Quantifiably Sustainable
Moving Beyond LEED

AMERICAN ENGINEERING TESTING, INC.

Learning Objectives

Upon completing this program, the participant should be able to:

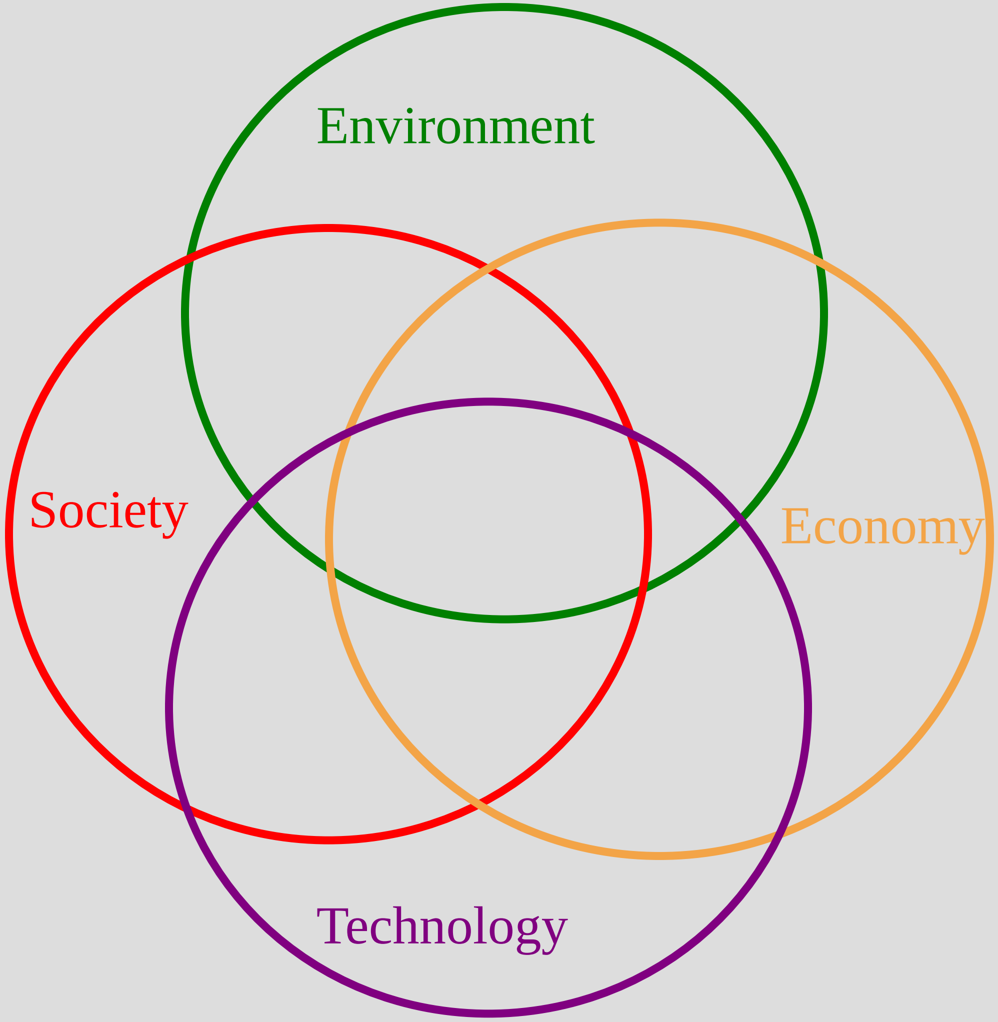
1. Compute Embodied Energy Content of Mixtures
2. Compute Greenhouse Gas Emissions of Mixtures
3. Use Criteria Functions and Optimization Equations
4. Understand the role of Life Cycle Assessment in Sustainability

Sustainability

Commonly used definition:

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

CONCRETE IS BY FAR THE MOST USED CONSTRUCTION MATERIAL IN THE WORLD


Environment
Society
Economy
Technology

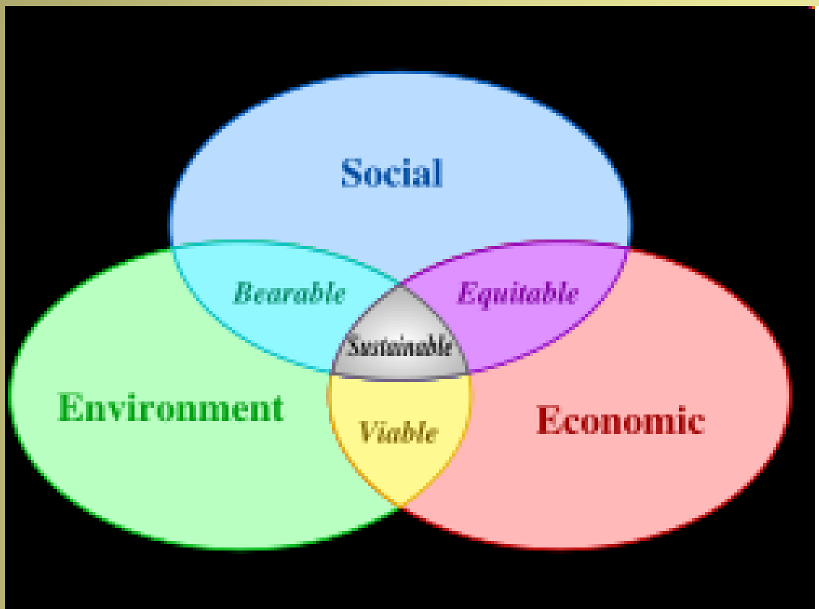
Sustainable Engineering

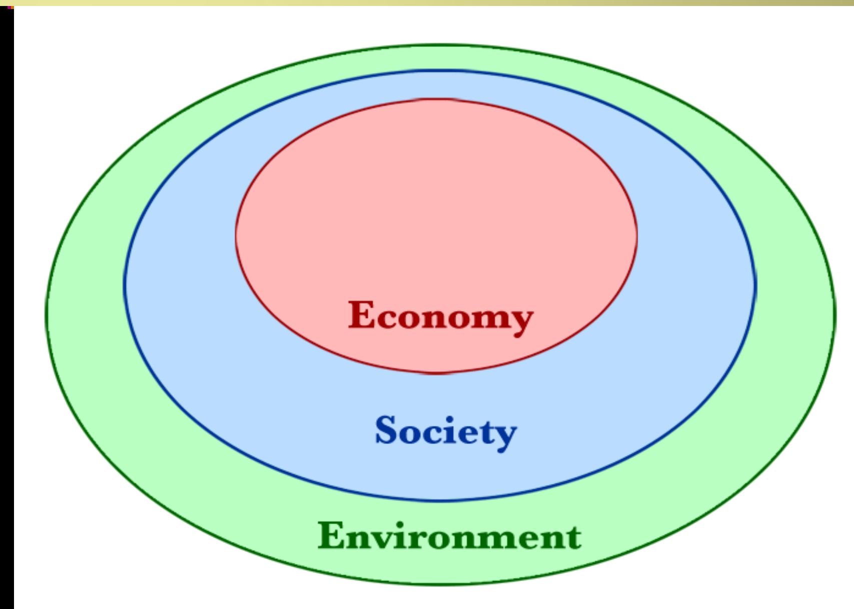
- **is the design of materials, processes, devices, and systems with the objective of minimizing overall environmental impact across the entire life cycle.**

- **considers life-cycle environmental impacts as *initial design constraints*. It recognizes that environmental impacts are more effectively minimized the further upstream they are considered.**

- **focuses at the interface between the environment, technology, economy, and society.**

Dimensions of Sustainability - 3 Pillars





Concrete International 2009

“ A major aspect of sustainability is continued functionality of the structure”

“ In other words, protection of the investment in energy and materials is a key (Green) construction goal”

What is LEED?

