Methods, Impacts, and Opportunities in the Concrete Pavement Life Cycle

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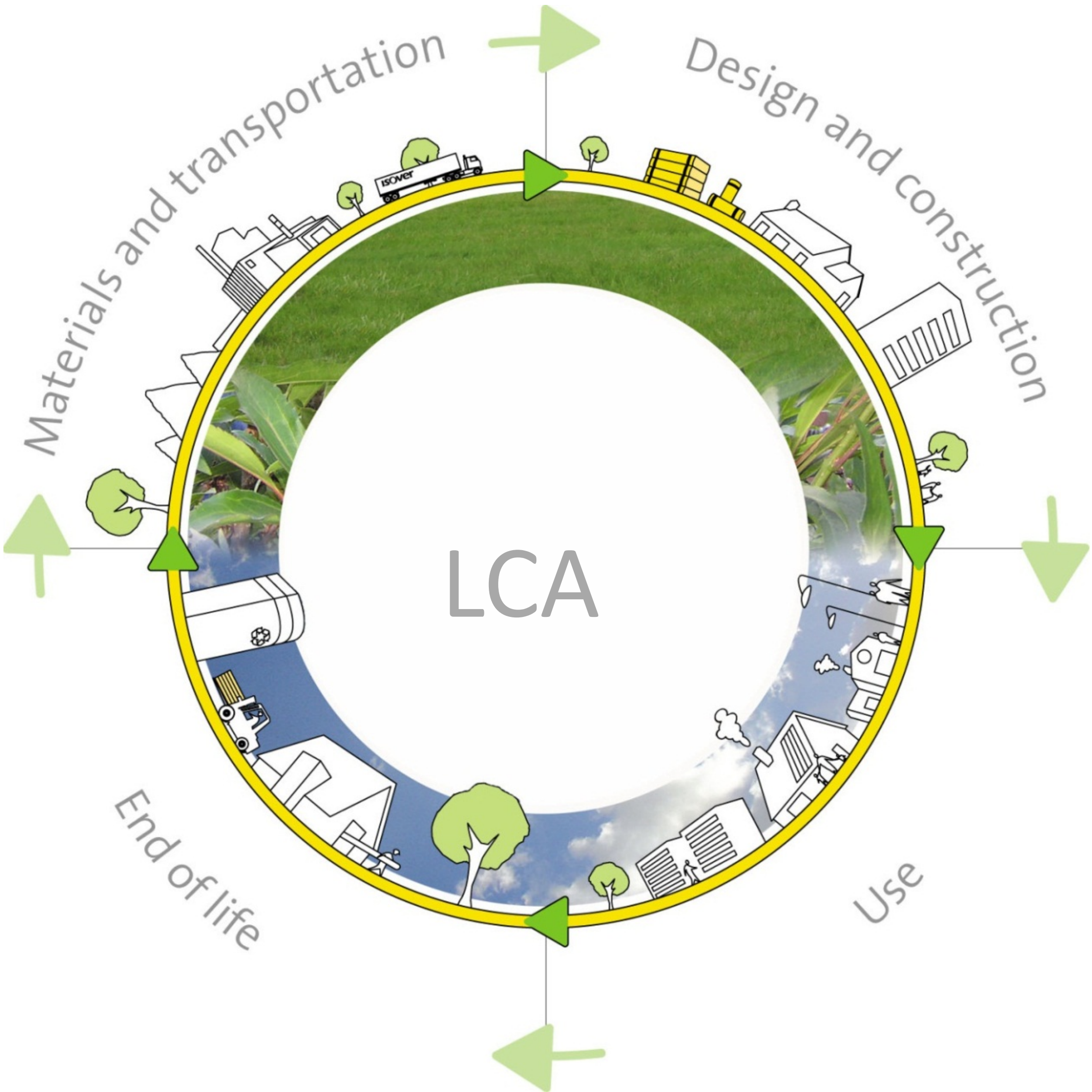
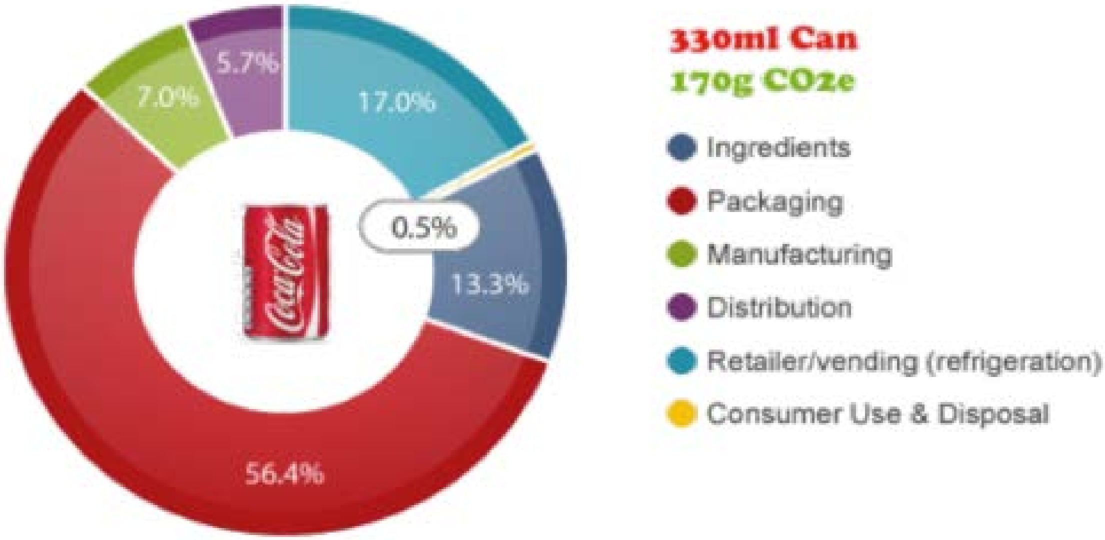
Life Cycle Assessment

