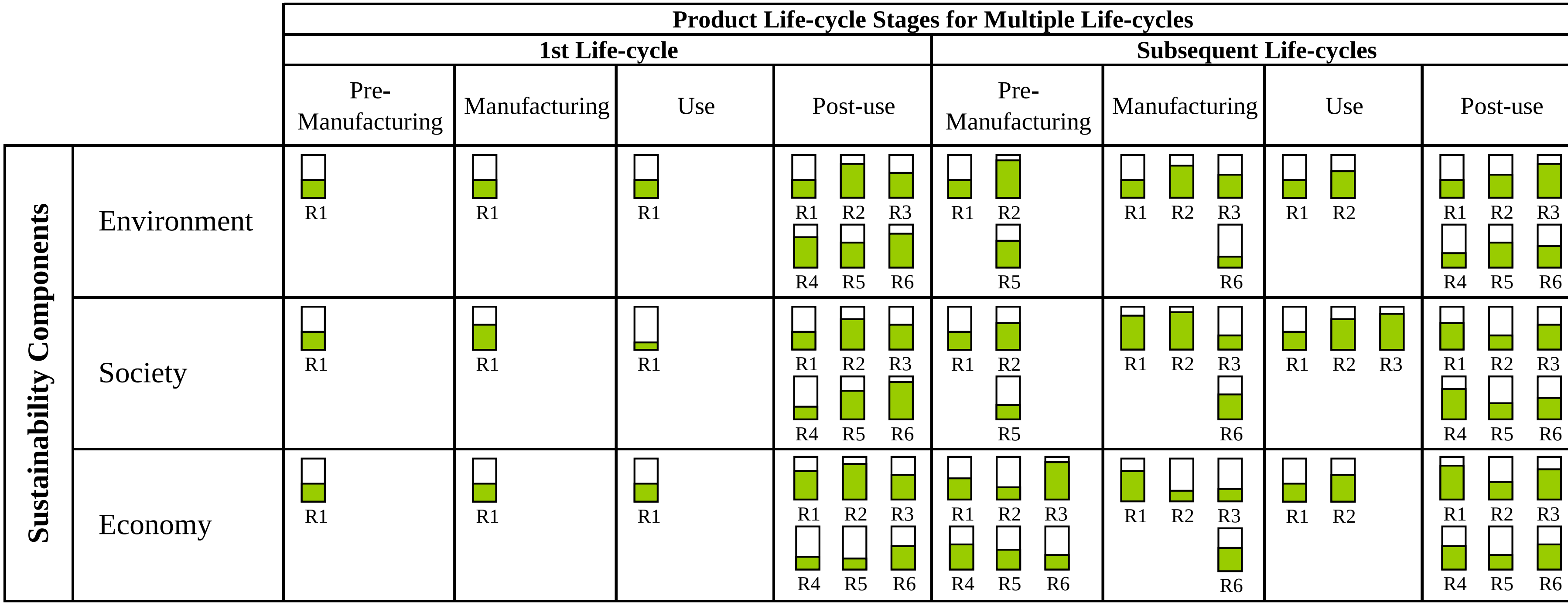
Matrix for Assessing the 6Rs



R1 - Reduce R2 - Reuse R3 - Recycle R4 - Recover R5 - Redesign R6 - Remanufacture

Matrix showing a generic scoring methodology for assessing the 6Rs in terms of economy, environment and society for multiple life-cycles.

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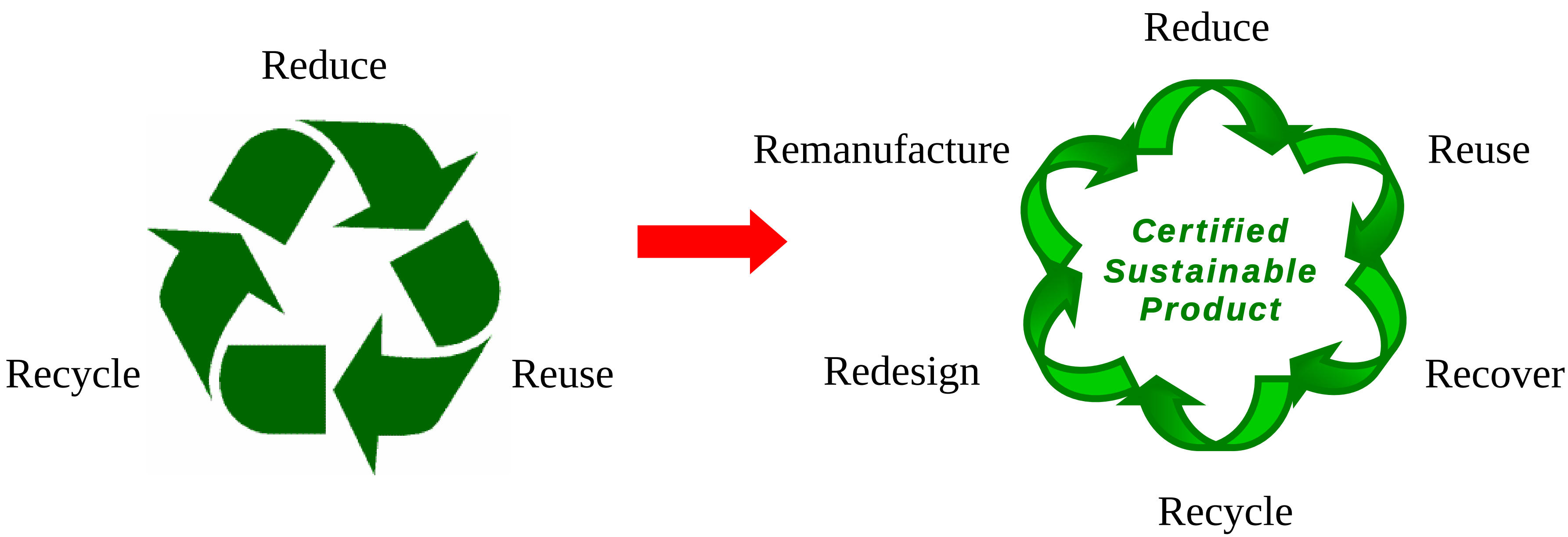
Reduce, Reuse, Recycle:
The Key to Sustainable Product Manufacturing

- Internal program for sustainable product design & manufacturing
- Reduces energy use
- Reduces manufacturing waste
- Reduces water use
- Reduces emissions
- ISO 14001 certification
- ISO 14040 compliant product life cycle assessments (LCAs)

Recyclable to Certified Sustainable Product



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Case Studies and Present Trends

Case Study 1

Machining Processes:
Sustainability Evaluation

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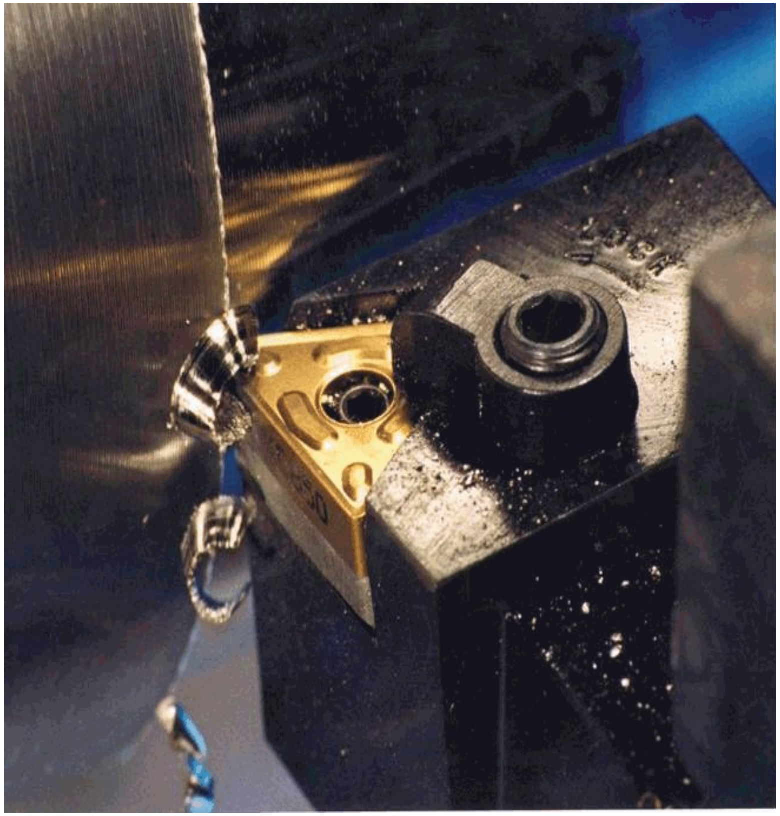
Turning Operations

2-D Cyclic Chip Formation



3-D Cyclic Chip Formation

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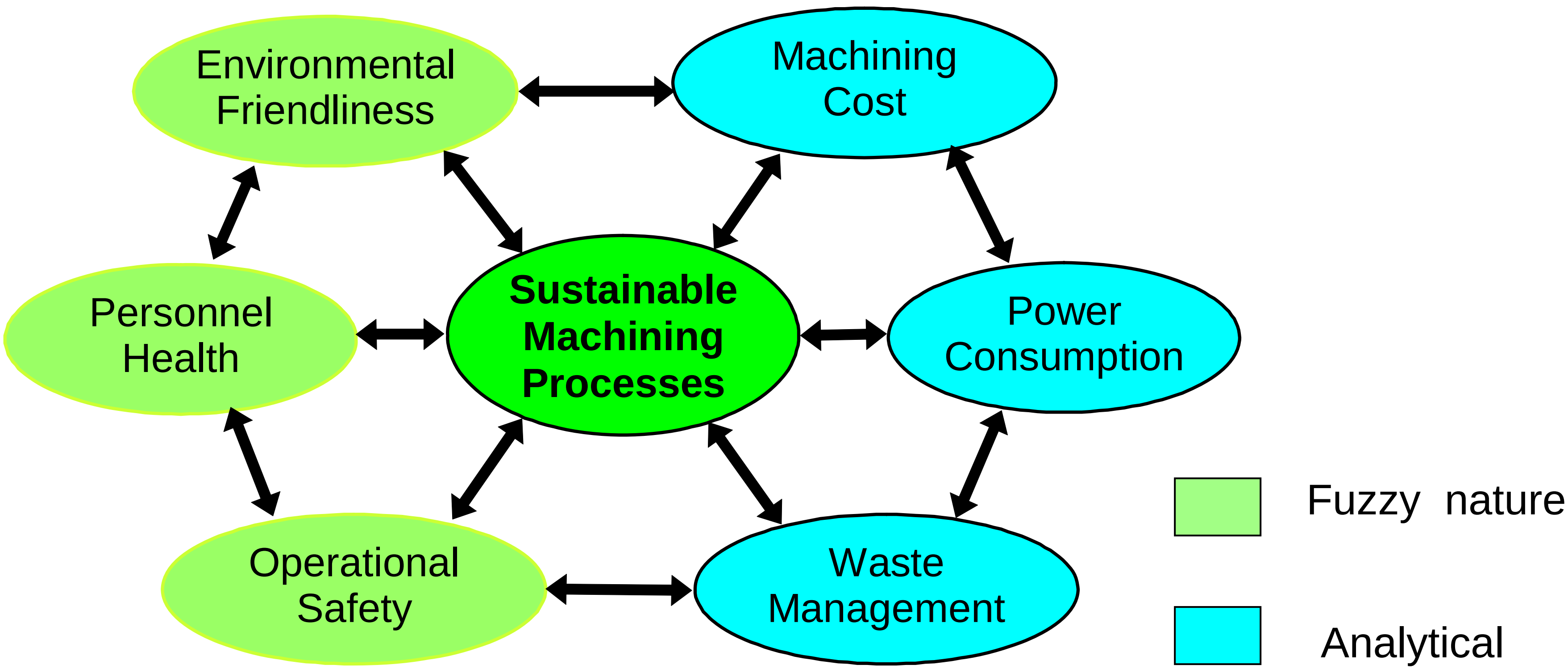
Basic Sustainability Elements in Machining



