Introduction to Life Cycle Analysis and Environmental Decision Making

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Outline

- Environmental Decision Making
- What is Life Cycle Analysis ?
- Main Components
- Process Flow Diagrams
- Uses of LCA
- Examples of LCA
- Streamlining and Functional Units

environmental decision making and energy production

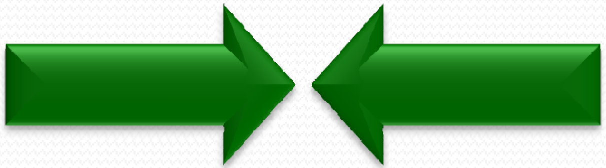
- Which energy source is better and why?

environmental decision making and energy production

- Decision making requires that we have the complete information or at least a good set of data/information
- We need to make the comparison of different energy sources on the same basis



Environmental Disputes

business  environmentalists

Traditional Conflict -
economic progress vs
environmental protection

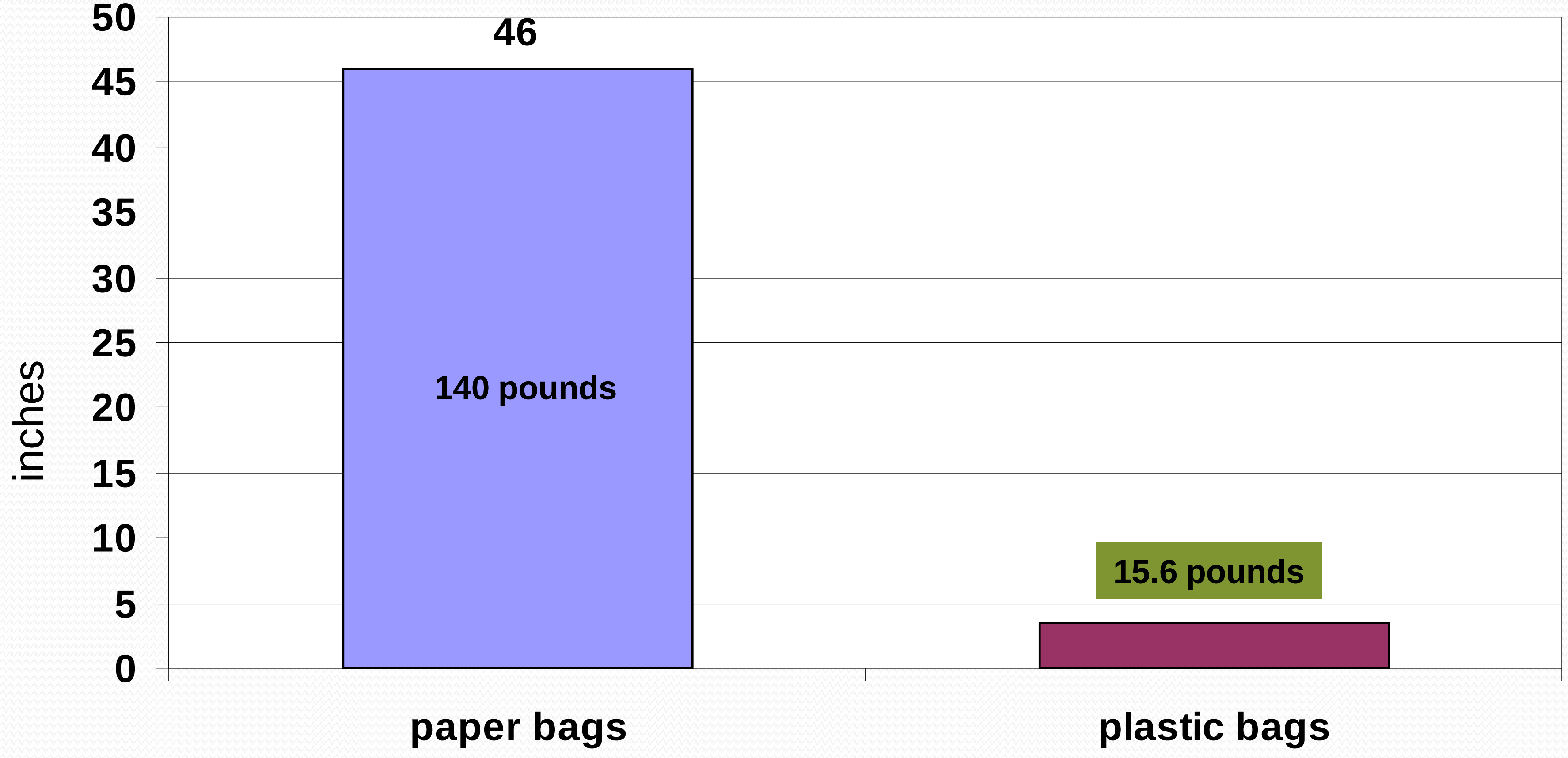
Paper vs Plastic

Per Cup	Paper Cup	Plastic Cup

Paper vs Plastic

Air Emissions		
Chlorine, kg	0.2	0
Chlorine dioxide, kg	0.2	0
Reduced sulfides, kg	1 to 2	0
Particulates, kg	2 to 3	0.3 to 0.5
CFC, kg	0	0
Pentane, kg	0	35 to 50
Sulphur dioxide, kg	10	3 to 4
Recycle Potential		
primary use	no	easy to reuse
Postconsumer	coating makes hard	resins easy
Ultimate Disposal		
incineration, MJ / kg	20	40
landfill mass, kg / per cup	10.1 g	1.5 g
biodegradable	yes	no

Paper vs Plastic – 1000 bags



Environmental Decision-Making Framework

What is Life Cycle Analysis ?

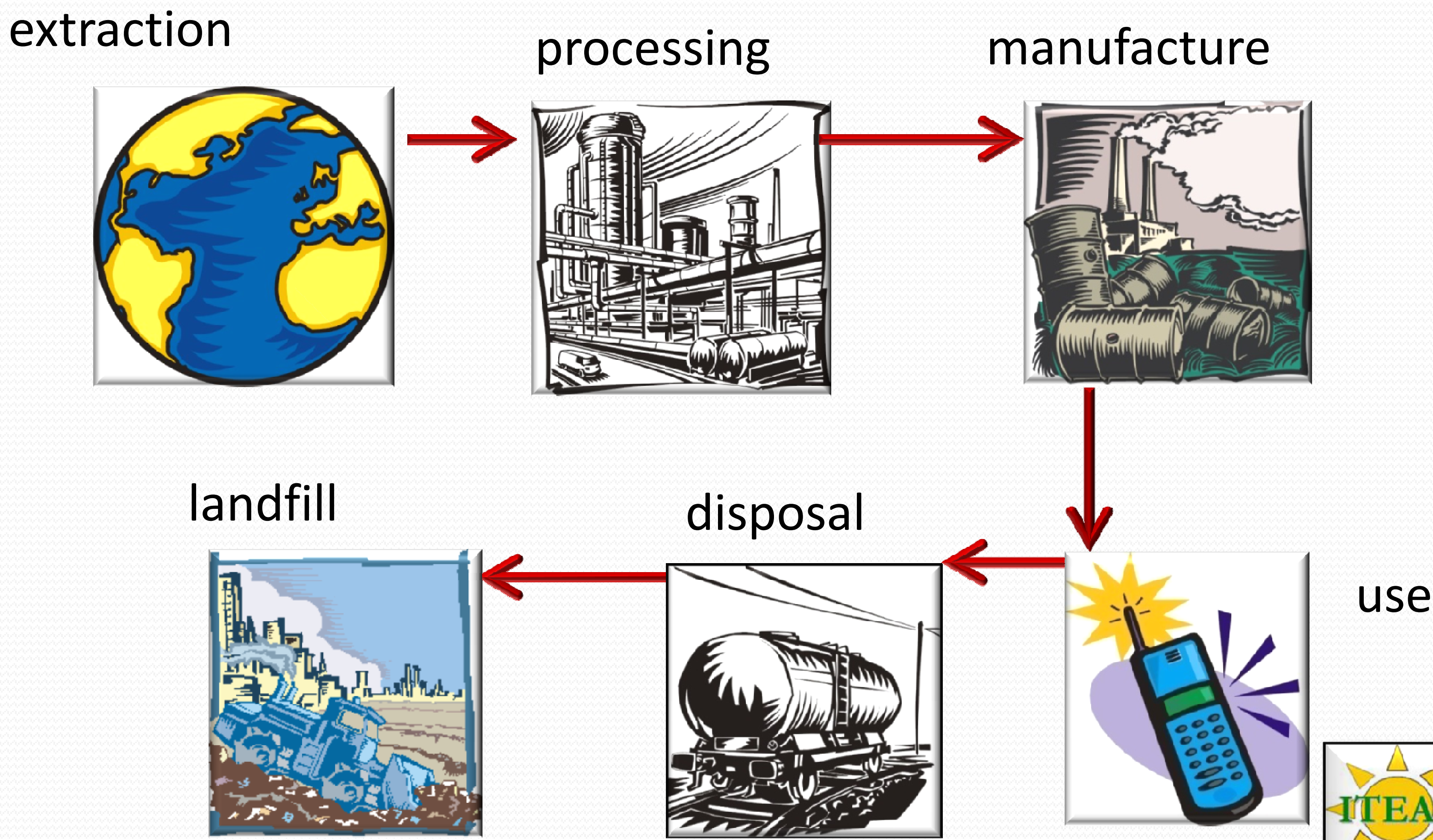
- The **Life Cycle Assessment** is an objective process to evaluate the environmental burdens associated with a product, process or activity by:
  - identifying energy, materials and benefits
  - assess the impact of the energy and materials
  - evaluate and implement improvement plans

Society of Environmental Toxicology and Chemistry

Life Cycle Assessment

- "The evaluation of the relevant environmental, economic and technological implications of a product, process or system from ***cradle to grave*** ".
- **LCA Stages**
  - material extraction and processing
  - manufacturing
  - transportation and distribution
  - use
  - end of life management

Product Life Cycle Stages



LCA Framework

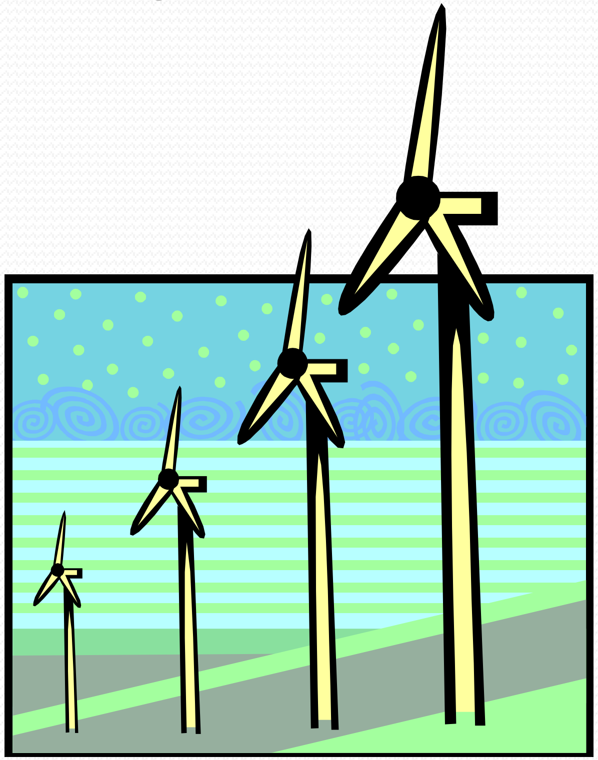
- Developed by the Society of Environmental Toxicology and Chemistry (SETAC) in 1990.
- Several workshops in the Netherlands and the United States gave birth to LCA as we know it today.
- Comprises three fundamental stages: inventory, impact and improvement.

LCA: An Environmental Decision-Making Tool

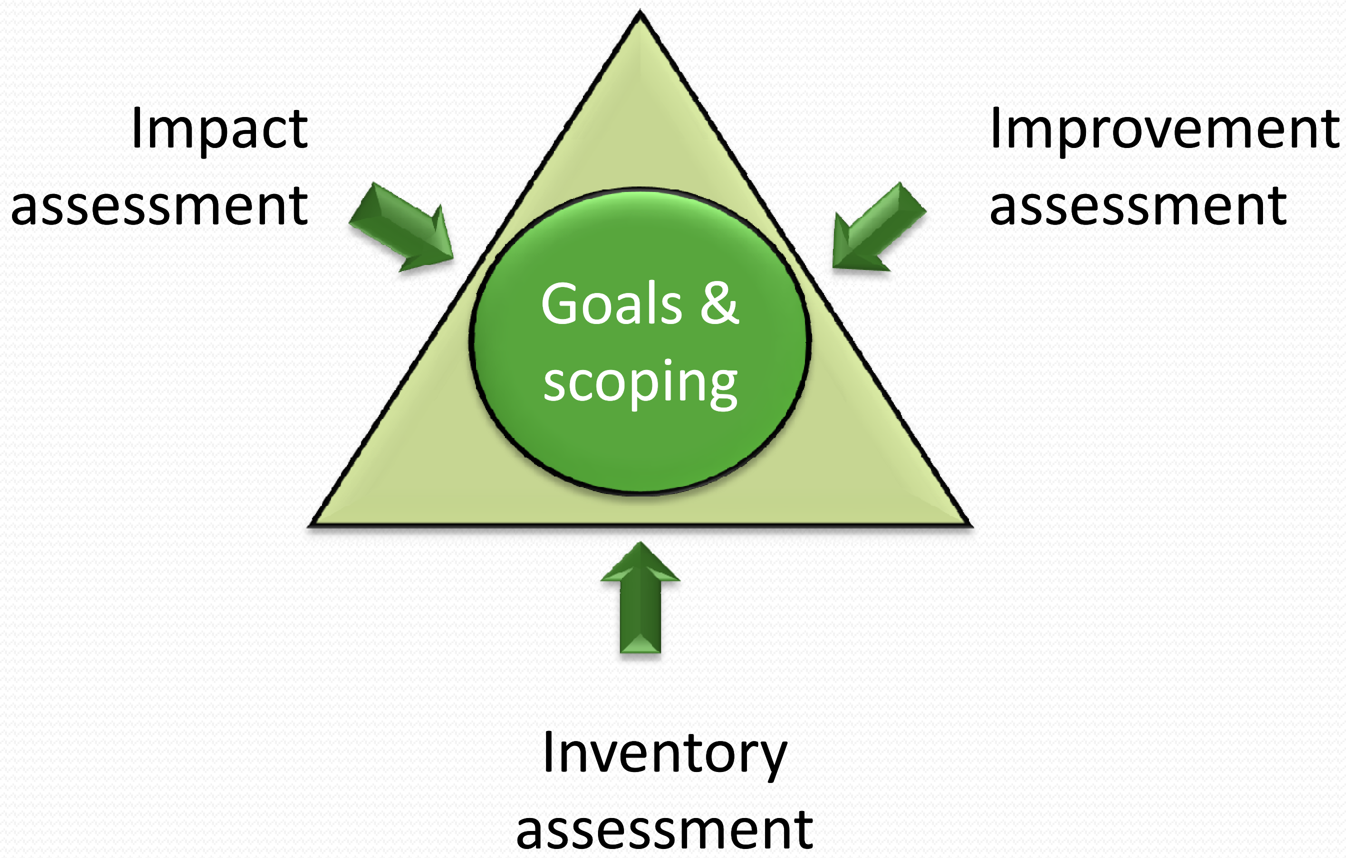
- Good environmental decision-making tool.
- Possesses two unique attributes:
  - Considers whole life-cycle of a product or service; avoids problem shifting.
  - Allocates all environmental burdens to the functional unit, making easier value/impact assessments.

Why is LCA Important?

