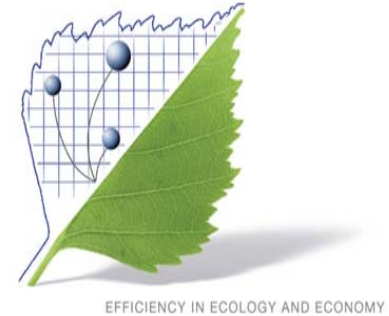


# Developing Sustainable Concrete Mixes with Eco-Efficiency Analysis



This is a .....

A) Cement Truck

**B) Concrete Truck**

C) Still No Idea



# Concrete in the World

**“Concrete is used more than any other man-made material in the world.”**

Lomborg, Bjørn (2001). *The Skeptical Environmentalist: Measuring the Real State of the World*. p. 138. ISBN 978-0-521-80447-9.

**“As of 2006, about 7.5 billion cubic metres of concrete are made each year—more than one cubic metre for every person on Earth.”**

"Minerals commodity summary – cement – 2007". US United States Geographic Service. 1 June 2007. <http://minerals.usgs.gov/minerals/pubs/commodity/cement/index.html>. Retrieved 16 January 2008.

**“Over 70% of the world’s population lives in concrete structures.”**

**“Globally, twice as much concrete is produced as plastic, steel, aluminum, and wood - combined.”**

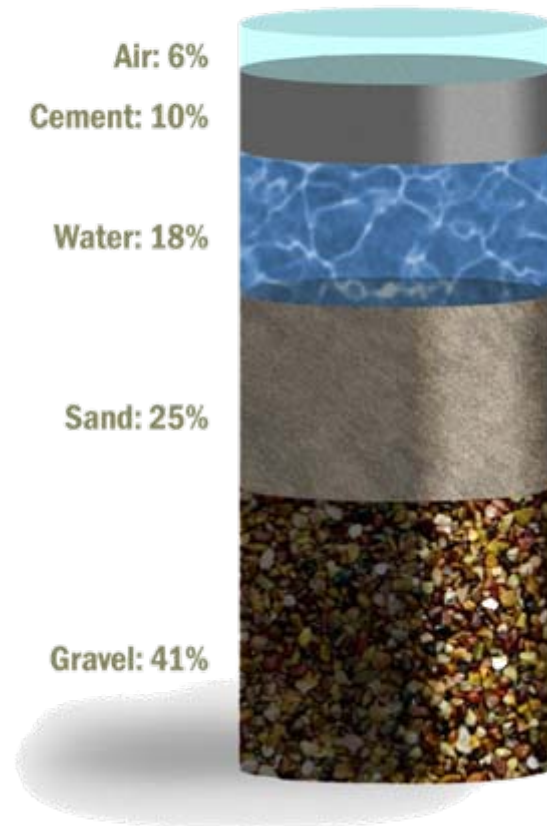
- Concrete Joint Sustainability Initiative



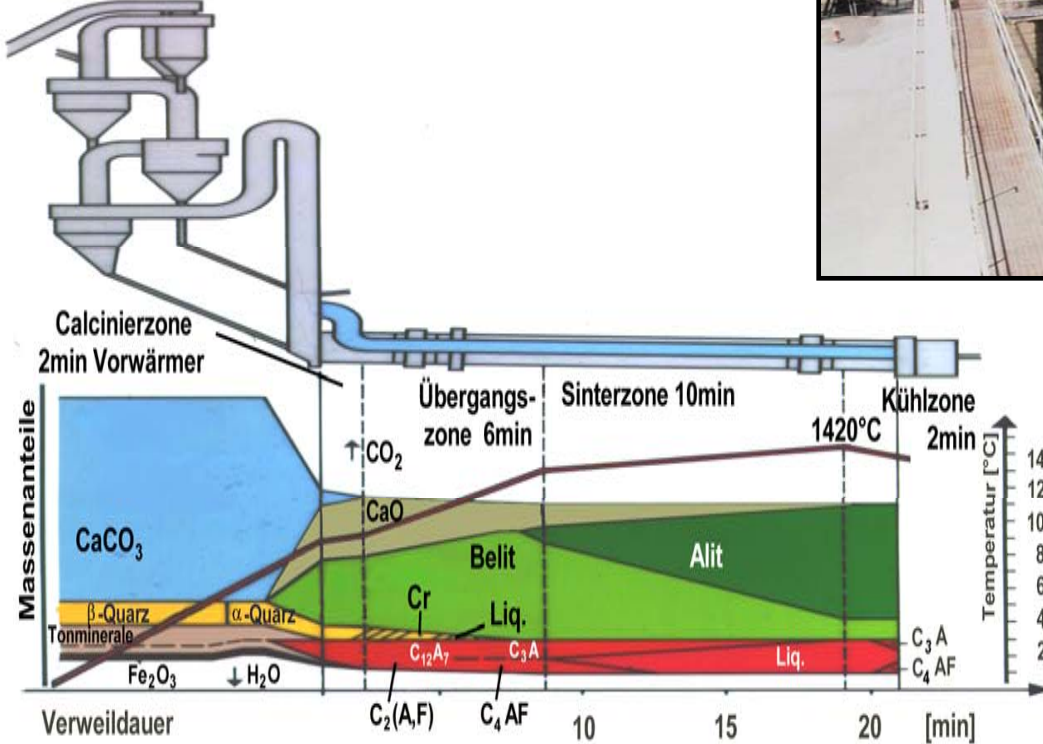
# What is Concrete?

In its simplest form, concrete is a mixture of paste and aggregates. The paste, composed of portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete.

## The Mix in Ready Mixed Concrete



# Cement Production



# Portland Cement Clinker

The production of one ton of portland cement clinker releases about one ton of CO<sub>2</sub> emissions to the atmosphere.



About 6 % of the world wide produced CO<sub>2</sub> Emissions are released from the cement industry.



# Concrete Industry

**Concrete is considered a green material, however threats to the concrete industry include:**

- **Cement Production Carbon Emissions**
- **Energy Intensity/Usage**
- **Natural Resource Depletion**
- **Health – noise, particulate emission, etc**
- **Water Quality**

## Sustainable Concrete Programs

- **Zero Waste Management**
- **Pervious Concrete**
- **Cool Colored Concrete**
- **Anti-washout Admixture**
- **Self Consolidating Concrete**
- **Cement Additives**
- **Eco-efficient Concrete - Mix Optimization**
- **Eco-Efficiency Analysis**



**Concrete  
Thinking**  
for a sustainable world

# Reducing Cement Content with Recycled Materials

|                        |  |
|------------------------|--|
| <b>Common</b>          | <ul style="list-style-type: none"><li>▪ Fly Ash (Type F or C)</li><li>▪ Slag</li><li>▪ Limestone Fines</li><li>▪ Aggregate Fines</li></ul>   |
| <b>Other Materials</b> | <ul style="list-style-type: none"><li>▪ Non Spec. Silica Fume</li><li>▪ Aged Cement Kiln Dust</li><li>▪ Rice Husk Ash</li><li>▪ Burnt Oil Shale Fines</li><li>▪ Glass Powder</li></ul> |



**Fly ash**



**Slag**



**Limestone fines**



**Granite fines**

# Chemical Admixtures

- Primarily used to modify the fresh & hardened properties of concrete
- Play an important role in the construction of environmentally conscious, sustainable concrete structures
- Can help to conserve natural resources