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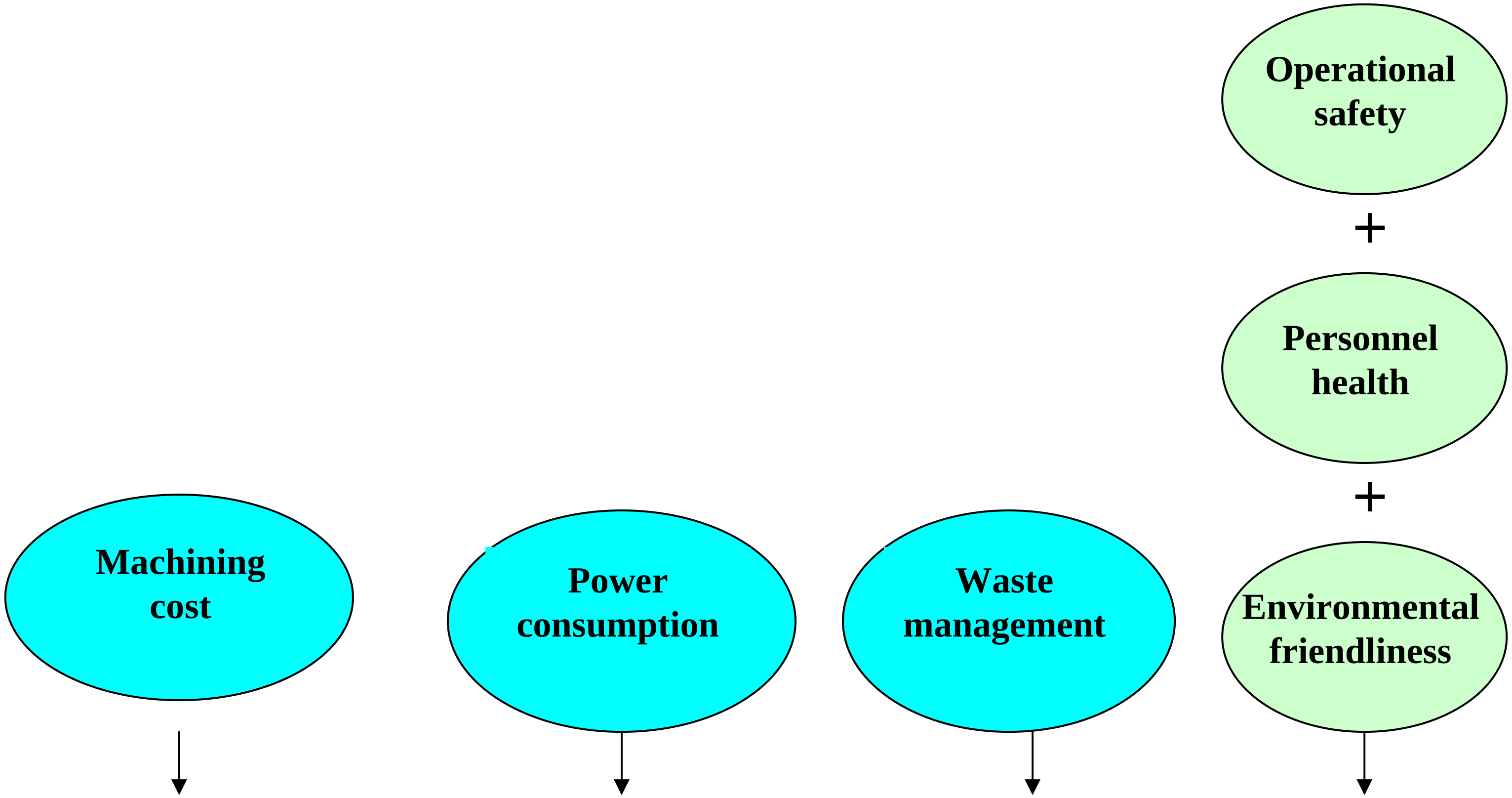
Regulating (Enforcing) Organizations

Methodologies to measure sustainability variables as well as regulations used to set the range of the variables can be obtained from many sources:

- National Institute for Occupational Safety and Health (NIOSH)
- Occupational Health and Safety Administration (OSHA)
- Environmental Protection Agency (EPA)
- Safety & Health Assessment & Research for Prevention (SHARP), etc.

Sustainability Index: First Approach



$$S = \underbrace{C_{MC} \cdot \left(\frac{MC_{\min} - MC}{MC_{\max} - MC_{\min}} + 1 \right) + C_{PC} \cdot \left(\frac{PC_{\min} - PC}{PC_{\max} - PC_{\min}} + 1 \right) + C_{CB} \cdot \left(\frac{CB - CB_{\min}}{CB_{\max} - CB_{\min}} \right)}_{f\,(V,\, f,\, d)} + \underbrace{S_{SHE}}_{F\,(s_i)}$$

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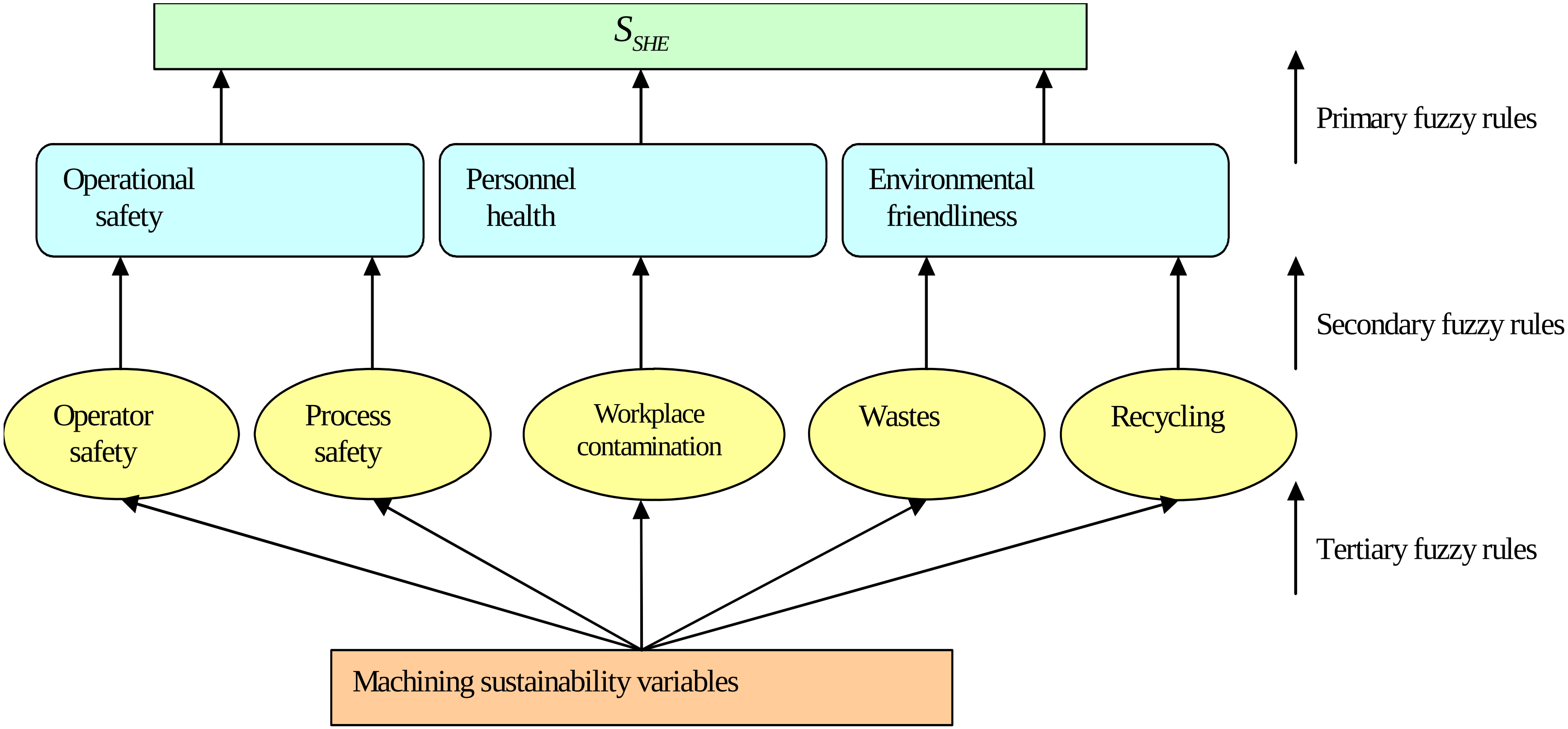
Methodology for S_{SHE}



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Proposed Overall Sustainability Index for Machining

$$S = C_{SHE} \cdot S_{SHE} + C_{op} \cdot S_{op}$$

where S_{SHE} = sustainability index for safety, health and environmental issues assessed using fuzzy logic,

S_{op} represents the operational sustainability level of the process according to the cost of machining, power consumption and waste management, and

C_{SHE} and C_{op} are weighting factors.

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Optimization for Operational Sustainability Index

For the multi-pass turning operation problems,

$$\overline{S_{op}}(V_i, f_i, d_i, (i = 1,2,\ldots N))$$

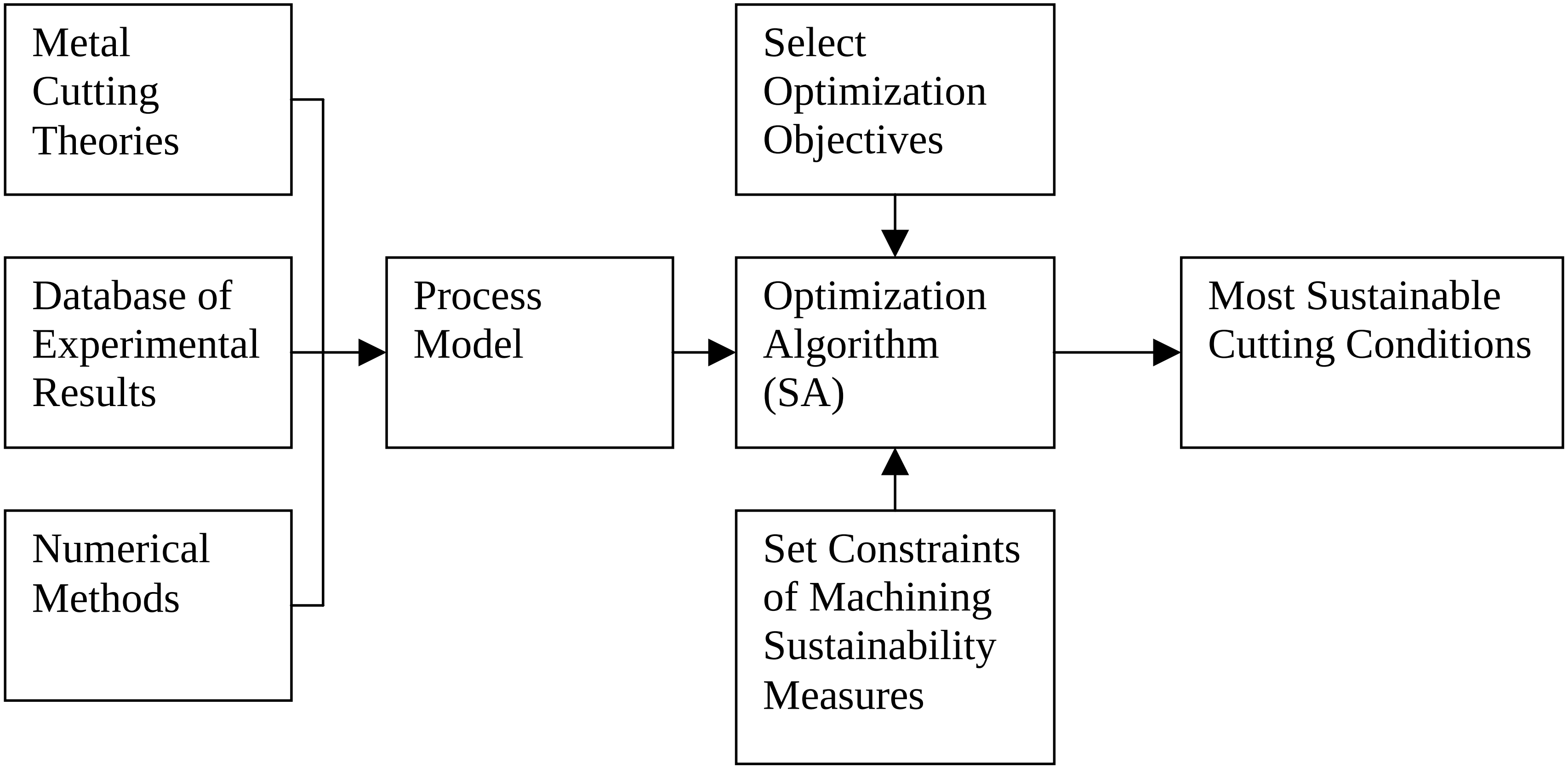
$$= \frac{1}{N}\sum_{i=0}^{N}\left[C_{MC}\cdot\left(\frac{MC_{\min} - MC_i}{MC_{\max} - MC_{\min}} + 1\right) + C_{PC}\cdot\left(\frac{PC_{\min} - PC_i}{PC_{\max} - PC_{\min}} + 1\right) + C_{CB}\cdot\left(\frac{CB_i - CB_{\min}}{CB_{\max} - CB_{\min}}\right)\right]$$

where the N parameter is the number of passes in a turning operation, V_i is the cutting speed, f_i is the feed rate and d_i is the depth of cut for each pass

Constraints are presented as :

$$MC_{\min} \le MC_i \le MC_{\max}, PC_{\min} \le PC_i \le PC_{\max}, CB_{\min} \le CB_i \le CB_{\max}, (i = 1,2,\ldots N)$$