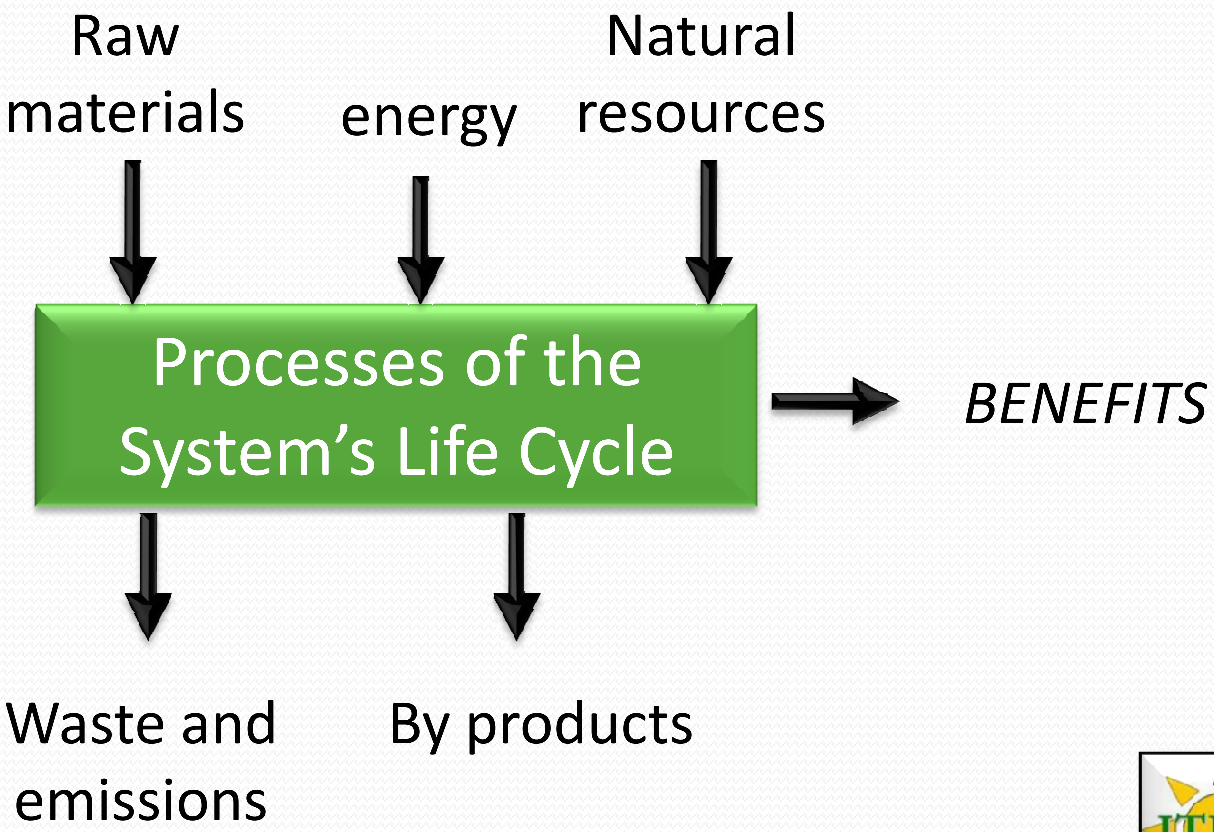
- Allows to identify when a selection of ***one alternative over another*** or when the modifications made to any part of the system ***has the desired end result of reducing environmental impacts*** from all life-cycle stages.



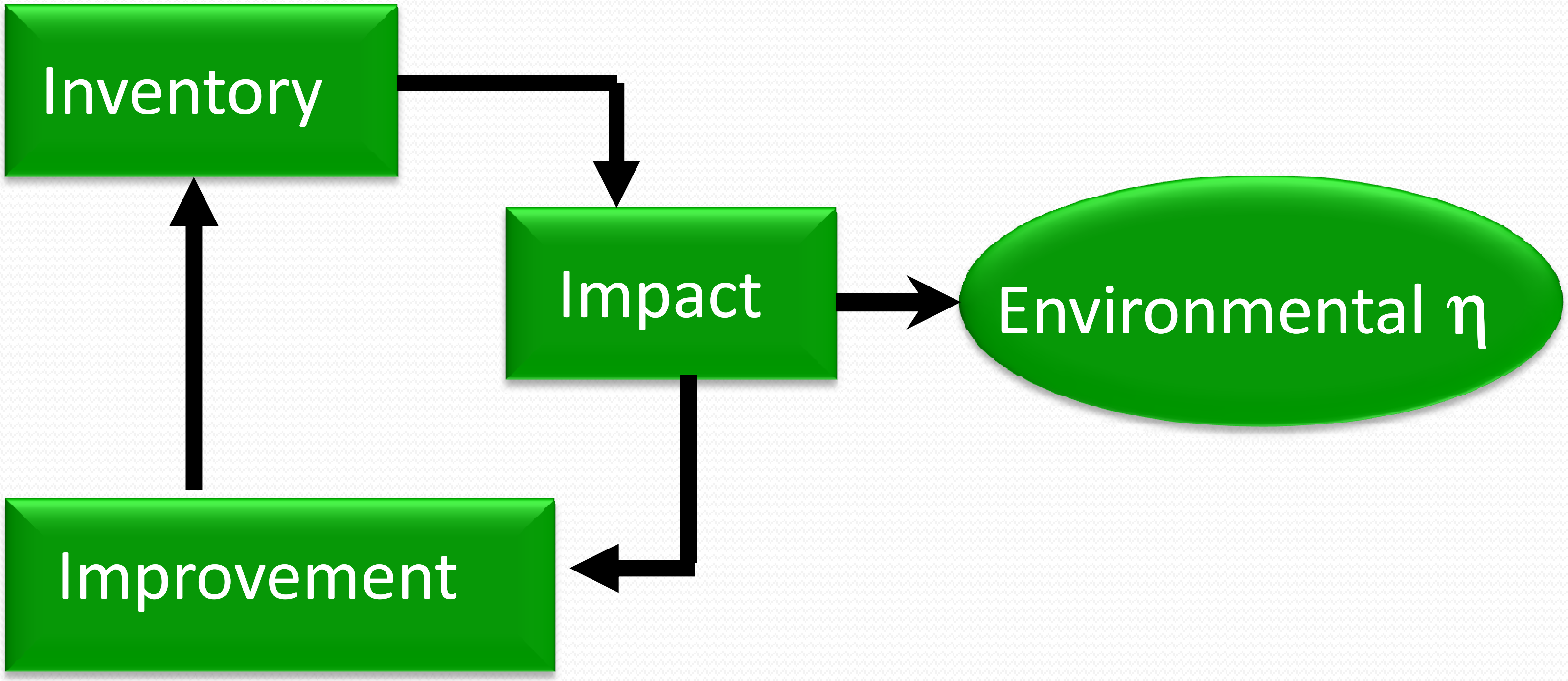
LCA Conceptual Model



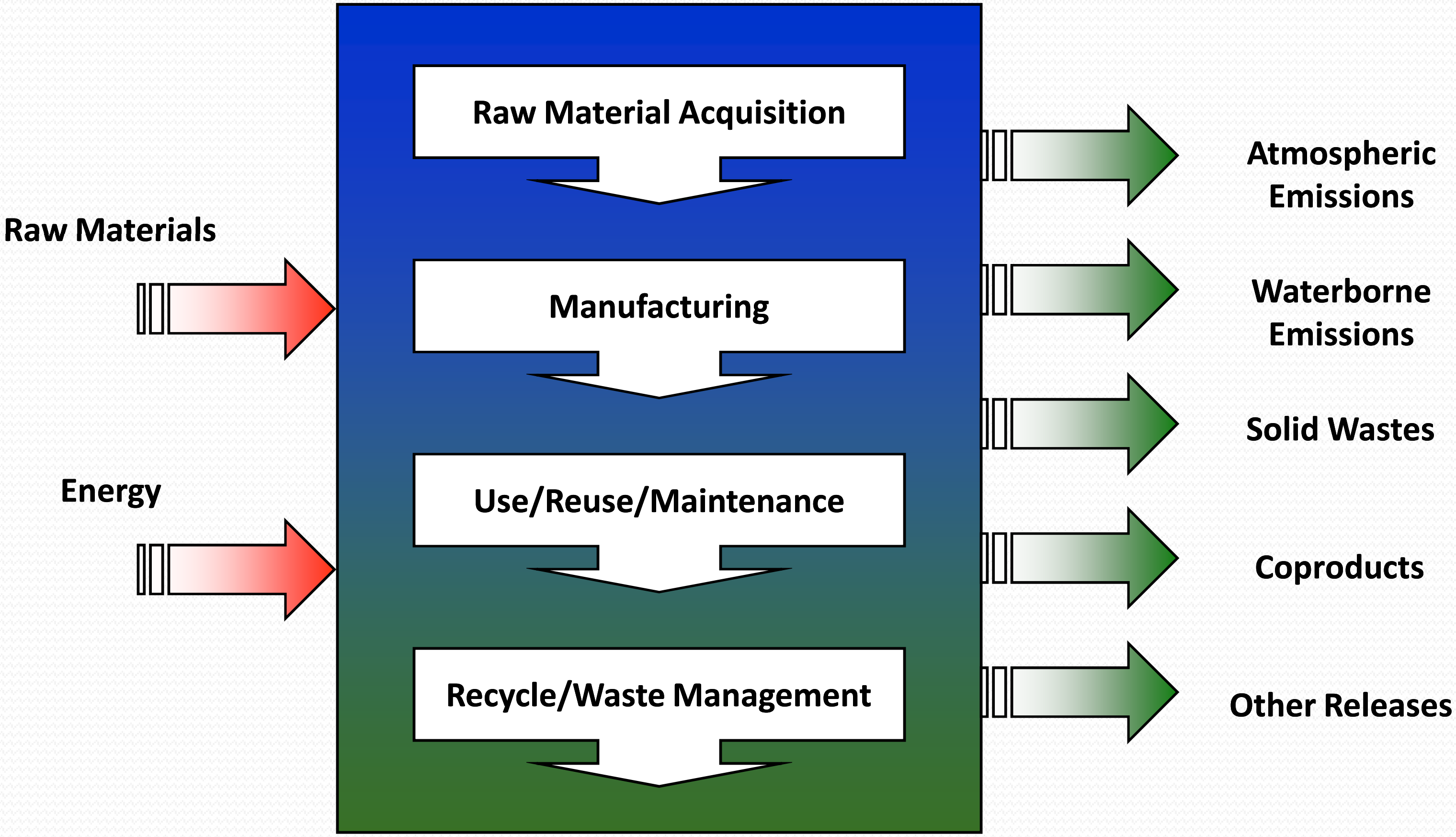
What is Life Cycle Analysis ?



Life Cycle Assessment *methodology*



Life Cycle Assessment



Goals and Scoping

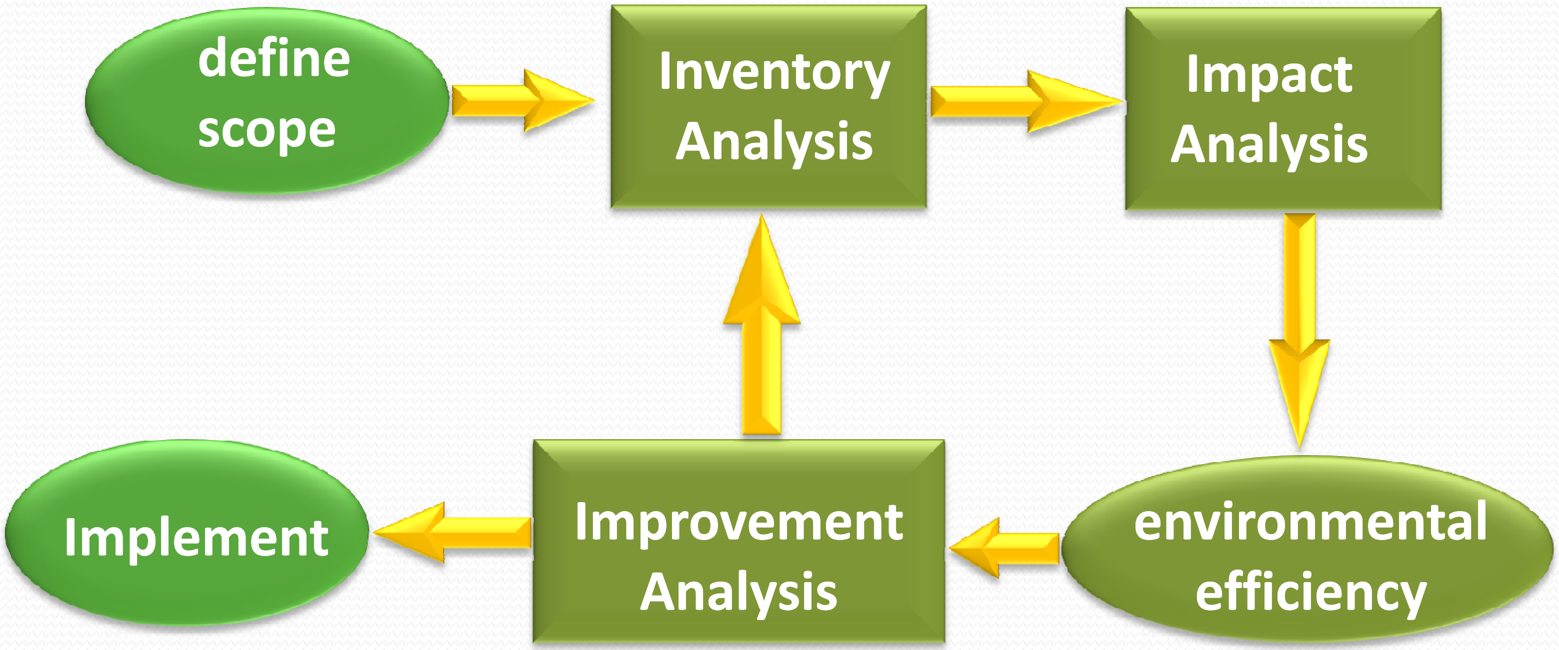
Goals and Scoping

- We must ask ourselves why we want to conduct an Life Cycle Assessment:
  - Implement a new product or process
  - Compare existing product or process to possible competitors
  - Determine the environmental friendliness of a product
  - Determine where to spend money on Environmental Improvement

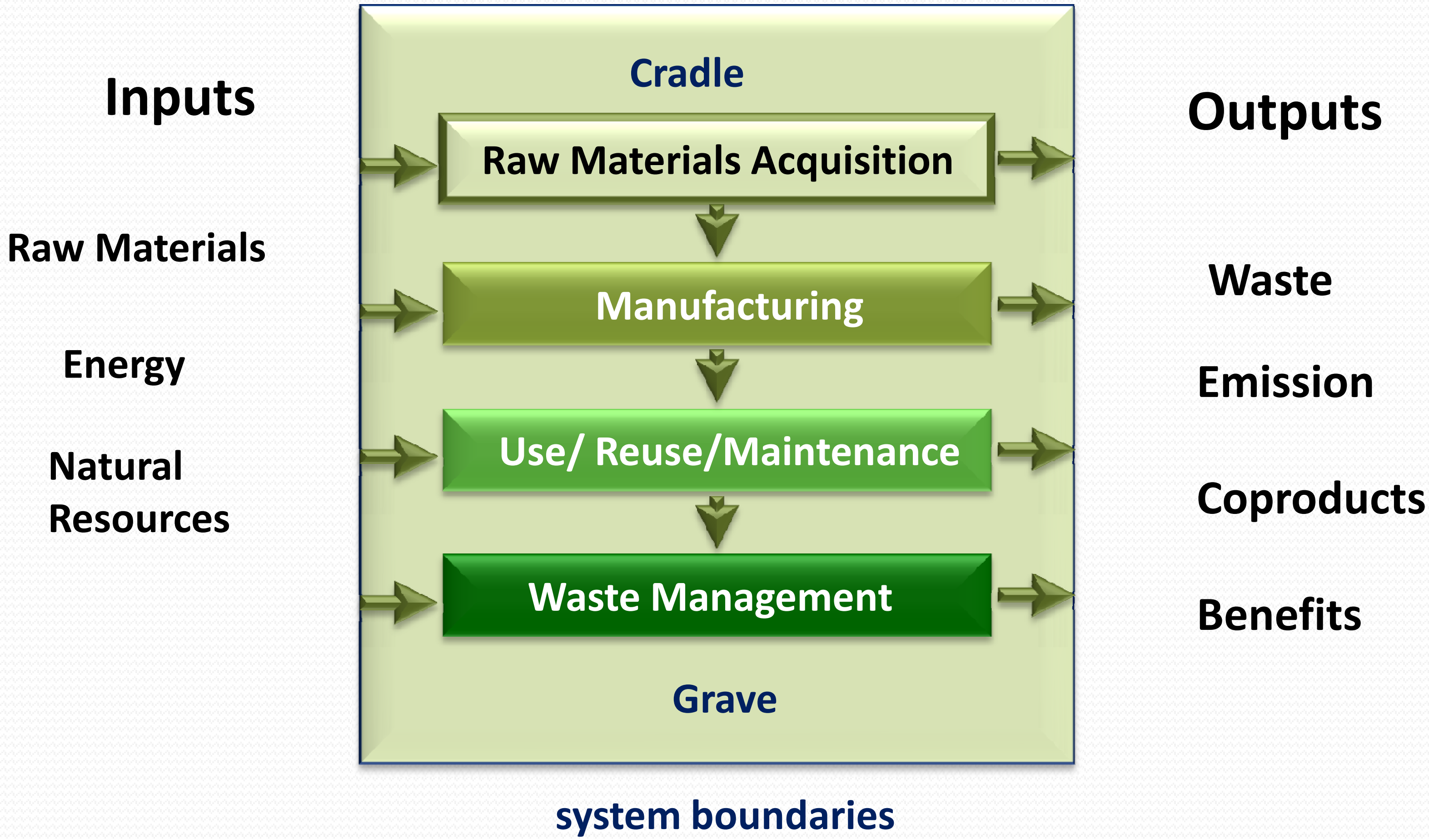
LCA - Components

- **LCA Inventory** - quantifying the energy and materials used, and wastes generated
- **LCA Impact** - assess the effects of the inventory.
- **LCA Improvement** - Systematic evaluation of the needs and opportunities to reduce of the environmental burden.

