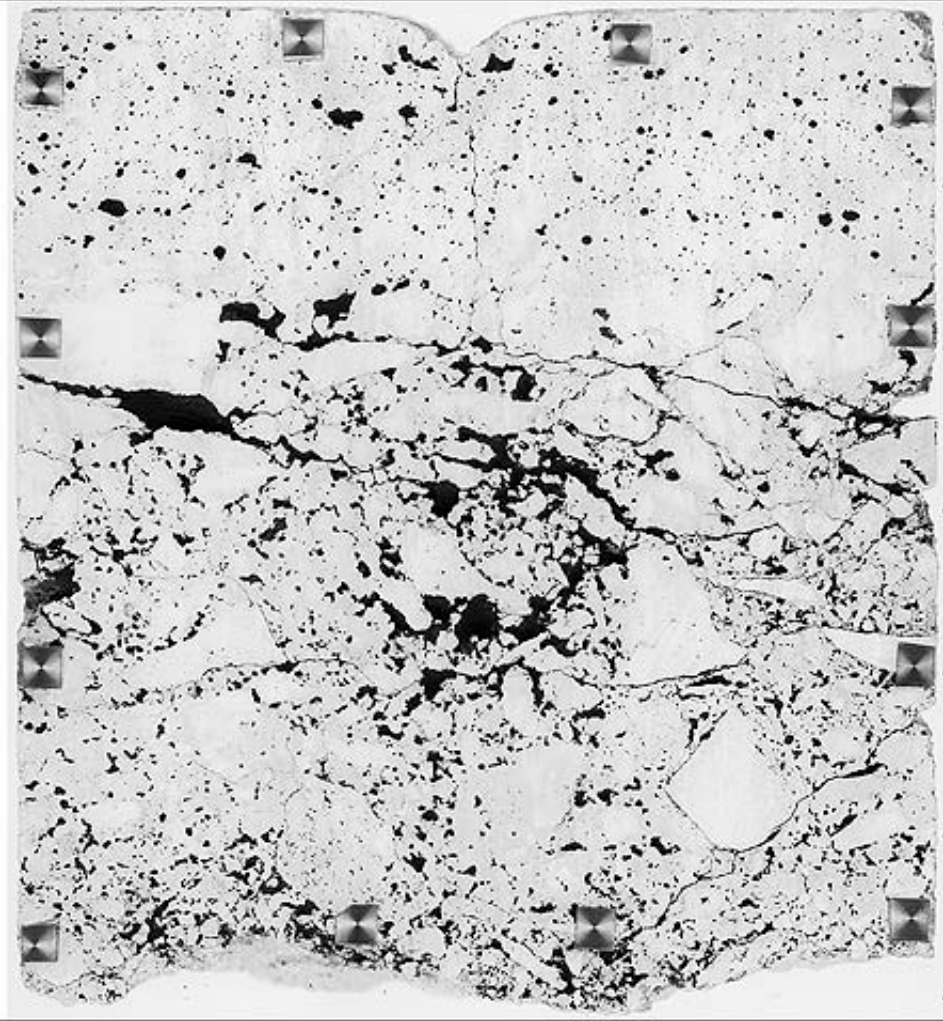
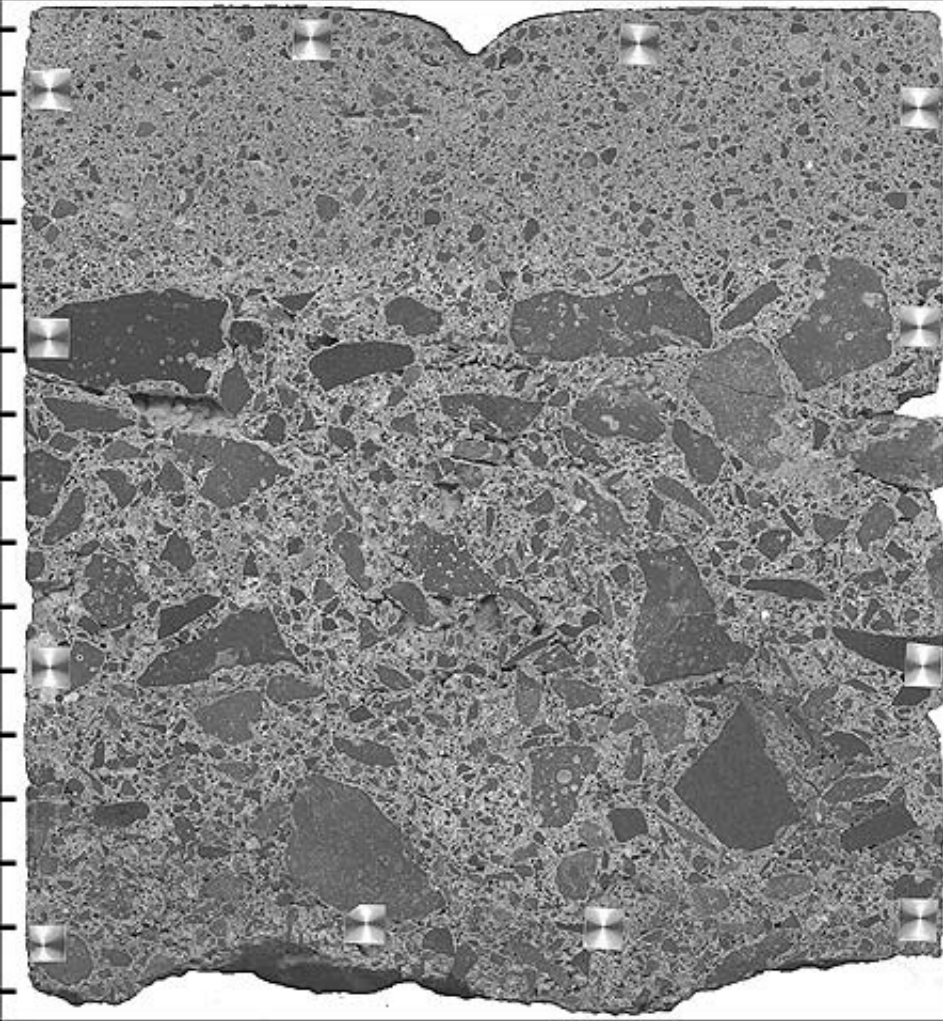