The Structure of the Optimization Process



Optimization Constraints

Constraints for two-pass turning

Turning pass	Two-pass turning	
	Roughing pass	Finishing pass
$V(m/\min)$	150-250	250-400
$f(mm/rev)$	0.15-0.254	0.056-0.15
$d(mm)$	1.20-1.905	0.254-1.20
$MC(\$)$	1.7-2.6	2.5-4.1
$PC(KW)$	2.5-3.4	1.3-2.2
CB	0.6	0.7
$R_a(\mu m)$	3.2	0.8
$F_c(N)$	1200	500
$M_R(mm^3/\min)$	30 000	15 000
$T(\min)$	6.00	2.00

Optimization Results for Two-pass Turning

Total depth of cut		2.7 (P)				2.9 (Q)			
$[C_{MC}, C_{PC}, C_{CB}]$		[0.8,0.15,0.05]		[0.6,0.35,0.05]		[0.8,0.15,0.05]		[0.6,0.35,0.05]	
Turning pass		Rough	Finish	Rough	Finish	Rough	Finish	Rough	Finish
Optimum cutting conditions	$V(m/\min)$	150	250	150	250	150	250	150	257
	$f(mm/rev)$	0.247	0.116	0.235	0.116	0.229	0.112	0.215	0.107
	$d(mm)$	1.613	1.087	1.613	1.087	1.771	1.129	1.817	1.083
Predicted machining performance and sustainability	$R_a(\mu m)$	2.491	0.800	2.227	0.800	2.153	0.775	1.866	0.739
	$F_c(N)$	1091	361	1037	361	1091	365	1051	337
	$M_R(mm^3/\min)$	59782	31440	56798	31432	60936	21756	58635	30002
	$T(\min)$	6.307	4.260	6.489	4.261	6.129	4.199	6.228	4.166
	$MC(\$)$	1.734	2.500	1.782	2.500	1.853	2.578	1.935	2.619
	$PC(KW)$	3.207	1.770	3.048	1.769	3.210	1.788	3.089	1.704
	CB	0.67	0.76	0.68	0.76	0.64	0.75	0.64	0.77
	S_{op}	83.58	92.17	71.80	81.73	73.38	94.12	67.47	92.41
	$\overline{S_{op}}$	**87.88**		**76.77**		**83.75**		**79.94**	

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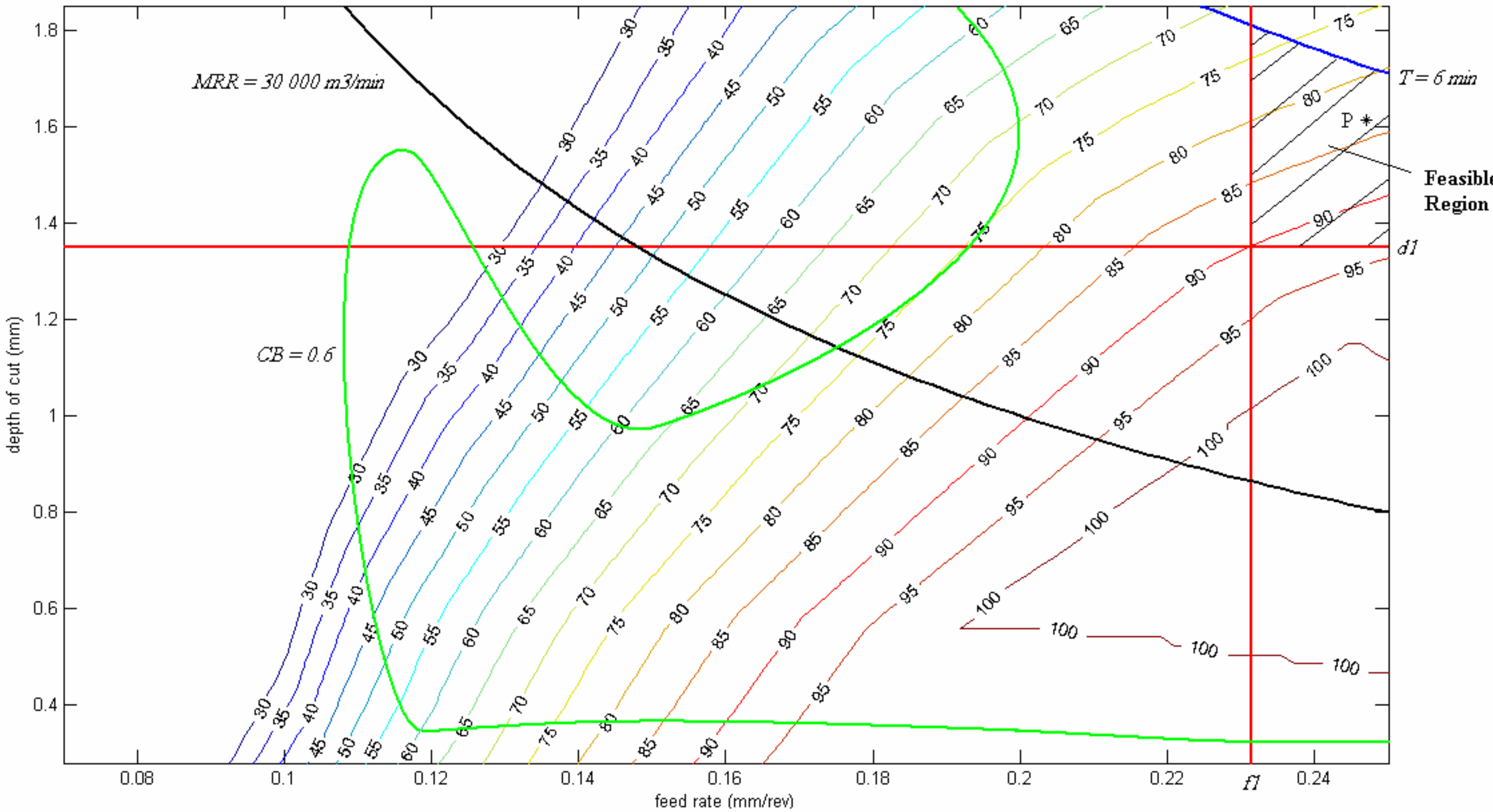
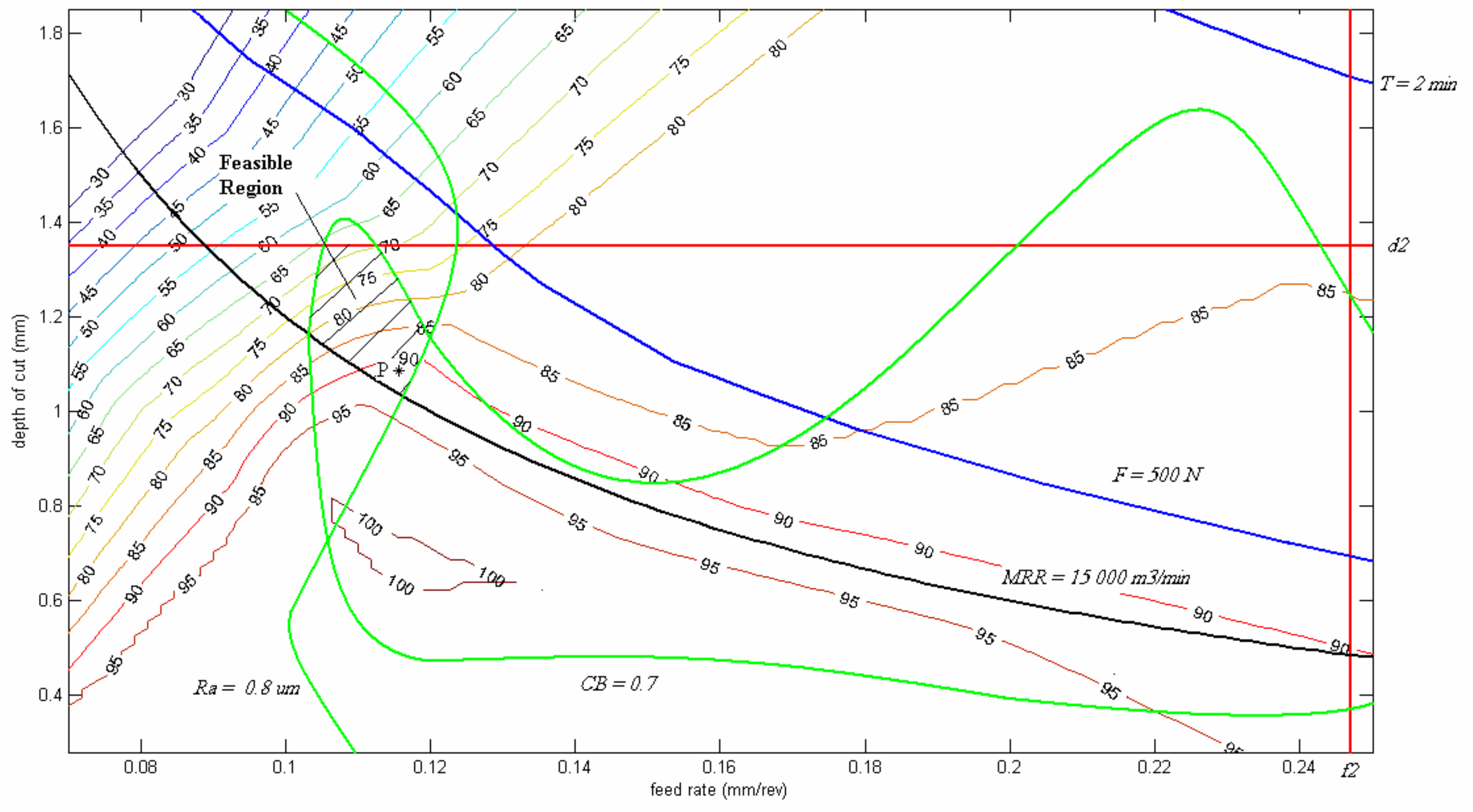
Contour Plot (Roughing)



Feasible region in rough turning, V = 150 m/min, d_t = 2.7 mm

$$\left[C_{MC}, C_{PC}, C_{CB}\right] = \left[0.8, 0.15, 0.05\right]$$

Contour Plot (Finishing)



Feasible region in finish turning, *V* = 150 m/min, d_t = 2.7 mm

$$\left[C_{MC}, C_{PC}, C_{CB}\right] = \left[0.8, 0.15, 0.05\right]$$

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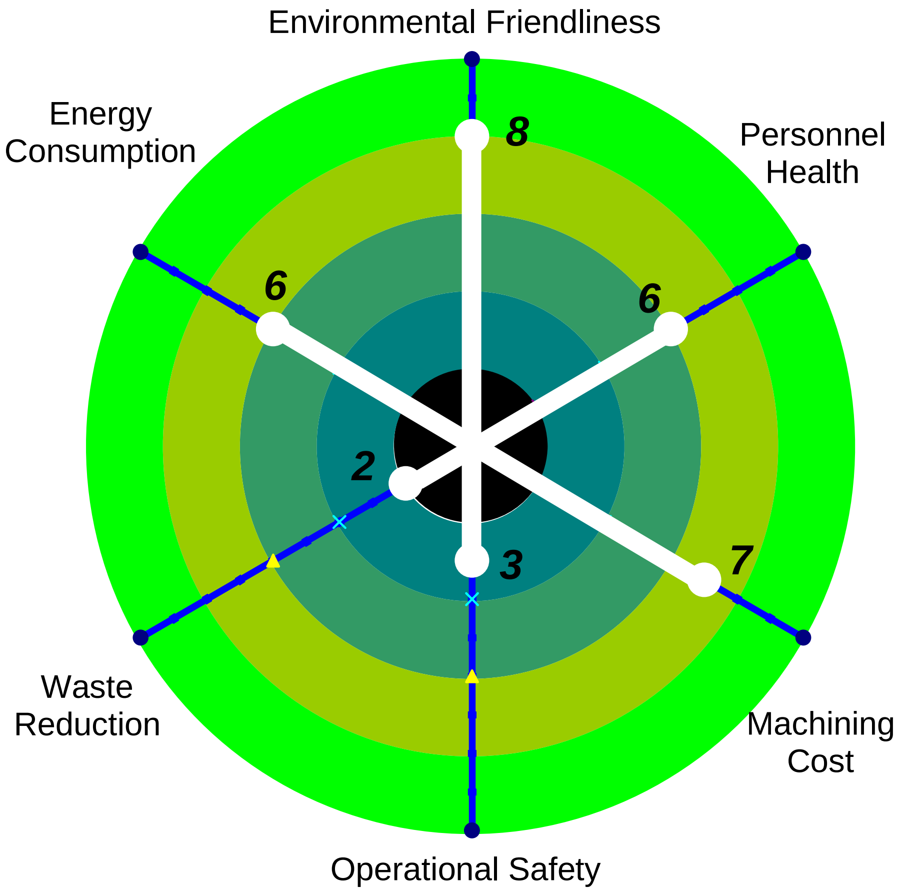
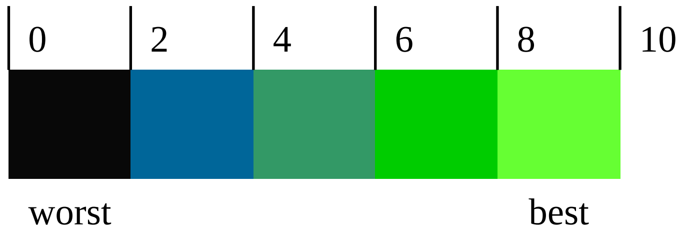
Proposed Sustainability Rating System