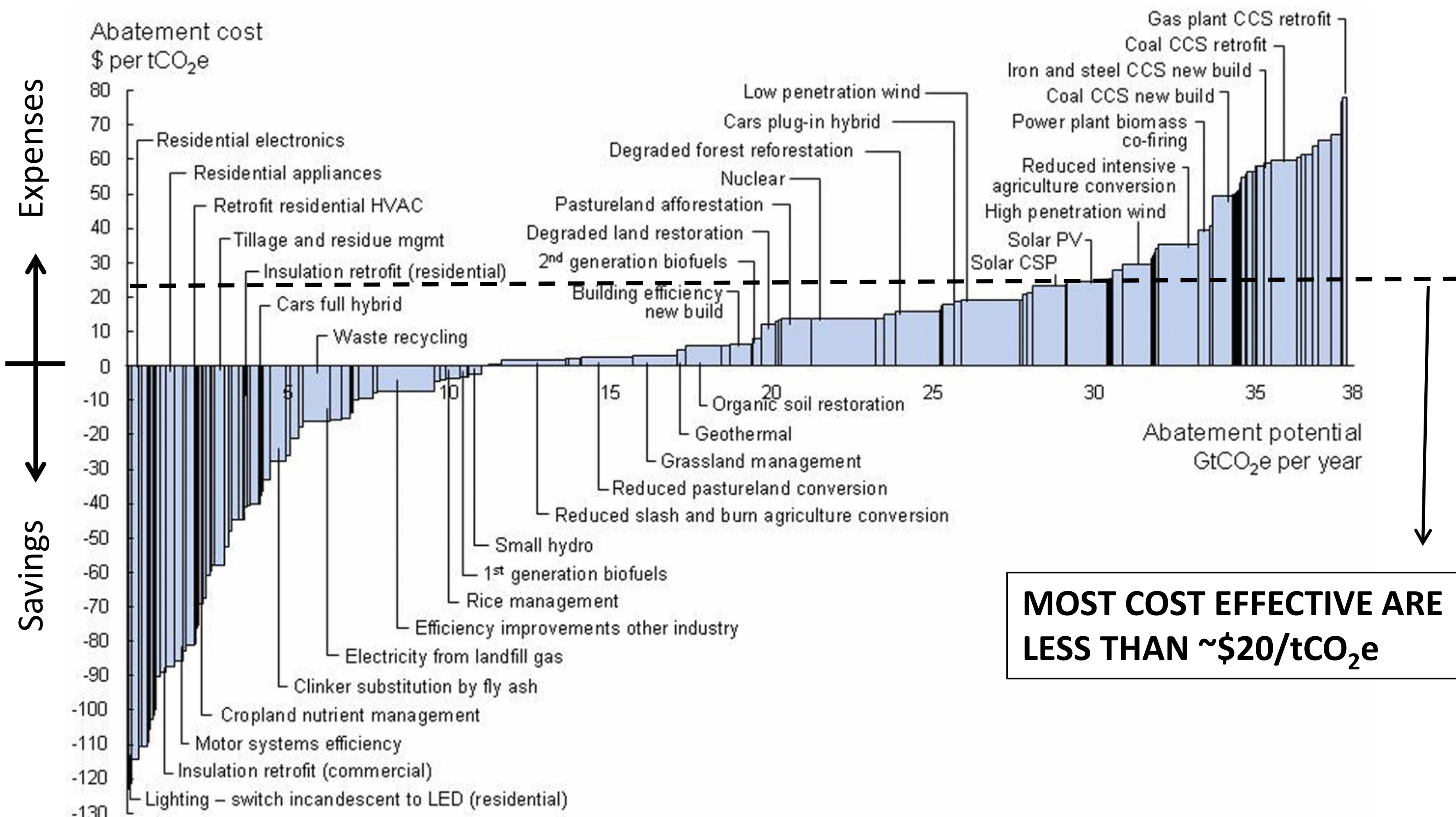


Why LCA?

- LCA quantifies environmental impacts
- Gives direction on areas for reductions
- Essential for future



Need for Life Cycle Cost Analysis (LCCA)