Analysis of Environmental Benefits of the Project



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First, A Word About Sustainability

- 👤 Sustainability considers the economic, environmental, and social costs over the life-cycle
- 👤 Sustainable design is simply good engineering
 - It entails working with limited resources to achieve design objectives
 - It is not about perfection, but instead about balancing competing, and often contradictory, interests



Enhanced Sustainability

Questions To Be Answered

- 👤 What environmental factors matter?
- 👤 How are environmental factors measured?
- 👤 How can two-lift paving provide environmental benefit?
- 👤 How does the US 141 two-lift stack up?
- 👤 What lies ahead?

What Environmental Factors Matter?

 Common environmental factors include:

- Emissions
 - Greenhouse gases (GHGs)
 - Pollutants
- Waste
 - Water and solid
- Energy Use
- Resource depletion

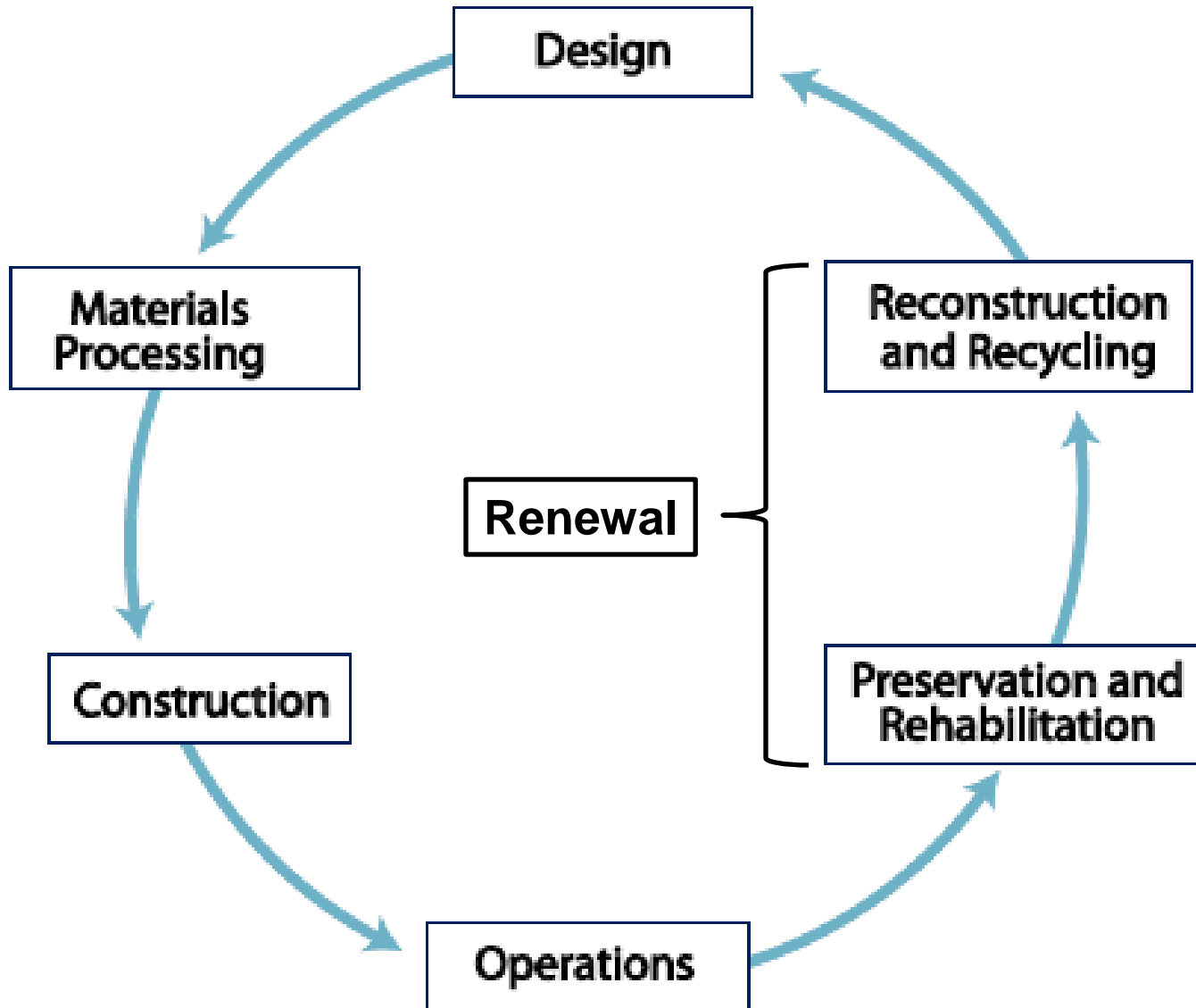
 Global warming potential (GWP) and energy are most common