# Sustainable Initiatives

## Benefits of Chemical Admixtures

### ■ Water Reducing Admixtures

▶ Lower w/cm ratios

- Less cement
- Higher strength
- Lower permeability

» Improved durability and increased service life

**Use Less  
Materials**



### ■ Set-control Admixtures

▶ Reduce perishable nature of concrete

### ■ Workability Retention Admixtures

▶ Maintain concrete workability for a defined period

### ■ Durability Enhancing Admixtures

▶ Help achieve design service lives

**Reduce  
Rejected  
Loads**



**Eliminate  
Rebuilding**



# Sustainable Initiatives

## Benefits of Chemical Admixtures

### ■ Hydration-control admixtures

- ▶ Reduce/eliminate return concrete waste & washwater pollution

**Reduce Waste**



### ■ Anti-washout admixtures

- ▶ Minimize washout of cement/fines in underwater concreting

**Reduce Water Emissions**



### ■ Specialty concrete mixtures

- ▶ Pervious concrete
- ▶ Very high-early strength concrete

**Manage Storm Water Run-off**

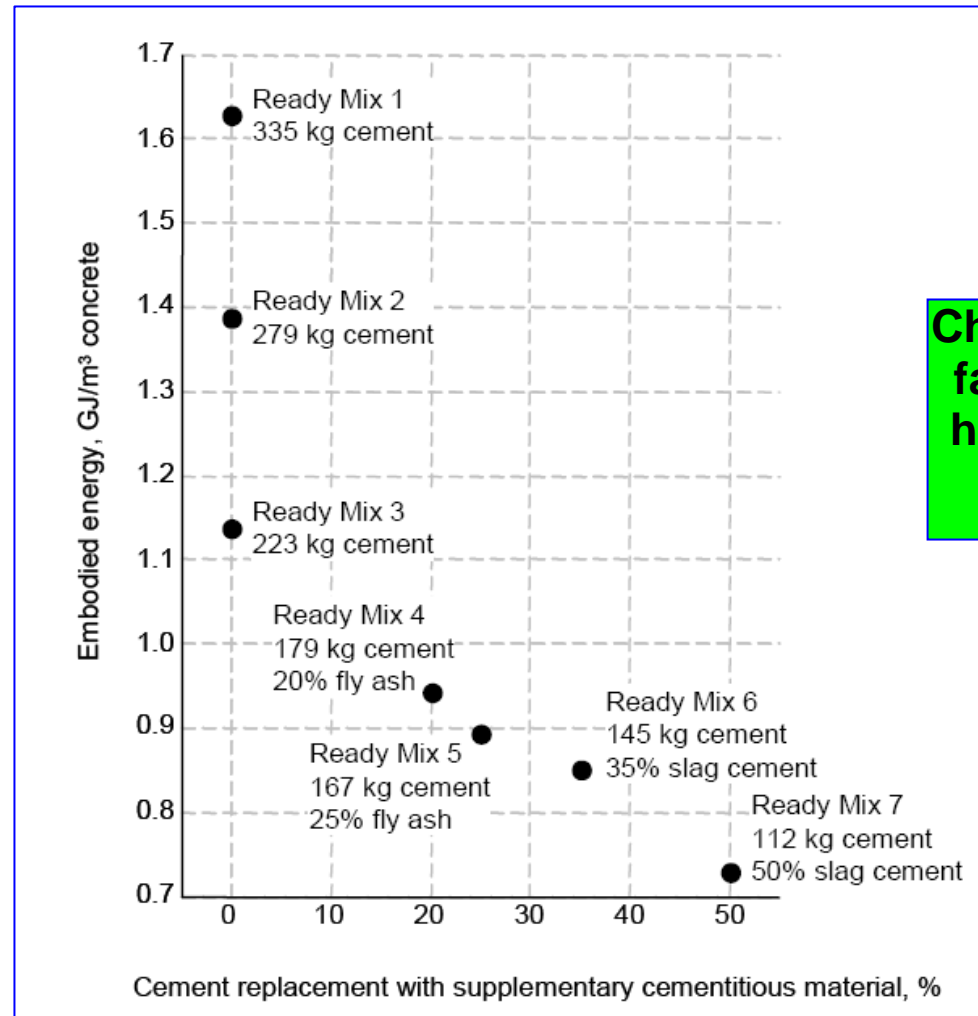


**Reduce Traffic Congestion**



# Sustainable Initiatives with Admixtures

## Reduce Embodied Energy



**Chemical admixtures facilitate the use of higher replacement levels of SCMs.**

Source:  
PCA R&D Serial no. 3011

# Sustainable Initiatives with Admixtures

## Conserve Energy

### Heat Island Effect

#### Dark surfaces contribute towards

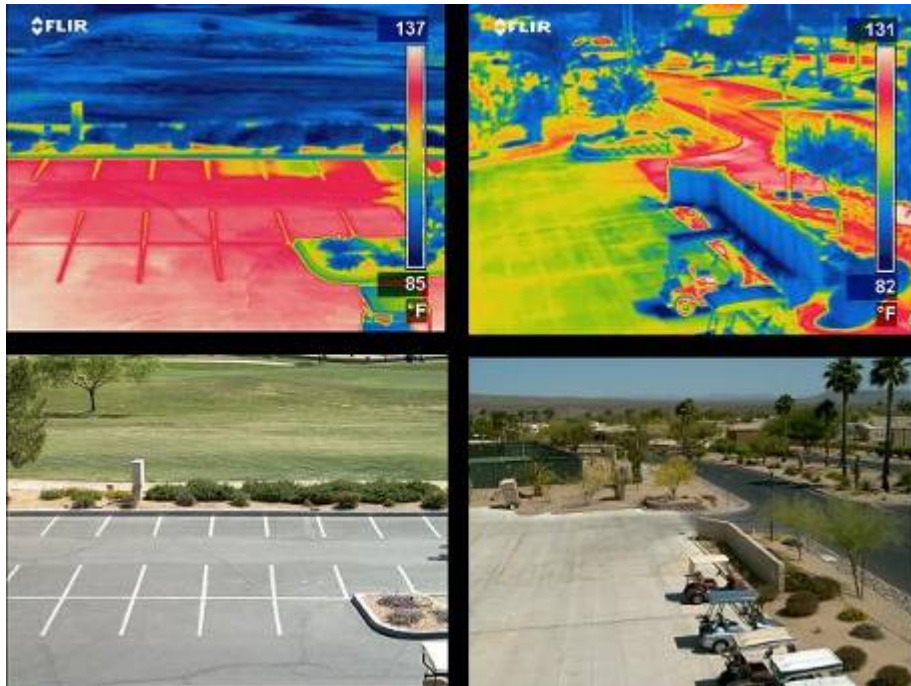
- “heat island” effects
- increased lighting requirements

#### Energy demands increase for

- cooling
- lighting

#### Result:

- increased power plant emissions**
- heat-trapping greenhouse gases**



Source: American Concrete Pavement Association (QD 007P)

Liquid-coloring admixtures can be used to produce “light-colored” concretes with high SRI values

# Sustainable Initiatives with Admixtures

## Manage Storm Water

### Pervious Concrete

- No stormwater collection and disposal
- No retention (detention) ponds
- No contaminated runoff to be treated
- Increased site utilization



# Sustainable Initiatives

## Reduce Delays

### High-early strength concrete (3 - 4 hours)

#### Benefits:

- Reduce traffic congestion
- Reduce gasoline waste and emissions
- Highly durable pavement increases service life – sustainable construction












# Advanced Concrete Benefits

## Producer

## Contractor

## Engineer

|                  |  |  |                         |  |                                  |                    |  |                             |
|------------------|--|--|-------------------------|--|----------------------------------|--------------------|--|-----------------------------|
| <b>Economics</b> |   | <b>Mix Cost</b>  | <b>Constructability</b> |   | <b>Reduced Construction Time</b> | <b>Performance</b> |   | <b>Improved Durability</b>  |
|                  |   | <b>High Workability Retention</b>                          |                         |   | <b>Improved Placeability</b>     |                    |   | <b>Less Cracks</b>          |
|                  |  | <b>Faster Discharge</b><br><b>Better Fleet Utilization</b> |                         |  | <b>No Jobsite Retempering</b>    |                    |  | <b>Strength Development</b> |

## Owner

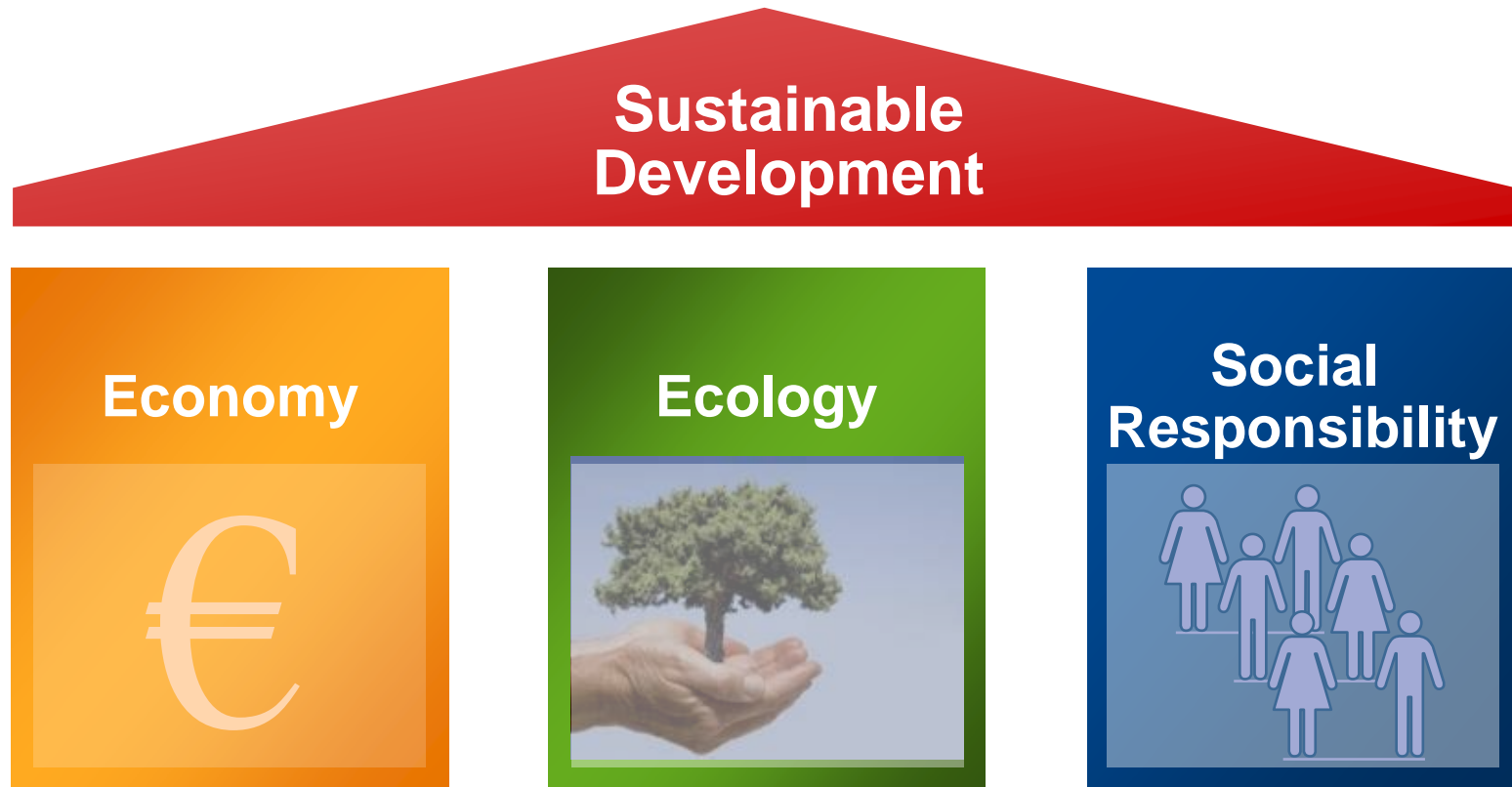
**Increased Service Life**

**LEED Point Potential**



# Defining Sustainable Development

**Sustainable Development comprises three dimensions to be balanced ...**



**Being able to measure sustainability is critical to its successful integration into business strategy and strategic decision making**

# Measuring the Claim of Sustainability

**Challenge:** many sustainability activities are actually “Greenwashing”

**Green•wash** (gren'wosh',-wôsh') – verb: the act of misleading consumers regarding the environmental practices of a company or the environmental benefits of a product or service.