MOST COST EFFECTIVE ARE LESS THAN ~$20/tCO_2e$

Source: McKinsey Consulting (2009)

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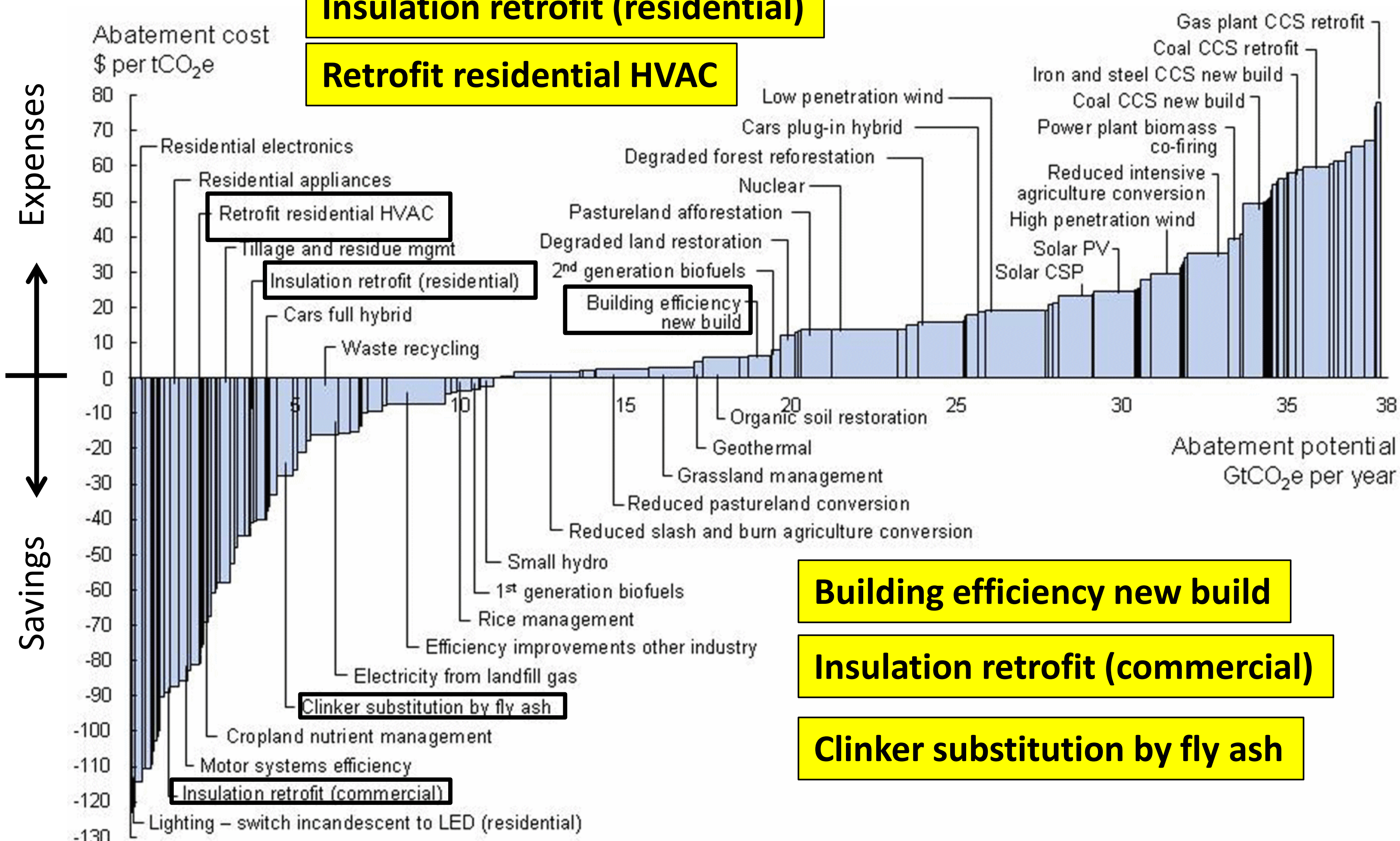