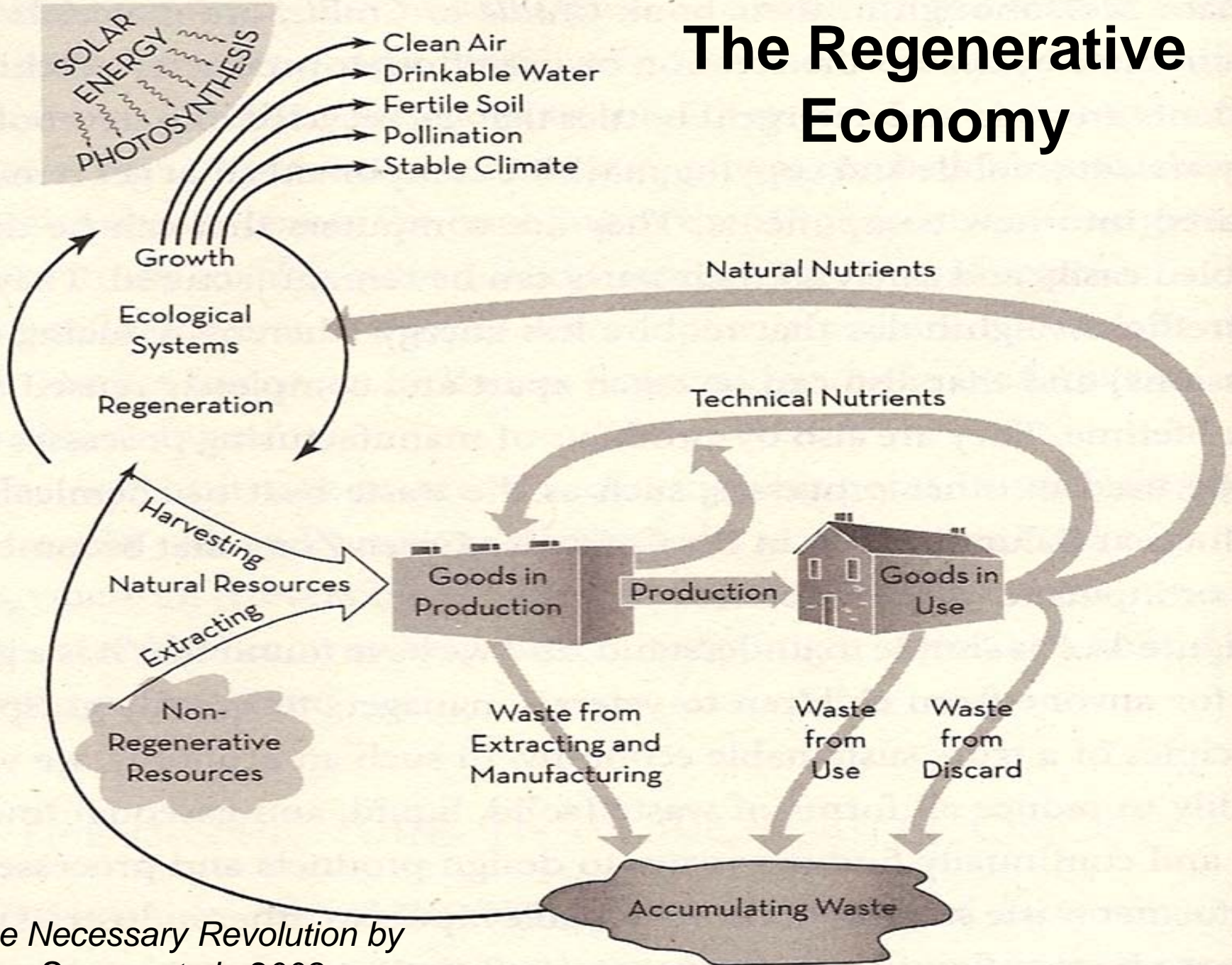
Environmental Factors

- 👤 Must consider life-cycle
 - This is difficult because the future is uncertain
 - Yet the use phase is responsible for upwards of 85% of the environmental impact (Wathne 2010)
- 👤 Models used to assess impact are less than certain
 - Global warming, human toxicity, ozone layer depletion, and so on
- 👤 The goal is to adopt a regenerative economy

Cradle-to-Cradle Life Cycle



The Regenerative Economy



*The Necessary Revolution by
Senge, et al., 2008*

How Are Environmental Factors Measured?