**Solution:** the ability to measure and compare the environmental impacts of a product or service differentiates one from another.

**Eco-Efficiency Analysis** is a credible methodology that achieves that goal.

# Sustainability Assessment Methods

ISO 14040 & 14044

## Life Cycle Inventory (LCI)

*... quantification of inputs and outputs*

## Life Cycle Assessment (LCA)

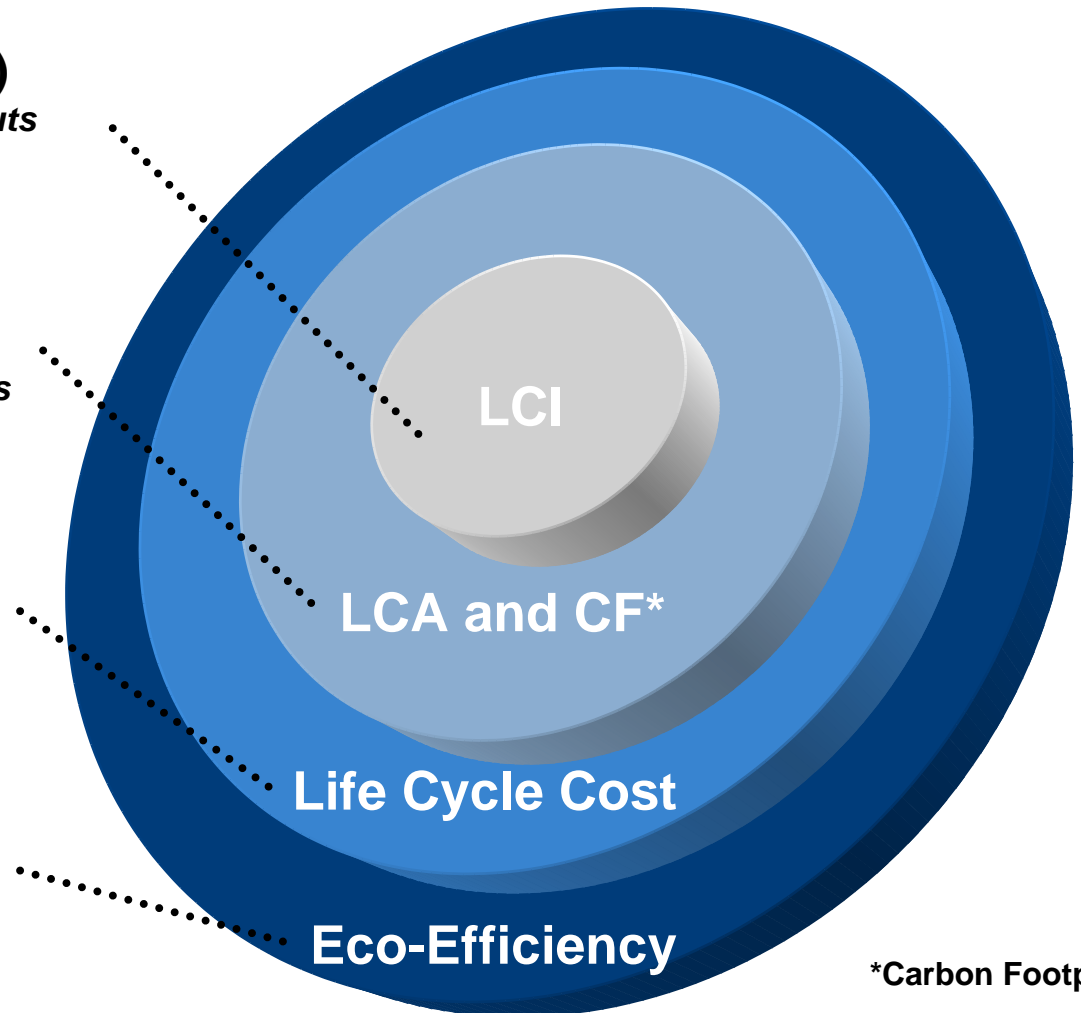
*...evaluation of environmental impacts  
...absolute results*

## „Life Cycle Costs“

*...total cost of ownership*

## „Eco-Efficiency Analysis“

*...including all life-cycle costs  
...comparison of products or processes  
...ecological and economic aspects  
have equal weight in the assessment  
...normalized results  
...method validated by TÜV and NSF*



\*Carbon Footprint

# Eco-Efficiency at a Glance :

- Method for a comprehensive and comparative assessment of products and processes
- The ecological calculation follows the ISO 14040 and 14044
- Ecology plus life cycle costing integrated into Eco-Efficiency
- Single impact assessments as well as comparative aggregated results
- Flexible scenario calculations



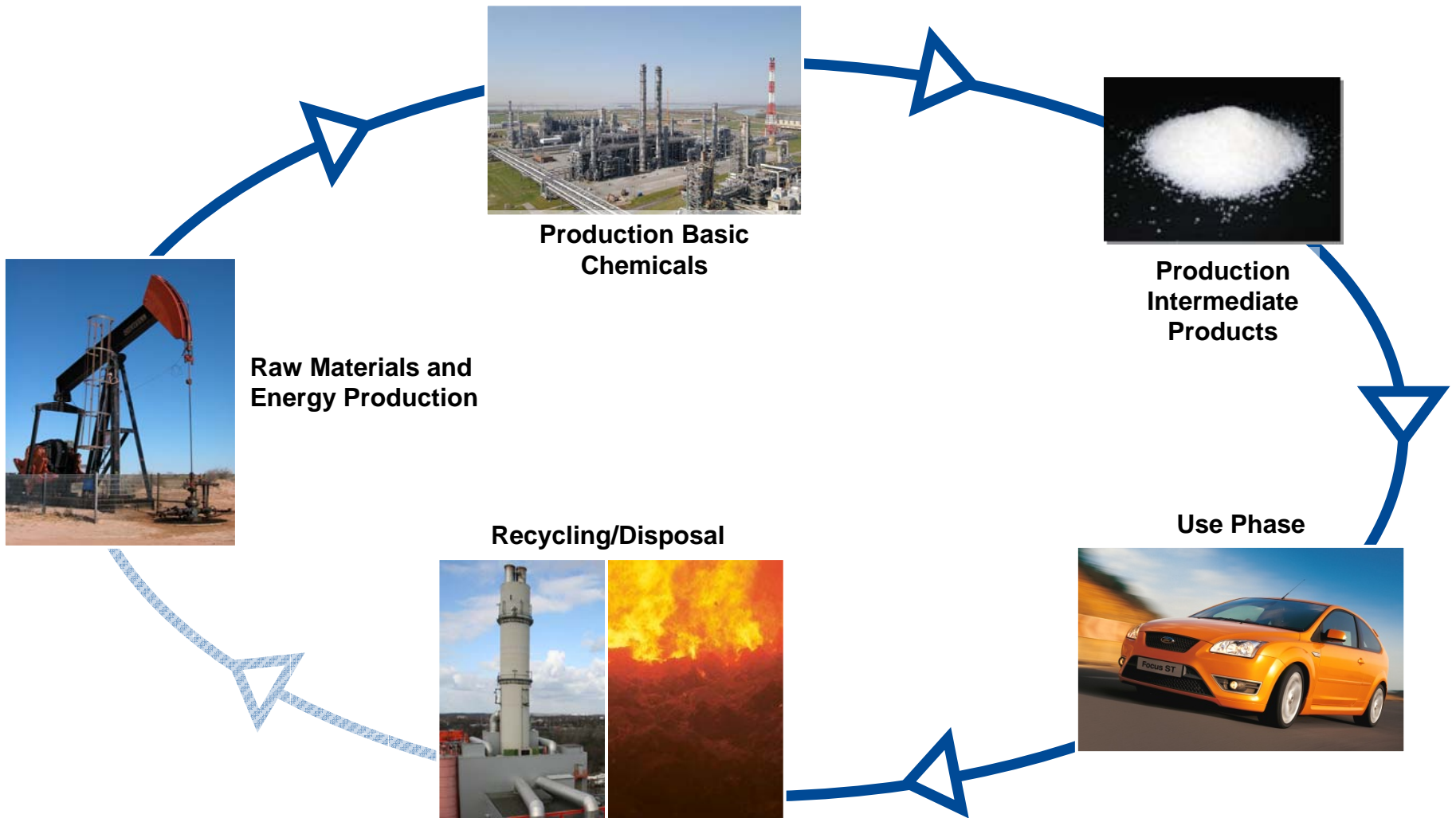
Validation with external partners for Eco-Efficiency

# Life Cycle Costing: Economic Metrics

- Raw material costs.
- Labor costs.
- Energy (electric and natural gas).
- Capital & non-capital investment costs.
- Maintenance.
- EH&S programs and regulatory costs.
- Illness & injury costs (medical, legal, lost time).
- Property protection & warehousing costs.
- Waste costs (hazardous, non-hazardous)
- Training costs.
- Other as applicable