Steps of a LCA

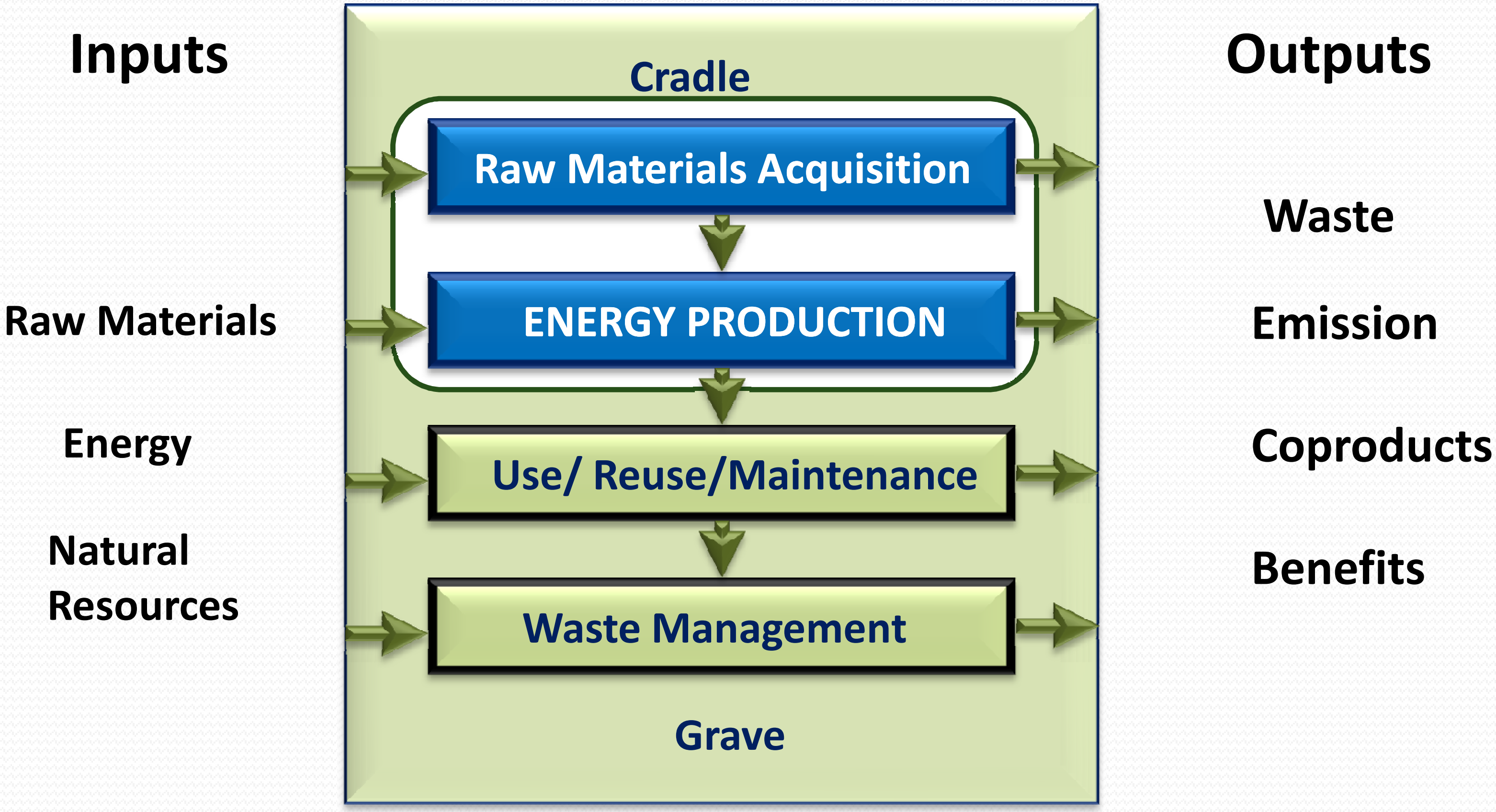


LCA Stages and Boundaries



LCA Scoping

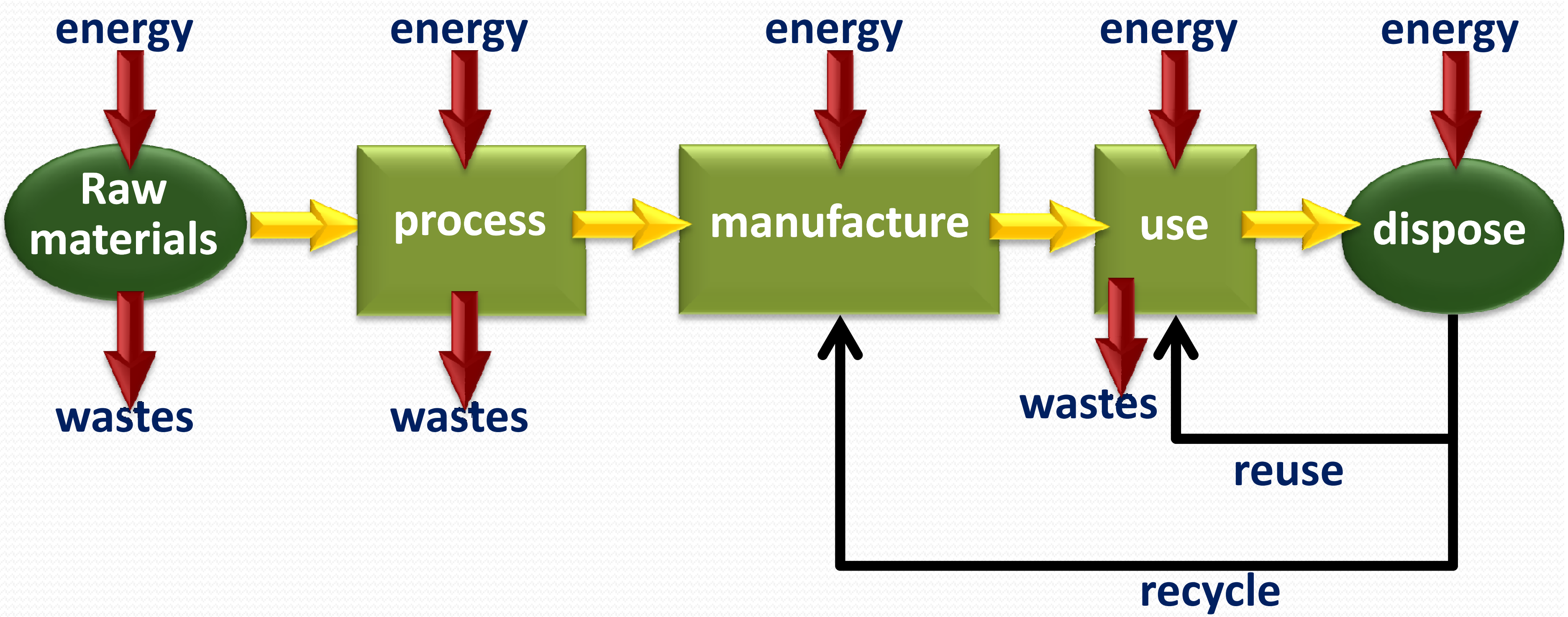
Example - Environmental Impact of using fossil fuels for energy production



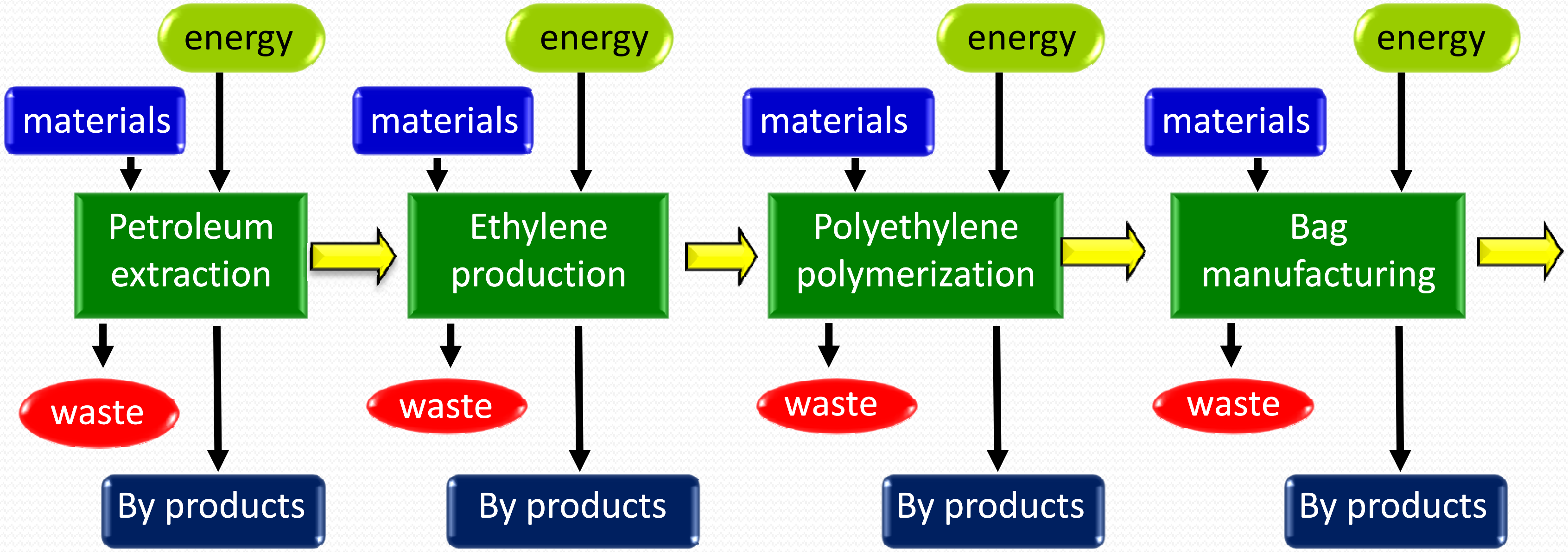
LCA Process Flow Diagrams

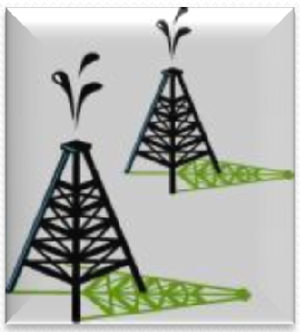
- ✓ **Process Flow Diagram** - It indicates the processes and the hierarchy of the system to be evaluated by a LCA Study
- ✓ The flow diagram indicates the processes for which materials and energy will be evaluated