Rating systems

- Rating systems have been developed and are being refined for pavements
 - Greenroads, MO DOT, and so on
- Useful in advancing sustainable practices
- Potentially limiting

Environmental life-cycle assessment (LCA)

What is Life Cycle Assessment?

- 👤 An LCA compares environmental impacts assignable to producing goods
- 👤 It accounts for the effects of “cascading technologies”
- 👤 The 'life cycle' infers that a fair, holistic assessment is done over all phases of a product's existence

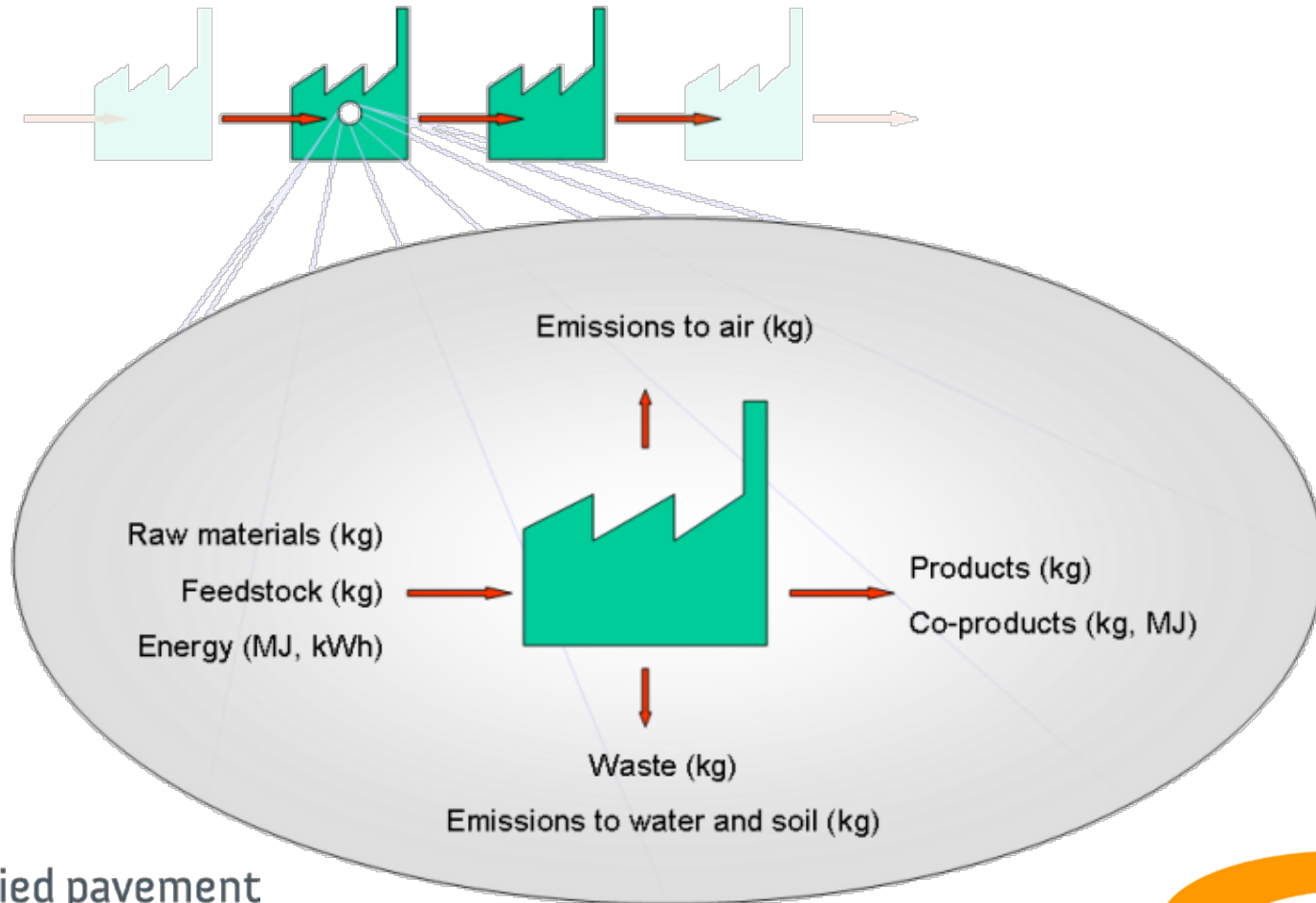
What is Calculated in an LCA?