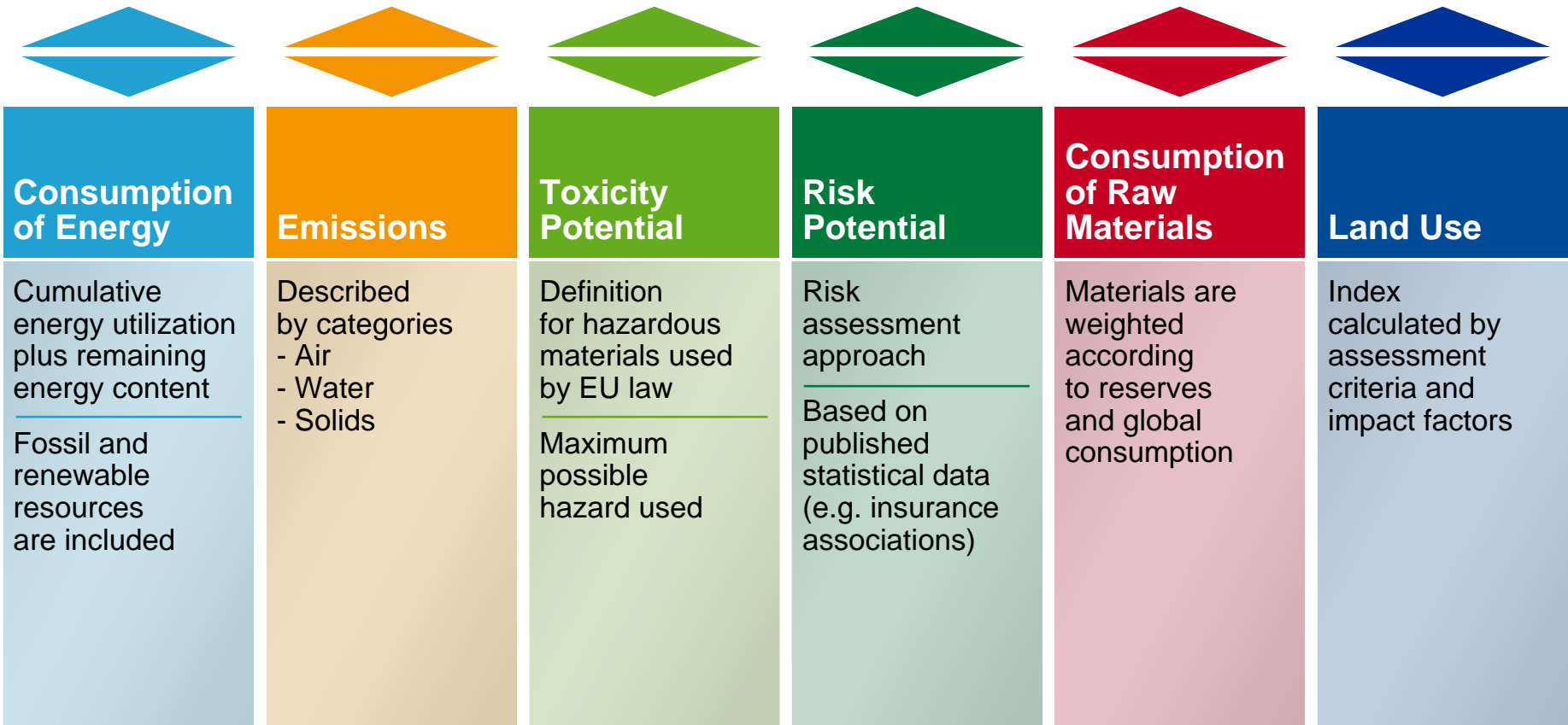


# Life Cycle Assessment (LCA): From Cradle to Grave



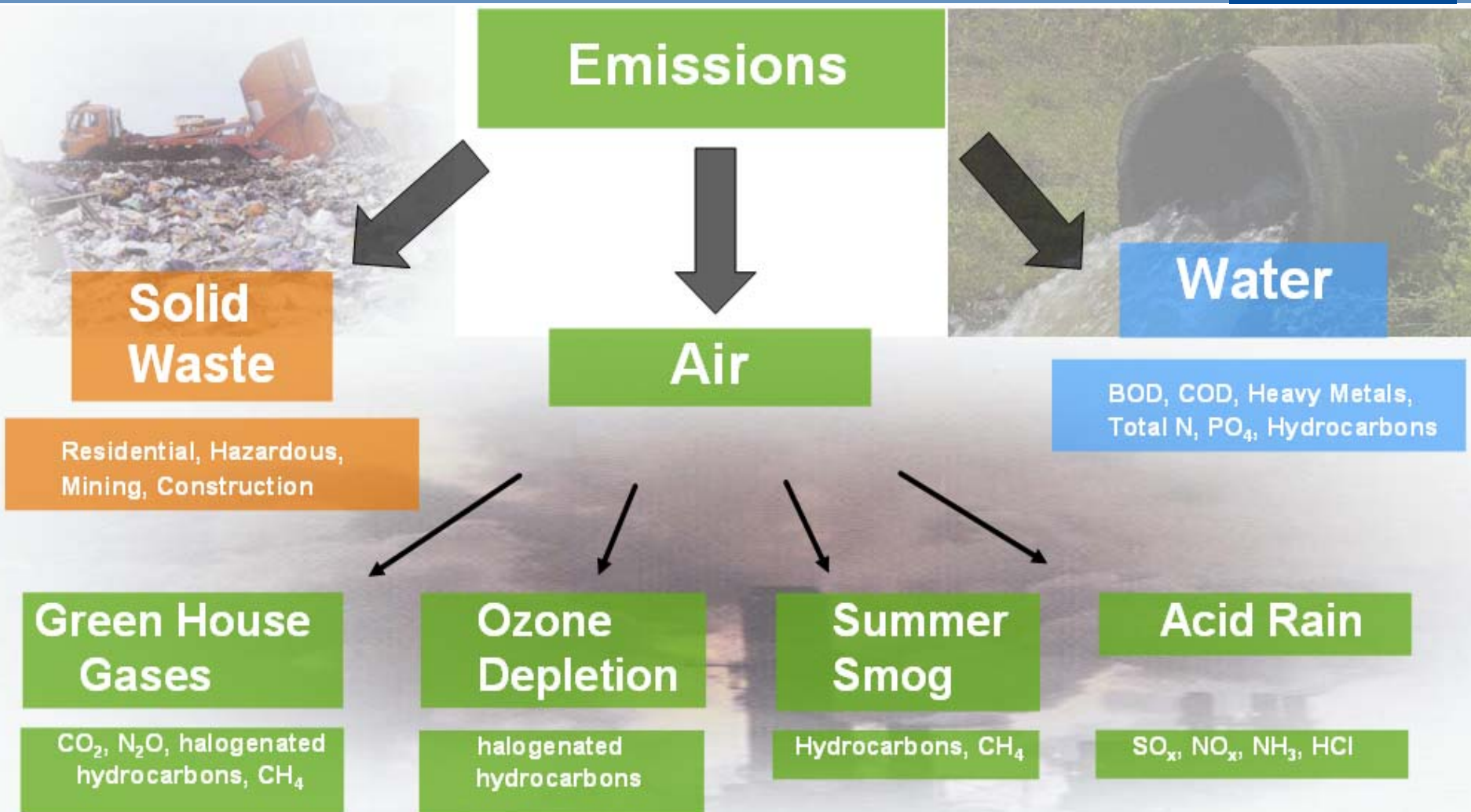
# Environmental Categories for Eco-Efficiency Analysis

## Environmental impact over the entire life cycle\*



\* Data acquisition and calculation is done according to ISO 14040 and 14044 (ecological part)

# Eco-Efficiency Analysis: Environmental Impact - Emissions

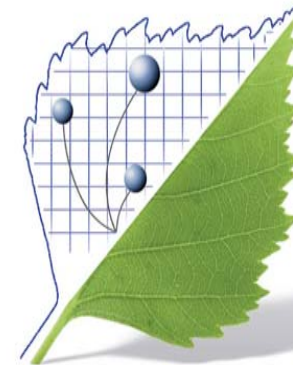


# Life Cycle Inventory

## Production of 1 kg of a Customer Benefit

| Fuels       |         |    |
|-------------|---------|----|
| Coal        | 4.646   | MJ |
| Oil         | 688.640 | MJ |
| Natural Gas | 39.680  | MJ |
| Hydro       | 1.408   | MJ |
| Nuclear     | 9.920   | MJ |
| Lignite     | 3.072   | MJ |
| Other       | -       | MJ |
| Biomass     | -       | MJ |
| SUM         | 747.366 | MJ |
| Material    |         |    |
| Water       |         | kg |
| Coal        | 160     | kg |
| Oil         | 15.235  | kg |
| Gas         | 763     | kg |
| Lignite     | 162     | kg |
| Uranium     | -       | kg |
| NaCl        | -       | kg |
| Sulfur      | -       | kg |
| Phosphorus  | -       | kg |
| Iron        | -       | kg |
| Lime        | -       | kg |
| Bauxite     | -       | kg |
| Sand        | -       | kg |
| Copper      | -       | kg |
| Titanium    | -       | kg |
| ...         | -       | kg |
| ...         | -       | kg |
| ...         | -       | kg |
| ...         | -       | kg |
| ...         | -       | kg |
| ...         | -       | kg |
| ...         | -       | kg |