- **LEED, or Leadership in Energy and Environmental Design, is an internationally-recognized green building certification system.**
- **Developed in March 2000 by USGBC**
- **Uses a rating system**

LEED Measurements

Sustainable Sites

Water Efficiency

Energy & Atmosphere

Materials & Resources

Indoor Environmental Quality

LEEED Measurements

Locations & Linkages

Awareness & Education

Innovation in Design

Regional Priority

So why move beyond LEED

- LEED does not always reflect all aspects of sustainability It is "coarse" in terms of concrete
- There are other systems – most are more quantifiable

Examples of Concrete Positives/Negatives

- Advantages
  - Reaches all three tenants of sustainability (environment, society, economy)
  - Recycle/reuse, thermal mass contributes to reduced energy demand for HVAC, formable, affordable, …
- Disadvantages
  - CO_2 produced in the manufacture of cement
    - Primarily from release from limestone and fueling the kiln

Strategies

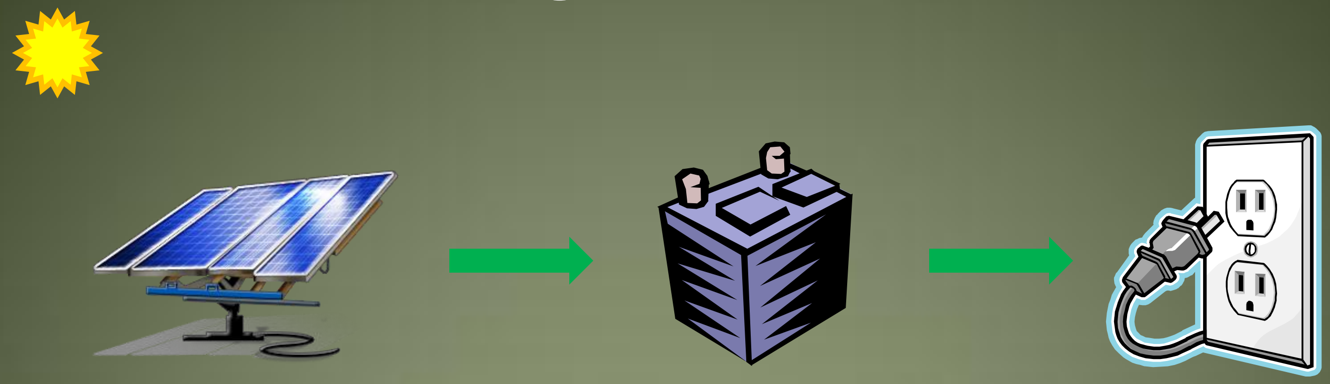
- Thermal Mass and Thermal Resistance
- Stormwater Management
- Economy
- Occupant comfort
- Longevity and Resilience
- Reduce/Reuse/Recycle

Thermal Mass

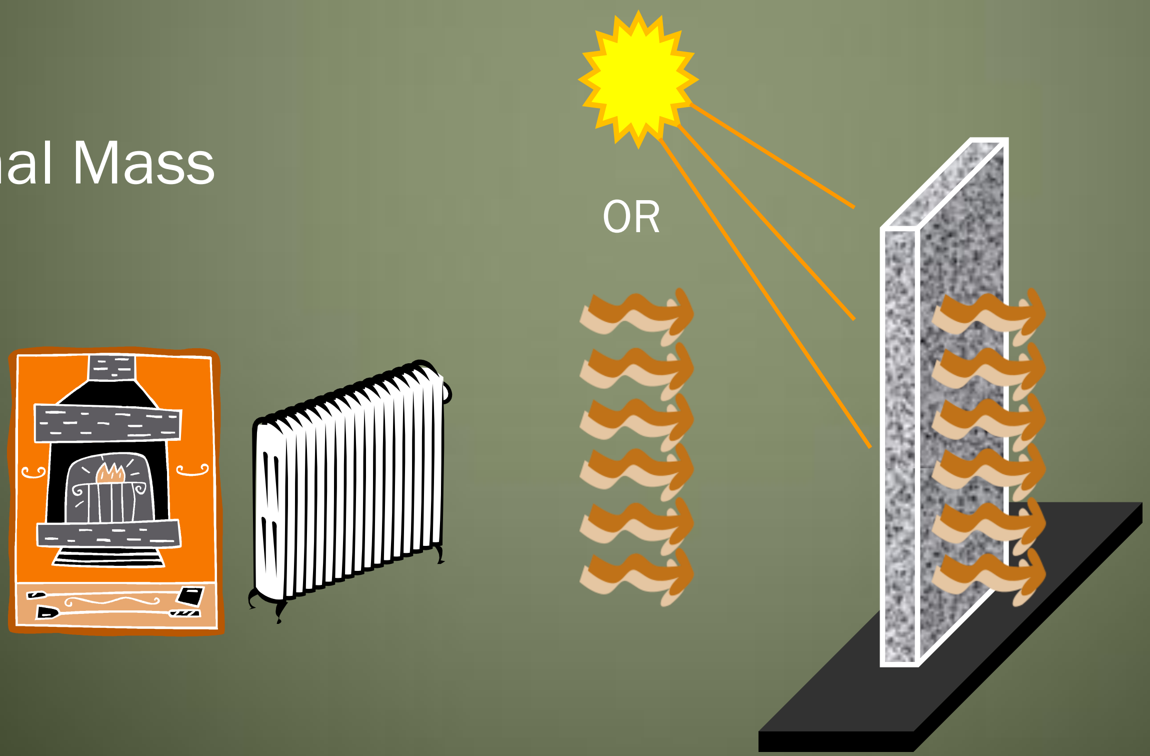
- Concrete has
  - High capacity to store heat
  - Slow transfer of heat
- Reduce temperature spikes
- Delay temperature effects to inside of building
- Reduced energy demand
- Effective with passive solar