Insulation retrofit (residential)

Retrofit residential HVAC

Building efficiency new build

Insulation retrofit (commercial)

Clinker substitution by fly ash

Source: McKinsey Consulting (2009)

Broad goals of MIT LCA Research

- Develop comprehensive methodology for LCA of buildings and pavements
- Determine the carbon emissions (CO_2e) for a range of concrete structures
- Identify cost-effective opportunities for carbon reductions

Outline

1. Introduction
2. GHG emissions from concrete pavements
3. Summary of findings and future work

1. Introduction

The U.S. Pavement System

Expansive

8 million lane-miles in place in the United States

Resource Intensive

Requires 350 million tons of materials annually

Vital Infrastructure

Supports over 3 trillion vehicle-miles annually

Review of Pavement LCA Tools

	Materials		Construction		Use				Maintenance				End-of-Life				
Tool	Extraction and production	Transportation	Onsite equipment	Traffic delay	Carbonation	Lighting	Albedo	PVI	Extraction and production	Transportation	Onsite equipment	Traffic delay	Onsite equipment	Transportation	Landfilling	Recycling processes	Carbonation
asPECT	•	•	•						•	•	•		•	•	•	•	
BenReMod	•	•															
CHANGER	•	•	•						•	•	•		•	•			
GreenDOT	•	•	•						•	•	•		•	•			
PaLATE	•	•	•						•	•	•		•	•	•	•	
PE-2	•	•	•	•					•	•	•	•	•	•	•		

Research Goals

1. Develop a comprehensive methodology that puts forth good-practice concepts for conducting a pavement LCA;

2. Use the developed methodology to quantify GHG emissions for concrete pavements;

3. Identify strategic opportunities for reducing emissions, and calculate the cost effectiveness of the reduction strategies.

Improving Pavement LCA Methodology

- Demonstrate good-practice
  - Transparency
  - Comprehensiveness
  - Realistic goals
- Move towards standardization
  - Equitably compare pavement improvements and alternatives
  - Need input from all stakeholders
  - Current research designed to influence standardization efforts
- Promote transparency
  - Reproducible research
  - Allows others to build upon research