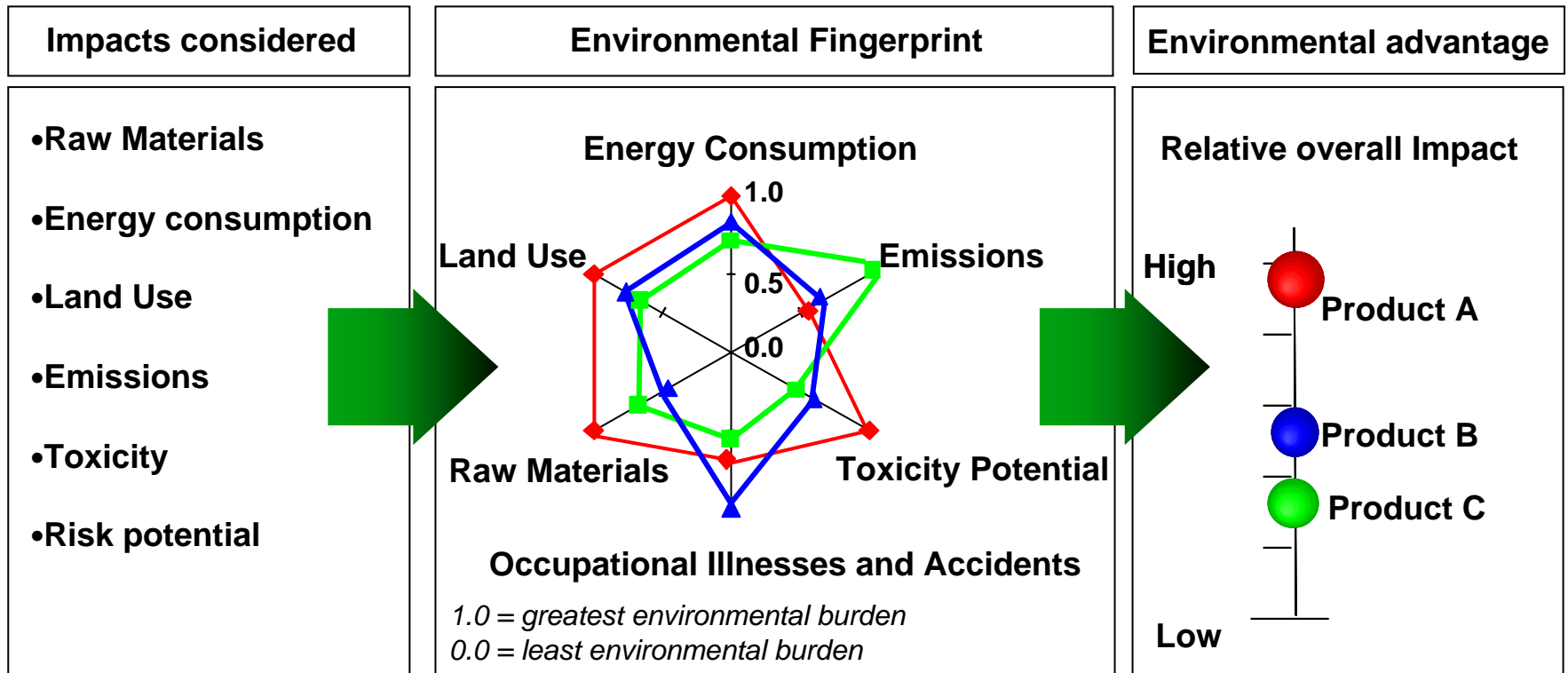
| Air Emissions      |          |      |
|--------------------|----------|------|
| CO2                | 1,07E+10 | mg   |
| SOX                | 1,06E+08 | mg   |
| NOX                | 5,57E+07 | mg   |
| CH4                | 1,56E+07 | mg   |
| NM-VOCs            | 2,67E+07 | mg   |
| halog. HC          | 0,00E+00 | mg   |
| NH3                | 0,00E+00 | mg   |
| N2O                | 0,00E+00 | mg   |
| HCl                | 0,00E+00 | mg   |
| Water Emissions    |          |      |
| COD                | 742.400  | mg   |
| BOD                | 742.400  | mg   |
| N-total            |          | mg N |
| NH4 as N           |          | mg N |
| PO4 as P           |          | mg P |
| AOX                |          | mg   |
| HM                 |          | mg   |
| HC                 | 742.400  | mg   |
| Sulfate            |          | mg   |
| Chloride           |          | mg   |
| Solid Wastes       |          |      |
| Municipal Waste    | 126      | kg   |
| Special Waste      | 81       | kg   |
| Construction Waste | 50       | kg   |
| Mining Waste       | 200      | kg   |
|                    | 0,00     | 0,00 |
| Land use           |          |      |
| Forest             | 10       | m2   |
| II                 | 5        | m2   |
| III                | 20       | m2   |
| IV                 | 40       | m2   |
| V                  | 10       | m2   |



EFFICIENCY IN ECOLOGY AND ECONOMY

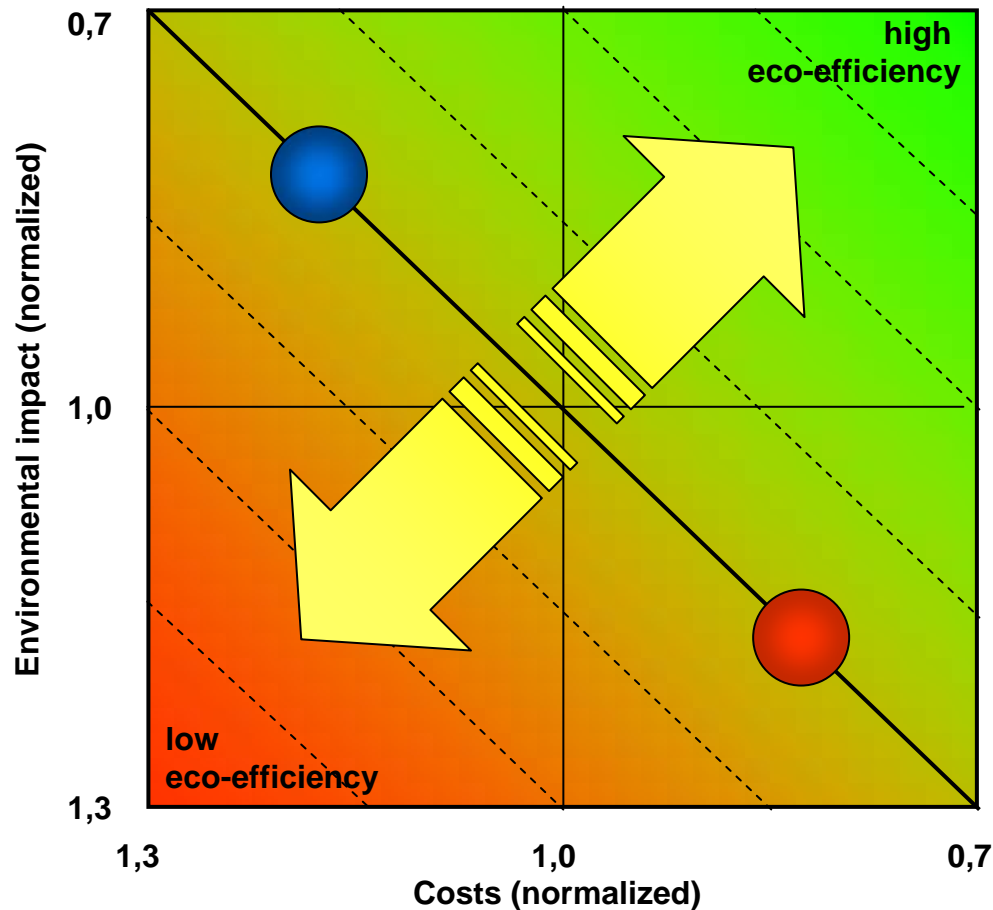


# Eco-Efficiency Analysis: Environmental Fingerprint



Life cycle data is gathered in six environmental categories and depicted on an environmental fingerprint. The data are then weighted, aggregated and normalized to obtain an overall environmental impact.

# Eco-Efficiency Portfolio



- Portfolio summarizes details in a concise manner
- Distance from diagonal line is a direct measurement for eco-efficiency

Alternative „blue“:

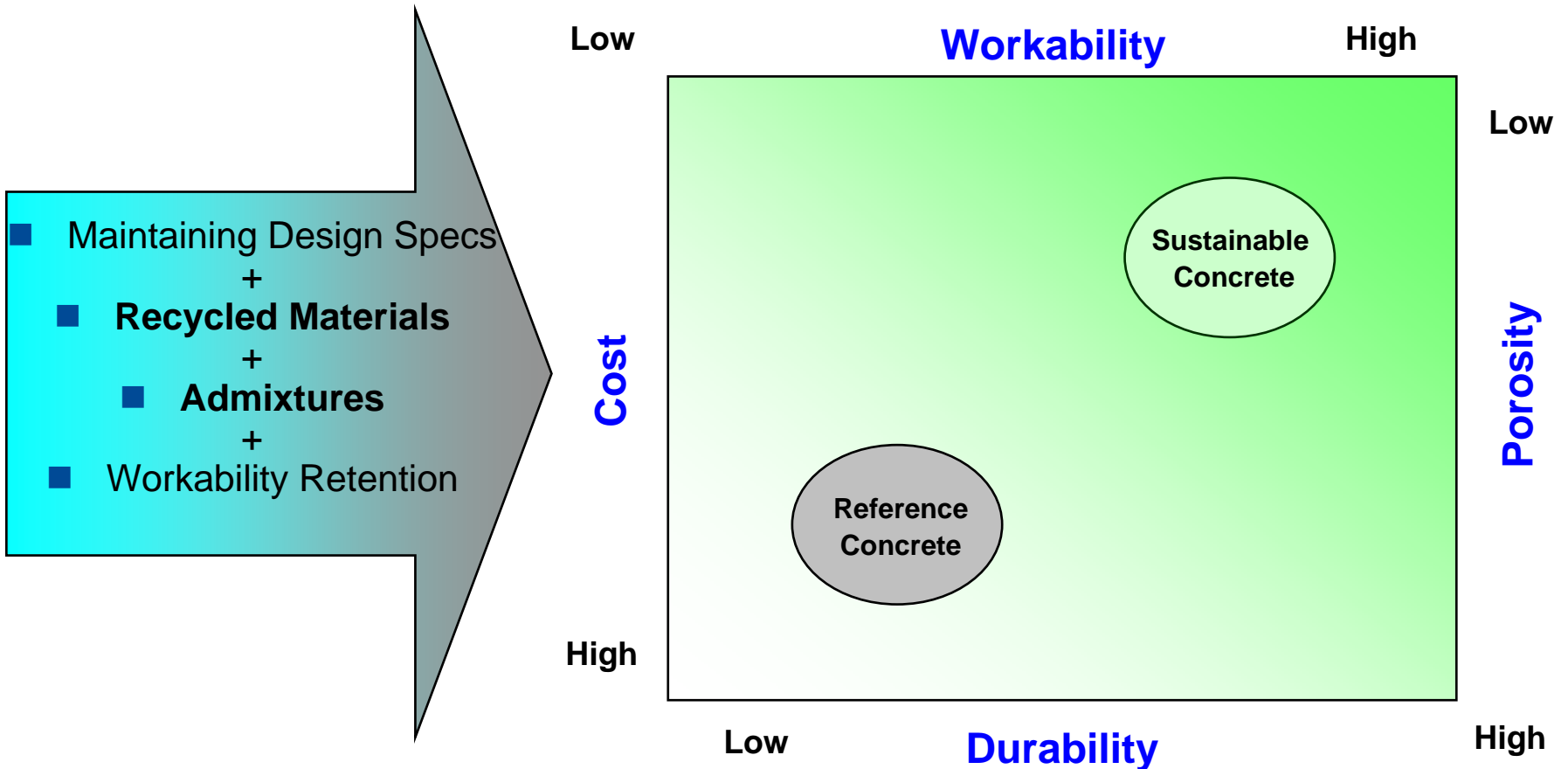
- ▶ High costs, low environmental impact