- 👤 Embodied primary energy and global warming potential are calculated
- 👤 In addition, acidification, eutrophication, smog, ozone layer depletion, human toxicity, aquatic ecotoxicity, terrestriotoxicity, land use change, land use occupation, and so on, can all be modelled
- 👤 Can be comparative or attributional

Four Phases of LCA (ISO 14044)

- 🔍 Goal and scope definition
 - Establish functional unit and system boundaries
 - Identify impact categories and how they are assessed
- 🔍 Life cycle inventory (LCI)
 - Inputs and outputs identified
 - Materials and energy flows into and out of the system
- 🔍 Life cycle impact assessment
 - Calculate impact potentials for selected categories
 - Normalization and weighting
- 🔍 Interpretation

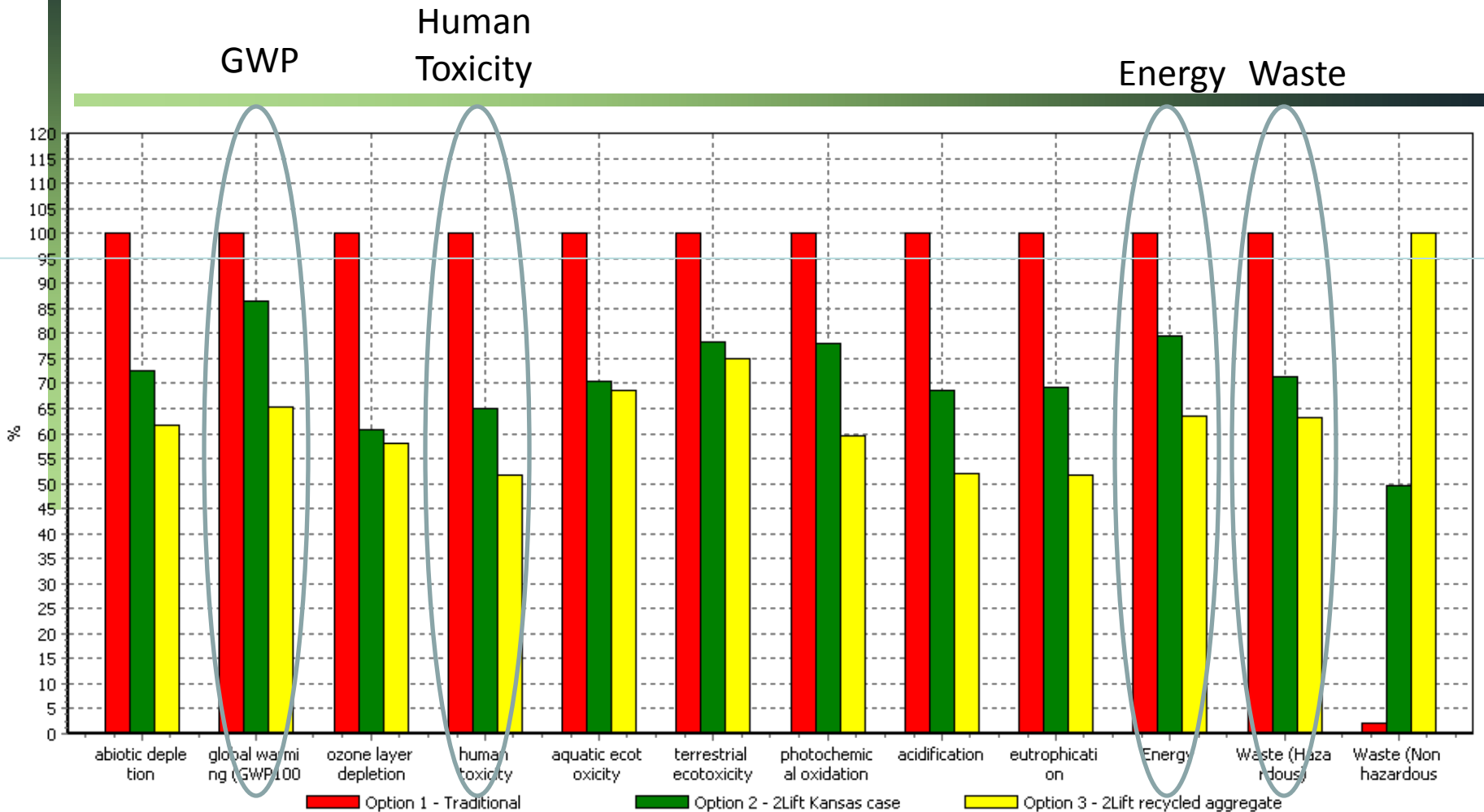
System Input-Output Concept



LCA Impact Assessment

- 👤 Outputs from LCI are used to assess environmental impact as part of the LCA
- 👤 Can be problematic
 - Accuracy in LCI computations
 - Limitations in impact assessment models
 - Accuracy
 - Some are subjective
- 👤 Still useful, just not perfect

LCA Comparison of Alternatives



Comparing 1 p 'Option 1 - Traditional', 1 p 'Option 2 - 2Lift Kansas case' and 1 p 'Option 3 - 2Lift recycled aggregate'; Method: VLCA2005-NEN8006; adapted by INTRON 0308 V2.04 / World, 2000 / charac

How Can Two-Lift Paving Provide Environmental Benefit?