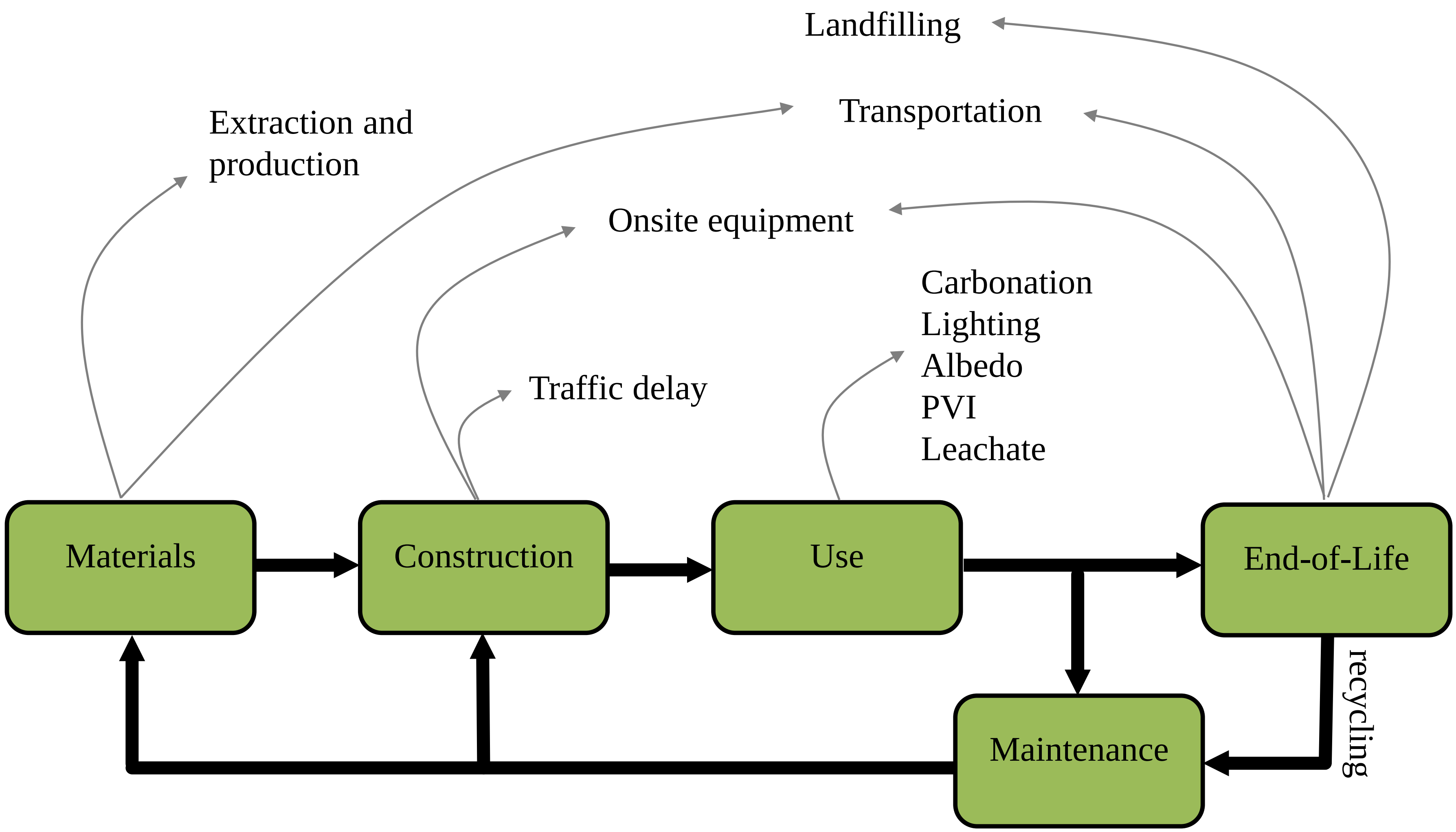
Basic Transparency Requirements

LCA + LCCA
- Goals
- Functional unit
- Analysis period
- Structural designs
- M&R schedule