Alternative „red“:

- ▶ Low costs, high environmental impact

# Advanced Concrete Technology

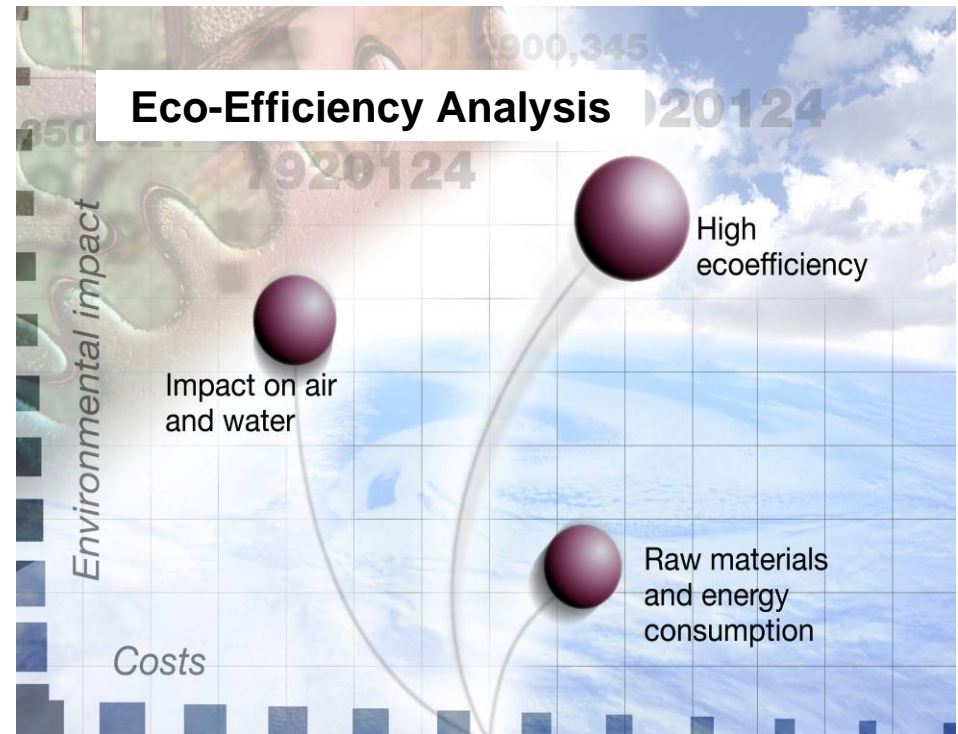
## Redefining the concrete space



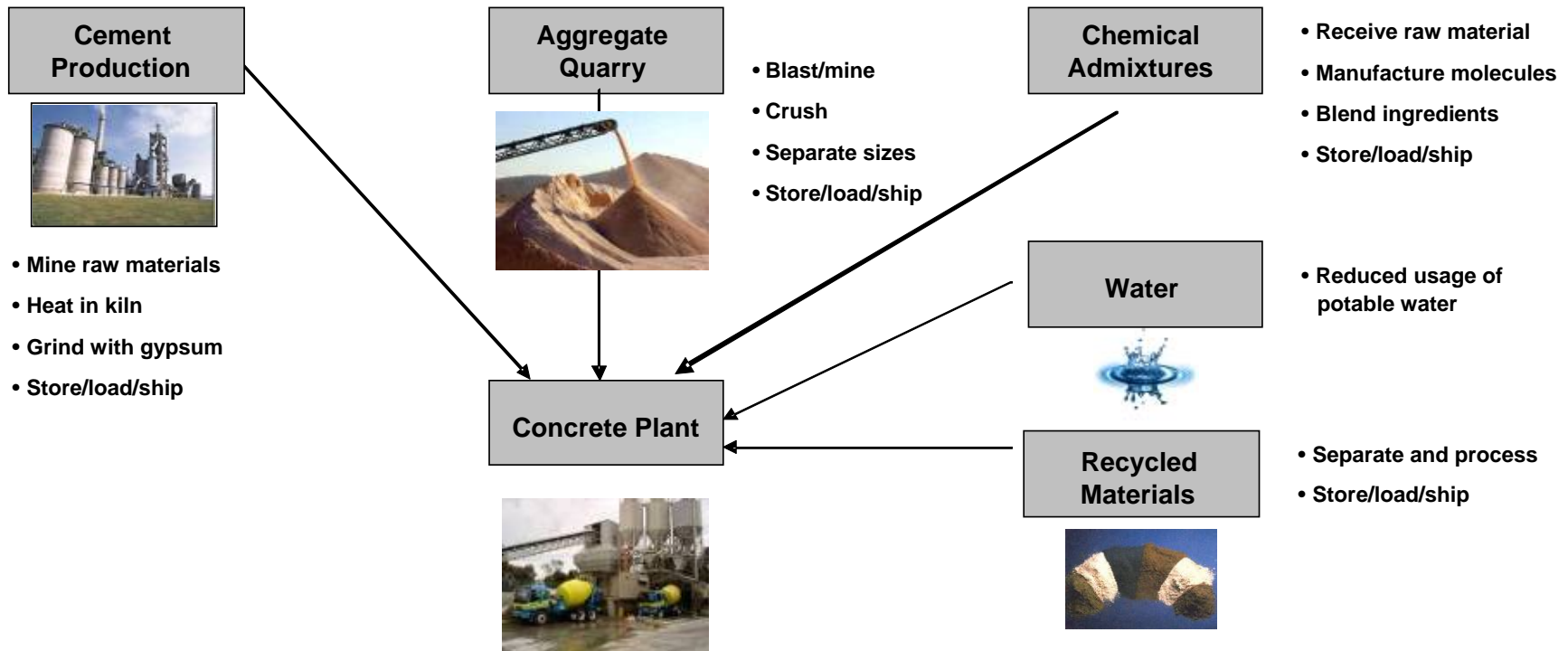
# Eco-efficiency Analysis (EEA)

**Eco-Efficiency Analysis quantifies the economical and ecological impact of Mix Optimized Concrete**

1. **Customized Interactive Program** specifically for concrete mix designs  
*Data gathered from Manufacturers, Industry Associations, Government Databases, Contract Consultants*
2. **Evaluates environmental and economical impact** of concrete ingredients based on input
3. **Compares five different concrete mix designs** for six environmental impact areas
4. **Quantifies environmental and economical impact** for each mix



# Eco-Efficiency Analysis for Concrete Cradle-to-Gate



**EEA concrete analyses can be conducted on ready mixed, precast, manufactured concrete products, paving, self-consolidating and pervious concrete.**

# Input Data: Mixture Proportions

## Mix Proportions (lb/yd<sup>3</sup>)

| Cement and Powder                   | Reference Mix | Fly Ash 15% | Fly Ash 40% | Slag 50%   | Green Sense |
|-------------------------------------|---------------|-------------|-------------|------------|-------------|
| Cement                              | 517           | 440         | 310         | 267        | 295         |
| Fly Ash                             |               | 77          | 207         |            | 100         |
| Slag                                |               |             |             | 250        |             |
| Limestone Powder                    |               |             |             |            | 140         |
| <b>Total Powder</b>                 | <b>517</b>    | <b>517</b>  | <b>517</b>  | <b>517</b> | <b>535</b>  |
| Aggregates                          |               |             |             |            |             |
| Fine Aggregate #1                   | 1,200         | 1,220       | 1,250       | 1,280      | 1,220       |
| Coarse Aggregate #1                 | 1,750         | 1,750       | 1,750       | 1,750      | 1,750       |
| Liquid                              |               |             |             |            |             |
| Water                               | 300           | 294         | 275         | 265        | 245         |
| Admixtures (fl oz/yd <sup>3</sup> ) |               |             |             |            |             |
| Pozzoloth WR                        |               | 20          |             |            |             |
| Glenium HRWR                        |               |             | 25          | 25         | 40          |

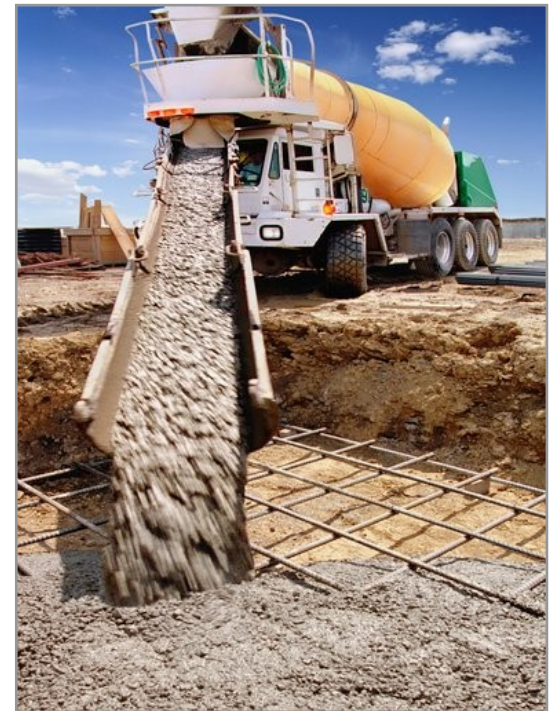
## Complex Comparisons:

- Water reduction
- Fly ash replacement
- Slag replacement
- Limestone, granite and other powders
- Multiple aggregates
- Admixture combinations