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Case Study 2

Consumer Electronic Products:

Development of a Sustainability Scoring Method for Laser Printers

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Various Types of Laser and Inkjet Printers

Laser Printers

Inkjet Printers

Ref: www.lexmark.com

products processes RISE systems

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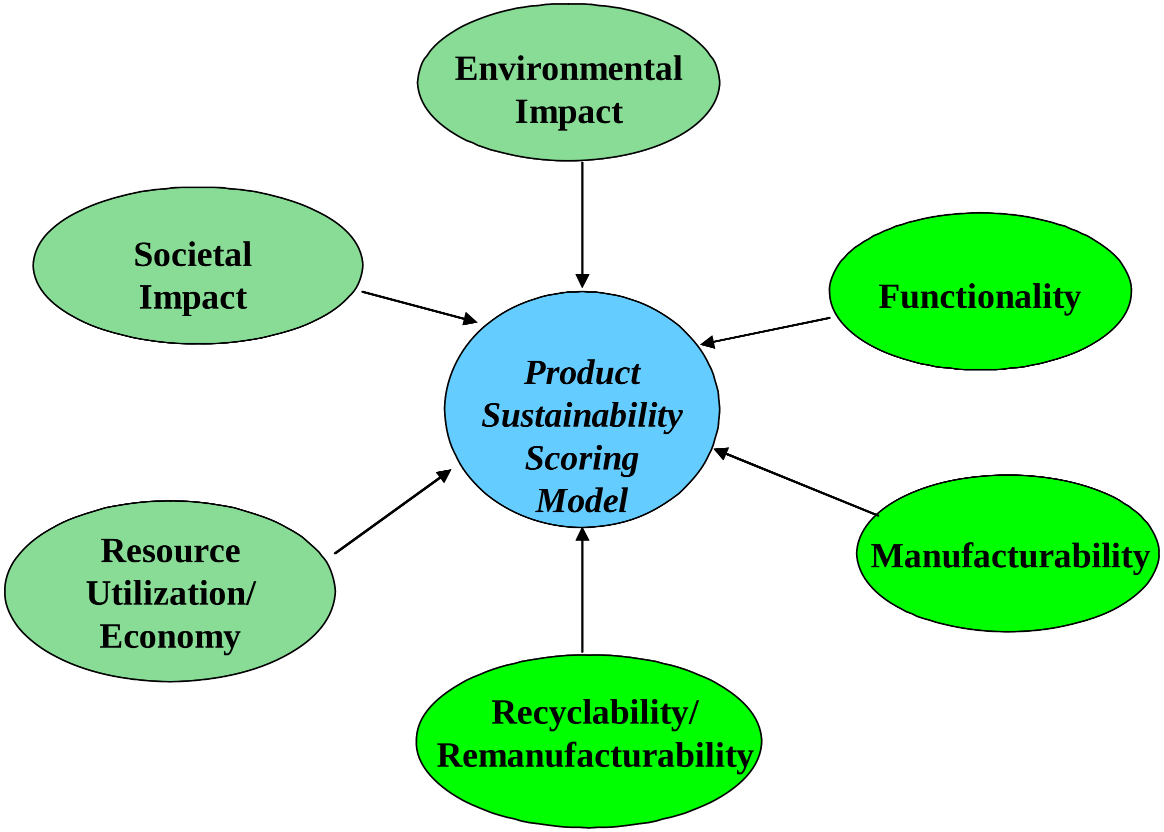
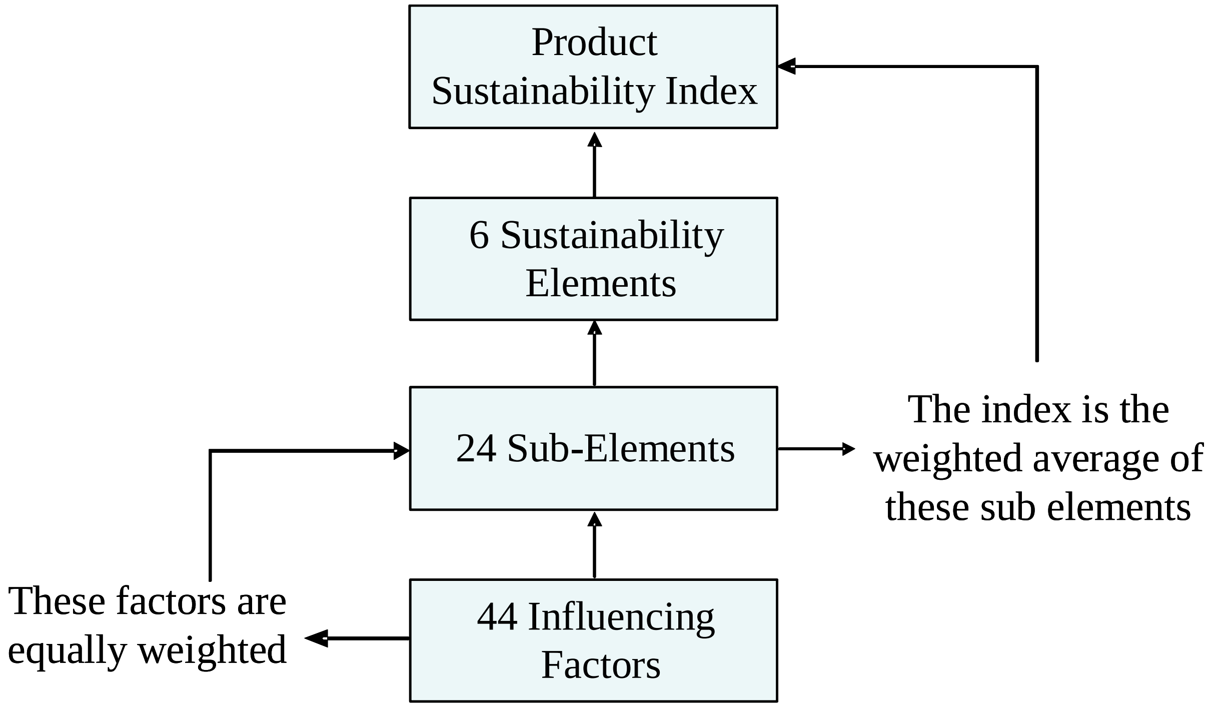
Elements of Sustainability



Framework for the Product Sustainability Model



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Environmental Impact

SUSTAINABILITY ELEMENTS	SUB-ELEMENTS	INFLUENCING FACTORS
Environmental Impact	Life-cycle factor	Recovery rate after first life
		Recovery cost
		Potential for next life
	Environmental effects	Toxic substances
		Emission

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Societal Impact

SUSTAINABILITY ELEMENTS	SUB-ELEMENTS	INFLUENCING FACTORS
Societal Impact	Ethical responsibility	Take back options
		Product pricing
	Societal impact	Safety
		Quality of life

Functionality

SUSTAINABILITY ELEMENTS	SUB-ELEMENTS	INFLUENCING FACTORS
Functionality	Reliability	Type of material
		Maintenance schedule
	Service life/Durability	Maintenance schedule
	Upgradeability	Ease of installation
		Option for upgrade
	Modularity	Modules available
	Ergonomics	Safety
	Maintainability/Serviceability	Maintenance schedule

Resource Utilization & Economy

SUSTAINABILITY ELEMENTS	SUB-ELEMENTS	INFLUENCING FACTORS
Resource Utilization and Economy	Energy efficiency	Production energy
		Energy for use
		Recycle energy
	Material utilization	Type of material
		Quantity of material
		Cost of material
	Use of renewable source of energy	Option for other energy sources
	Market value	Current market value
	Operational cost	Cost to operate

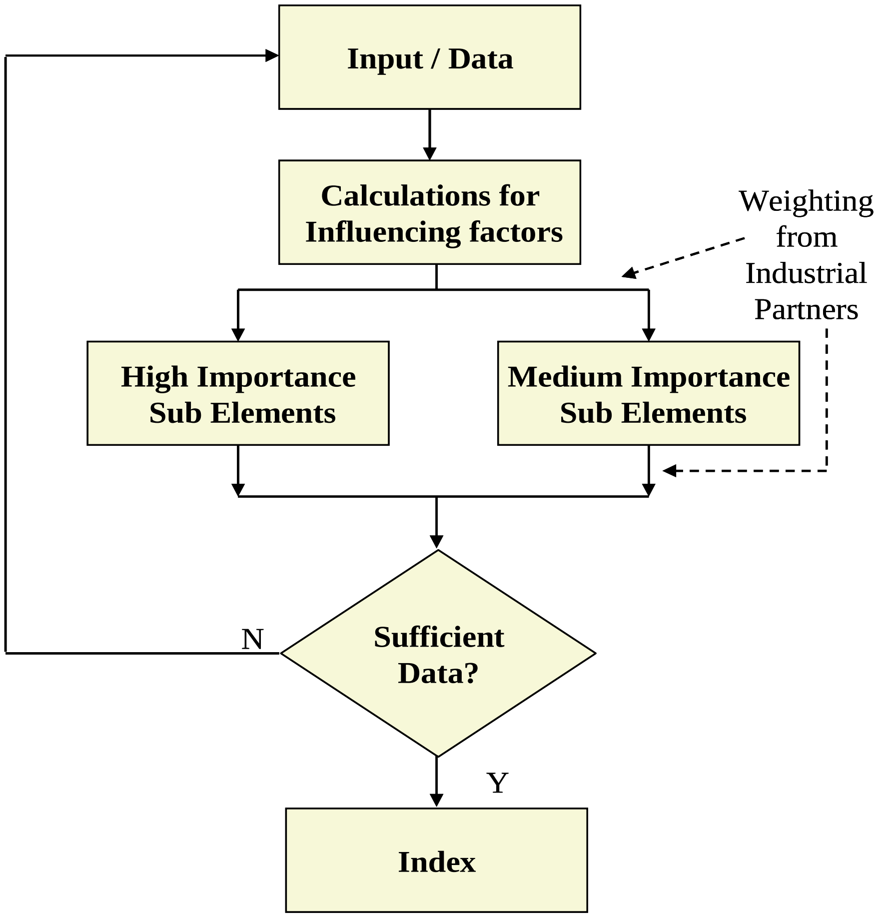
Manufacturability

SUSTAINABILITY ELEMENTS	SUB-ELEMENTS	INFLUENCING FACTORS
Manufacturability	Packaging	Take back options
		Packaging material
		Quantity used
	Assembly	Number of parts/components
	Transportation	Cost of transportation
	Storage	Cost for storage
		Duration of storage

Methodology

- Each influencing factor can be quantified differently, and they are all on a scale of 0-1, where 0 is the lowest and 1 being the highest rating.
- Three categories represent the relative importance of all sub-elements against each other: high, medium and low.
- This grouping technique creates a weighting factor as well as the simplification for any customization or changes for the future.
- Specific weighting can also be calculated according to the number of influencing factors in each category.

Case Study Model



Weighting for High and Medium Categories

High Importance	Weighting (%)
Energy efficiency	29
Material utilization	20
Life-cycle factor	13
Environmental effects	19
Recyclability	19
Medium Importance	**Weighting (%)**
Reliability	27
Service life/ Durability	22
Ethical responsibility	16
Packaging	21
Upgradeability	14

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Sustainability Scoring Methodology

High Importance Category Index = (Energy Efficiency Index * 29%) +
(Material Utilization Index * 20%) +
(Life-cycle Factor Index * 13%) +
(Environmental Effects * 19%) +
(Recyclability * 19%)

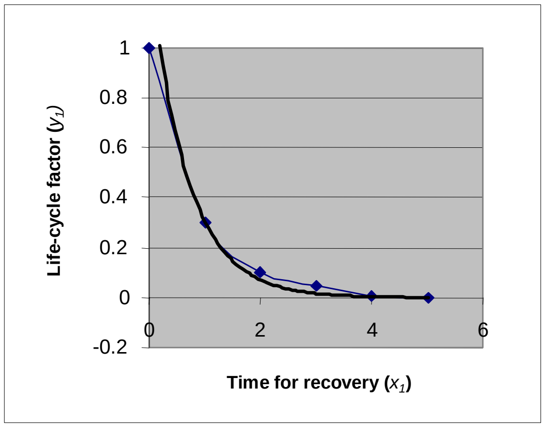
Medium Importance Category Index = (Reliability Index * 27%) +
(Service Life Index * 22%) +
(Ethical Responsibility Index * 16%) +
(Packaging Index * 21%) +
(Upgradeability Index * 14%)

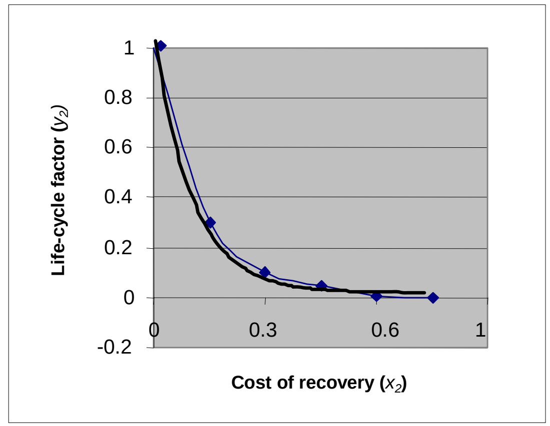
Total Product Score = (High Importance Category Index * 70%) +
(Medium Importance Category Index * 30%)

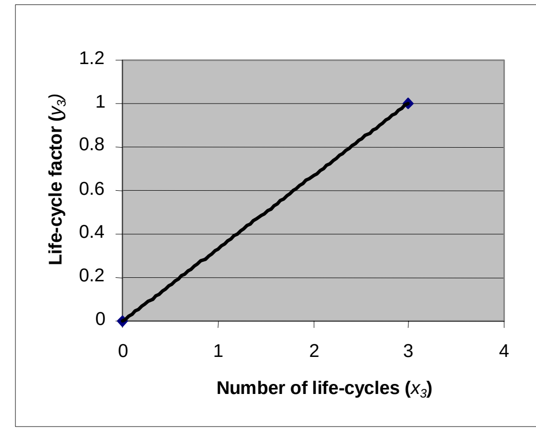
Life-cycle Factor

- The level of expectation for multi-life-cycles is defined using Life-cycle factor. The best level of expectation is considered as 1.
- Influencing factors are plotted against sub-elements.
- All *y* values denote an ‘index’.
- The trend is predicted by using arbitrary values and curve fitting.