LCA
- LCA system boundaries
- LCI environmental factors
- LCIA methodology

LCCA
- LCCA system boundaries
- Discount rate
- Costs

Using Comprehensive System Boundaries

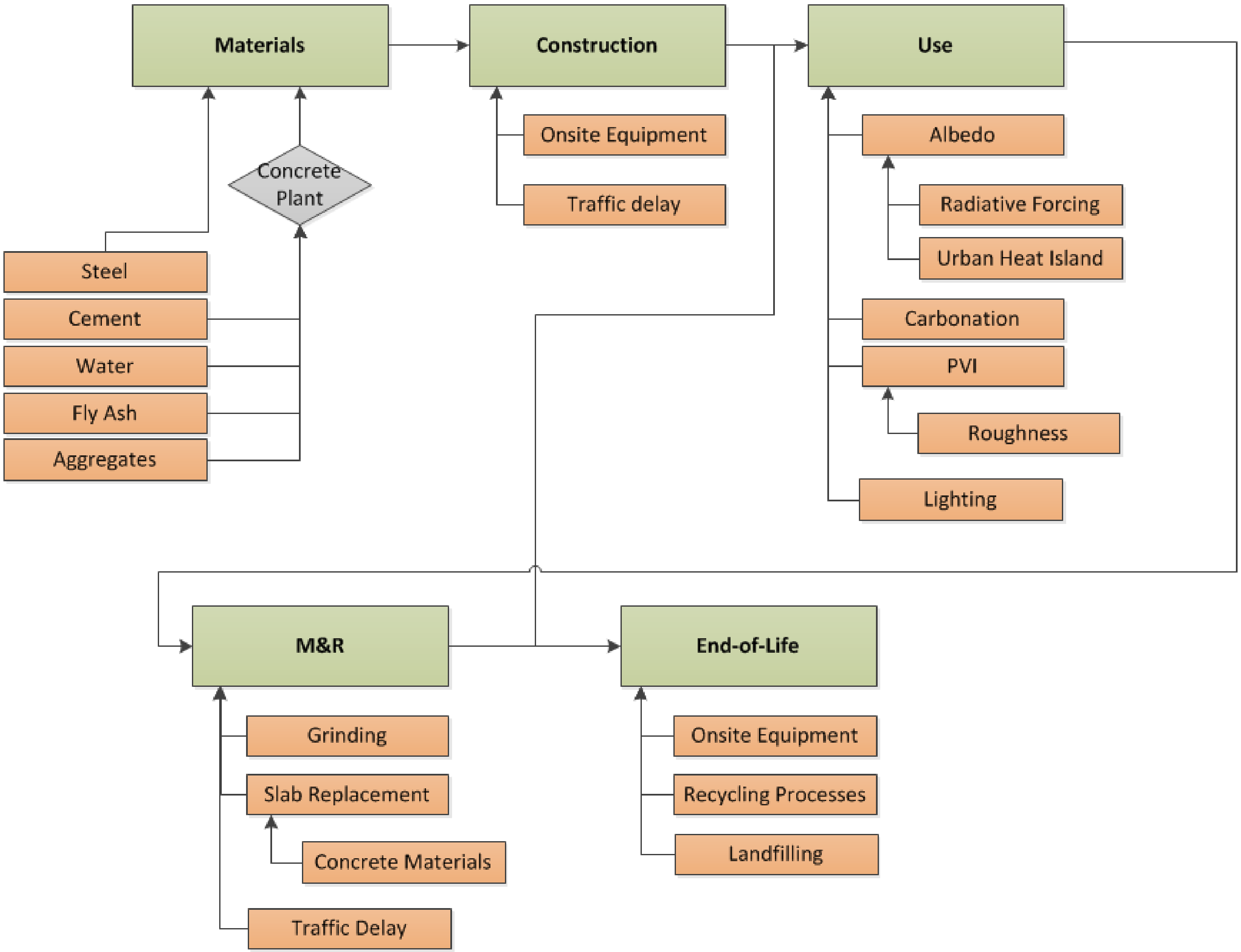


2. GHG Emissions from Concrete Pavements

Concrete Pavement LCA Objectives

- Develop and apply a comprehensive pavement LCA methodology for concrete pavements;
- Quantify life-cycle GHG emissions using global warming potential, GWP)
  - Each FHWA roadway classification
  - All relevant life-cycle phases;
- Identify and quantify opportunities for GHG reduction
- Estimate the cost-effectiveness of the reduction opportunities using LCCA principles.