- Can maximize the use of locally available and recycled materials
 - The lower lift can be made with materials that might not perform well in a surface layer
 - The top lift can be designed to withstand the harsh environmental and loading conditions at the pavement surface
 - Innovations include RCA in lower layer and photocatalytic cement in the top lift

Additional Innovations

Surface lift

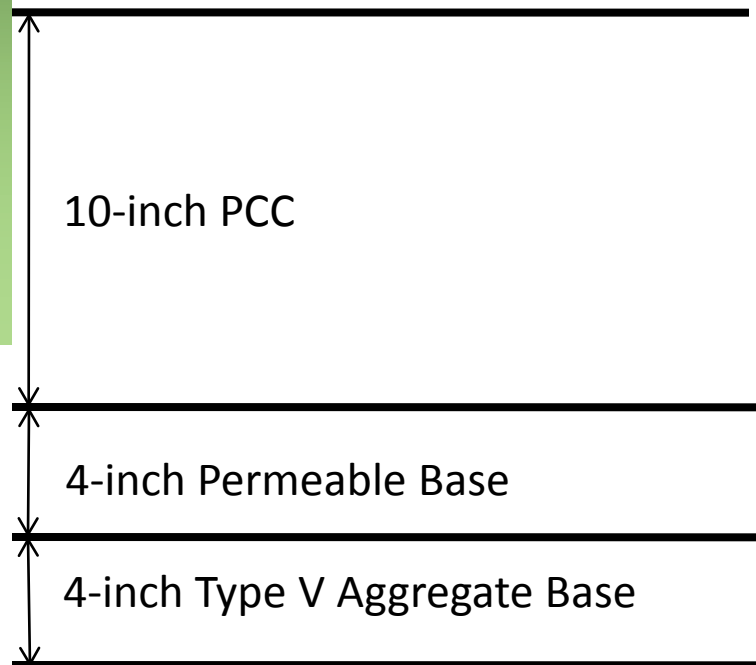
- Pervious concrete surface lift
- Exposed aggregate surface
- Highly reflective surface

Bottom-lift

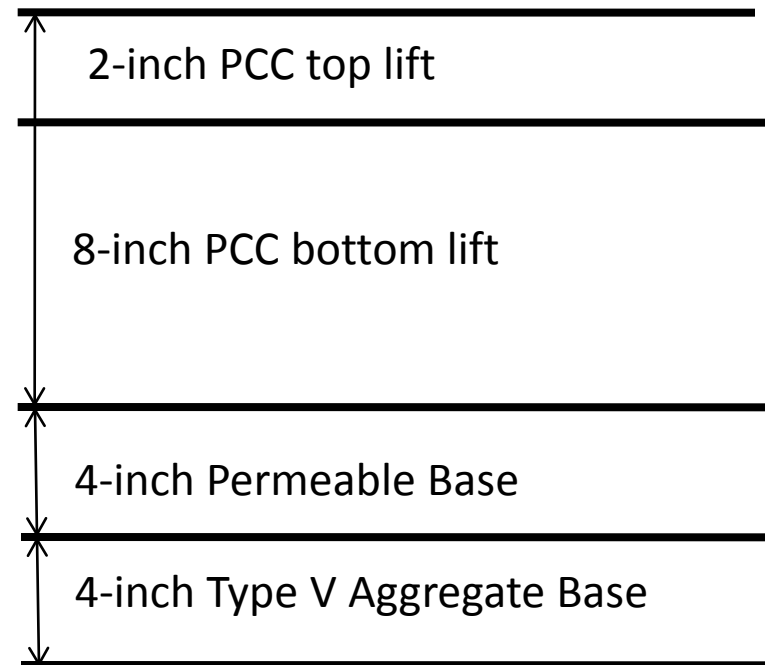
- RAP
- Polishing susceptible aggregate
- Large stone/low cementitious content
- High volume SCM

MO Two-Lift Pavement Design

Conventional Design



Two-Lift Design



The only difference is the concrete materials and method of construction

MO Two-Lift Mix Designs

Material	Conventional (lbs/yd³)	Top-Lift (lbs/yd³)	Bottom-Lift (lbs/yd³)
Cement	560	405	344
Fly Ash	0	135	115
Water	224	216	184
Fine Agg	1177	1246	1406
Coarse Agg	1927	1877	1871

How Does The US 141 Two-Lift Stack Up?