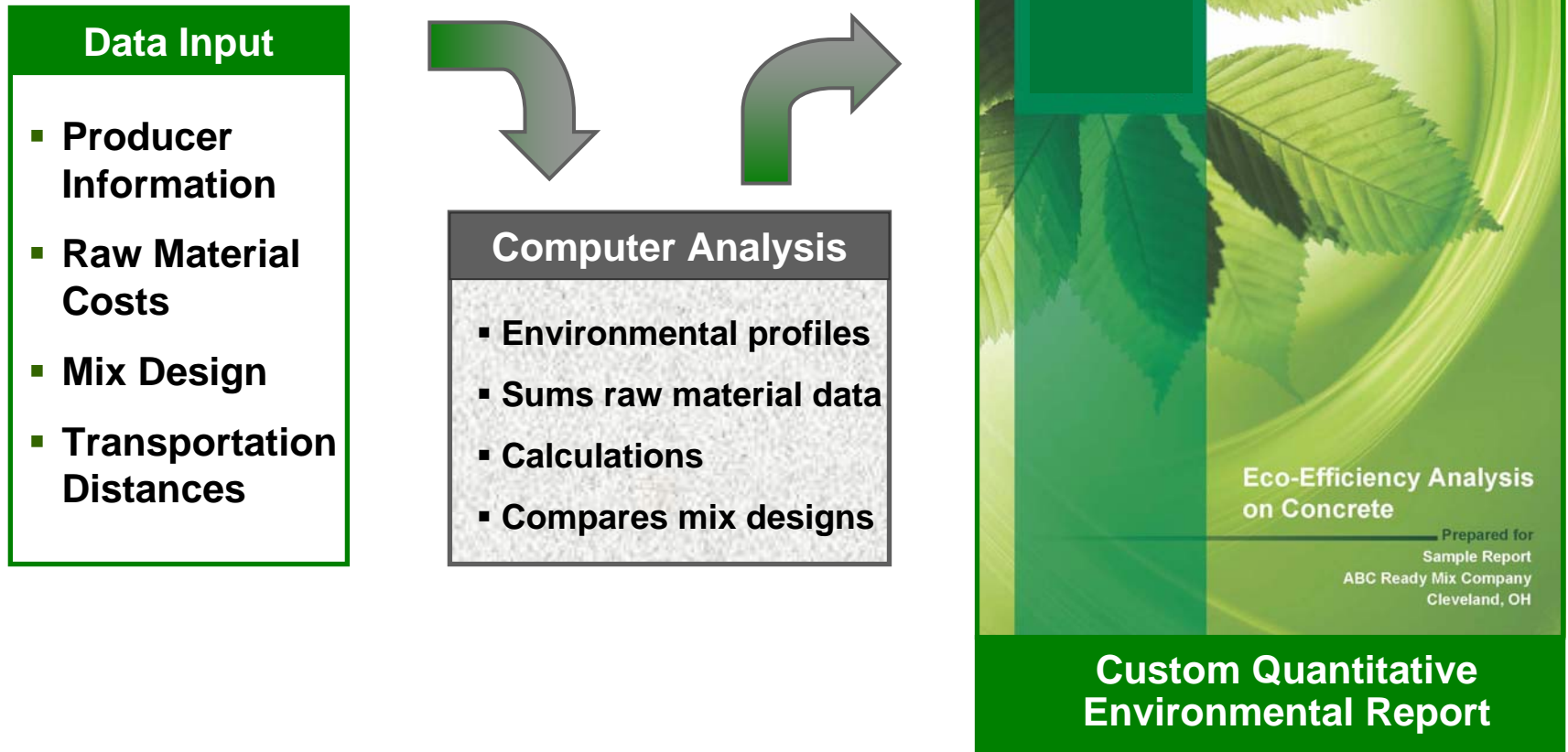
# Economical Analysis

## Mix Costs (\$/yd<sup>3</sup>)

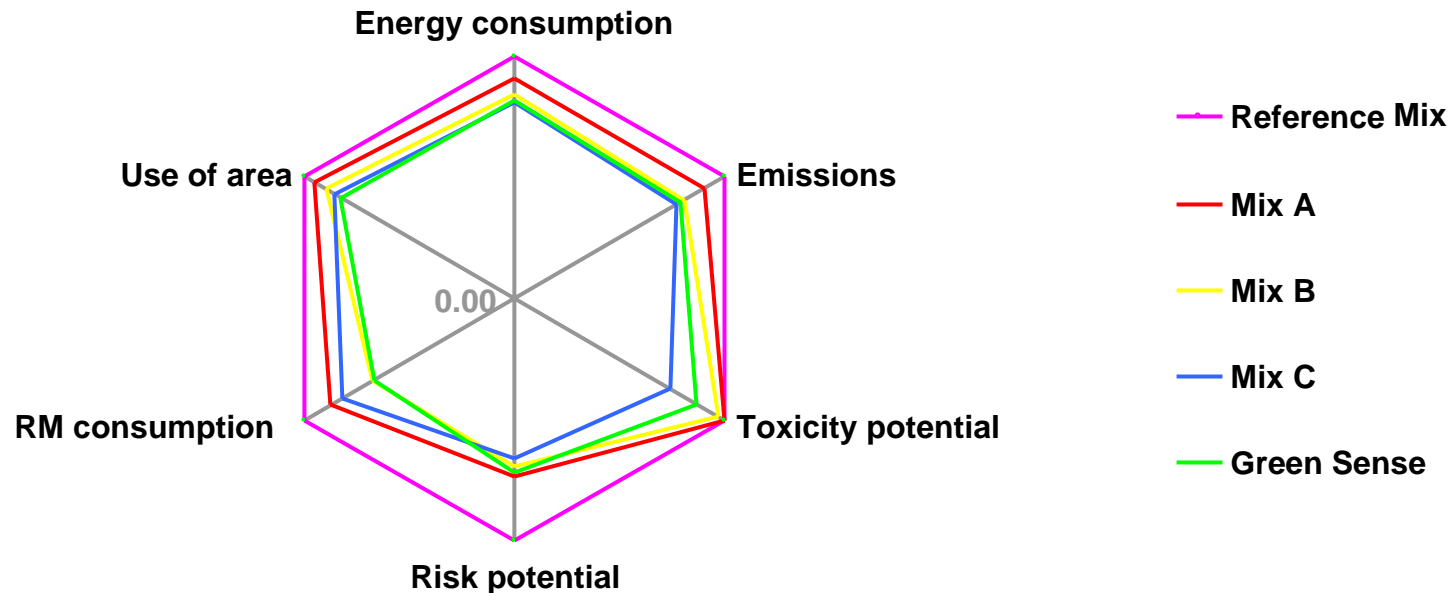
| Cement and Powder                | Reference Mix  | Fly Ash 15%    | Fly Ash 40%    | Slag 50%       | Green Sense    |
|----------------------------------|----------------|----------------|----------------|----------------|----------------|
| Cement                           | \$25.85        | \$22.00        | \$15.50        | \$13.35        | \$14.75        |
| Fly Ash                          | \$0.00         | \$1.93         | \$5.18         | \$0.00         | \$2.50         |
| Slag                             | \$0.00         | \$0.00         | \$0.00         | \$11.25        | \$0.00         |
| Limestone Powder                 | \$0.00         | \$0.00         | \$0.00         | \$0.00         | \$1.05         |
| <b>Total Powder</b>              | <b>\$25.85</b> | <b>\$23.93</b> | <b>\$20.68</b> | <b>\$24.60</b> | <b>\$18.30</b> |
| <b>Aggregates</b>                |                |                |                |                |                |
| Fine Aggregate #1                | \$7.80         | \$7.93         | \$8.13         | \$8.32         | \$7.93         |
| Coarse Aggregate #1              | \$7.00         | \$7.00         | \$7.00         | \$7.00         | \$7.00         |
| <b>Liquid</b>                    |                |                |                |                |                |
| Water                            | \$0.09         | \$0.09         | \$0.09         | \$0.08         | \$0.08         |
| <b>Admixtures</b>                |                |                |                |                |                |
| Pozzoloth WR                     | \$0.00         | \$0.94         | \$0.00         | \$0.00         | \$0.00         |
| Glenium HRWR                     | \$0.00         | \$0.00         | \$2.73         | \$2.73         | \$4.38         |
| <b>Total (\$/yd<sup>3</sup>)</b> | <b>\$40.74</b> | <b>\$39.89</b> | <b>\$38.62</b> | <b>\$42.74</b> | <b>\$37.68</b> |