from *The Sustainable Concrete Guide*

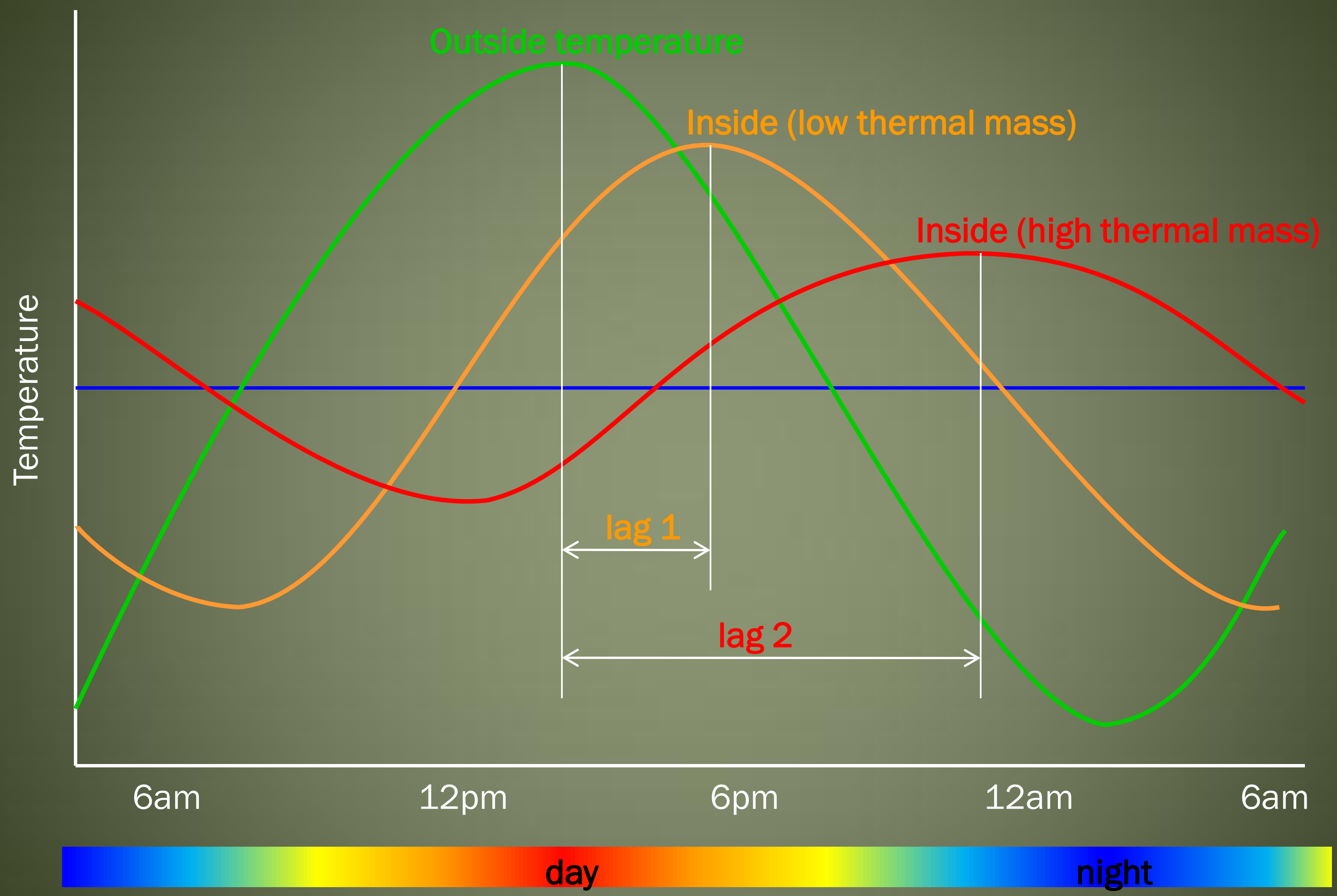
Solar Collection and Storage



Thermal Mass



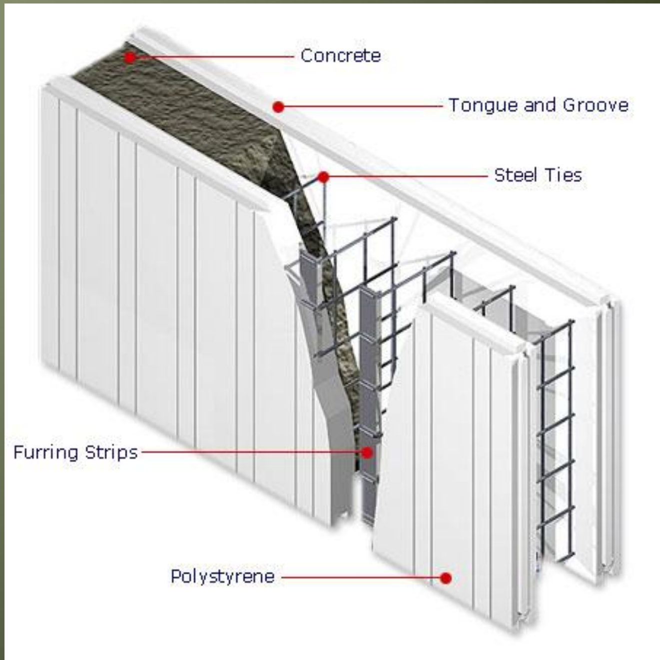
from *The Sustainable Concrete Guide*



from *The Sustainable Concrete Guide*

Thermal Resistance

- Standard concrete generally does not have good insulating properties when used alone
  - Lightweight concrete has lower conductivity
  - Autoclaved Aerated Concrete (AAC)
- In conjunction with other materials
  - CMUs, cavity walls, precast sandwich panels, ICFs (insulating concrete forms)



Stormwater Management

- Pervious concrete
- Pavers
  - Grid, interlocking

Economy

- A long-time goal in the concrete industry

Occupant Comfort

- Indoor Air Quality
  - low VOCs with concrete as the finished surface
  - No mold growth or rot
- Daylighting
- Acoustics (transmission reduction)
- Occupant comfort
- Aesthetics
- Heat island decrease

from *The Sustainable Concrete Guide*

Longevity and Resilience

- Life cycle assessment (LCA) and cradle-to-grave (or cradle-to-cradle)
- Corrosion resistance / durability
- Low maintenance
- Robust for safety
- Adaptable to changing climate

Repair

- Large amount of existing inventory
- Small amount of money

= Focus on repair

from *The Sustainable Concrete Guide*

Reduce/Reuse/Recycle

- Waste for kiln fuel
- Waste in concrete mix
- Crush concrete for reuse

"Here's what I want: Your concrete should pour like, Niagara and have the strength of Gibraltar."

The Society of Environmental Toxicology and Chemistry

life cycle assessment is an objective 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 uses and releases on the environment, and to evaluate and implement opportunities to affect environmental improvements.

Transportation Equity Act for the 21st Century

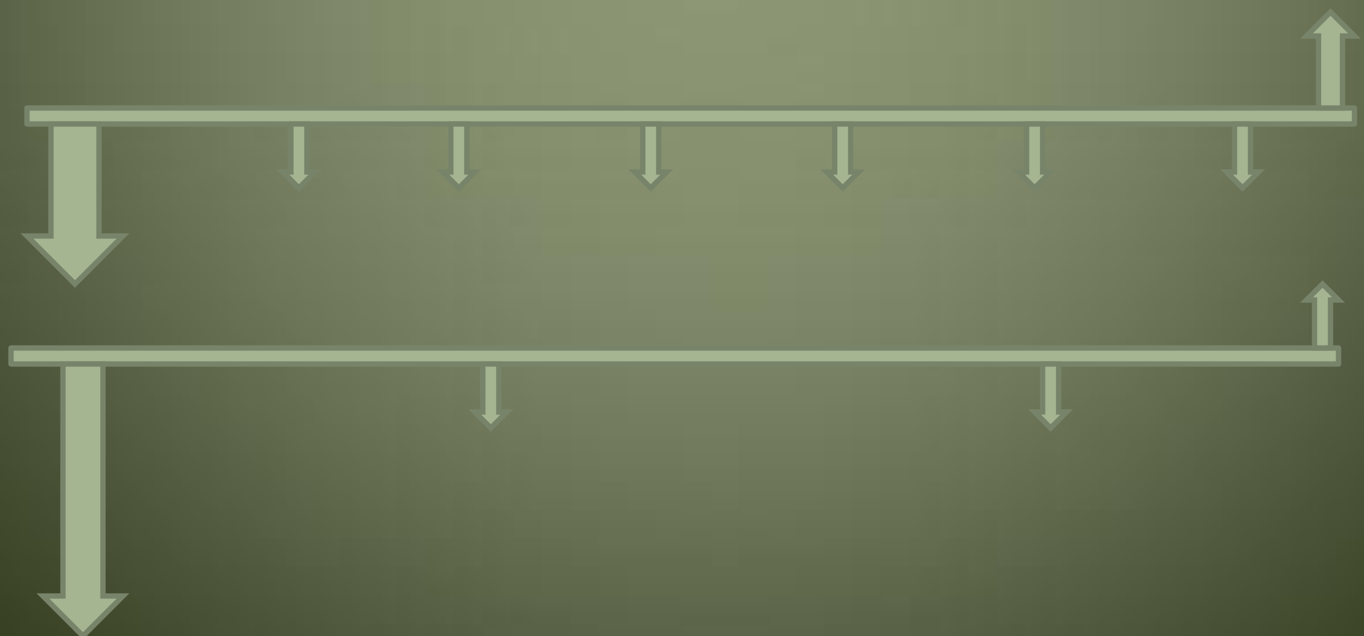
- Life-cycle cost analysis is a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment.