- 👤 Conducted a comparative analysis, including:
 - Materials
 - Transportation (to plant and to site)
 - Batch plant operations
- 👤 Assumed similar pavement performance
- 👤 Considered only carbon footprint
- 👤 Looked at one lane-mile of pavement

Greenhouse Gas Emissions From Materials Only

- Includes extraction and processing
- Conventional PCC
 - 367.5 tons CO₂ eq.
- Two-lift PCC
 - 237.1 tons CO₂ eq.
- Use of two-lift reduced GHG emissions by 36% for the materials

Total Emissions for Conventional PCC

GHG emissions

- Materials: 367.5 tons CO₂ eq.
- Transportation: 12.3 tons CO₂ eq.
- Batching: 1.3 tons CO₂ eq.
- Total: 381 tons CO₂ eq.

 Materials are responsible for 96% of the GHG emissions associated with construction of concrete surface

Total Emissions for Two-Lift PCC

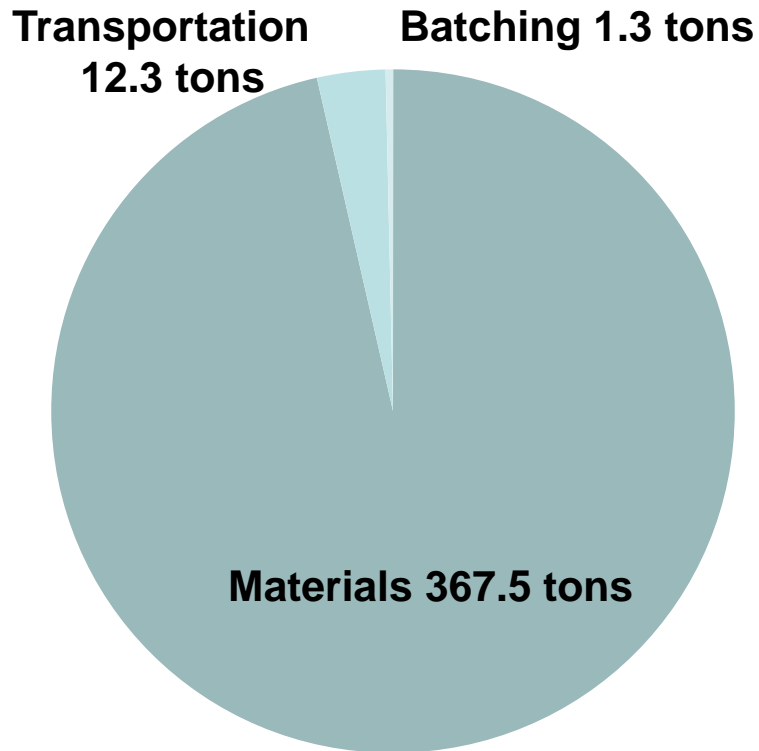
GHG emissions

- Materials: 237.1 tons CO₂ eq.
- Transportation: 11.2 tons CO₂ eq.
- Batching: 1.3 tons CO₂ eq.
- Total: 250 tons CO₂ eq.

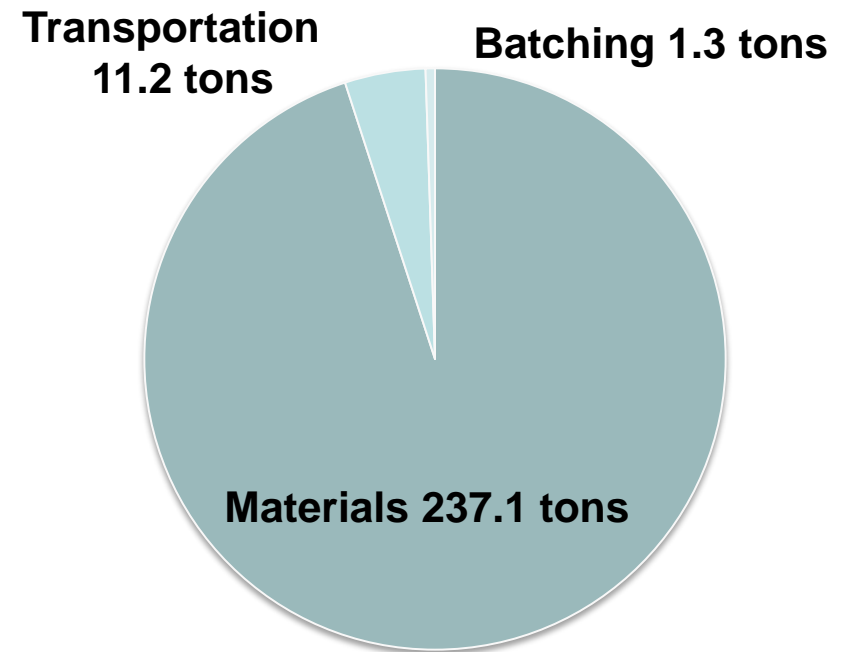
 Materials are responsible for 95% of the GHG emissions associated with construction of surface