Simplified Flow Chart of the MIT Concrete Pavement LCA Model



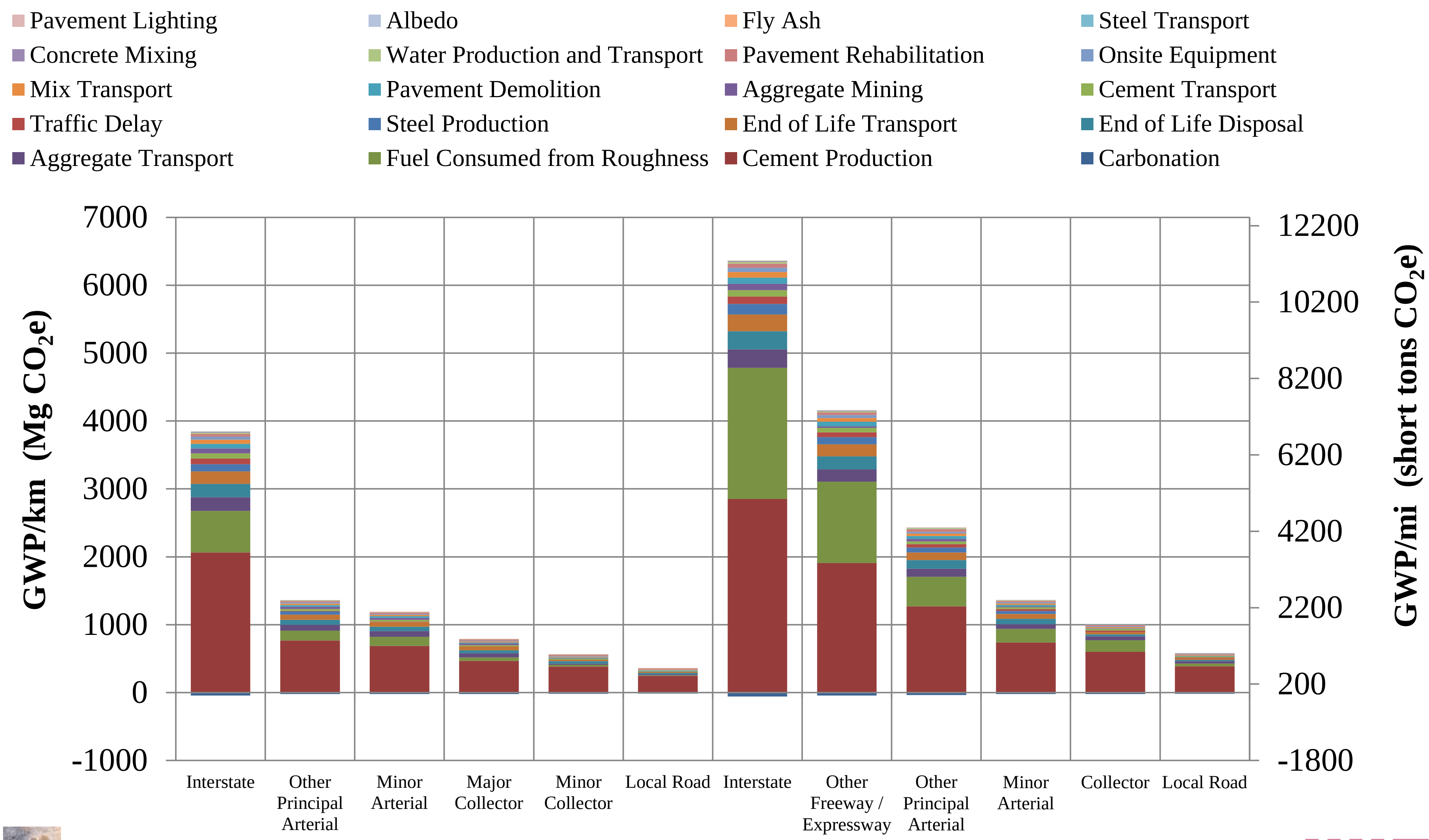
Functional Units

- Examine "average" structure for 12 FHWA roadway classifications
  - 6 urban, 6 rural
  - Does not capture atypical structures (e.g., very high volume)
- Used AASHTO design methods
  - Tested sensitivity to more advanced design methods (i.e., MEDPG)

	Rural						Urban					
	Interstate	Principal Arterial	Minor Arterial	Major Collector	Minor Collector	Local	Interstate	Freeway	Principal Arterial	Minor Arterial	Collector	Local
AADT	22,000	6,400	3,100	1,200	570	180	79,000	54,000	20,000	9,700	4,200	980
Lanes	4	2	2	2	2	2	6	4	4	2	2	2
Concrete (mm)	292	203	191	152	129	102	305	279	216	178	165	127