Life Cycle Costing

- “He, therefore, who is desirous of producing a lasting structure, is enabled, by what I have laid down, to choose the sort of wall that will suit his purpose. Those walls which are built of soft and smooth-looking stone, will not last long. Hence, when valuations are made of external walls, we must not put them at their original cost; but having found, from the register, the number of lettings they have gone through, we must deduct for every year of their age an eightieth part of such cost, and set down the remainder of the balance as their value, inasmuch as they are not calculated to last more than eighty years.”
- Vitruvius II.8

Life Cycle Costing

- Look at the Present value of an option to make design decisions
- Traditional Engineering approach



Sustainable Engineering Design

1. **Consider the entire life cycle**
   - *Environmental impacts occur across multiple life cycle phases for products/processes and are most effectively minimized by good design*
2. **Materials Selection**
   - *The mass and production energy of materials used are key factors for determining life cycle environmental impact*
3. **Consider waste as a design flaw**
   - *Waste from all life cycle phases should be minimized through the use of materials which either return to nature or can be recycled indefinitely*
4. **Look to nature for sustainable designs**
   - *Nature designs materials and systems with high performance, efficient energy use, and no waste*

A Life Cycle Approach Promotes …

- **… Awareness that our selections are not isolated,**
- **… Making choices for the longer term**
- **… Improving entire systems, not single parts of systems,**
- **… Informed selections, but not necessarily ‘right’or ‘wrong’ ones.**

Avoid Shifting Problems from One Part of the Environment to Another

MTBE (Methyl Tertiary Butyl Ether) is added to gasoline to increase octane levels and enhance combustion, which in turn reduces polluting emissions.

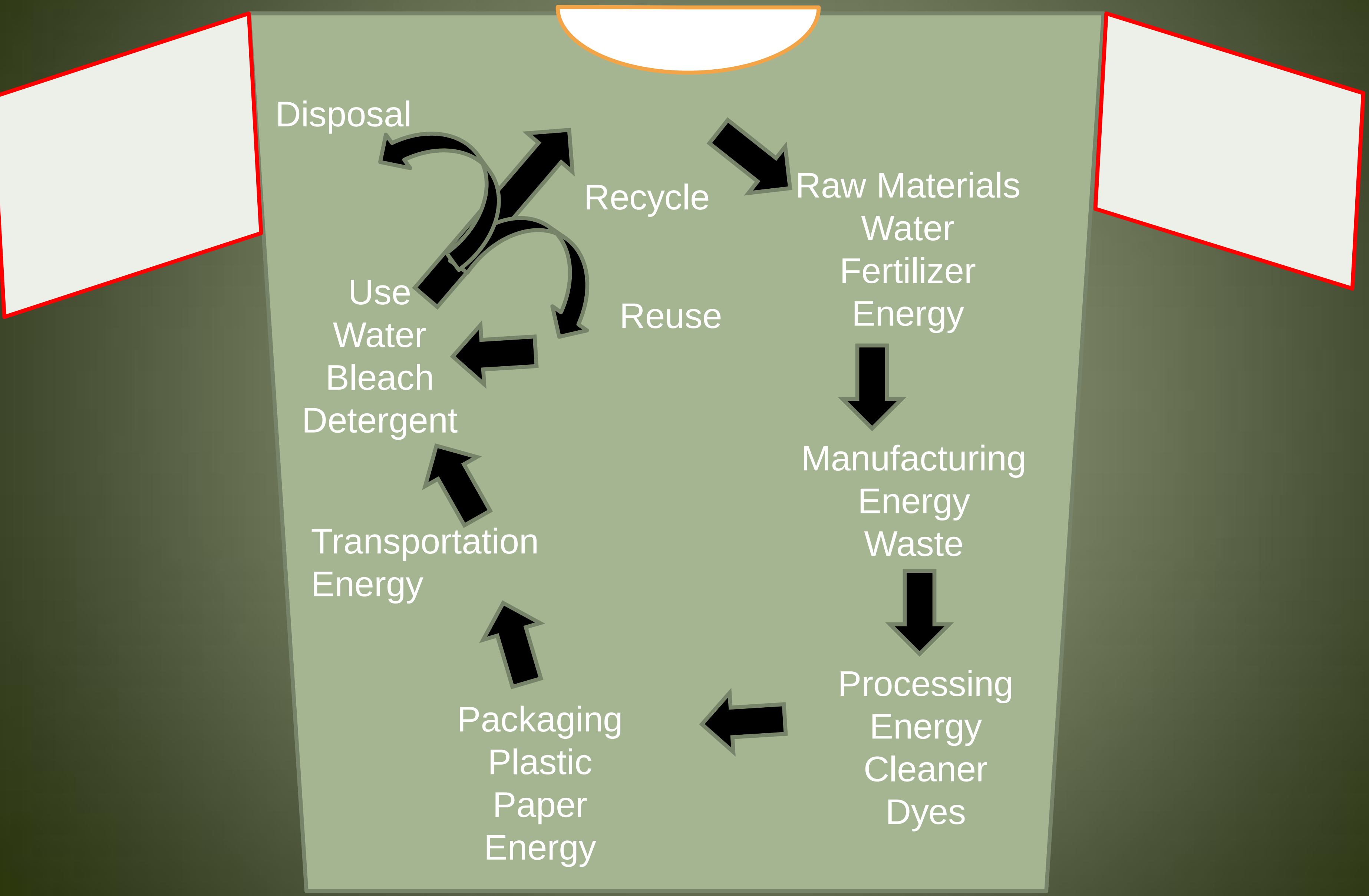
- MTBE in gasoline can
- reduce ozone precursors by 15%,
- benzene emissions by 50%,
- CO emissions by 11%.

But in another Part of the Environment

Levels of MTBE in the environment are now measured when MTBE is suspected to have evaporated from gasoline or leaked from storage tanks, lines and fueling stations.