LCA Process Flow Diagrams



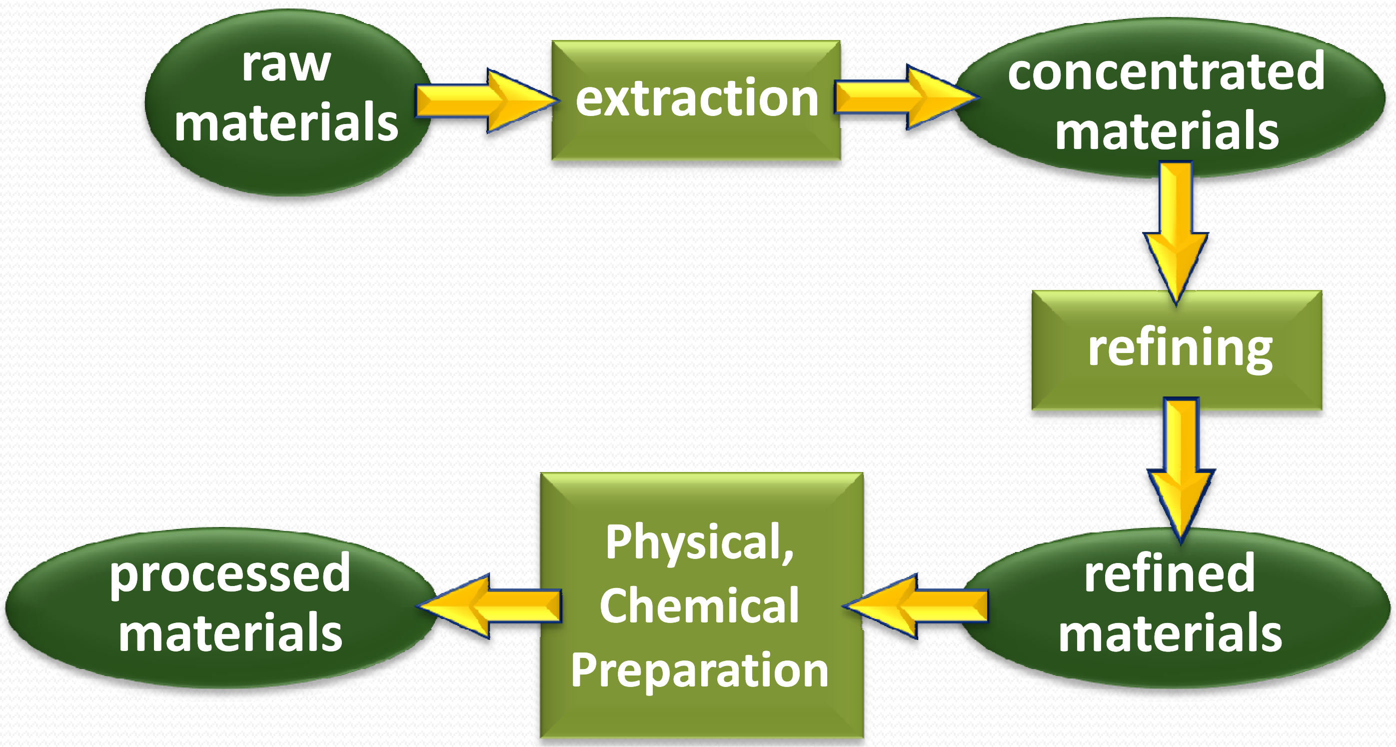
From materials to products





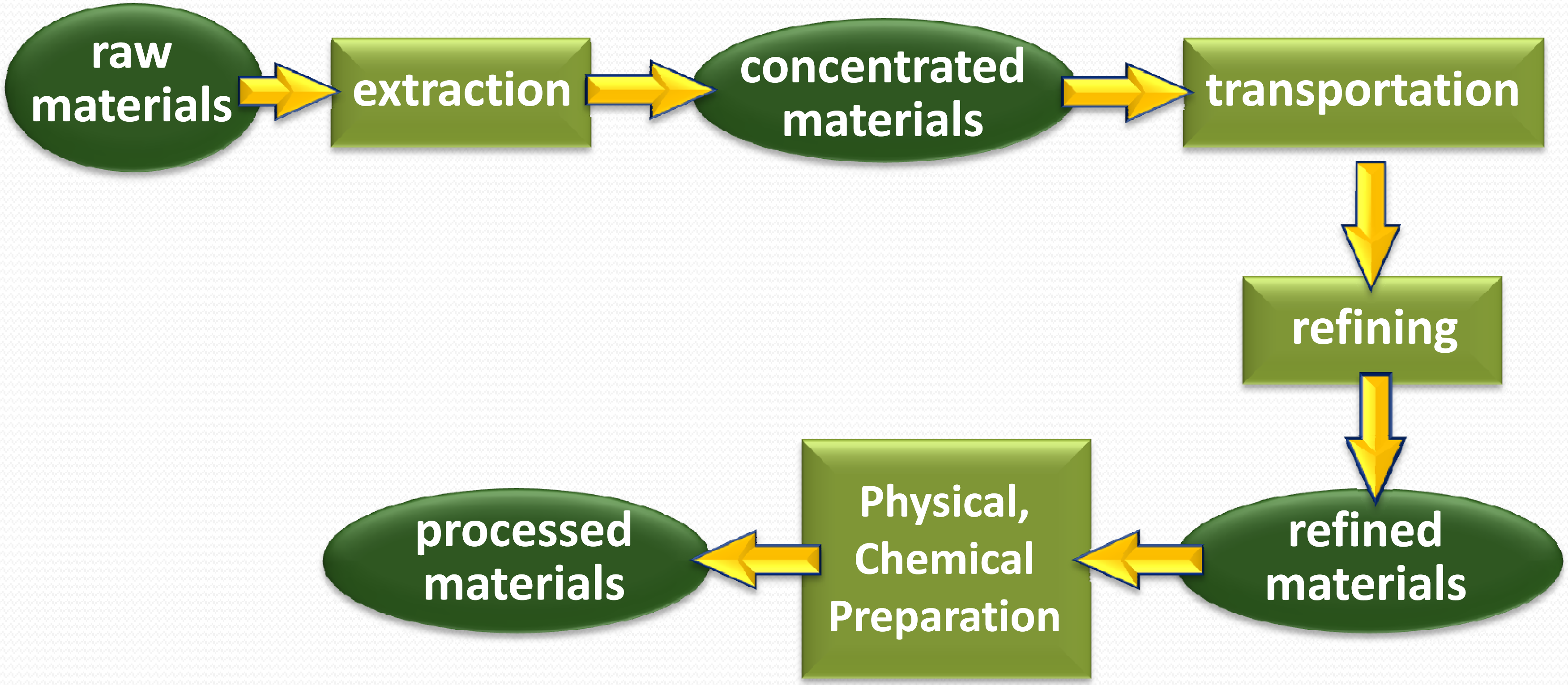
LCA Scoping, Flow Diagram

Raw Materials Extraction and Processing



LCA Scoping, Flow Diagram

Raw Materials Extraction and Processing – fossil fuels

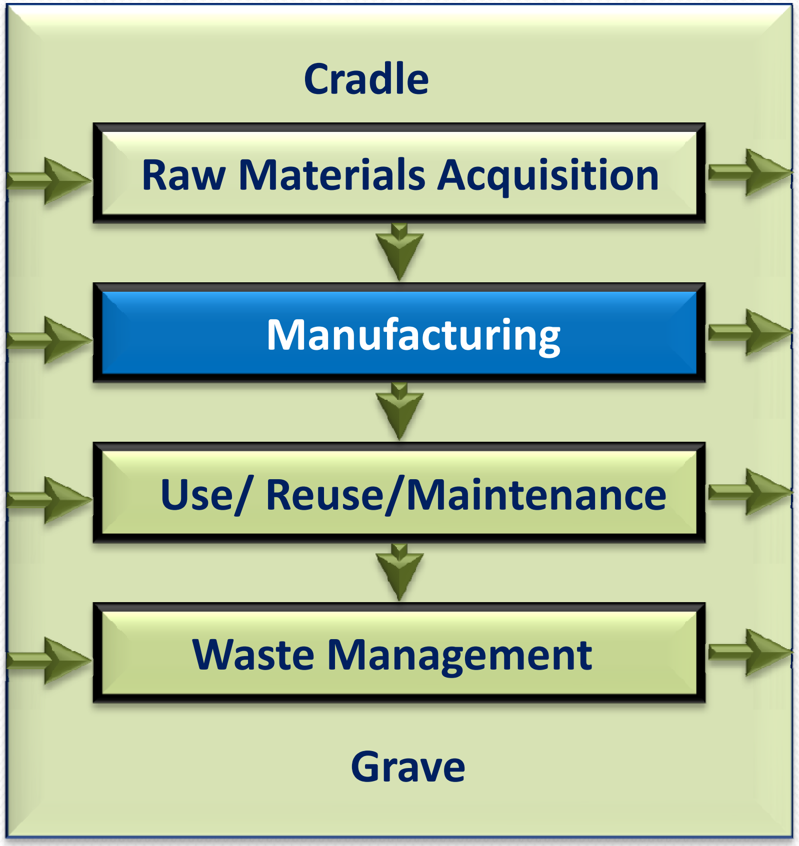


LCA Scoping

Example - Environmental Impact of making coffee cups

Inputs

- Raw Materials
- Energy
- Natural Resources



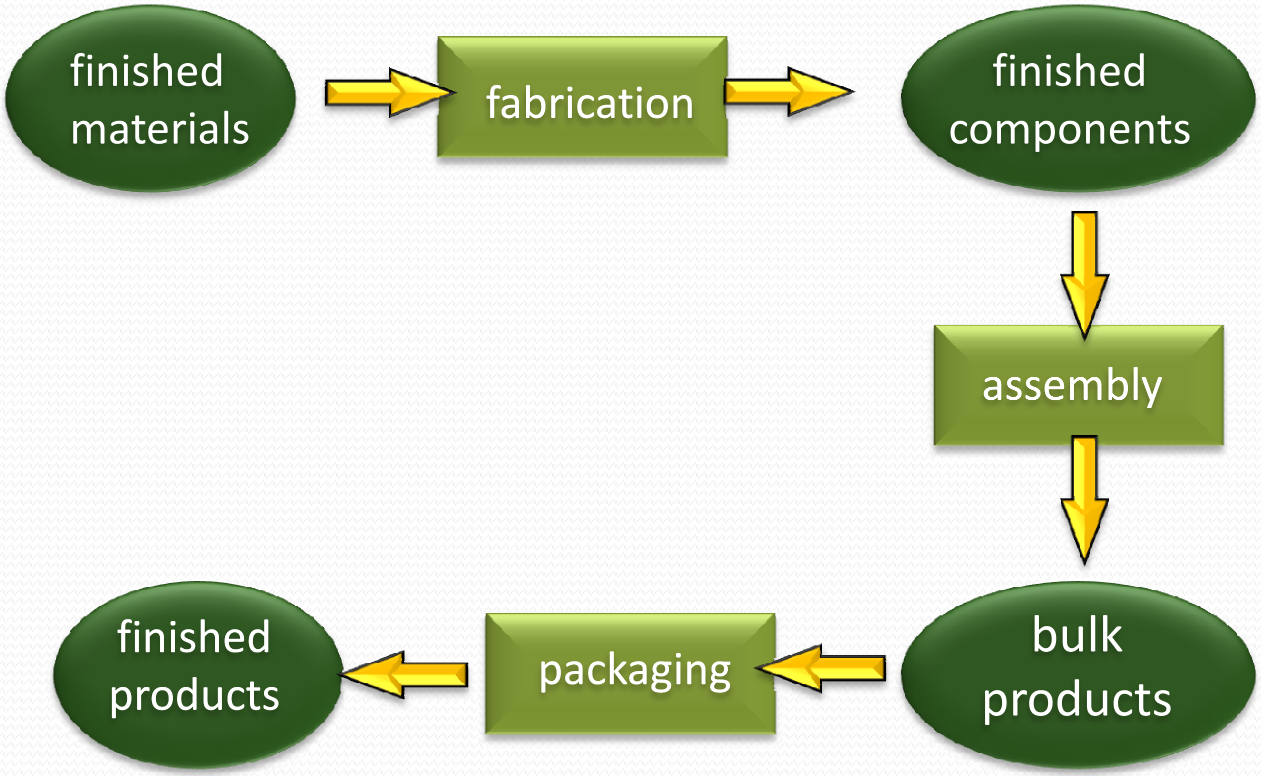
system boundaries

Outputs

- Waste
- Emission
- Coproducts
- Benefits

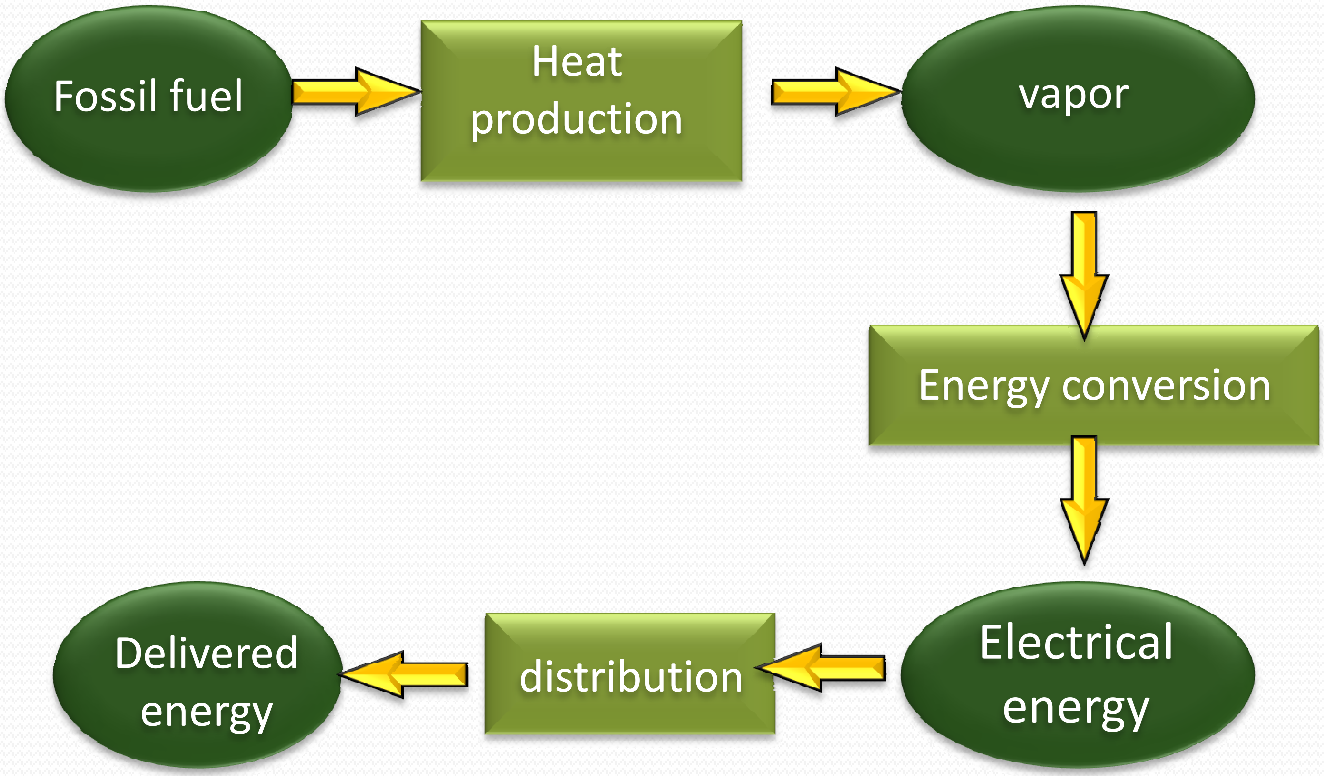
LCA Flow Diagrams

Manufacturing



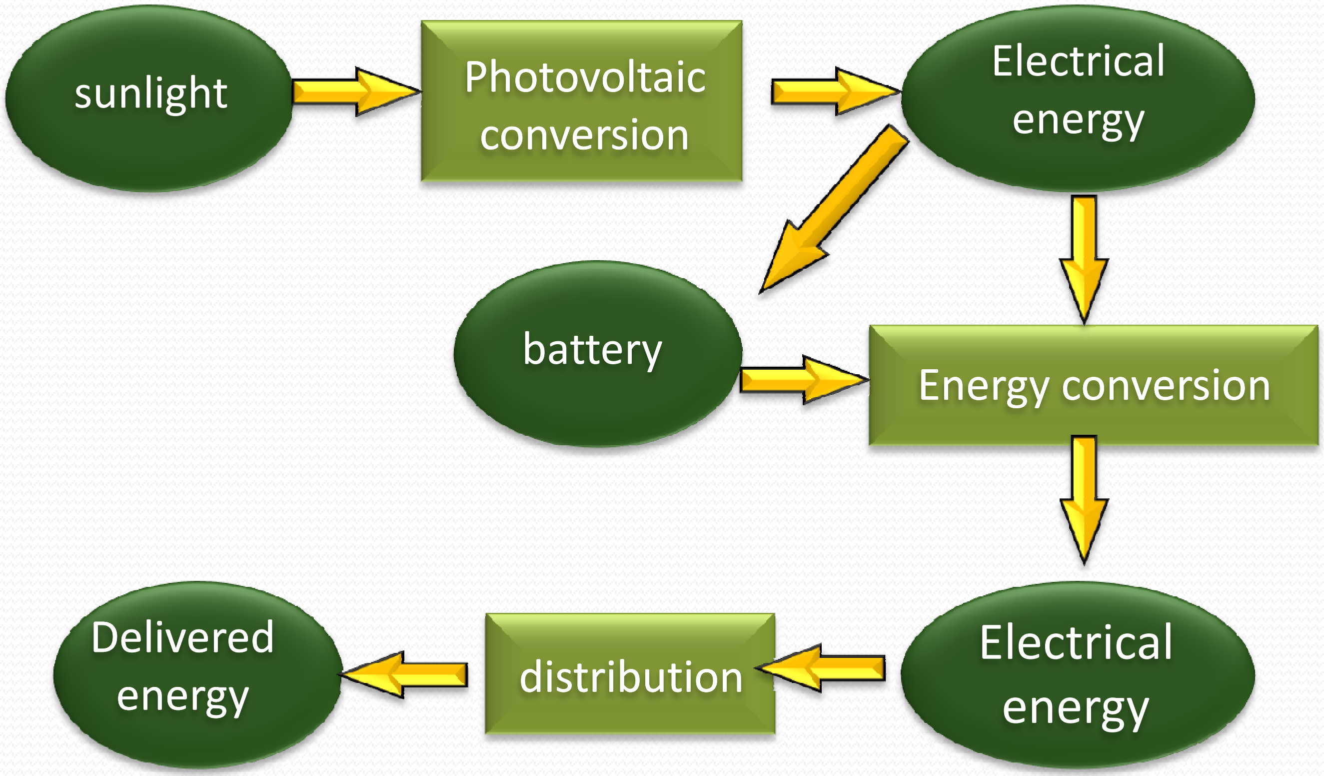
LCA Flow Diagrams

Energy production with fossil fuels / biofuels



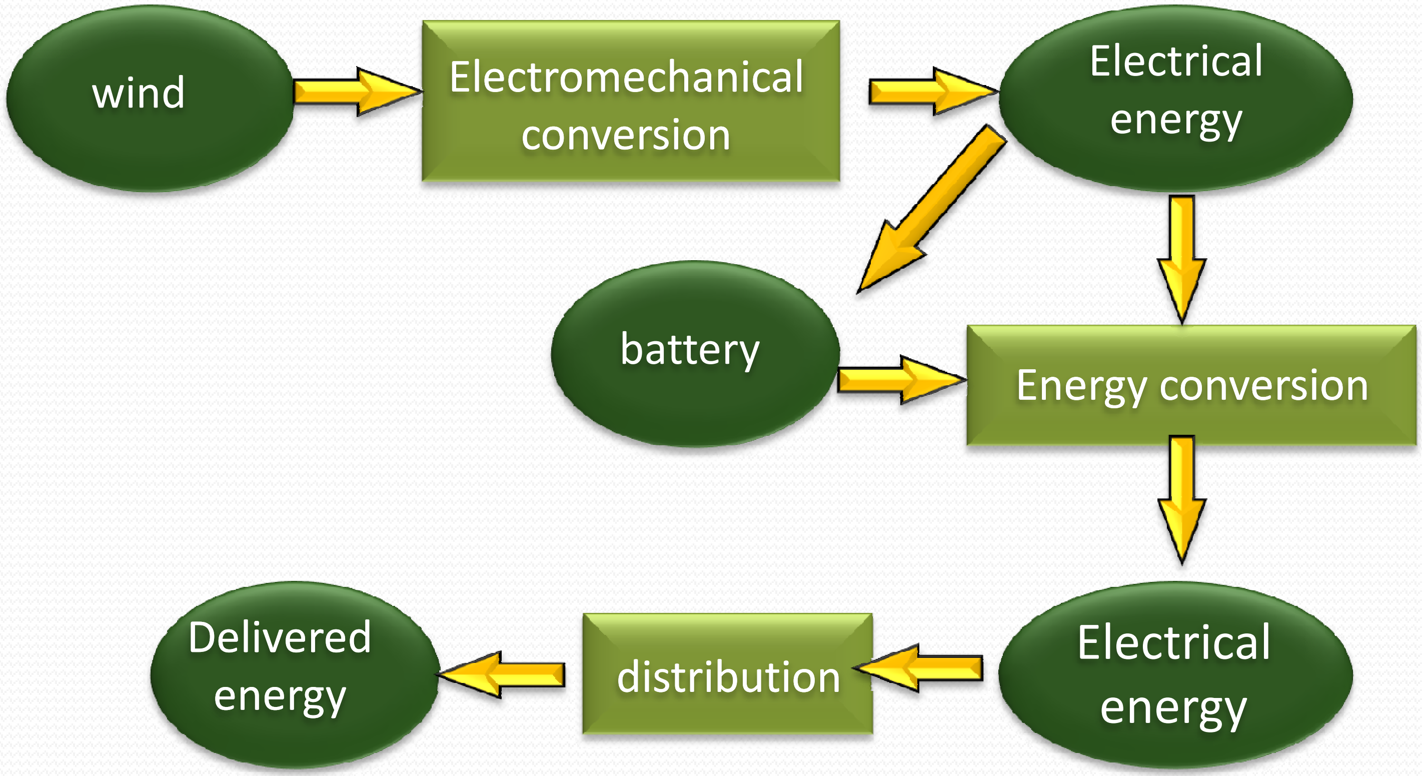
LCA Flow Diagrams

Energy production with solar radiation



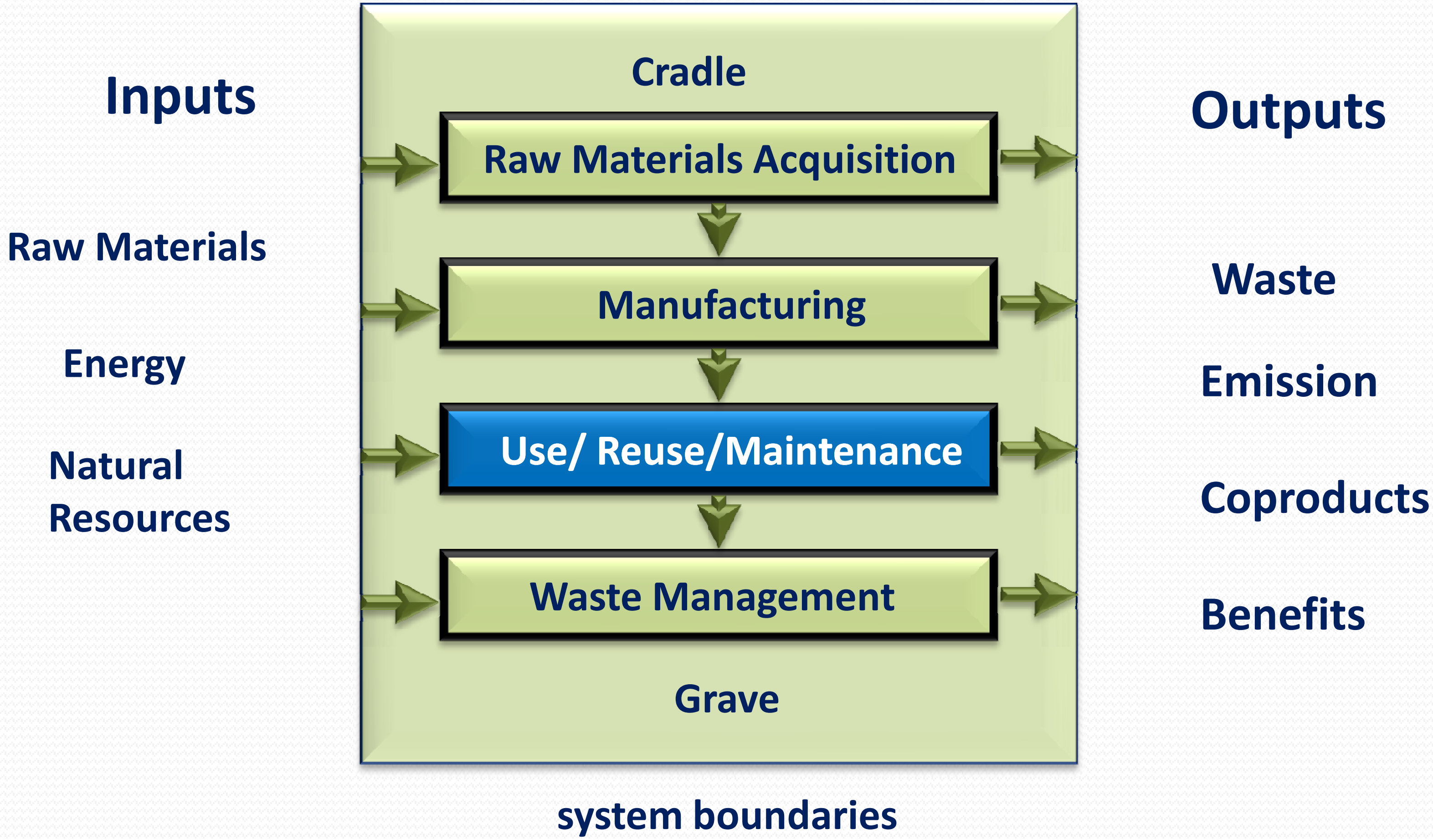