Life-cycle Factor







yi= Life-cycle factor index for *xi*

x1= Time for recovery

x2= Cost of recovery

x3= Number of life-cycles

$y1 = A1\ e\text{-}B1x1$

$y2 = A2\ e\text{-}B2x2$

$y3 = C3x3$

Ai, *Bi*, *Ci* depends on the empirical data.

Life-cycle factor

$= (1/3)\ [\ A1\ e\text{-}B1x1 + A2\ e\text{-}B2x2 + C3x3\ ]$

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Calculated Sustainability Score for Product 1

Calculations Product 1					
High Importance Sub Elements	**Weighting**				
Energy efficiency	0.29	0.75	0.22		
Material utilization	0.20	0.12	0.02		
Life-cycle factor	0.13	0.35	0.05		
Environmental effects	0.19	1.56	0.30		
Recyclability	0.19	0.35	0.07		
Weighting for high importance sub-elements	0.70		0.65	0.46	
Medium Importance Sub Elements					
Reliability	0.27	0.56	0.15		
Service life/ Durability	0.22	1.00	0.22		
Ethical responsibility	0.16	0.94	0.15		
Packaging	0.21	0.56	0.12		
Upgradeability	0.14	0.20	0.03		
Weighting for med importance sub-elements	0.30		0.67	0.20	
	Product 1 Sustainability Index			0.66	

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Calculated Sustainability Score for Product 2

Calculations Product 2					
High Importance Sub Elements	**Weighting**				
Energy efficiency	0.29	0.63	0.18		
Material utilization	0.20	0.10	0.02		
Life-cycle factor	0.13	0.26	0.03		
Environmental effects	0.19	1.45	0.28		
Recyclability	0.19	0.35	0.07		
Weighting for high importance sub-elements	0.70		0.58	0.40	
Medium Importance Sub Elements					
Reliability	0.27	0.56	0.15		
Service life/ Durability	0.22	1.00	0.22		
Ethical responsibility	0.16	0.65	0.10		
Packaging	0.21	0.66	0.14		
Upgradeability	0.14	0.10	0.01		
Weighting for med importance sub-elements	0.30		0.63	0.19	
	Product 2 Sustainability Index			0.59	

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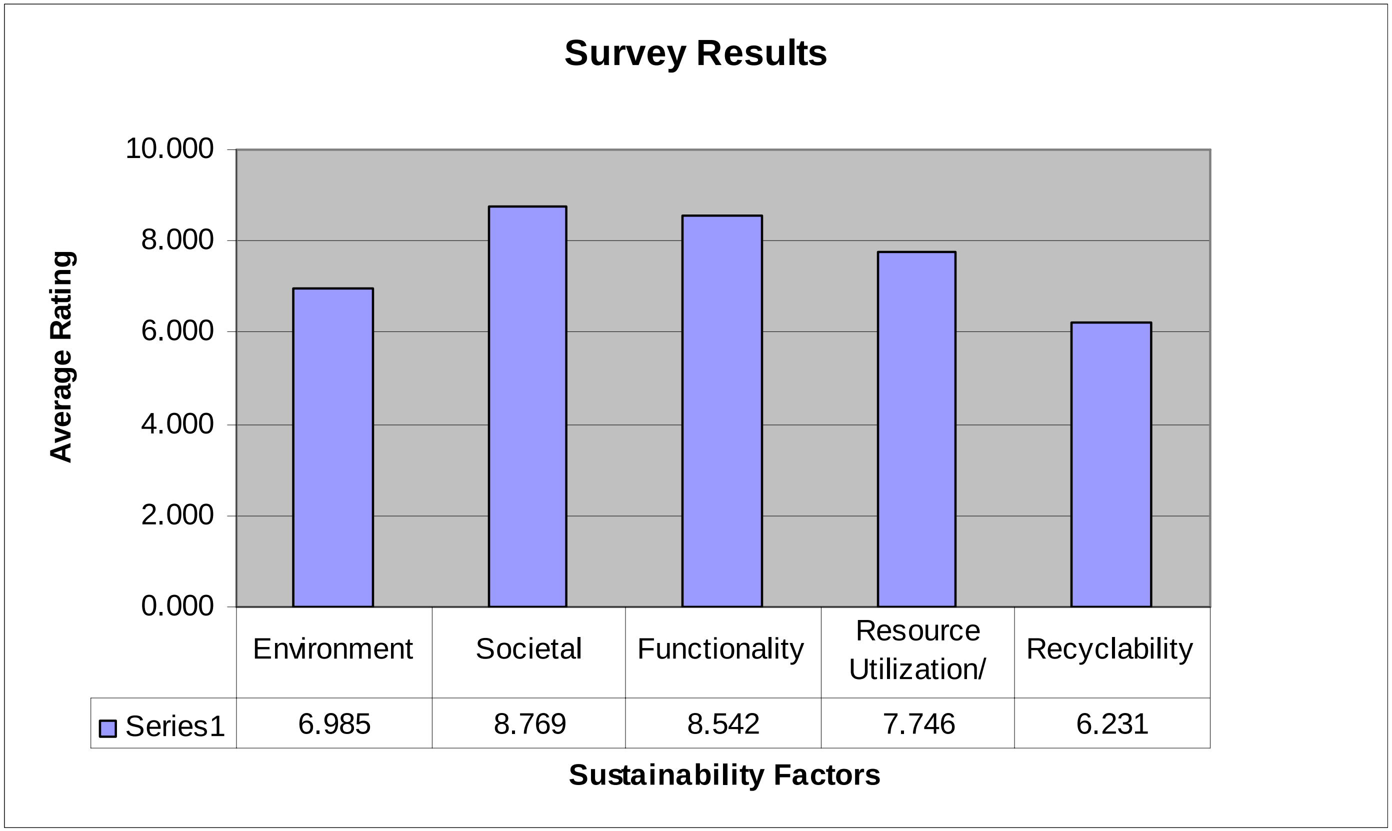
Consumer Oriented Model

A survey was conducted to find out consumer expectations



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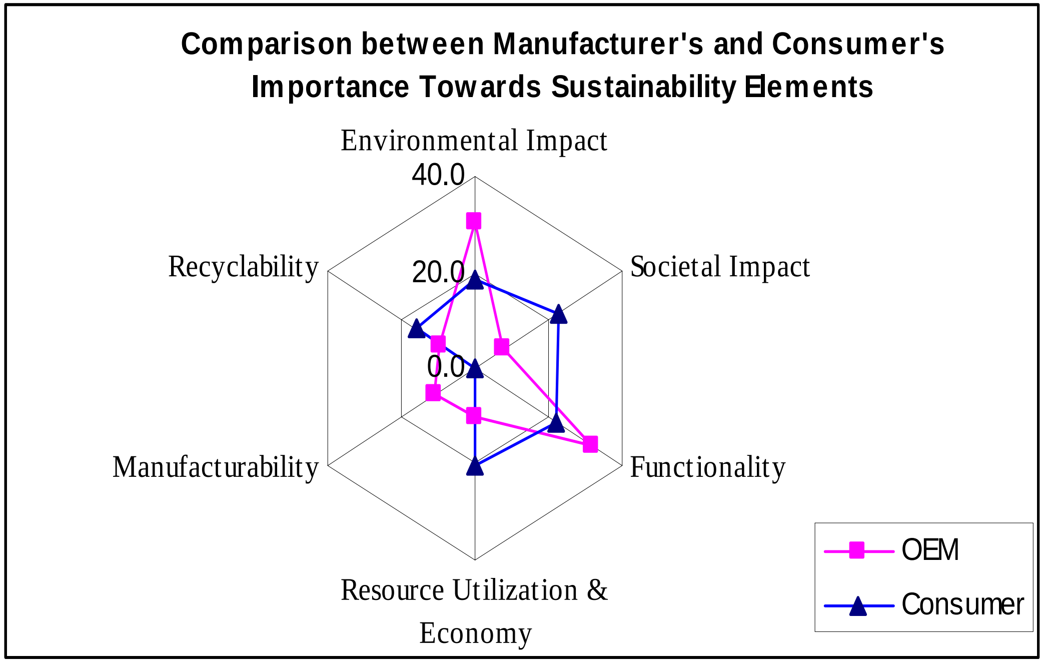
Results of the Consumer Survey

Sustainability Element	OEM (%)	Consumer (%)
Environmental Impact	30.5	18.3
Societal Impact	8.0	22.9
Functionality	31.5	22.3
Resource Utilization & Economy	10.0	20.2
Manufacturability	10.5	N/A
Recyclability/Remanufacturability	9.5	16.3

OEM and Consumer Expectation Comparisons

- Expectations need to be closer
- Education of consumers on proper sustainability values
- OEM commitment and responsibility for sustainability applications



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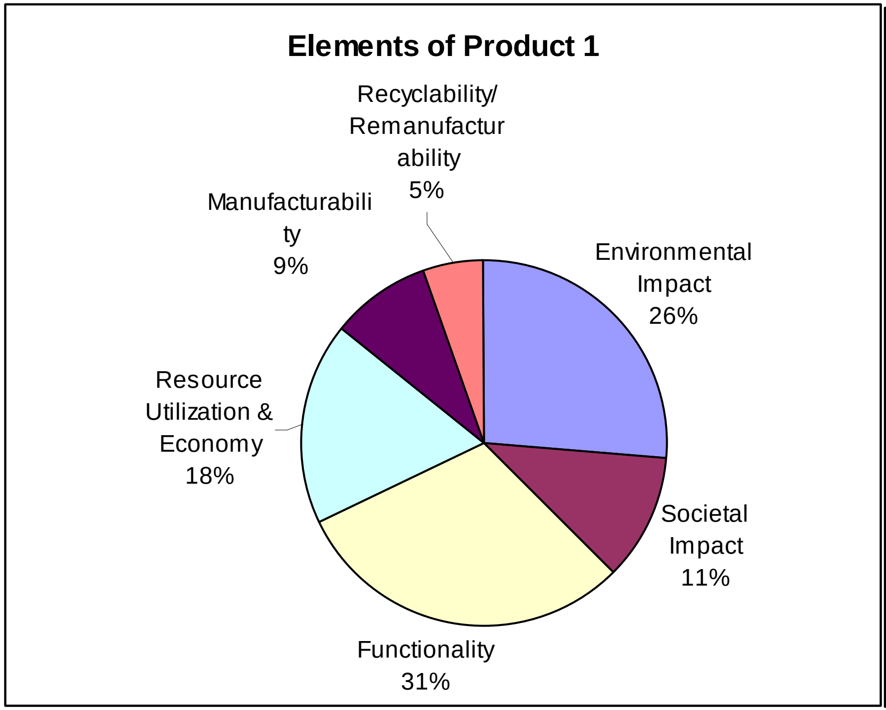
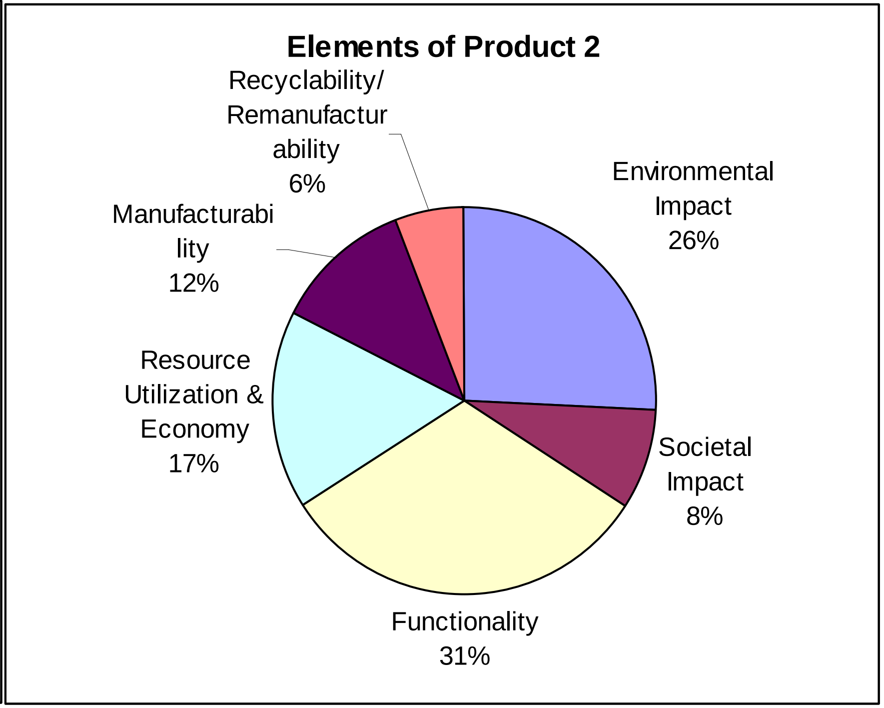
Case Study Results