MTBE found in lakes, reservoirs, and groundwater for potable water supplies. In some cases, MTBE concentrations already exceed standard indicators for potable water, including "taste and odor" and "human health"

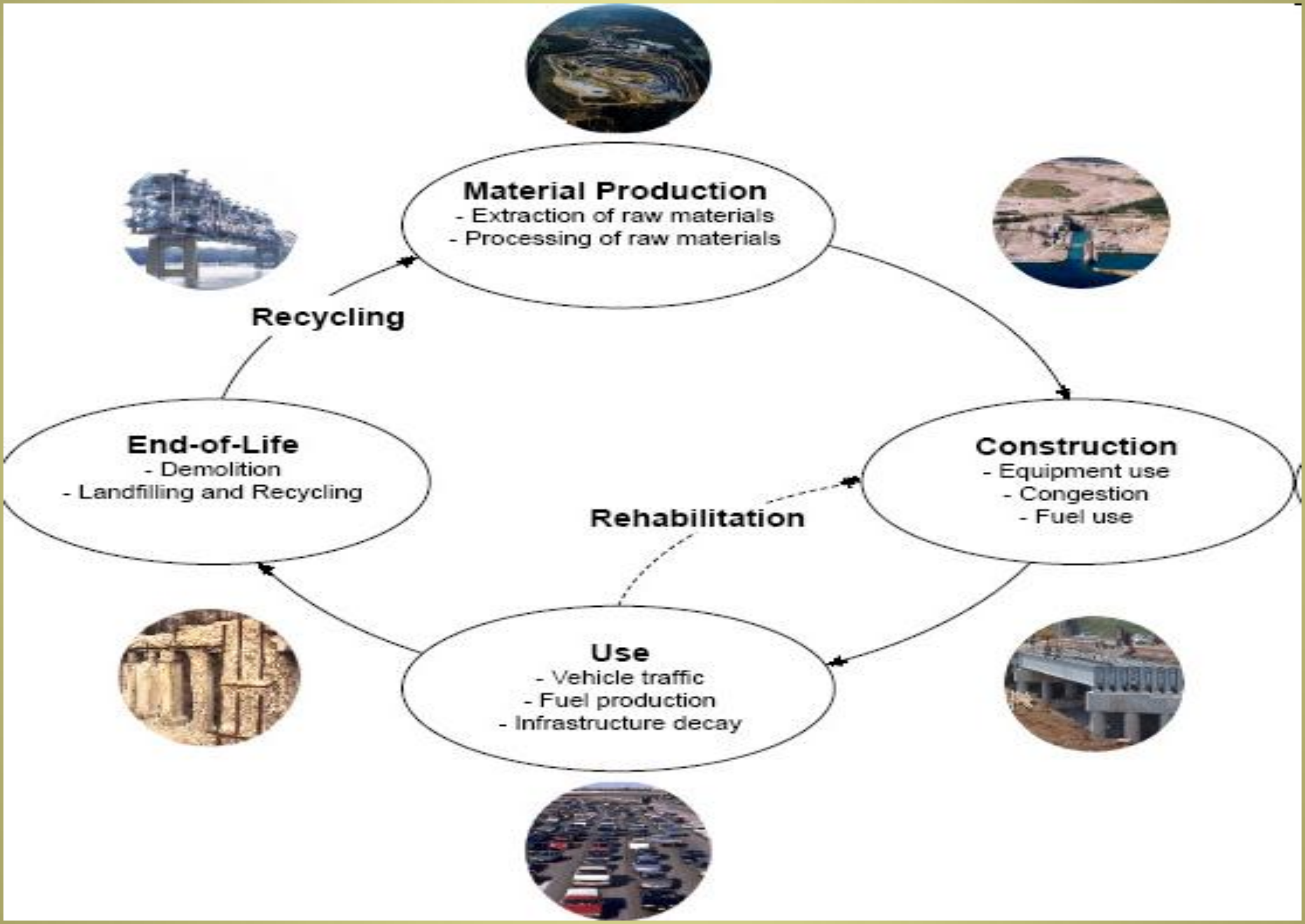
T-Shirts


Disposal
Recycle
Raw Materials
Water
Fertilizer
Energy
Reuse
Use
Water
Bleach
Detergent
Manufacturing
Energy
Waste
Transportation
Energy
Processing
Energy
Cleaner
Dyes
Packaging
Plastic
Paper
Energy

The Life Cycle of Concrete

- Extraction and processing of raw materials
- Concrete production
- Construction and re-building/extension of buildings and structures
- Operation and maintenance of buildings and structures
- Demolition and waste treatment/recycling

Sustainability Cycle



Life Cycle Assessment

- A life cycle assessment LCA) is the most rigorous of these method, requiring an accounting for all emissions and inputs, not merely those with economic or engineering significance.

- There are three phases to an LCA: inventory, impact assessment, and evaluation. These types of environmental assessment follows standard protocols of life cycle assessments.

- International Organization for Standardization (ISO), the Society of Environmental Toxicology and Chemistry (SETAC),
- U.S. Environmental Protection Agency.
- Each of these entities have documented standard procedures for conducting an LCA based upon a standard, repeatable procedure.

- Life cycle assessment can be thought of as an expanded life cycle cost, except considering emissions as well as economic input. Engineers and designers have been considering costs for millennia [Vitruvius].


3
4
5
2
1
6

Functional Unit

- The basic unit used in the analysis
- Concrete – the cubic meter
- Steel - Ton

Life Cycle Inventory

- GLOBAL WARMING POTENTIAL
- EUTROPHICATION POTENTIAL
- ACIDIFICATION POTENTIAL
- PHOTOCHEMICAL OXIDANT CREATION POTENTIAL
- ENERGY CONSUMPTION
- TOXICITY

Embodied Energy

- Embodied Energy is a measure of the amount of energy required to extract, process, transport, mix and install a functional unit