LCA Flow Diagrams

Energy production with wind



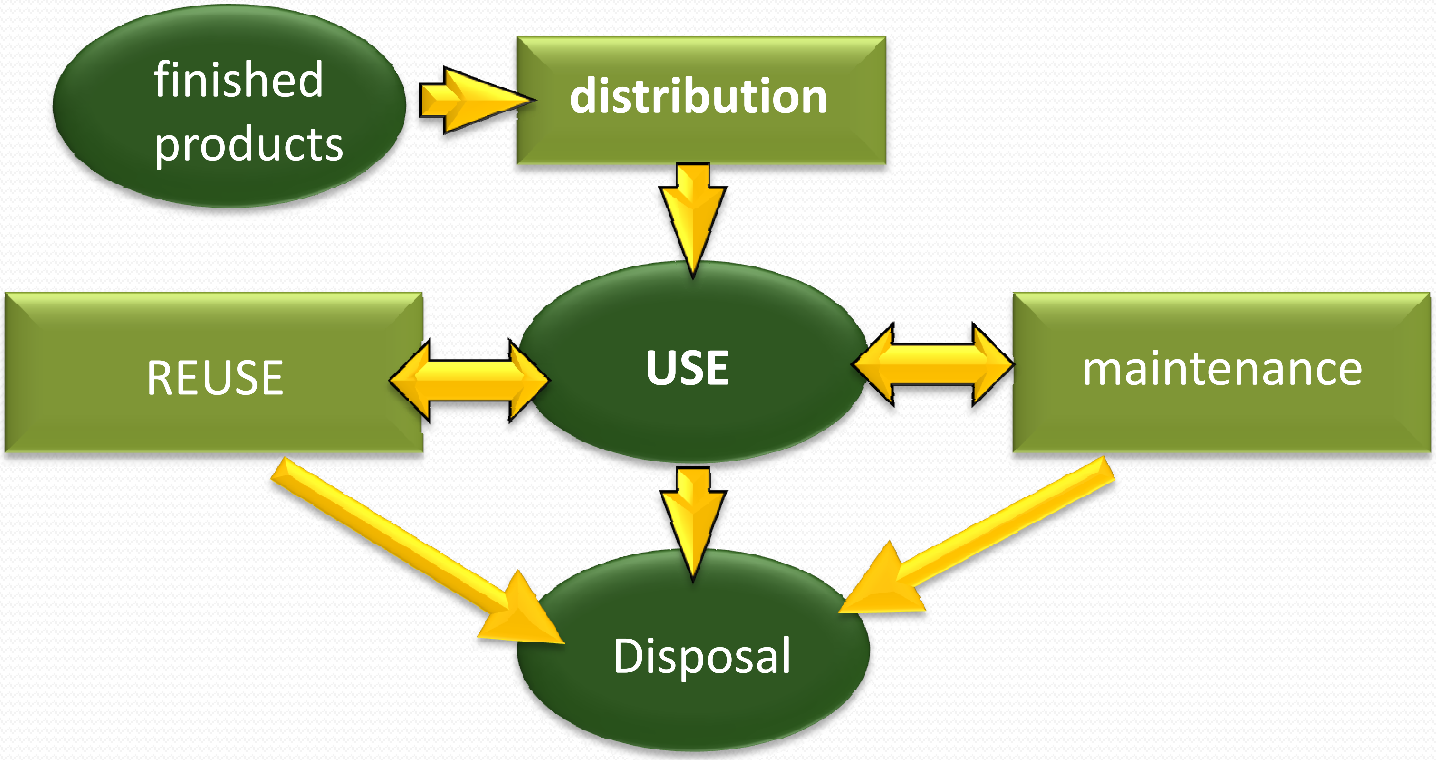
LCA Scoping

Example – Environmental Impact of Operating a Car



LCA Flow Diagrams

Use / Reuse / Maintenance

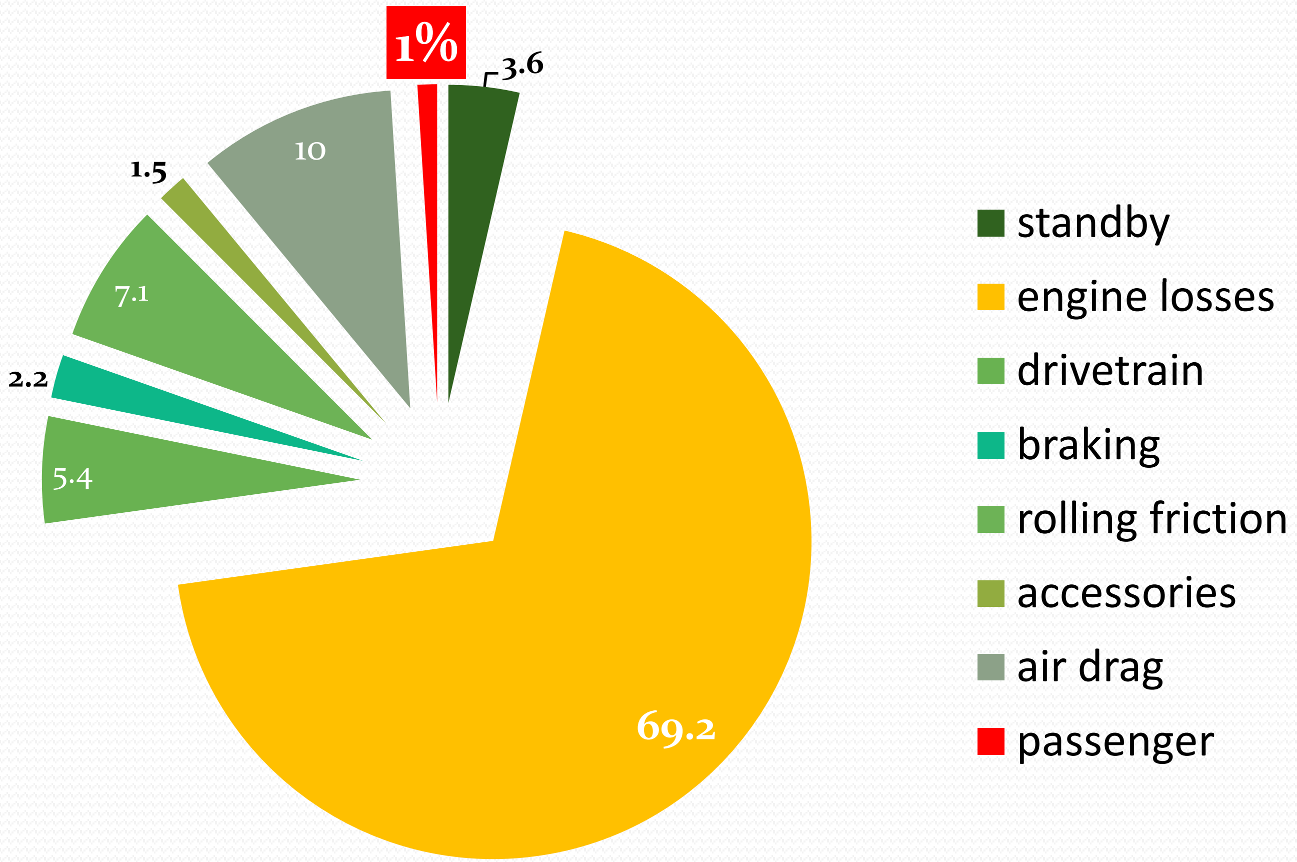


Inventory Assessment and Applications of LCA

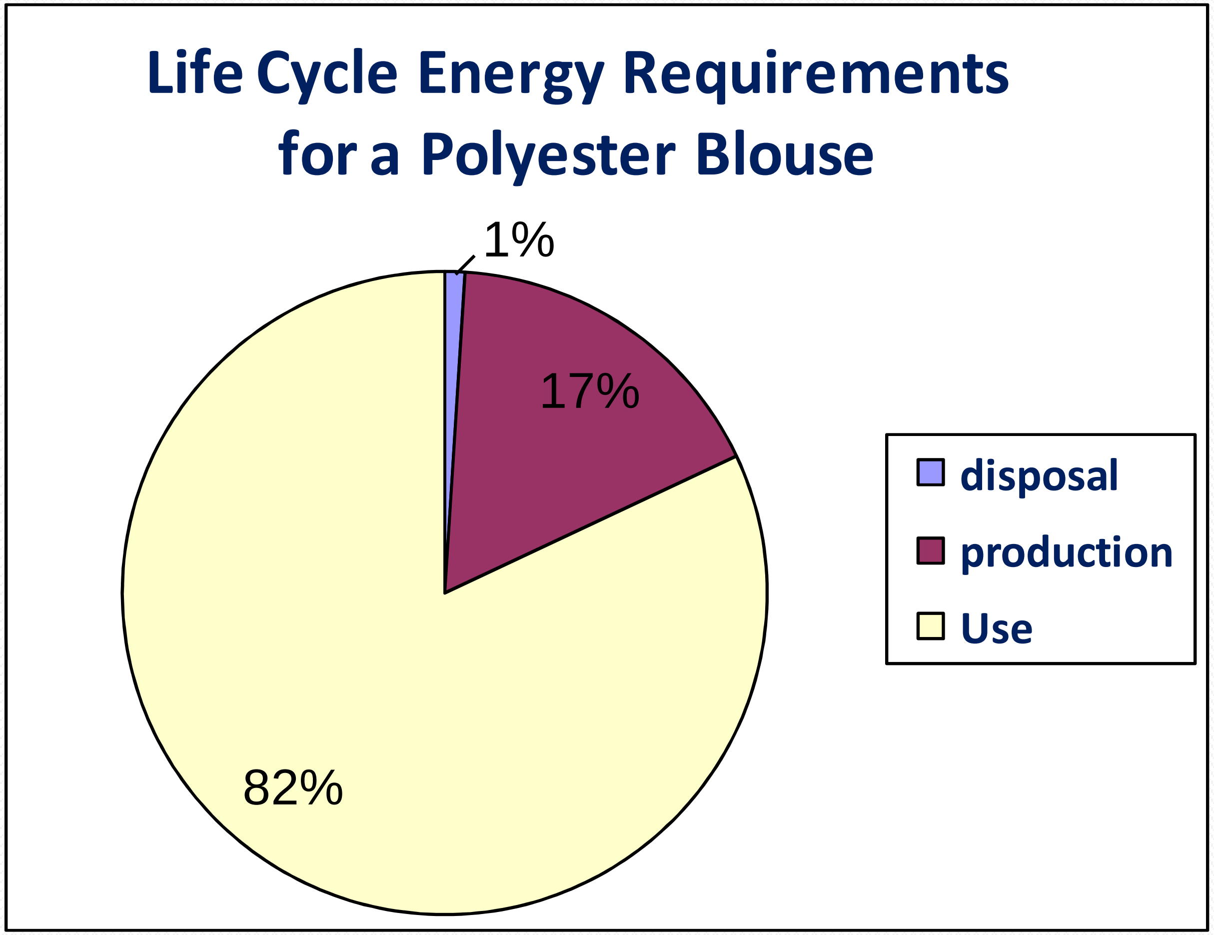
Application of LCA Studies

- Identify major contributors to environmental impact
- Compare options based on environmental impact
- System Environmental Strategic Planning
- Evaluate resource effects of existing and new systems

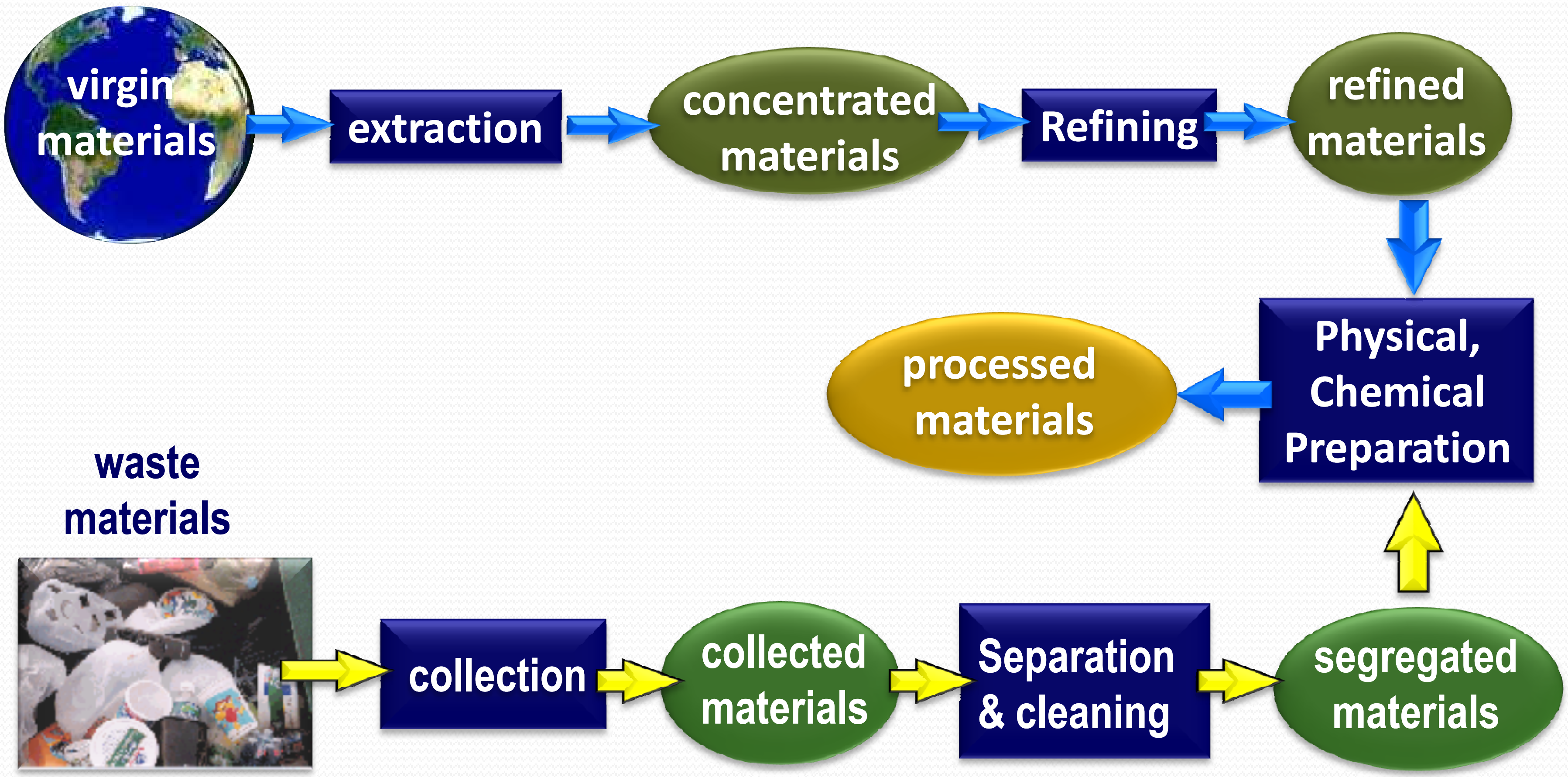
Energy use in IC vehicle



Examples of LCA Studies



Material Processing



Aluminum Can Production

Aluminum Ore extraction

Energy Savings Recycling

- Energy Δ = 66.7 kw hr/kg
- Energy % = 90.4%

Aluminum production → **Sheet production** → **Sheet transport** → **Can production**