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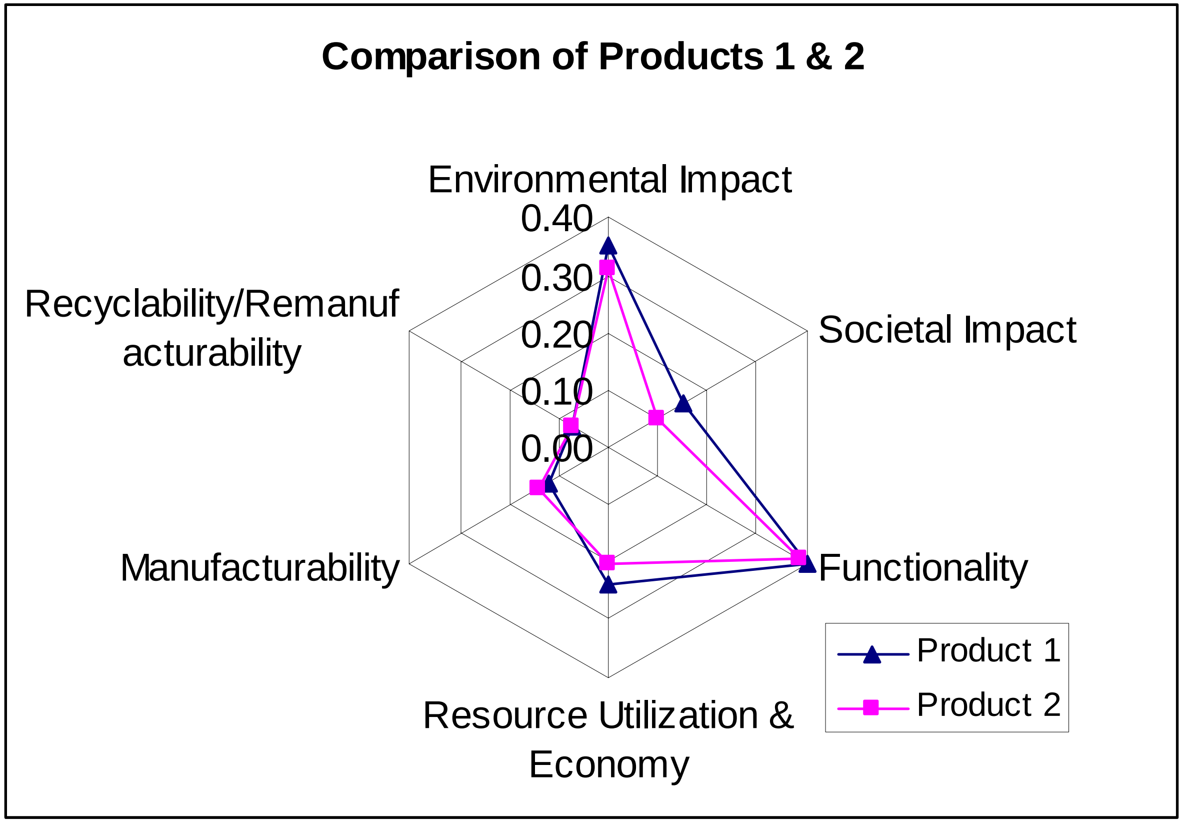
Case Study Results *(Cont'd)*



Comparison of the two product evaluations

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Case Study 3

Autobody Design and Manufacture:
Total Life-cycle Analysis and Applications

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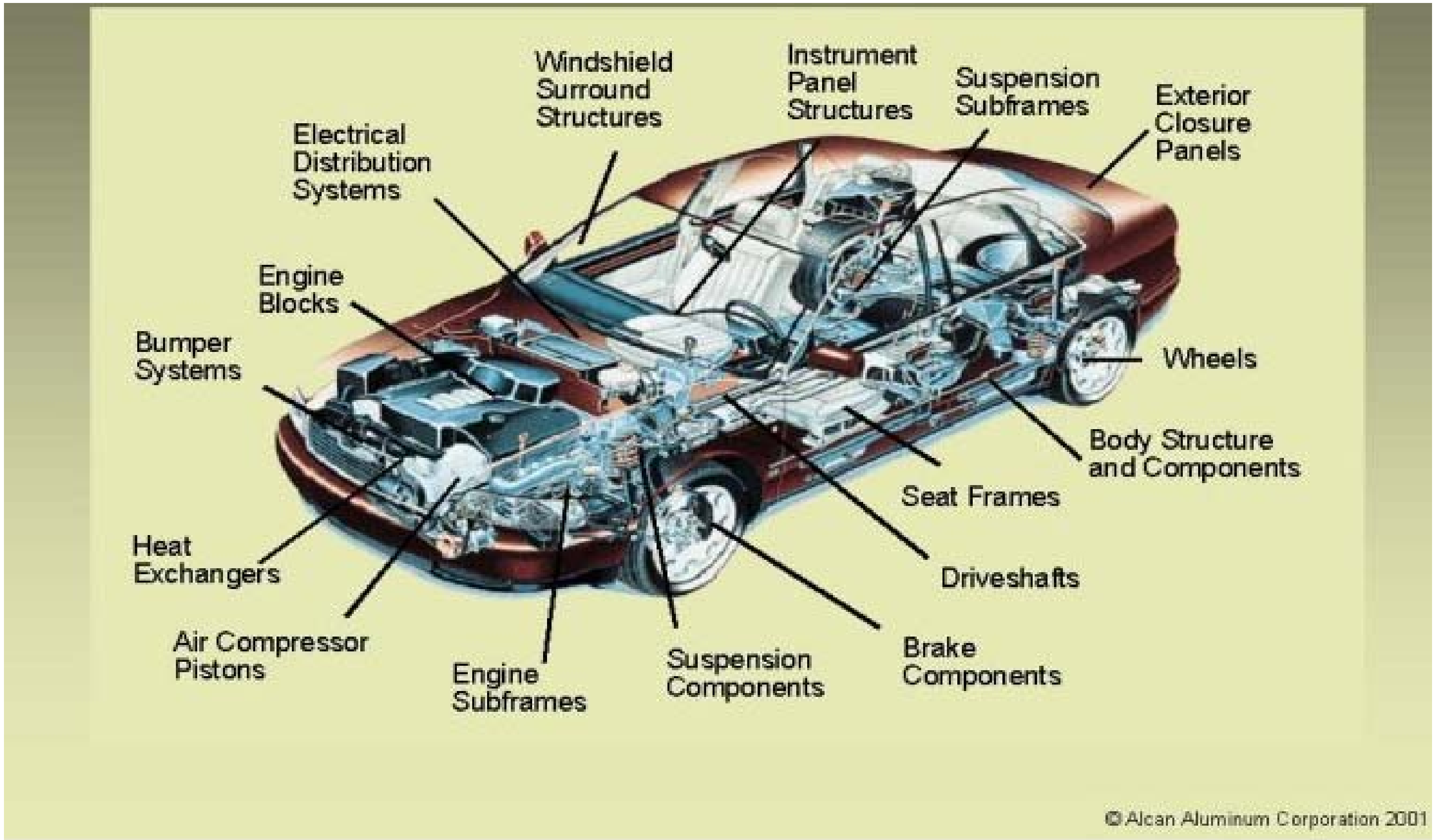
Current and Potential Use of Aluminum Alloys in Vehicles



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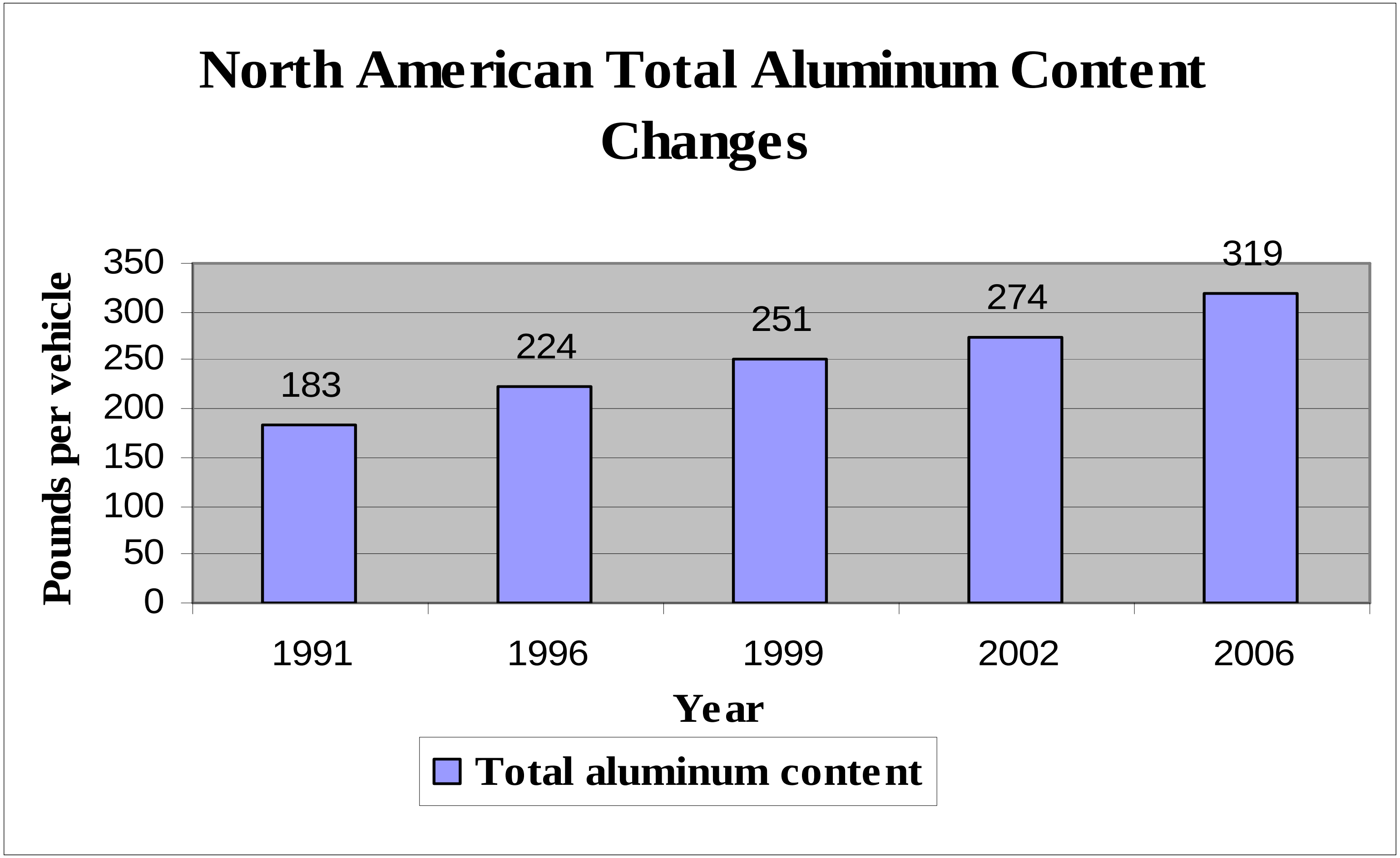
Increasing Use of Aluminum in Automobiles



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Aluminum Characteristics

- A light metal, 35 percent as dense as conventional steel. When aluminum replaces steel, only 1 kg. is required to perform the same function as 2 kg. of steel.
- A major structural material in the aerospace industry for many years due to its properties (i.e., lightweight, highly resistance to corrosion, strong alloys, excellent conductor of electricity and heat, and a highly workable material).
- Using aluminum to cut a vehicle's weight by 10% can boost its fuel economy up to 8%, or as much as 2.5 extra miles per gallon.
- Fuel savings, due to weight reduction, can more than offset, over the life of the vehicle, the initial higher material cost of using aluminum.
- A vehicle that uses less fuel (by lowering its weight with aluminum), produces fewer greenhouse gas emissions.