The Life Cycle of Concrete

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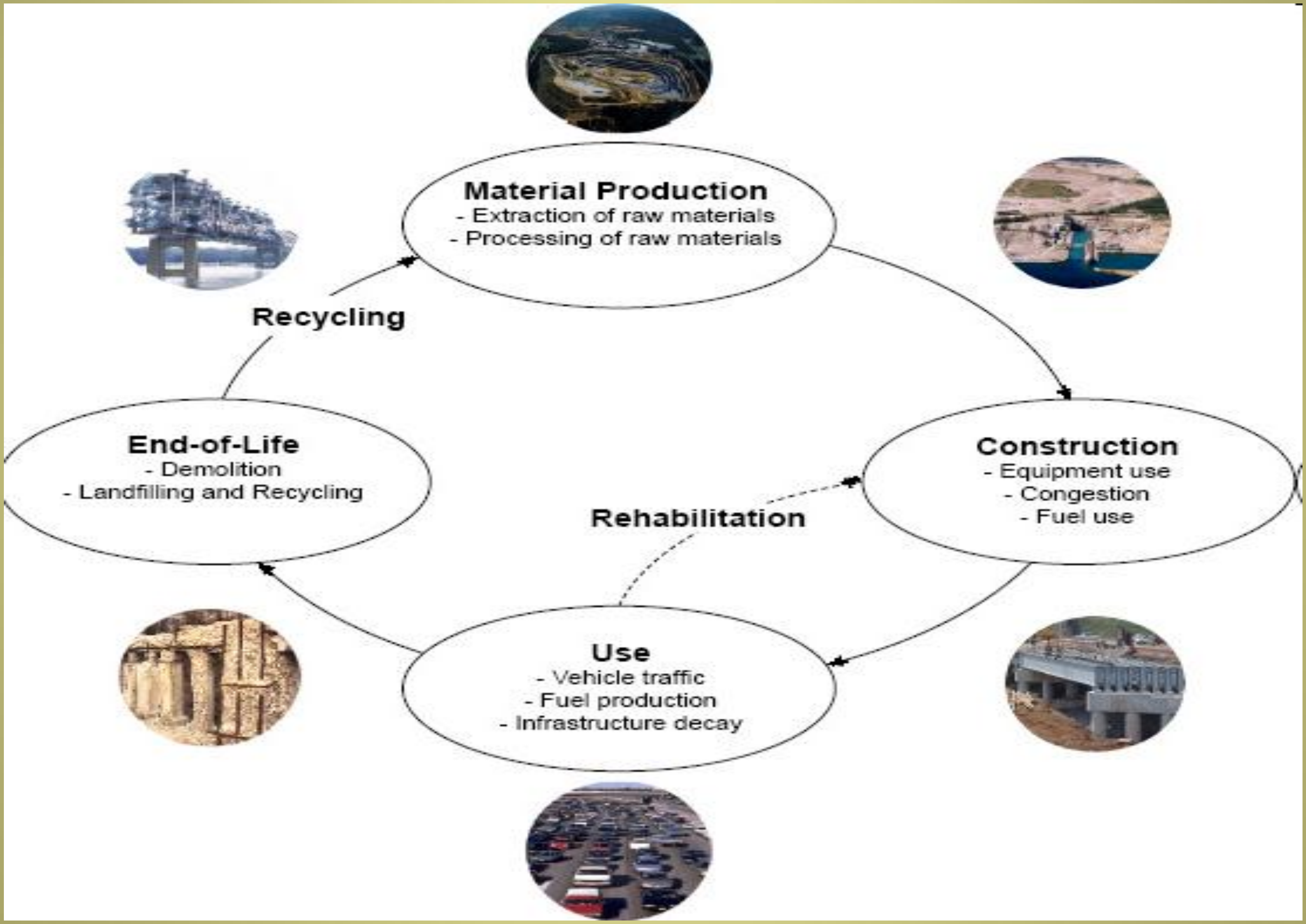
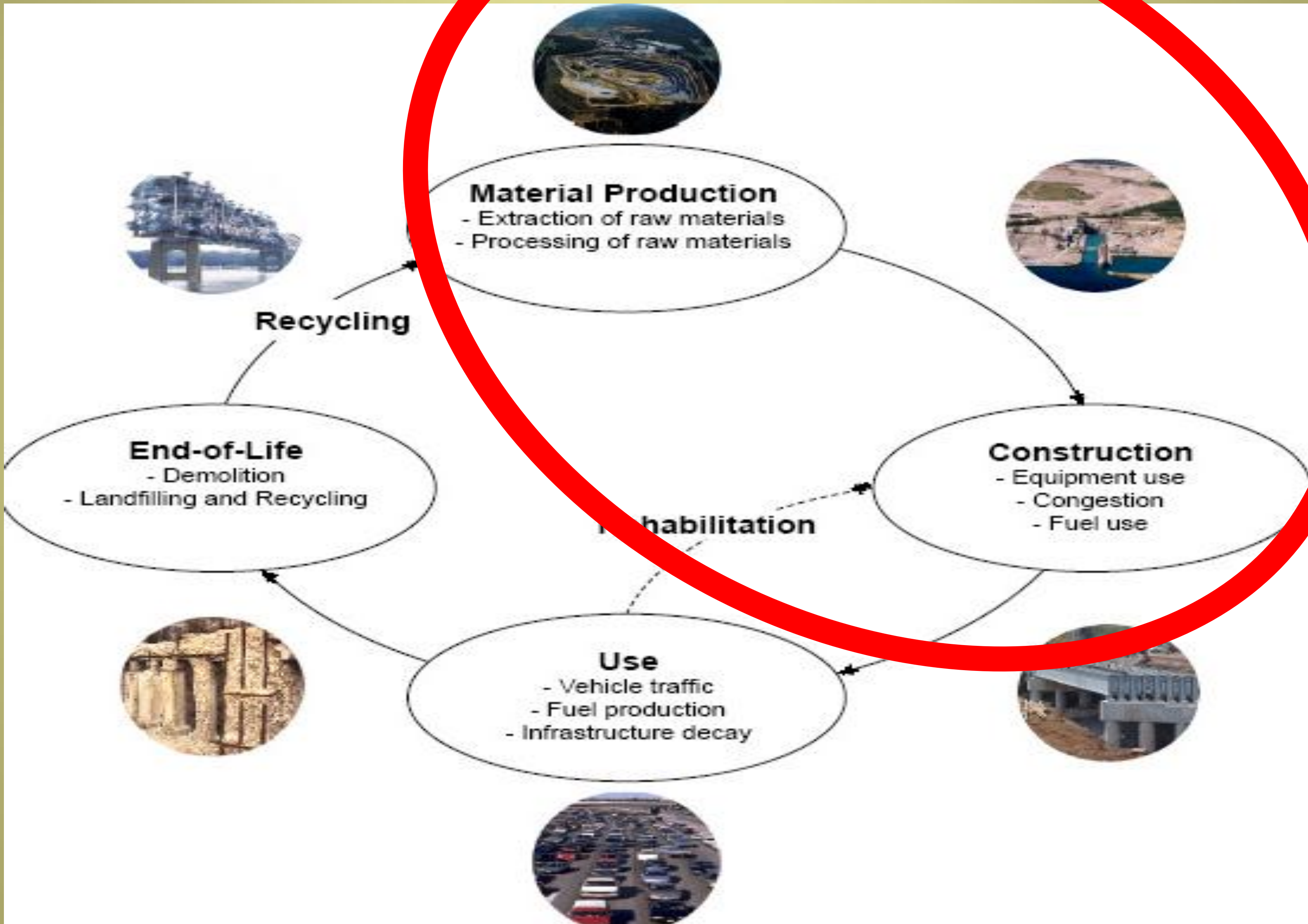
Sustainability Cycle



Sustainability Cycle



Energy Requirements

Material		Energy Consumption GJ/t
Cement	High Early	6.9
	Low Alkali SO_4 resistant	9.7
	Basic	5.8
Aggregate	Quarried	.068
	Gravel Pit	.044
Pozzolans	Fly Ash	0
	Silica Fume	0

- Each material requires energy to be made
- Pozzolans are "free" in this model as it does not consider transportation

Source : Glavind, M; Haugaard, M; *Survey of Environemental Aspects of the Danish Concrete Industry*, DTI Concrete Center