70.4 kw hr/kg

7.3 kw hr/kg **0.07 kw hr/kg** **16.6 kw hr/kg**

Ingot production ← **material transport** ← Recycling

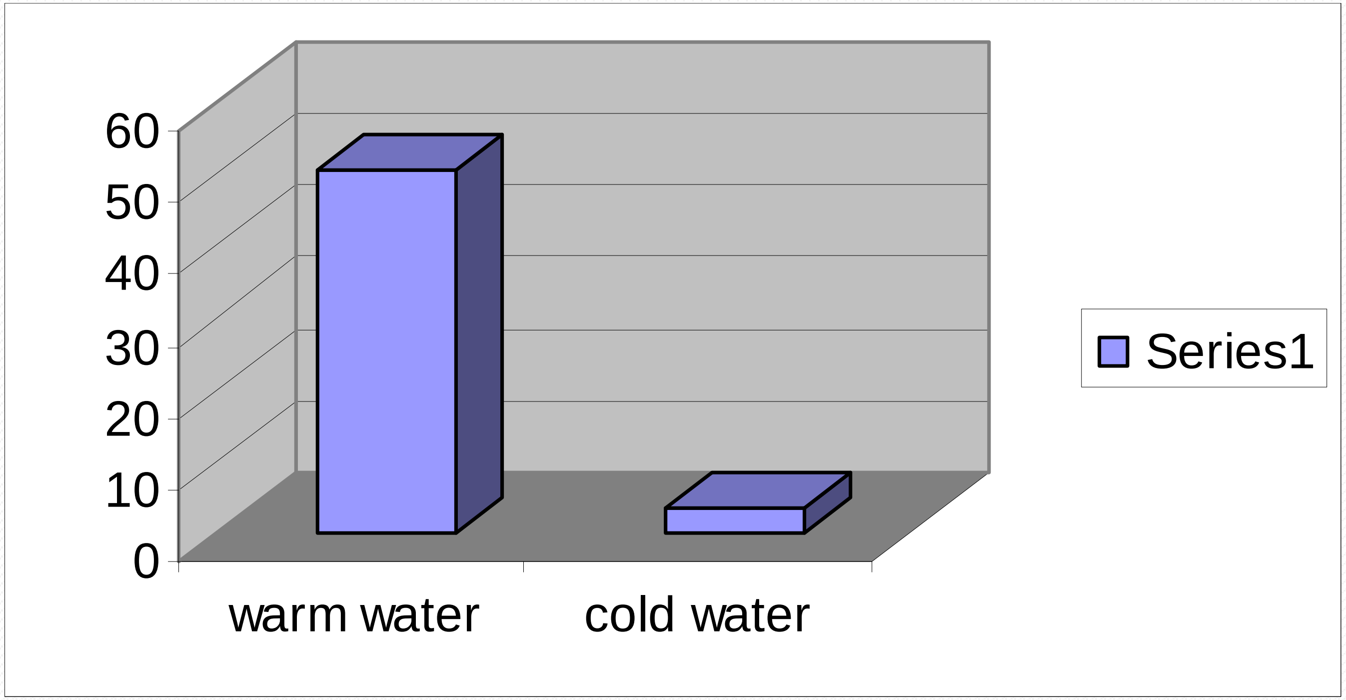
Recycling

0.07 kw hr/kg

3.9 kw hr/kg

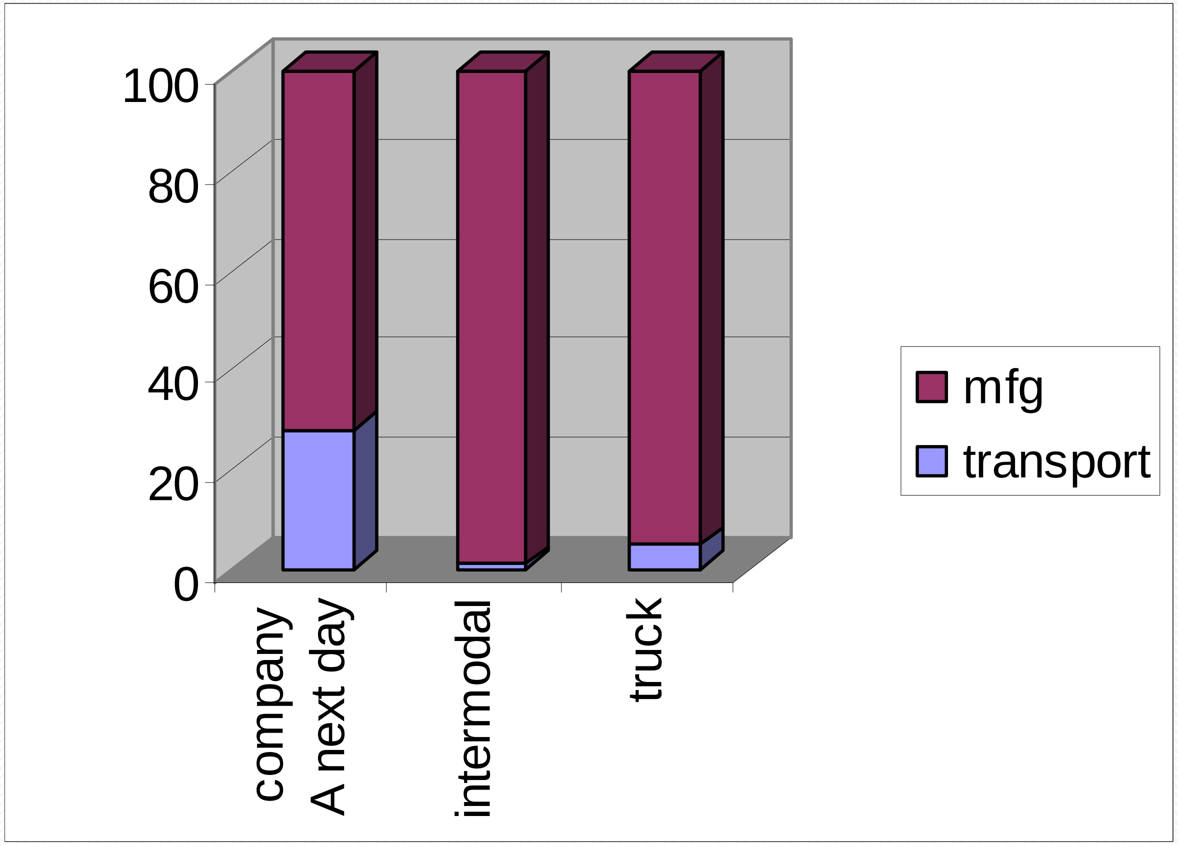
Examples of LCA Studies

Energy used to wash and dry a Polyester Blouse



Examples of LCA Studies

Transportation Energy for Mail Order Business



Examples of LCA Studies

Liquid Detergent Packaging – energy & waste reduction

strategies	Pkg	Trans	Solid waste
25% recycled plastic	3	0	9
25% consumer recycling	3	2	11
Triple concentrate	55	53	55
Product soft pouch	3	18	85
3X in soft pouch	68	73	95
3X in carton box	53	58	91
25% composting	53	58	92

Examples of LCA Studies

Disposable vs Cloth Diapers

Impact	Wash Home	Dispose	Wash Comm.
Energy	1.0	0.5	0.55
Solid waste	1.0	4.1	1.0
Water waste	1.0	0.14	0.95
Water required	1.0	0.27	1.3

The *REAL* environmental impact of driving

Material	Automobile	Total US use	Automobile %
Aluminum	1.3 Tg	6.8 Tg	18.9
Copper	0.3 Tg	3.0 Tg	10.0
Cotton	4.8 Tg	2.2 Tg	0.2
Iron	16.8 Tg	48.6 Tg	34.5
Lead	0.86 Tg	1.24 Tg	69.5
Plastic	1.0 Tg	30.7 Tg	3.2
Platinum	26.4 Tg	63.7 Tg	41.4
Rubber	1.80 Tg	2.86 Tg	62.9
Steel	11.3 Tg	83.6 Tg	13.5
Zinc	0.3 Tg	1.2 Tg	23.0

The *REAL* environmental impact of driving

characteristic	1950's Auto (kg)	1990's Auto (kg)
Plastics	0	101
Aluminum	0	68
Copper	25	22
Lead	23	15
Zinc	25	10
Iron	220	207
Steels	1290	793
Glass	54	38
Rubber	85	61
Fluids	96	81
Other	83	38
TOTALS	**1901**	**1434**

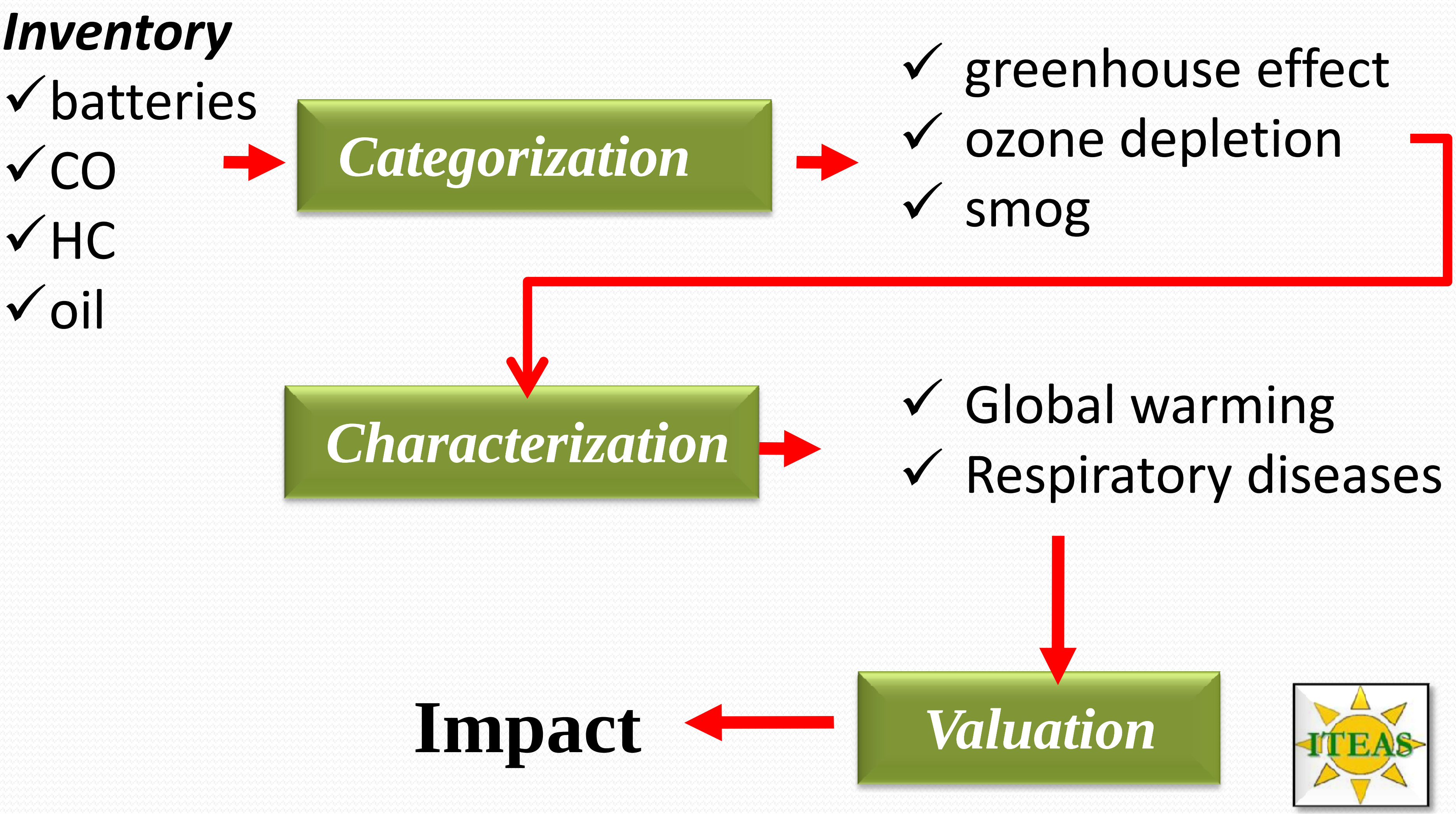
Impact Assessment

Life Cycle Impact Assessment

STEPS

- **Categorization** - determine impact consequences
- **Characterization** - determine how the actions affect the categories
- **Valuation** - determine which impact are more relevant to society

Life Cycle Impact Assessment



Impact Assessment
Stressors - Categories

Stressors describe Impact Categories,

The main stressors are :

- Resource Consumption - How an action affects the supply of important resources
- Ecological Health - How an action affects the Ecosystem
- Human Health - How an action affects the wellbeing of human beings

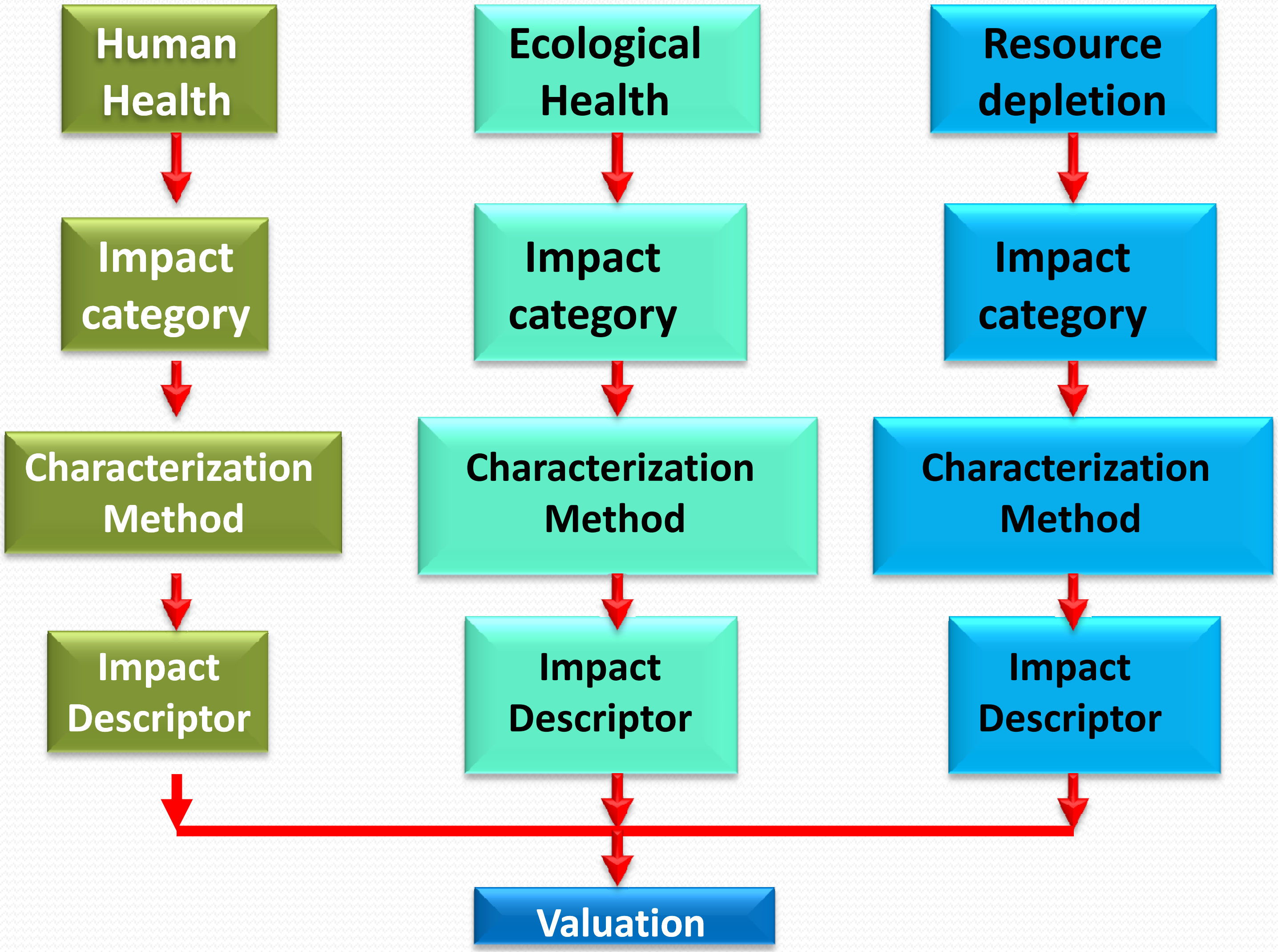
Impact Assessment

Linkage between Stressors and Impact

SO_2

Loss of Biodiversity

Life Cycle Impact Assessment



Improvement Assessment

LCA Improvement - Env. Responsibility Matrix

Life Stage	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	Totals
Resource Extraction	1,1	1,2	1,3	1,4	1,5	
Product Manufacture	2,1	2,2	2,3	2,4	2,5	
Product Delivery	3,1	3,2	3,3	3,4	3,5	
Product Use	4,1	4,2	4,3	4,4	4,5	
Reuse, Recyle, Disposal	5,1	5,2	5,3	5,4	5,5	
Totals						

Environmentally Responsible Product Matrix element 1, 1 resource extraction / materials choice

question	Yes =1 , no = 0
Are all materials the least toxic for the function?	
Are all materials environmentally preferable for the function ?	
Is the product designed to minimize the use of nonrenewable materials ?	
Is the product designed to use renewable materials?	