Aluminum Characteristics *(Cont'd)*

- Over the average lifetime of a vehicle, every pound of aluminum that replaces two pounds of steel can save 20 pounds of CO_2 from being emitted.
- Aluminum enjoys "sustained recyclability" - which means it can be recycled again and again with no loss in material performance or quality.
- Approximately 70 to 80% of aluminum used in today's vehicles is sourced from recycled metal.
- While aluminum today accounts for less than 5 to 10% of a car's content by weight, it accounts for almost 35 to 50% of the total material scrap value at the end of the vehicle's useful life.
- An estimated 85 to 90% of post-consumer automotive aluminum scrap, at least one billion pounds per year, is recycled today.
- Recycling aluminum consumes only 5% of the energy required to produce new aluminum.

Aluminum Limitations

- Aluminum sheet per pound costs about 3 to 5 times more, compared to the cost per pound for steel sheet.
- Aluminum is only one-third as stiff compared to steel (this can be solved by making aluminum thicker than steel panels to ensure that they perform equally well but this imposes higher material cost and offsets the weight advantage to a certain extent).
- Primary aluminum production – highly energy intensive

Impact and Inventory Matrix of Life-Cycle Stages

Sustainability Measures		Body-in-White Life-Cycle Stages									
		PRE-MANUFACTURING		MANUFACTURING		USE		POST-USE		TOTAL	
		Aluminum	Steel	Aluminum	Steel	Aluminum	Steel	Aluminum	Steel	Aluminum	Steel
Resource usage (energy use)		0	3	2		5	5	5	2	12/20	13/20
Waste output	Solid/Liq. Residues	2	2	4		4	4	4	3	14/20	12/20
	Air Emissions	1	3	2	3	5	2	4	3	12/20	11/20
Environmental impact (e.g., toxicity, air pollution, etc.)		2	3	3	3	5	3	5	3	15/20	12/20
Societal impact (e.g. , health, safety, and quality of life)		3	3	2	2	4	3	4	3	13/20	11/20
Economic impact (e.g., costs, waste stream values)		3	4	2	3	5	3	5	3	15/20	13/20
Total		11/30	18/30	15/30	17/30	28/30	20/30	27/30	17/30	81/120	72/120

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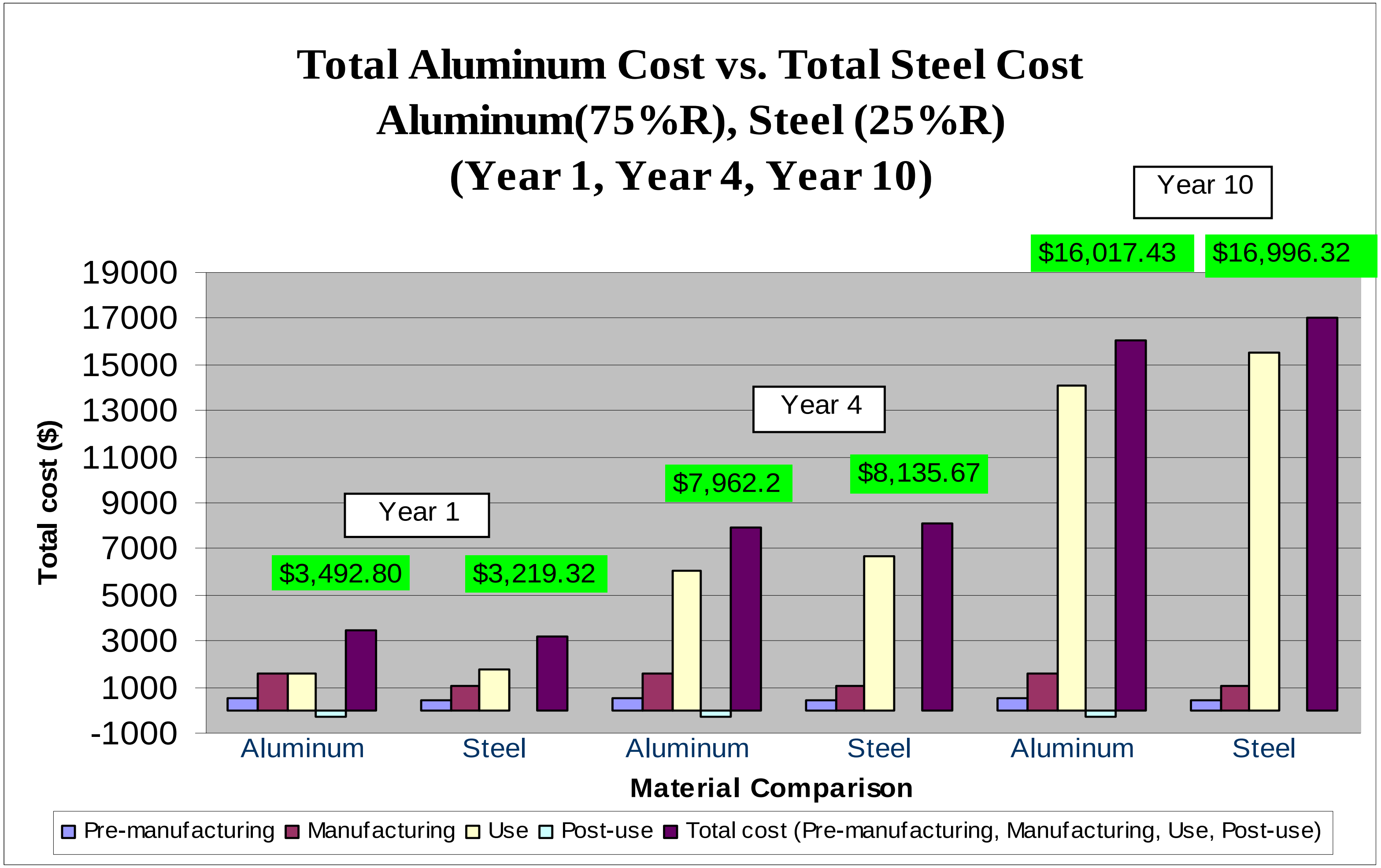
Total Cost Comparison for Total Product Life-cycle



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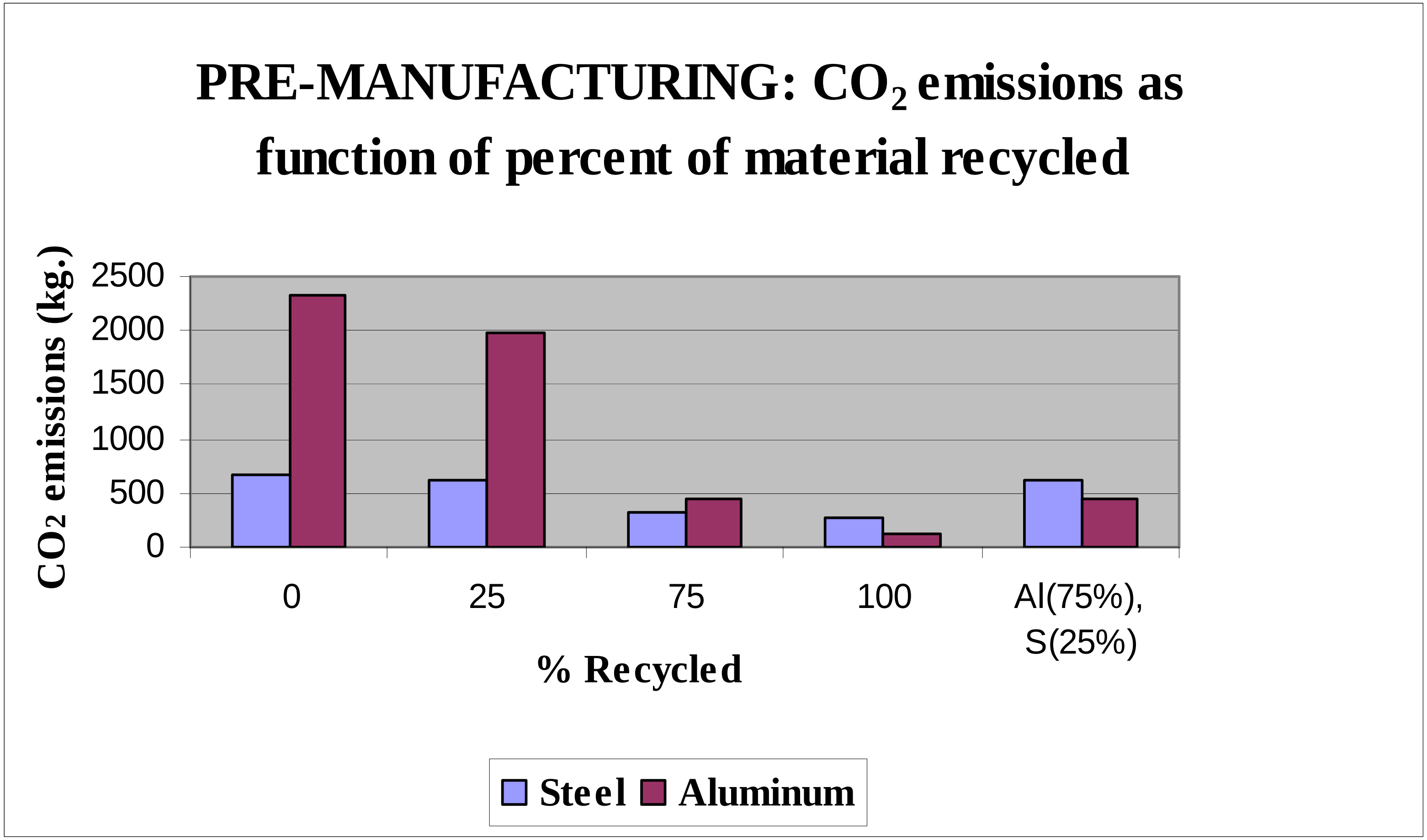
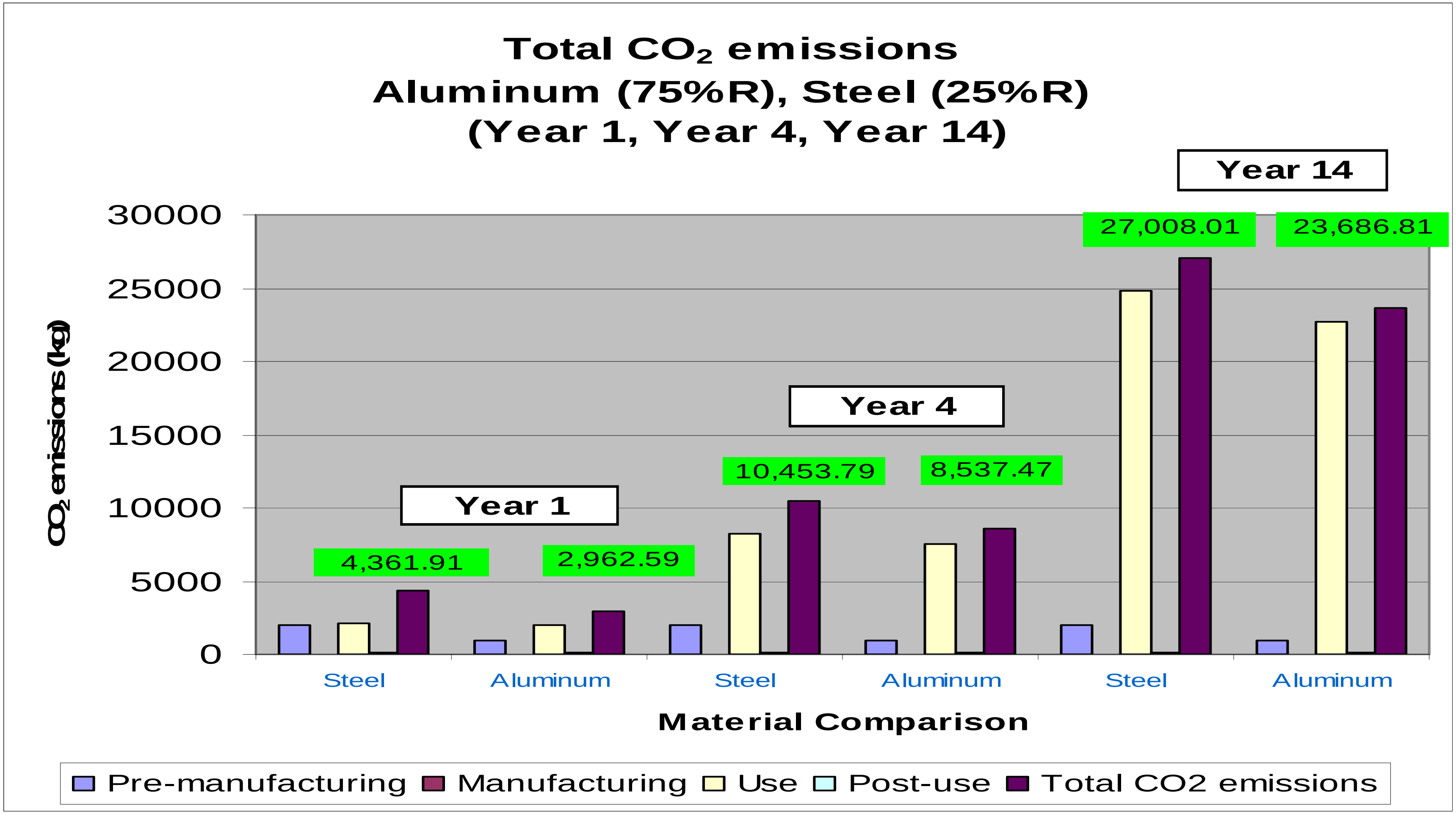
Environmental Impact: *Pre-manufacturing Stage*