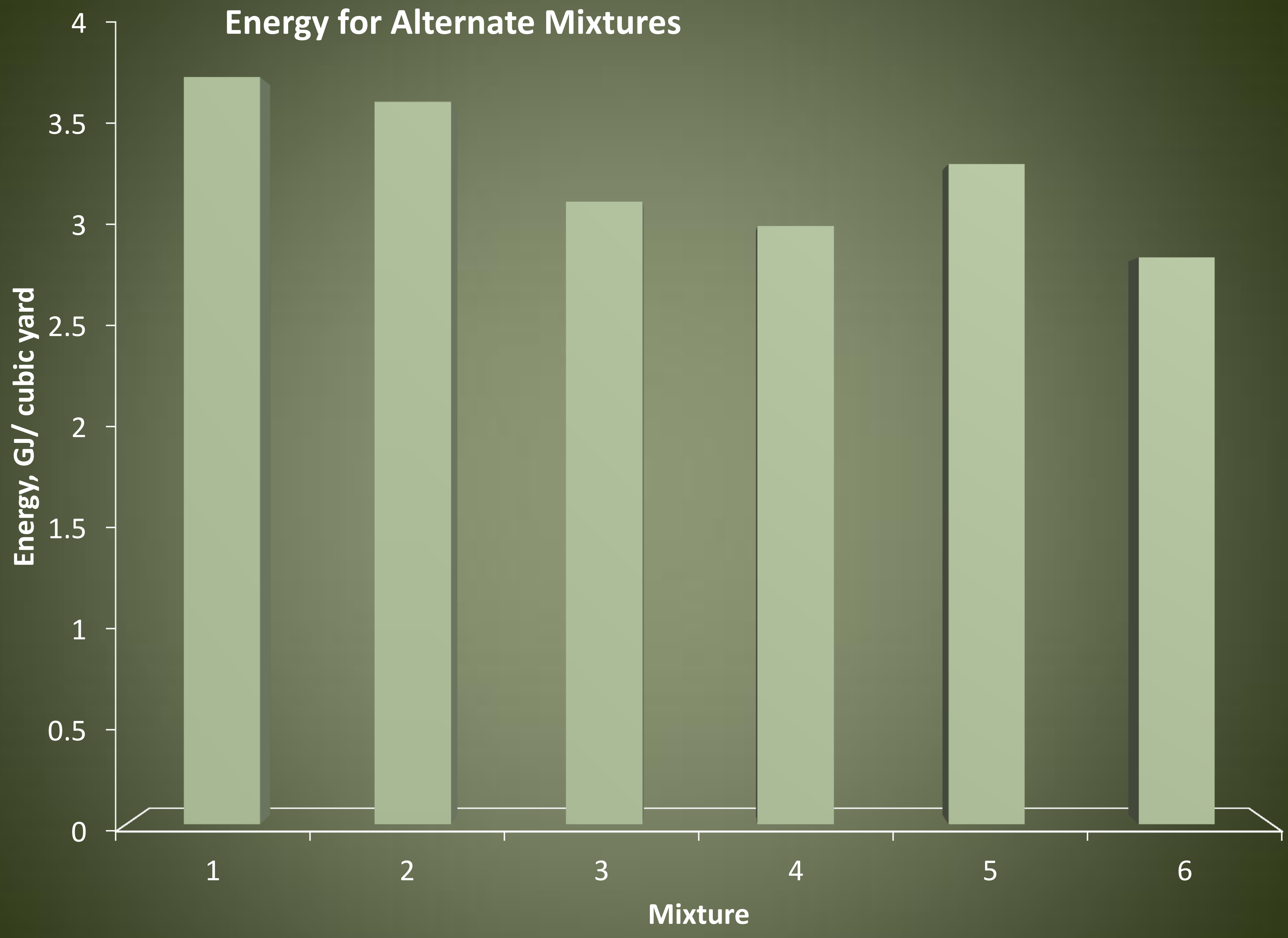
Energy Requirements

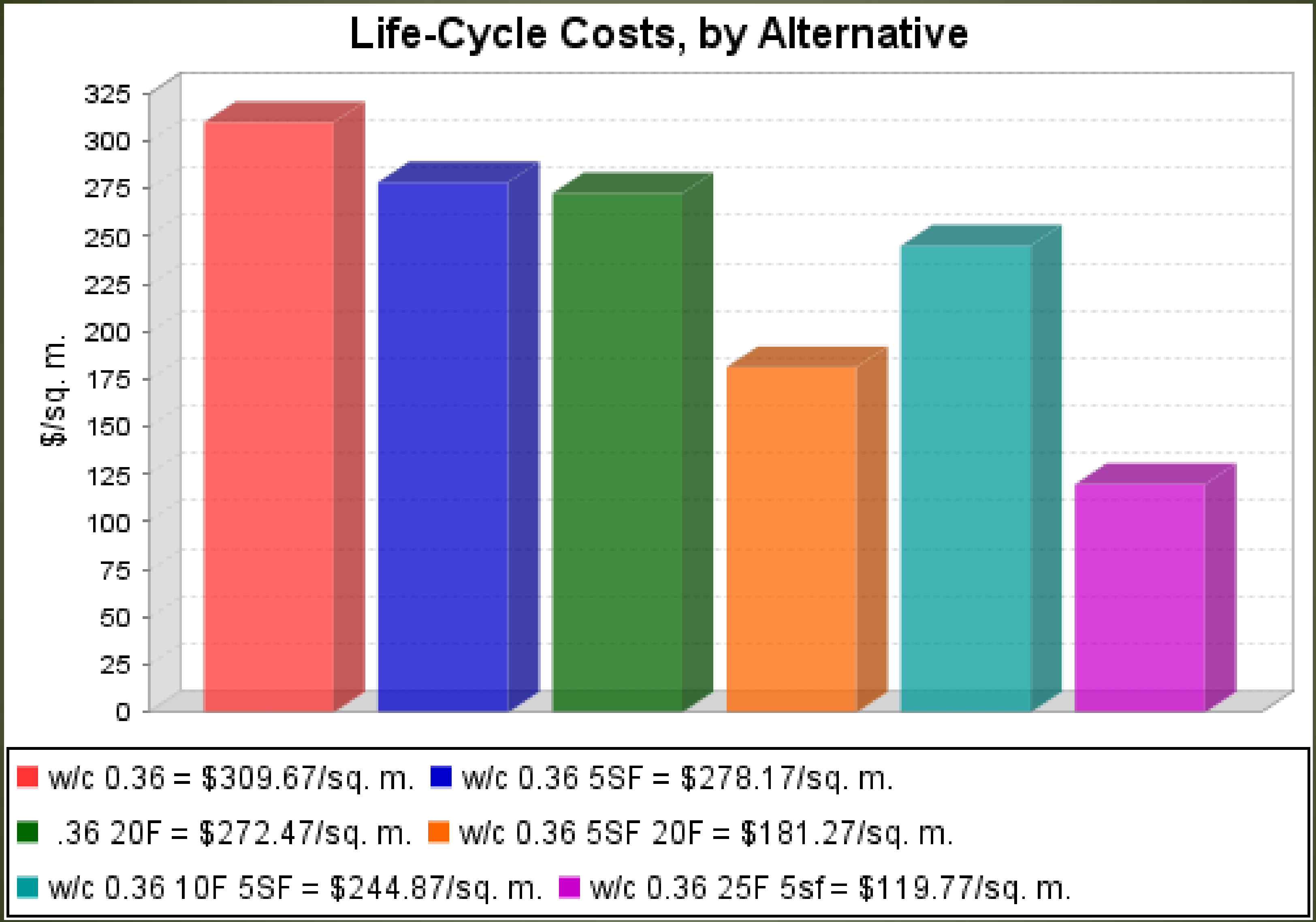
Material		Energy Consumption GJ/t
Cement	High Early	7.5
	Low Alkali SO_4 resistant	10.3
	Basic	6.4
Aggregate	Quarried	.13
	Gravel Pit	.10
Pozzolans	Fly Ash	.6
	Silica Fume	1.8

- Each material requires energy to be made
- Pozzolans are not “free” in this model
- Transport Cement and Flyash 50 miles, silica fume 150
- Aggregates 10 miles

Source : Glavind, M; Haugaard, M; *Survey of Environemental Aspects of the Danish Concrete Industry*, DTI Concrete Center

Example – Calculating Embodied Energy


Energy for Alternate Mixtures
Energy, GJ/ cubic yard
0
0.5
1
1.5
2
2.5
3
3.5
4
1
2
3
4
5
6
Mixture



Is in energy per square meter , (kJ) assumes repairs are 300 kJ/square meter

Example 1 : Energy Requirements

Material		Qty	Energy GJ
Cement	Low Alkali SO_4 resistant	600	3.09
Aggregate	Quarried	1700	.11
	Gravel Pit	1300	.065
Pozzolans	Fly Ash	0	0
	Silica Fume	0	0
Total			3.265

Material		Qty	Energy GJ/t
Cement	Basic	300	1.92
Aggregate	Quarried	1700	.11
	Gravel Pit	1300	.65
Pozzolans	Fly Ash	300	0
	Silica Fume	0	0
Total			2.095