Environmentally Responsible Product Matrix element 1, 2 resource extraction / energy use

question	Yes =1 , no = 0
minimize the materials which transport is energy intensive?	
minimize the materials which extraction is energy intensive?	
minimize the materials which reuse is energy intensive?	
minimize the materials which renewal is lengthy?	

LCA Improvement - Env. Responsibility Matrix

Life Stage	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	Totals
Resource Extraction	2	2	3	3	2	*12*
Product Manufacture	0	1	2	2	1	*6*
Product Delivery	3	2	3	4	2	*14*
Product Use	1	0	1	1	0	*3*
Reuse, Recyle, Disposal	3	2	2	3	1	*11*
Totals						*46%*

Benefit Assessment and Streamlining

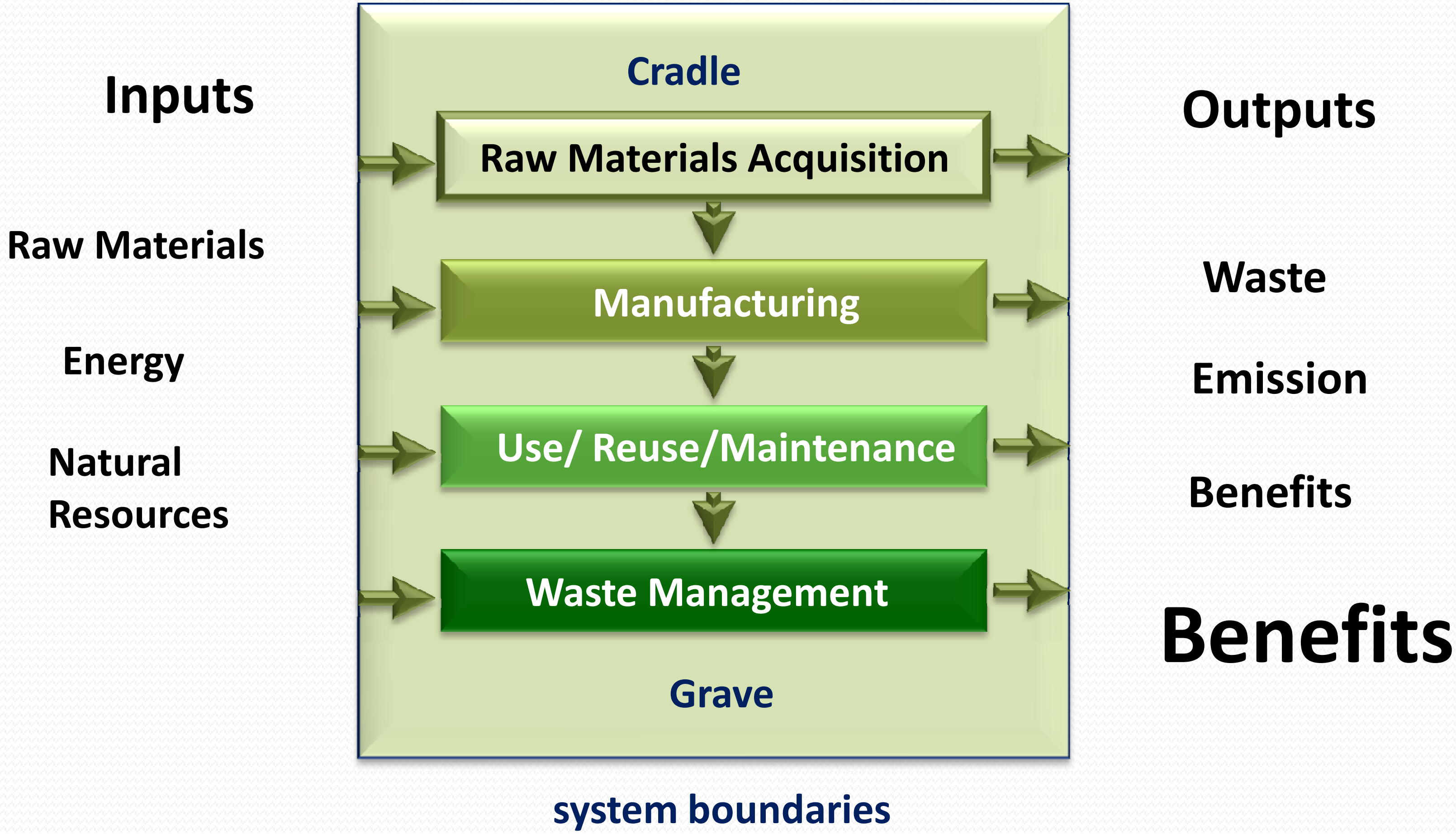
Which one is better?

16 Oz GLASS BOTTLE

12 Oz Aluminum Can

64 Oz PET Bottle

LCA Benefits



LCA Functional Unit

- The Functional Unit is the basis used to establish the LCA Study.
- It is very important that FU be carefully selected, if not it can invalidate the LCA Study
- An inappropriate FU can be used to develop a misleading LCA Study

Selecting the FU

Soft Drink Containers on a 1000 gallon basis -

	PET 64 oz	Al 12 oz Can	Glass 16 oz
Energy Tbtu	*14.6*	*15.9*	*20.9*
Emissions lb	*44.8*	*48.3*	*73.5*
Solid waste lb	*189.5*	*198.3*	*762.5*

Selecting the FU for Energy Production

- ✓ KW hr produced
- ✓ KW hr produced / $ spent
- ✓ KW hr produced / m^2 of used area
- ✓ KW hr produced / m^3 of greenhouse gases
- ✓ KW hr produced /environmental impact
- ✓ KW hr produced / energy of infrastructure

Streamlining LCA

- LCA Studies can be time-consuming and costly.
- Streamlining is an approach for making LCA more accessible
- The main limitation on Full Scale LCA is the amount of data required

Streamlining LCA Approaches

- Limit or eliminate LCA Stages
- Focus on specific environmental impacts or issues
- Eliminate specific inventory parameters
- Limiting impact assessment
- Use qualitative and quantitative data

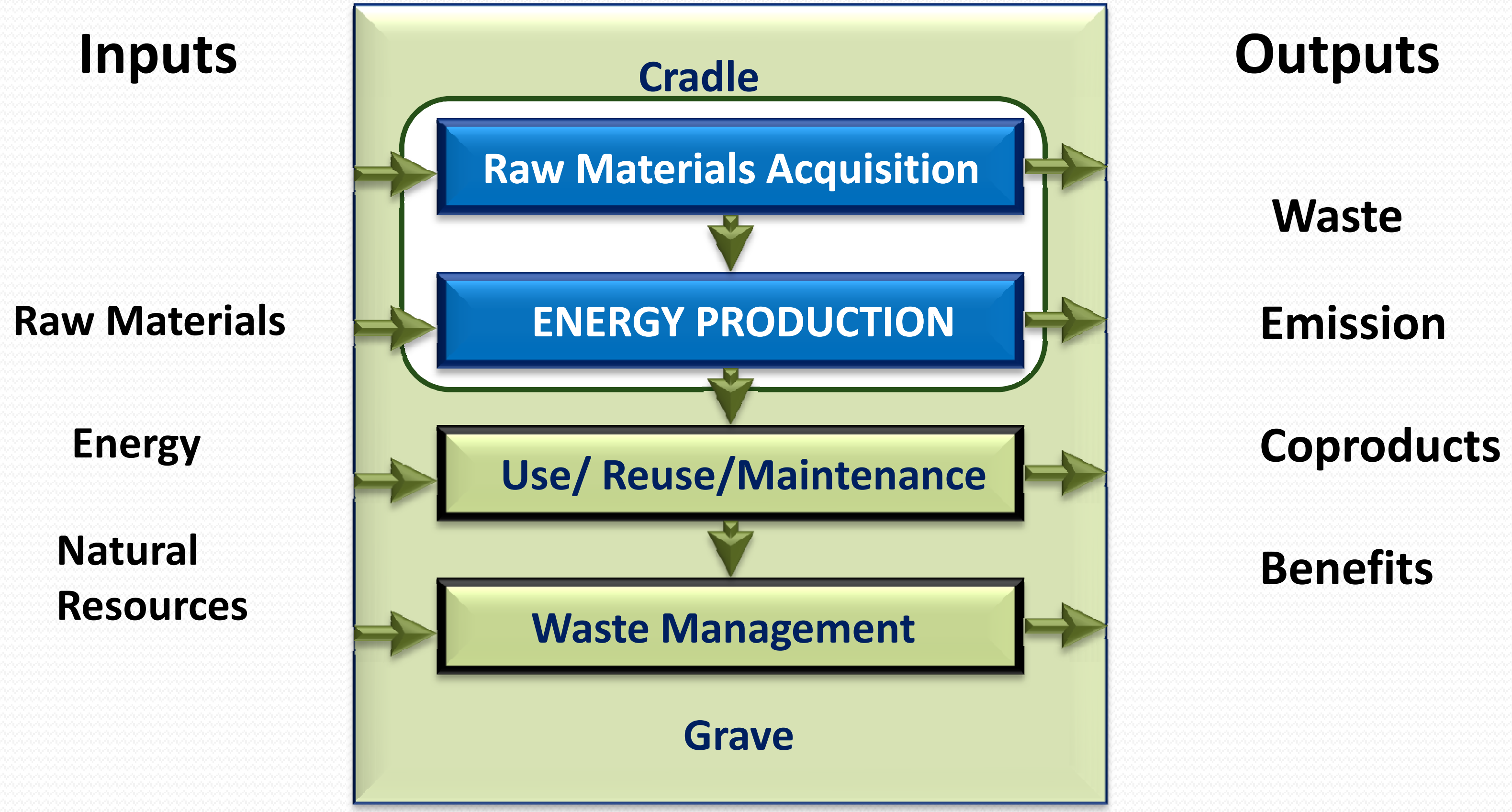
Streamlining LCA Approaches

- Use surrogate data
- Establish criteria to be used as “showstoppers”
- Limit constituents studied to those meeting a threshold quantity
- Combine streamlining approaches

Streamlining LCA Energy Production

- Focus on the raw material and "energy manufacturing" stages
- Evaluate the equipment manufacturing impact
- Use EPA and DOT Data
- Use qualitative scales for comparing energy alternatives

Streamlining LCA
Energy Production



Application of LCA Studies

- Training of environmental professionals
- Develop Environmental Policy
- Determine Resource Allocation
- Develop Eco-Labeling Programs
- Develop Environmental Standards

LCA and transportation

Car Emissions - A Problem

- In numerous cities across the country, the personal automobile is the single greatest polluter
- Many countries have established vehicle emissions programs in an effort to attack this problem.

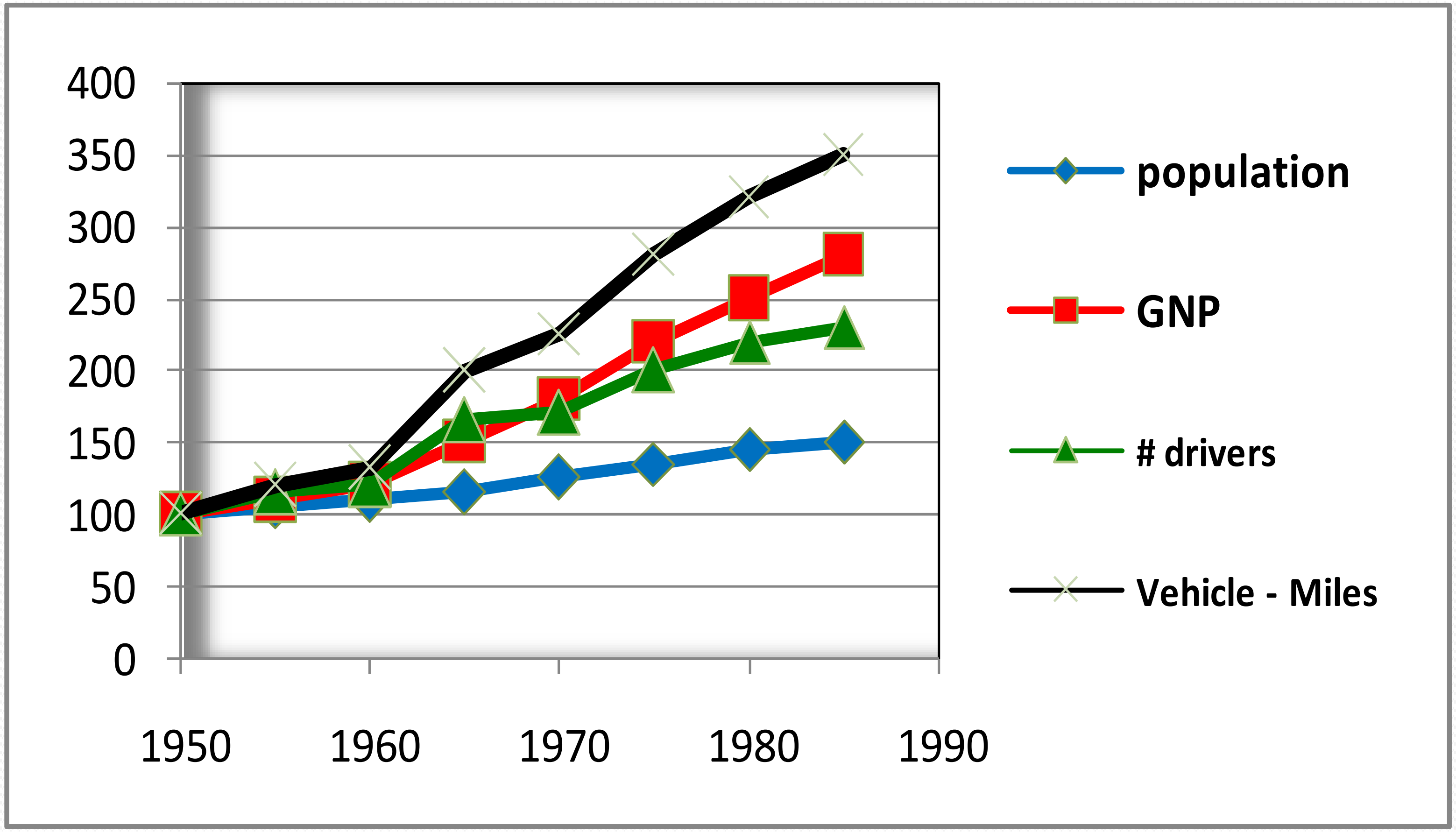
PR Inspection and Maintenance '98

- Established by law in 1995
- Started in April '98
- Uses Florida Standards
- 4 gases test
- *CO, CO_2, O_2 and HC*
- *two RPM settings*
- *Static test*
- *Uses percentages of gases*

Think.....

- Do we need to control emissions?
- Are emissions the main problem with cars?
- How do we do it?
- Do we have to own cars?