# Conducting an Eco-Efficiency Analysis



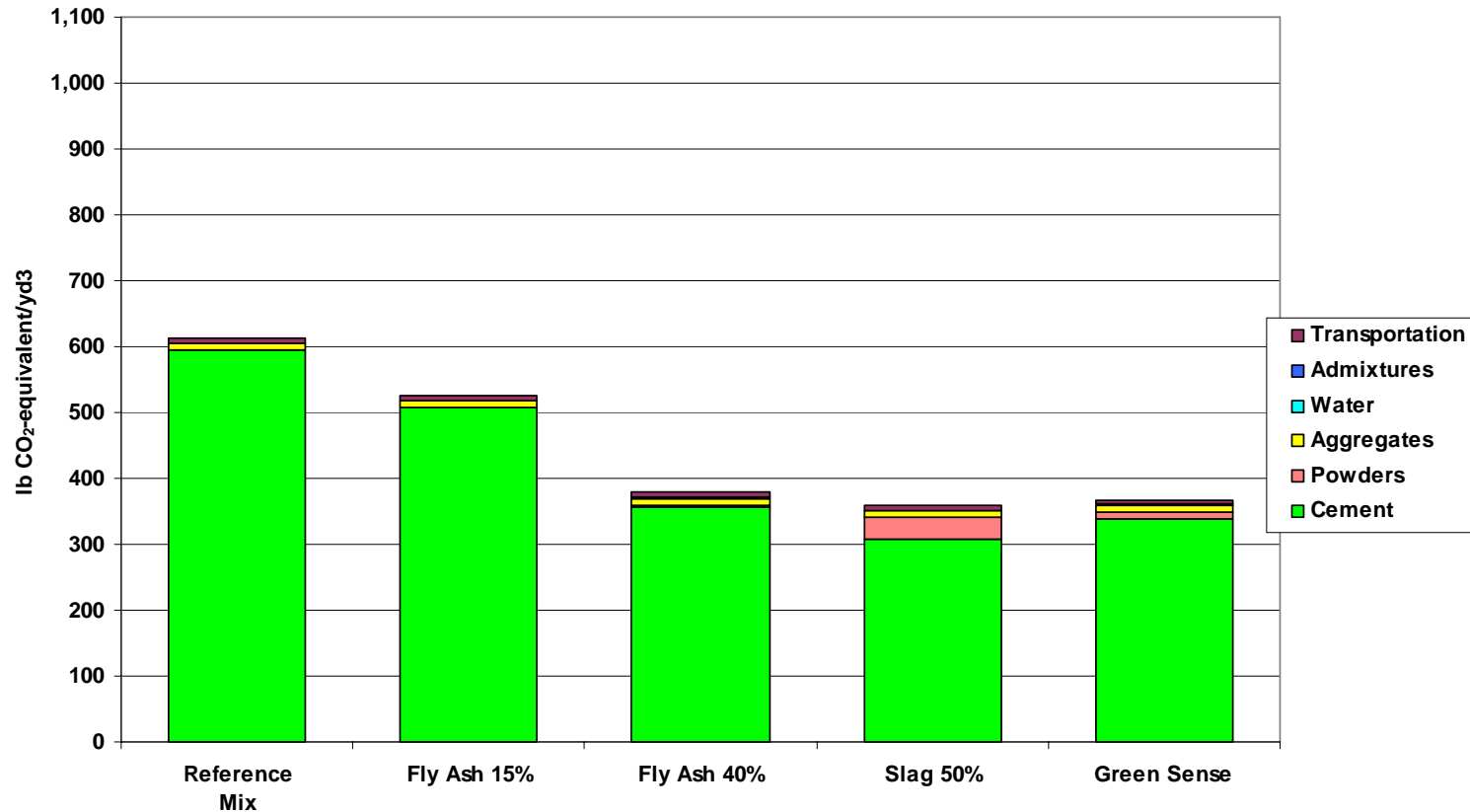
# Ecological Fingerprint



**The four concrete alternatives are shown to be progressively more environmentally preferable in relation to the Reference Mix.**

# Ecological Analysis by Ingredient

## Emissions Potential



**The impact of each ingredient is determined for each of the six environmental impact categories and more.**

# Ecological Analysis

| Smaller Carbon Footprint - Volume of Gasoline Equivalent |  |  |   |
|--|--|--|---|
| Alternative  | Emissions Saved<br>(lb CO <sub>2</sub><br>equiv./yd <sup>3</sup> ) | Annualized<br>Emissions<br>Saved (lb CO <sub>2</sub><br>equiv./yr) | Annualized Volume<br>of Gas Saved<br>(gal/yr) |
| Fly Ash 15%  | 87   | 5,245,325  | 276,070                                       |
| Fly Ash 40%  | 235  | 14,084,608   | 741,295                                       |
| Slag 50%   | 254  | 15,218,338   | 800,965                                       |
| Green Sense  | 247  | 14,807,727   | 779,354                                       |

| Energy Saved - US Homes Equivalent |  |  |   |
|------------------------------------|--|--|---|
| Alternative                        | Energy Saved<br>(kWh/yd <sup>3</sup> ) | Annualized<br>Energy Saved<br>(kWh/yr) | Annualized US<br>Energy Savings<br>Equivalent<br>(homes/yr) |
| Fly Ash 15%                        | 69                                     | 4,116,295                              | 356   |
| Fly Ash 40%                        | 181                                    | 10,884,852                             | 941   |
| Slag 50%                           | 158                                    | 9,480,149                              | 819   |
| Green Sense                        | 199                                    | 11,945,185                             | 1,032   |

| Water Saved - Truck Washout and Bottled Water |                                       |                                       |   |   |
|---|---------------------------------------|---------------------------------------|---|---|
| Alternative                                   | Water Saved<br>(gal/yd <sup>3</sup> ) | Annualized<br>Water Saved<br>(gal/yr) | Equivalent<br>Annualized<br>Number of Truck<br>Washouts | Equivalent<br>Number of<br>1/2 liter<br>Bottles of<br>Water |
| Fly Ash 15%                                   | 1                                     | 43,217                                | 192   | 327,155   |
| Fly Ash 40%                                   | 3                                     | 180,072                               | 800   | 1,363,145   |
| Slag 50%                                      | 4.20                                  | 252,101                               | 1,120   | 1,908,403   |
| Green Sense                                   | 7                                     | 396,158                               | 1,761   | 2,998,920   |

**Example of CO<sub>2</sub> emissions, energy usage, and annual water consumption savings and practical equivalents compared to reference mix.**

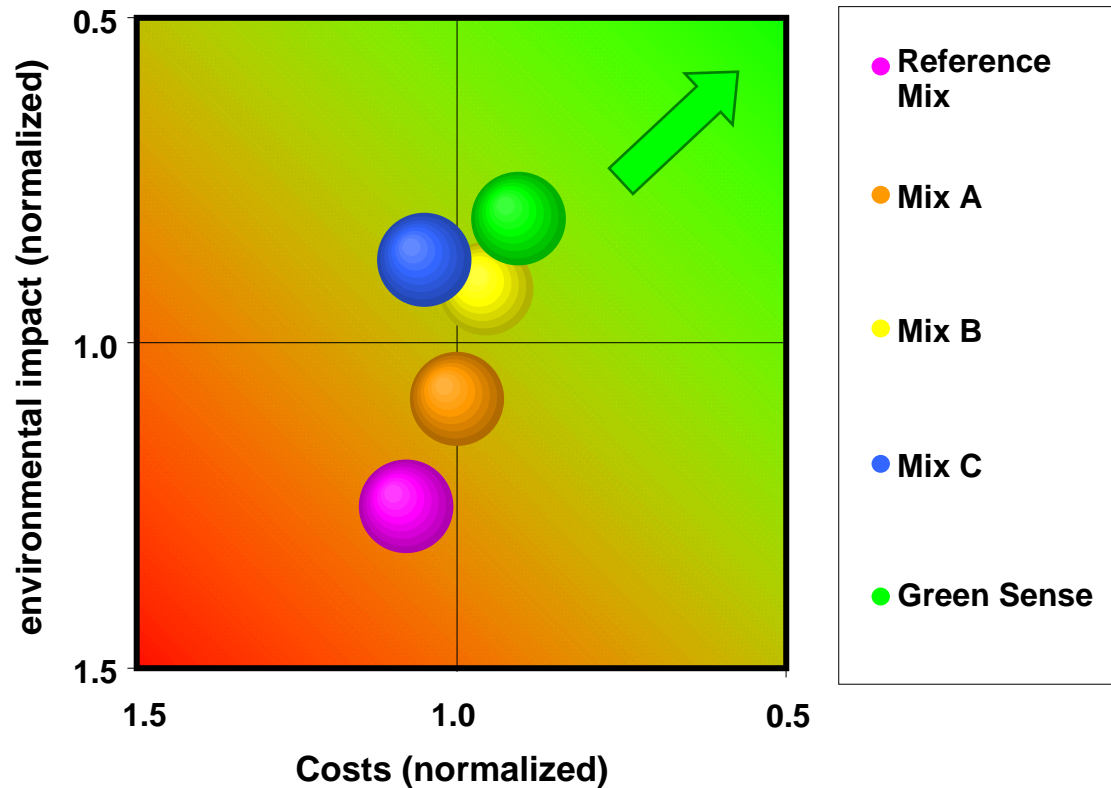
**Environmental impact categories include:**

- Energy consumption
- Emissions (air, water, and solid waste)
- Toxicity potential
- Risk potential
- Raw material consumption
- Use of area (land)

*Based on an annual production of 60,000 yd<sup>3</sup> of concrete*

# Eco-Efficiency Portfolio

## Economic and Ecological Impact



**The Eco-efficient Concrete has the lowest overall environmental burden and the least economic impact to produce.**

# Application of Eco-Efficiency Analysis

## Strategic Decisions

- Investment decisions
- Technology decisions
- Site decisions
- Evaluate product portfolio

## Marketing, Customers

- Demonstration of product advantages
- Improved customer relations
- Product differentiation
- Better understand competitive advantages

## Research and development

- Quantification of the most important factors
- Drive sustainable products and processes
- Drive production/process improvements

## Stakeholder and Government Dialogue

- Communication with authorities
- Impact assessment
- REACH

# Eco-Efficiency Analysis

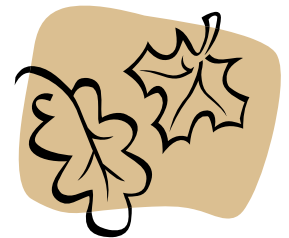
- ❑ Is much more than a CO<sub>2</sub> footprint.....
- ❑ Is much more than Life Cycle Assessment....
- ❑ Eco-Efficiency Analysis
  - ❖ measures multiple environmental categories
  - ❖ addresses economic aspects
  - ❖ includes social relevance
  - ❖ provides comprehensive environmental impact data to make good decisions on sustainability based on facts!



# Sustainable Initiatives – In Summary

## Benefits of Chemical Admixtures

- Provide Sustainable Concrete Construction Opportunities
  - ▶ Reduce water usage & facilitate use of SCMs → ↓ CO<sub>2</sub> emissions
  - ▶ Reduce and help manage returned concrete and washwater
  - ▶ Help in facilitating stormwater management
  - ▶ Contribute towards reducing heat island effect
  - ▶ Reduce energy consumption, gasoline waste & emissions
  - ▶ Help protect aquatic life
  - ▶ Quantify the benefits with Eco-Efficiency Analysis



**Performance-Based Sustainable Construction**

# World Trade Center



**For Additional Information:  
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Office: 216-839-7803  
david.r.green@basf.com**

***THANK YOU***