Source : Glavind, M; Haugaard, M; *Survey of Environemental Aspects of the Danish Concrete Industry*, DTI Concrete Center

Example 3 Rapid Construction

- Use high early cement
- Use 100 lb cement extra
- Use silica fume

Example 1 : Early Strength

Material		Qty	Energy GJ
Cement	Basic	600	1.92
Aggregate	Quarried	1700	.11
	Gravel Pit	1300	.065
Pozzolans	Fly Ash	0	0
	Silica Fume	0	0
Total			2.095

Material		Qty	Energy GJ
Cement	High early	600	2.25
Aggregate	Quarried	1700	.11
	Gravel Pit	1300	.65
Pozzolans	Fly Ash	0	0
	Silica Fume	0	0
Total			2.425

Source : Glavind, M; Haugaard, M; *Survey of Environemental Aspects of the Danish Concrete Industry*, DTI Concrete Center

Example 1 : Early Strength

Material		Qty	Energy GJ
Cement	Basic Cement	700	2.275
Aggregate	Quarried	1700	.11
	Gravel Pit	1300	.065
Pozzolans	Fly Ash	0	0
	Silica Fume	0	0
Total			2.45

Material		Qty	Energy GJ
Cement	Basic	450	1.44
Aggregate	Quarried	1700	.11
	Gravel Pit	1300	.65
Pozzolans	Fly Ash	120	0
	Silica Fume	30	0
Total			1.615

Source : Glavind, M; Haugaard, M; *Survey of Environemental Aspects of the Danish Concrete Industry*, DTI Concrete Center

Comparison

- For embodied energy the mixtures are ranked:
- Basic Cement 2.095
- Type III 2.425
- Increased Cement 2.45
- Ternary Blend 1.615 + .2 for accelerator
- If accelerators are used they need to be accounted for as well

Costs

- For normalized costs the mixtures are as follows:
- Basic Cement 1
- Type III 1.05
- Increased Cement 1.15
- Ternary Blend 1.32

Risk of Failure

- For risk analysis the mixtures are as follows:

Basic Cement	.05
Type III	.07
Increased Cement	.10
Ternary Blend	.15

Criteria

- Embodied Energy is 40 percent
- Cost is 50 percent
- Risk is 10 percent

Criteria Function Analysis

- But how did they do
- Normalize the data

- Example 1:
- Ranking

Criteria Function

$$C = \sum_{i=1}^{n} Q_i f_i$$

Results

- Type III Cement
- Extra Cement
- Pozzolans

Greenhouse Gas Emissions

- Global Warming Potential is expressed in terns of CO2 emissions

- Calculated like Energy

Commercial LCA Software

- Athena
- Developed in Canada
- A free trial is available

- BEES
  - Developed by NIST
  - Free on the internet
  - Many concrete options

	Concrete aspects considered by two ecocalculators analyzed		
	Functional units	Dimensions	Composition
BEES	Slab Basement Wall Column Beam	No	Suggested generic and brand name compositions: e.g. up to 35% Fly-ash up to 50% Slag Silica fume
ATHENA	Based on assembly type. E.g. Precast Double T concrete; Decking System with concrete topping	Yes, including reinforcement length	Fly-ash content option only.

	Physical properties	Transportation distance	Other life-cycle information	Other inputs
BEES	compressive strengths.	From manufacture to use of concrete.	3 compressive strengths	Relative importance of economic vs. environmental performance, on a total of 100%; weights of different environmental categories
Athena	compressive strengths; live load (Where applicable)	No, but project location is selected from list of North-American cities.	Building life expectancy Operational energy consumption	Project location (from list of North American cities.

BEES

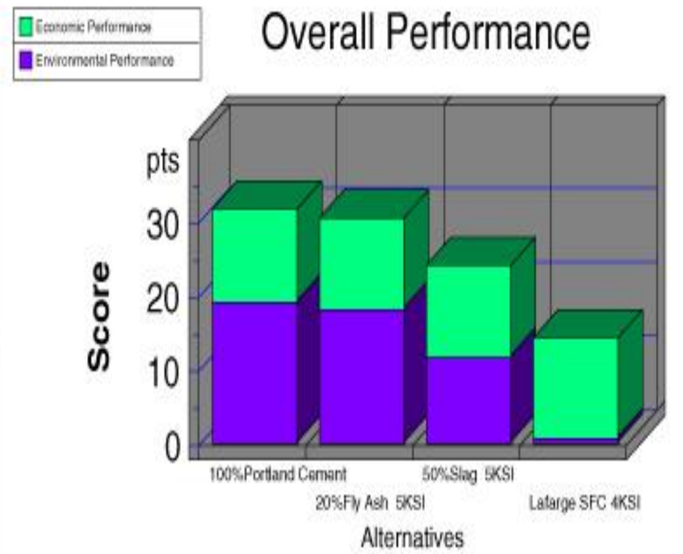
- Allows user setting of economic and environmental performance
- Allows the comparison of options
- Is limited due to the small number of products
- Uses criteria function and embodied energy/ greenhouse gas production as well as

User inputs **product alternatives** for construction project.

Note: input is quantity & does not include design information

BEES database

Environmental and economic database on close to 200 building products



Category	100% OPC	20Ash5KSI	50Slag5KSI	LafargeSFC
Economic Perform.--50%	12.5	12.1	12.2	13.2
Environ. Perform.--50 %	19.1	18.3	11.7	0.9
Sum	31.6	30.4	23.9	14.1

IMPACT	Equal Weights	EPA Science Advisory Board-based	BEES Stakeholder Panel
Global Warming	**9**	**16**	**29**
Acidification	**9**	**5**	**3**
Eutrophication	**9**	**5**	**6**
Fossil Fuel Depletion	**9**	**5**	**10**
Indoor Air Quality	**8**	**11**	**3**
Habitat Alteration	**8**	**16**	**6**
Water Intake	**8**	**3**	**8**
Criteria Air Pollutants	**8**	**6**	**9**
Smog	**8**	**6**	**4**
Ecotoxicity	**8**	**11**	**7**
Ozone Depletion	**8**	**5**	**2**
Human Health	**8**	**11**	**13**
Sum:	**100**	**100**	**100**

BEES Example

Optimization

- Example

Blended Products- Embodied Energy

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Table 1. Summary of Embodied Energy and Carbon Dioxide for 1 Ton of Generic Portland Cement and Three Generic Blended Cements

Product composition	**100% portland cement**	**10% limestone blend**	**25% slag cement blend**	**25% fly ash blend**
Portland cement, lb	2000	1800	1500	1500
Limestone, lb	0	200	0	0
Slag*, lb	0	0	500	0
Fly ash, lb	0	0	0	500
Life cycle flows				
Energy, MBtu**	3.85	3.50	3.06	2.91
Carbon dioxide, lb	2030	1850	1570	1530

*Slag cement is ground granulated blast furnace slag.
**MBtu is million British thermal units.

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Conclusions

- Life Cycle Inventories are an important part of sustainability
- Durablity is important - with LCI it can be quantified.
- The emissions and energy associated with raw materials in a mixture can be calculated and used in analysis of options
- The criteria function and optimization tools can be applied to these concepts to help with decisions.

Conclusions

- Software is available to perform these calculations at low or no cost.
- These approaches allow comparison between mixtures which would get the same LEED points.

Thank You!

Any Questions?

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from *The Sustainable Concrete Guide*
Questions?