Total CO_2 Emissions throughout Total Life-cycle



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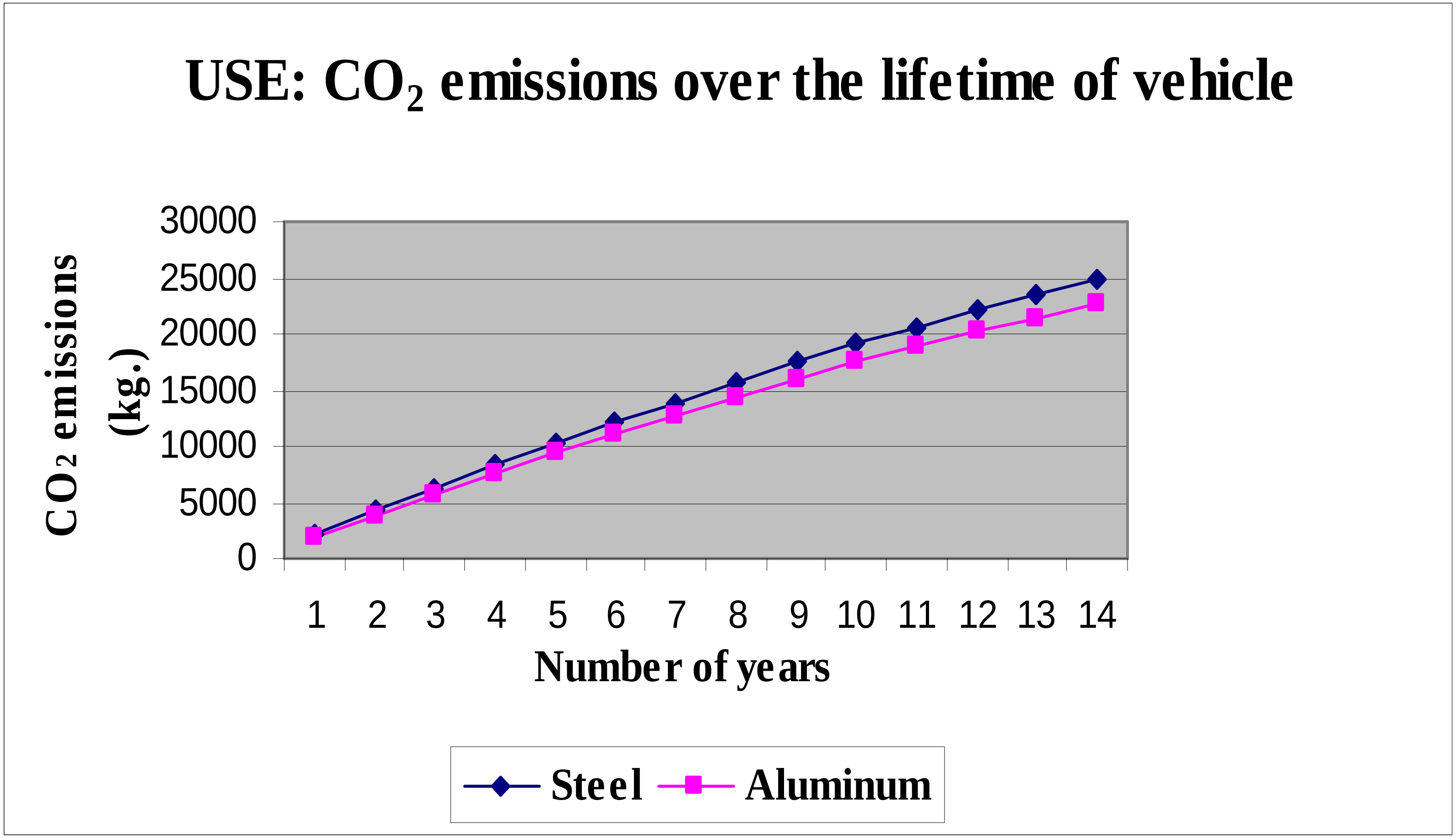
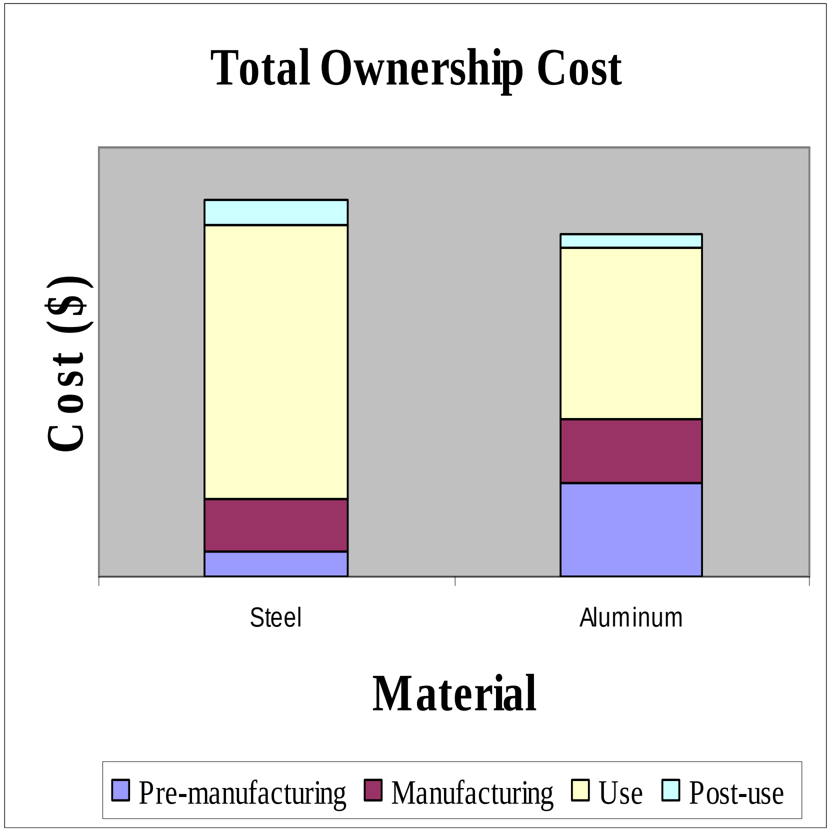
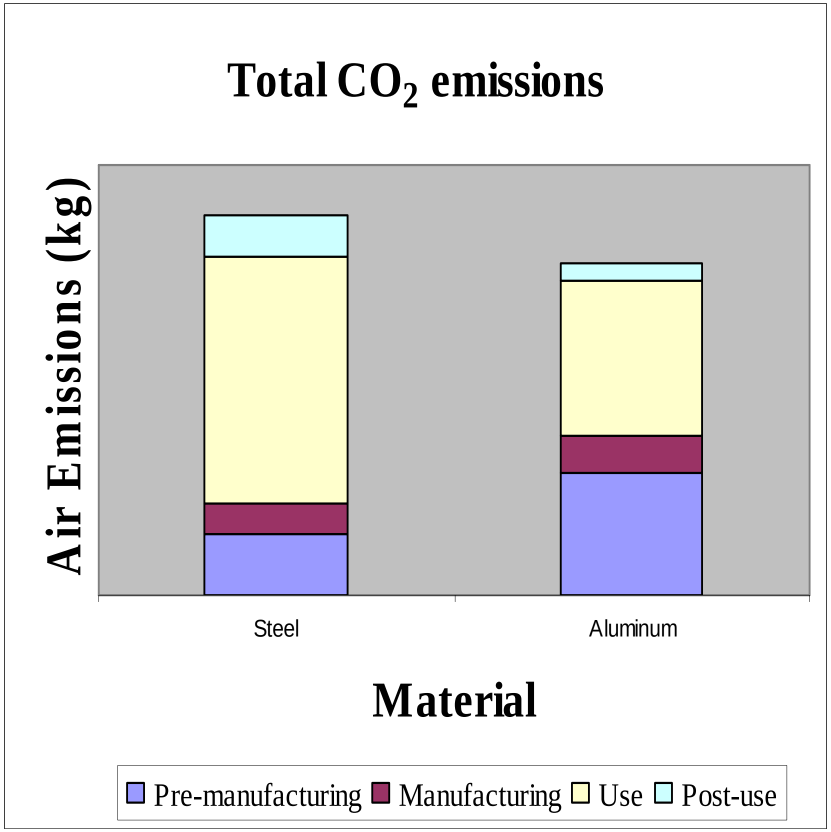
Environmental Impact: Use Stage



The Total Anticipated Relative Benefit





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Present National Trends:

ASME's Newest Research Committee
on
Sustainable Products and Processes

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Proposed ASME-sponsored Activities

- Developing an *ASME handbook* on "Sustainable Products and Processes"
- Promoting nationwide the development and implementation of *educational and training programs* on sustainability science and engineering
- Developing *Codes and Standards* for design and manufacture sustainable products and for developing manufacturing processes
- Organizing and hosting of *annual workshops* and *major international conferences*, all focusing on *sustainability of products and processes*
- Interacting with *funding agencies, national laboratories and universities* and initiating partnerships for collaborative research projects
- Developing interactions with the *National Academy of Engineering (NAE)* for creating a National Task Force on Innovative Products and Processes for Sustainability in order to retain the competitive advantage in global manufacture

Present International Trends:

International Academy for Production Engineering (CIRP)

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CIRP Initiatives

- Life-cycle Engineering Working Group – began in 1983
- Life-cycle Engineering Annual Conference Series – started 15 years ago
- Sponsorship of numerous international conferences including the following major series:

  (a) International Conference on Design and Manufacture for Sustainable Development (United Kingdom)

  (b) International Life Cycle Engineering Conference Series

  (c) Carbon-free Manufacturing Working Group (Currently Proposing)

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Present International Trends:

International Journal of Sustainable Manufacturing (IJSM)

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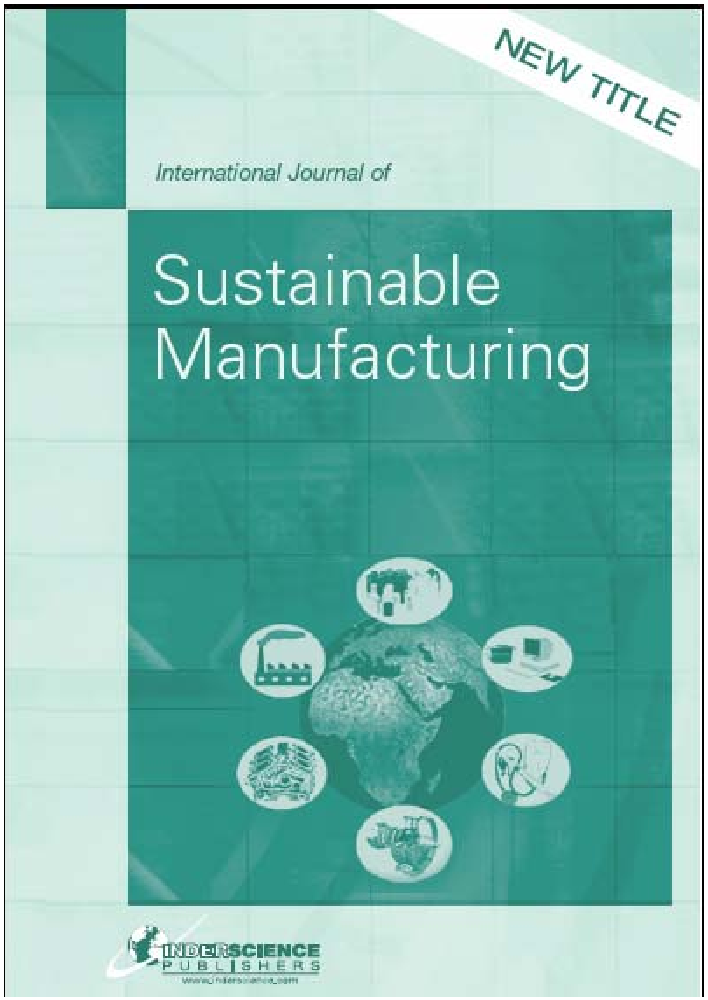
New Journal (Summer 2008)



www.inderscience.com/ijsm

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Scientific and Technological Challenges

- Developing *scientific principles of sustainability* for product design and manufacture
- *Education, training and dissemination* of new knowledge on sustainability science and engineering
- *Application of sustainability principles* in product design and manufacture
- Developing economic models for sustainable products and sustainable manufacturing
- Developing and marketing *sustainable products*, *processes and systems*