Automobile Usage



The Car as Symbol- "I'm too Sexy for my car "

I have a car because:

- How it looks
- To get a girlfriend
- To show off my wealth
- I am too cool to walk
- Everybody has one
- I need it
- To show my independence

The "Benefits" of having a Car

- ☑ Mobility
- ☑ Accessibility
- ☑ Independence
- ☑ Commute
- ☑ Transportation
- ☑ "Investment"

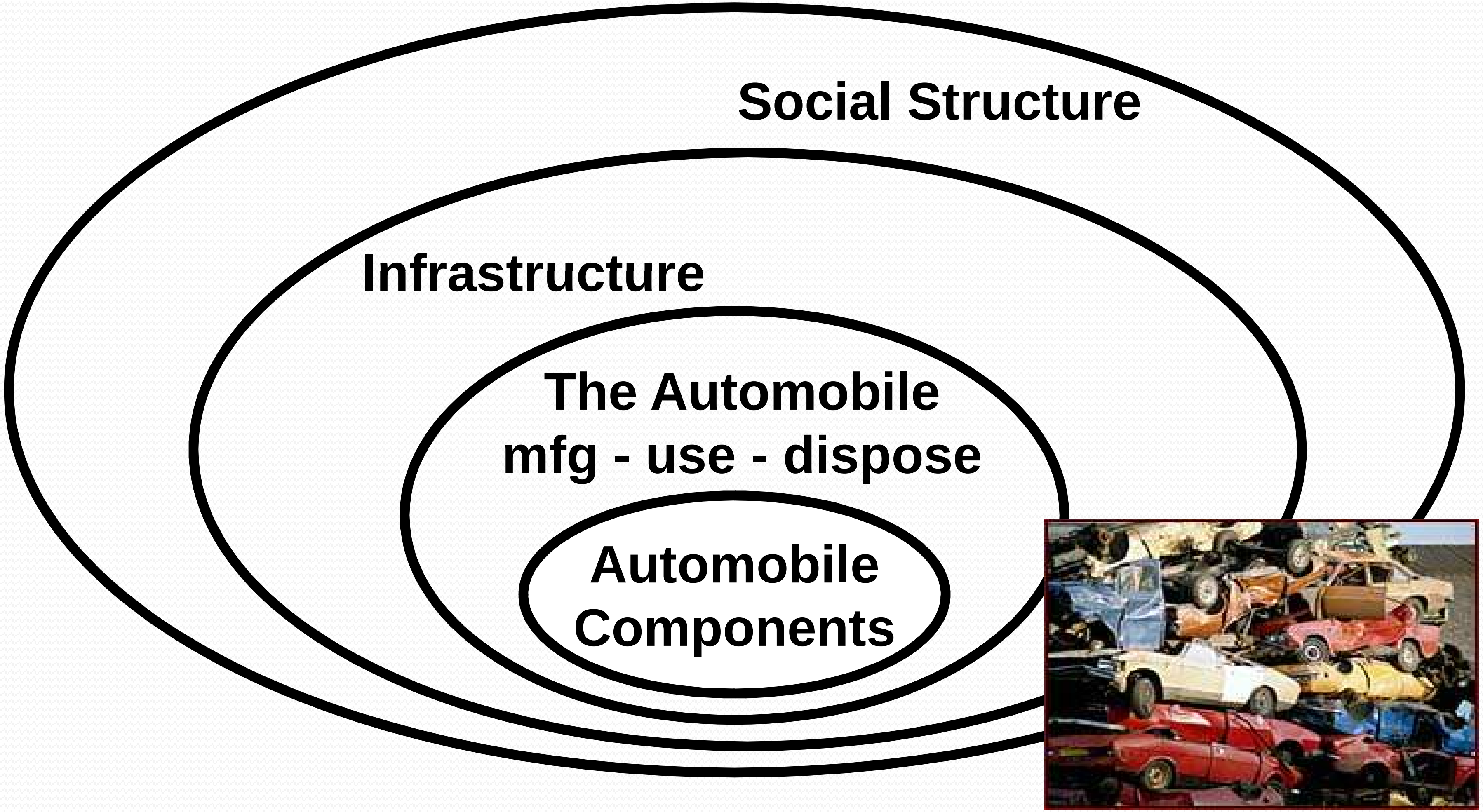
The Present "Needs"

- Motor 8.6L
- Weight - 6,400 lbs.
- Gas mileage – 15/10 mpg
- 32 gallons/tank
- $80 to $90 tank
- Price $80,000 +

The *REAL* environmental impact of driving

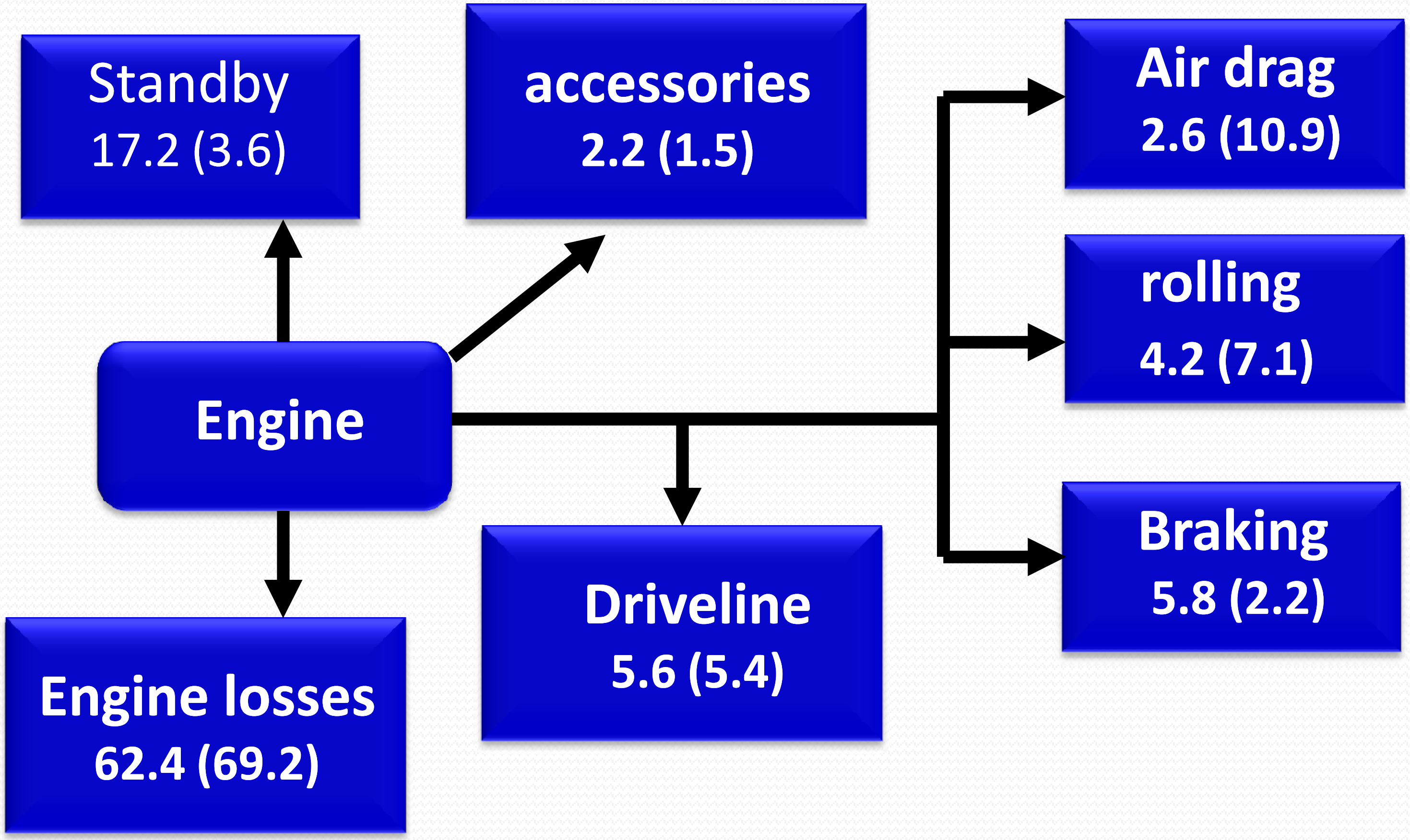
Materials	vehicle manufacture, use, infrastructure, consumables and disposal
Energy	Vehicle use, infrastructure development, material disposal
Ecological	Air Quality, Water Quality, Habitat Destruction, Noise
Social	Urban burden, health degradation

The *REAL* environmental issue
The automobile and Society

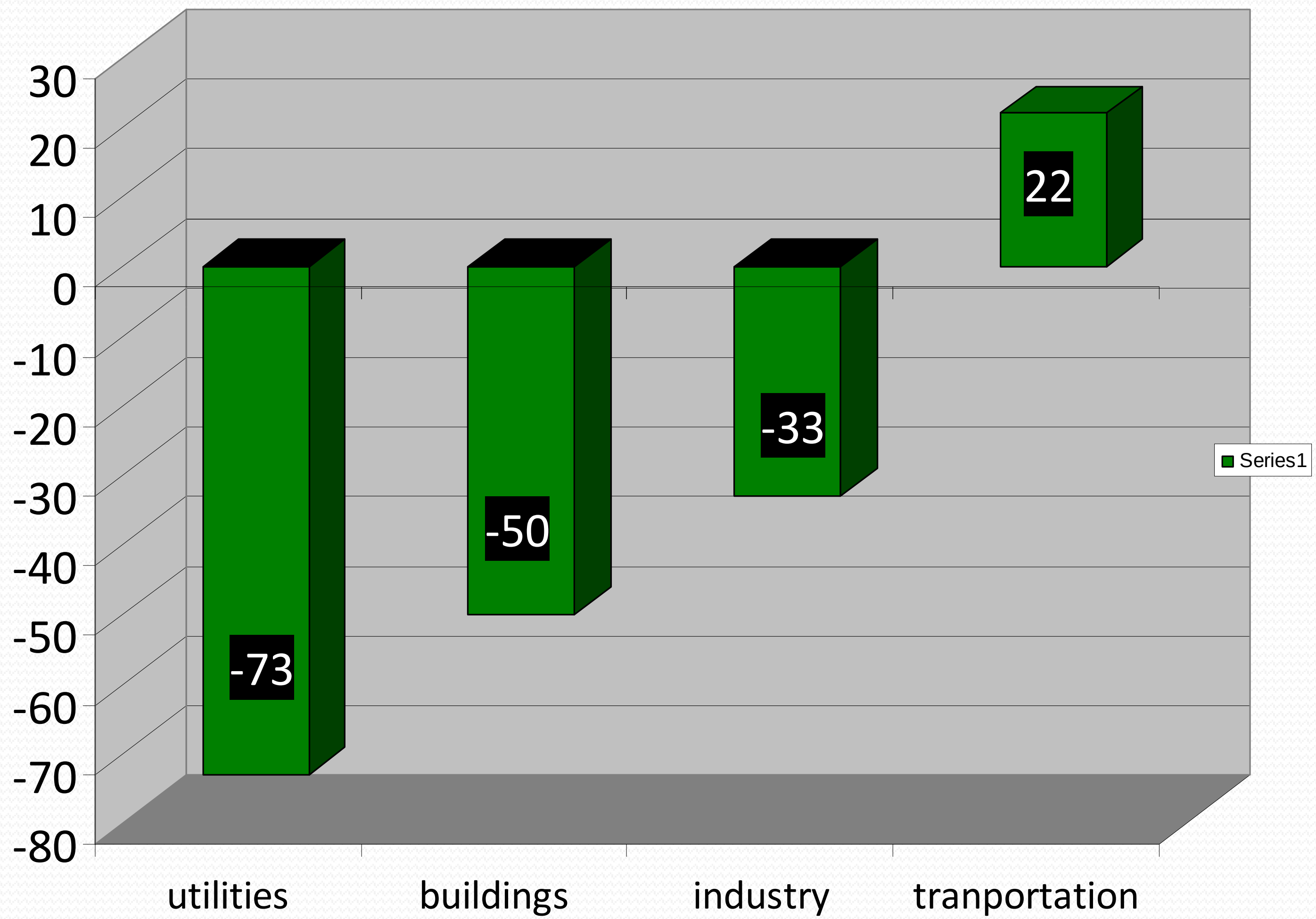


The *REAL* environmental impact of driving

- ***Energy*** -



The *REAL* environmental impact of driving - oil use %



The *REAL* environmental impact of driving

- ***Energy*** -

Category	Embedded Energy
Rural Highways	
Energy per lane	8.4 TJ / km
Energy per 12 m bridge	1.6 TJ
World road distance	9.5 x million kms
Embedded roadway energy	**170 EJ**
Embedded bridge energy	0.73 EJ
TOTAL	**191.5 EJ**

Think

- Could we substitute the Car Emissions Program with a program that
  1. Consider the real impacts of a vehicle
  2. Would assess part of the costs of these impacts to the owners
  3. The greener vehicle, the lower these imposed costs to the owners
  4. We would develop a vehicle green index or environmental score

Evaluating the *Ecoefficiency Matrix*

Life Stage	Materials Choice	Energy Use	Solid Residue	Liquid Residues	Gaseous Residues
Resource Extraction	1,1	1,2	1,3	1,4	1,5
Product Manufacture	2,1	2,2	2,3	2,4	2,5
Product Delivery	3,1	3,2	3,3	3,4	3,5
Product Use	4,1	4,2	4,3	4,4	4,5
Reuse, Recyle, Disposal	5,1	5,2	5,3	4,5	5,5

Evaluating the Matrix element 2,1 manufacturing / materials choice

question	Yes = 1	No = 0
Are materials used generate the less amount of toxics in manufacturing ?		
Has the product been designed to minimize materials restricted supply ?		
Has the use of radioactive materials been reduced ?		
TOTAL		

Evaluating the Matrix element 4,1 product use / material choice

question	Yes = 1	No = 0
If the product is disposable, have other options been developed with the same performance ?		
Are the consumables in restricted supply ?		
Do the consumables contain toxic materials ?		
TOTAL		

Evaluating the Matrix element 4, 2 product use / energy use

question	Yes = 1	No = 0
Has the product been designed to reduce energy consumption during use ?		
Have energy saving measure been incorporated in the design ?		
Can the product monitor and display energy use ?		
TOTAL		

Evaluating the Matrix element 4, 3 product use / solid residues

question	Yes = 1	No = 0
Does the product require the periodical disposal of solid materials ?		
Have alternatives to solid consumables been developed ?		
Do intentional emissions of the product enter the land ?		
TOTAL		

Evaluating the Matrix

Life Stage	Materials Choice	Energy Use	Solid Residue	Liquid Residues	Gaseous Residues	Totals
Resource Extraction	2 3	2 3	3 3	3 3	2 3	12/20 15 / 20
Product Manufacture	0 3	1 2	2 3	2 3	1 3	6/20 14 / 20
Product Delivery	3 3	2 3	3 3	4 4	2 3	14/20 16 / 20
Product Use	1 1	0 2	1 2	1 3	0 2	3/20 10 / 20
Reuse, Recyle, Disposal	3 3	2 2	2 3	3 3	1 2	11/20 13 / 20
Totals	9/20 13 / 20	7/20 12 / 20	7/20 12 / 20	7/20 12 / 20	7/20 12 / 20	46/100 68 / 100

Evaluating the Matrix

weighting life cycle stages

Life Stage	Materials Choice	Energy Use	Solid Residue	Liquid Residues	Gaseous Residues
Resource Extraction	0.15	0.15	0.15	0.15	0.15
Product Manufacture	0.10	0.10	0.10	0.10	0.10
Product Delivery	0.25	0.25	0.25	0.25	0.25
Product Use	0.30	0.30	0.30	0.30	0.30
Reuse, Recyle, Disposal	0.20	0.20	0.20	0.20	0.20

Environmental Efficiency

Life Stage	Materials Choice	Energy Use	Solid Residue	Liquid Residues	Gaseous Residues	Totals
Resource Extraction	0.075 0.1125	0.075 0.1125	0.112 0.112	0.067 0.0675	0.03 0.045	0.36 0.45
Product Manufacture	0 0.075	0.025 0.05	0.05 0.075	0.03 0.045	0.01 0.03	0.115 0.275
Product Delivery	0.1875 0.1875	0.125 0.1875	0.187 0.187	0.15 0.15	0.05 0.075	0.70 0.7875
Product Use	0.075 0.075	0 0.15	0.075 0.15	0.045 0.135	0 0.06	0.195 0.57
Reuse, Recyle, Disposal	0.15 0.15	0.1 0.1	0.1 0.15	0.09 0.09	0.02 0.04	0.46 0.53
Totals	0.4875 0.6	0.325 0.6	0.525 0.675	0.382 0.4875	0.11 0.25	*1.83* *2.6125*

Life Cycle Assessment

- Allows to evaluate the complete environmental impact of a product, process or system during its complete life cycle.
- The LCA is still an evolving, unfinished methodology.

Questions ???