Total CO₂ Emissions

Conventional PCC



Two-Lift PCC



Role of Portland Cement

Conventional

- 351.9 tons CO₂ eq. from cement manufacturing
- 92% of the as-placed total

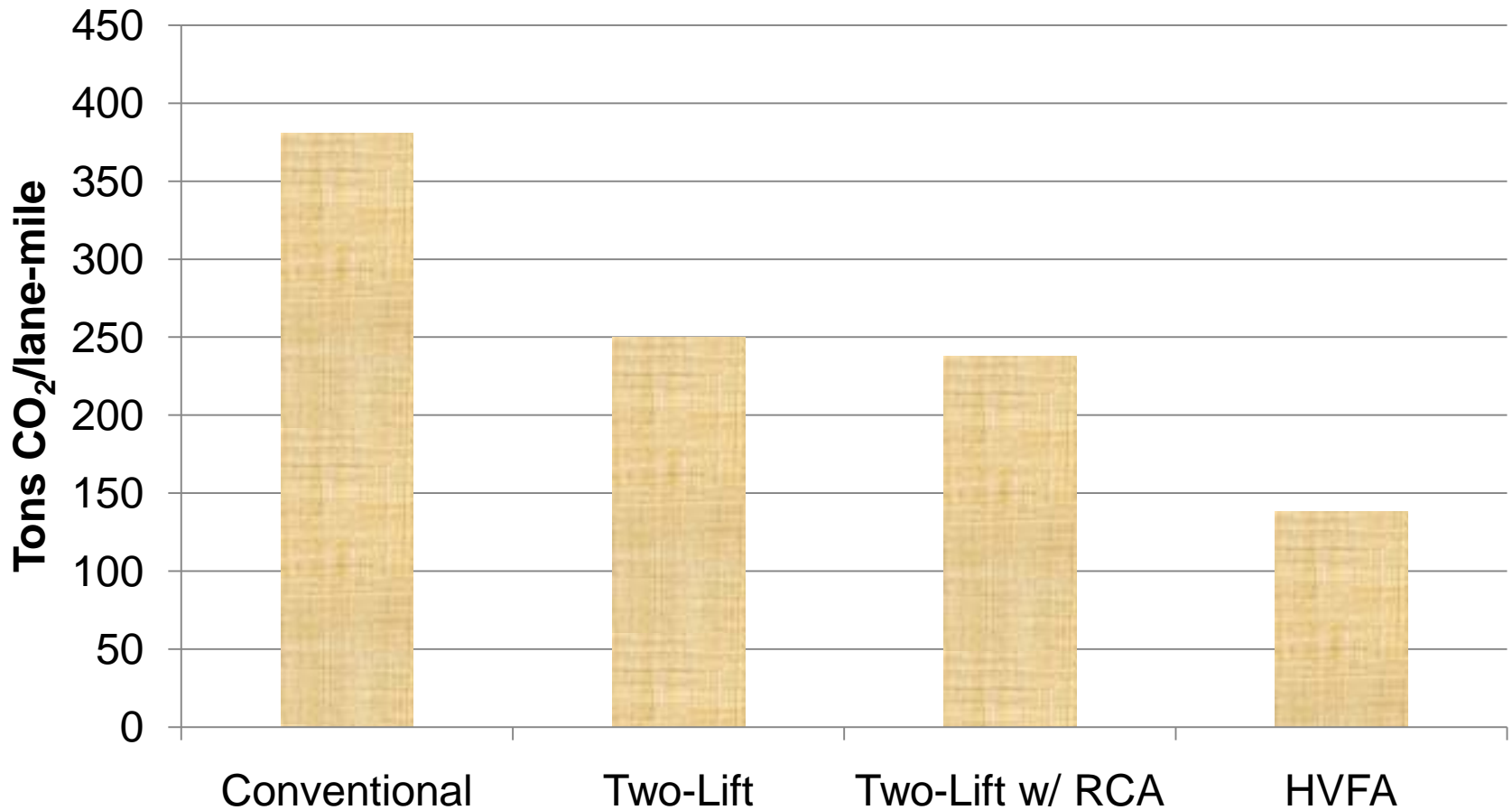
Two-Lift

- 220.5 tons CO₂ eq. from cement manufacturing
- 88% of the as-placed total

What-If?

- Recycled coarse aggregate used in bottom lift of two-lift
 - 238.4 tons CO₂ eq. instead of 250 tons CO₂ eq. for original design
 - 95.4% CO₂ eq compared to as-built two-lift
- A 30%-70% cement/fly ash mixture is also used in bottom lift
 - 138.4 tons CO₂ eq. instead of 250 tons CO₂ eq. for original design
 - 55.4% CO₂ eq. compared to as-built two-lift

GHG Summary



What Lies Ahead?

- 👤 Add use and end of life phases
 - Already possible in detailed process LCA
 - Consider longevity, reduced fuel consumption, urban heat island effect
- 👤 For example, the environment costs and benefits of using TX Active photocatalytic cement could be calculated
 - High reflectivity and treatment of pollution

Summary

- 👤 Increasingly the consideration of environmental factors will be required for pavement design
- 👤 LCA approaches offer a scientifically-based method to assess many factors
- 👤 Two-lift paving provides tremendous opportunities to lower the environmental footprint of concrete pavements over the life cycle

Questions?