LCA Results

Absolute GWP per centerline-kilometer and centerline-mile



GHG Reduction Opportunities

Categories and Scenarios

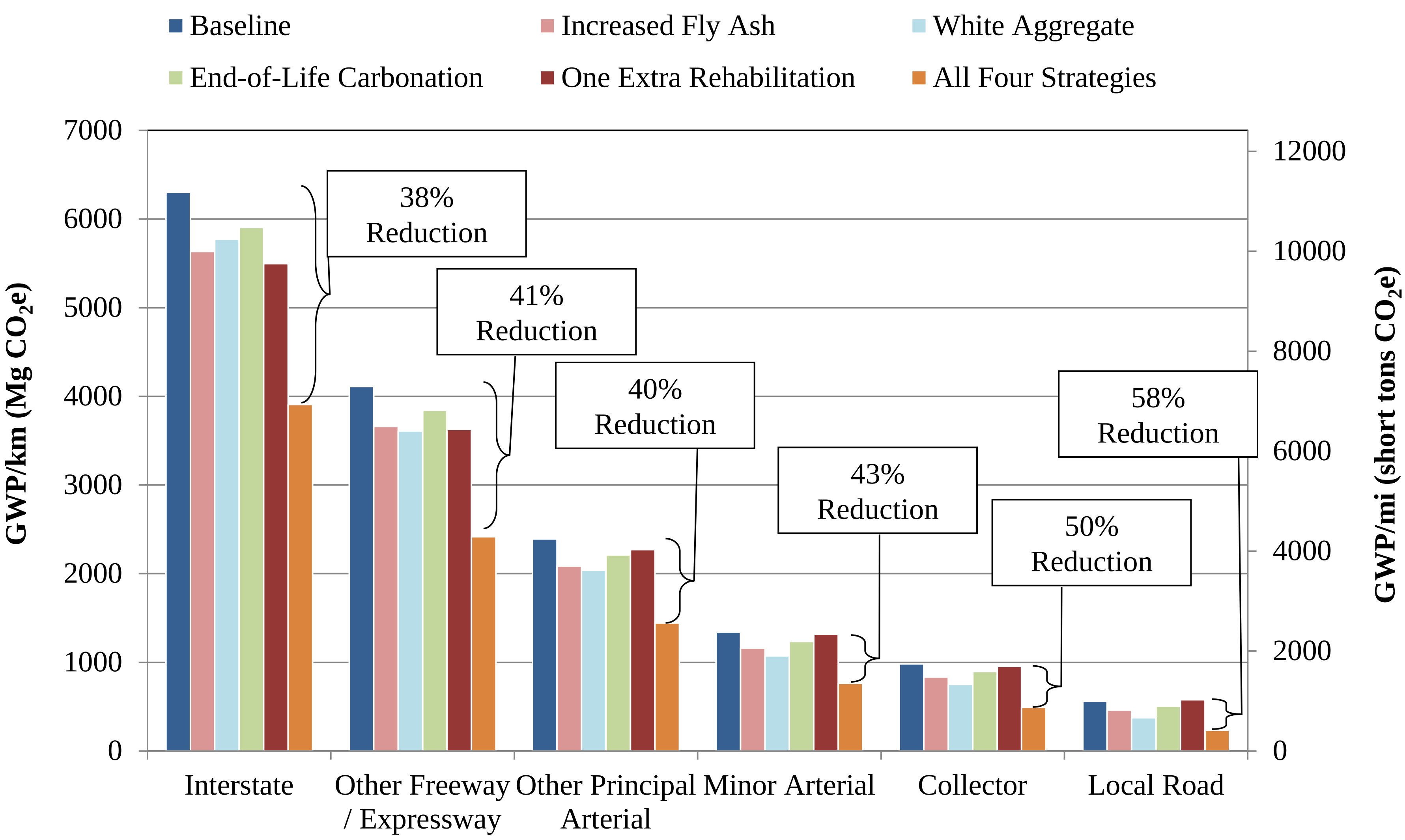
- A strength of LCA is identifying and comparing reduction opportunities
  - Where are the low-hanging fruit for emission reductions?
  - How can transportation agencies and industry achieve emission reduction targets?

- Different categories of emission reduction strategies are evaluated
  - Many different methods of reducing emissions exist
  - Quantitatively exploring a subset of possible solutions
  - Qualitatively discuss other options in the report

- Categories (scenarios) evaluated
  1. Embodied emissions (fly ash replacement, MEPDG case study)
  2. Albedo (white aggregate)
  3. Carbonation (EOL crushing and exposing)
  4. Rolling resistance (additional grinding)

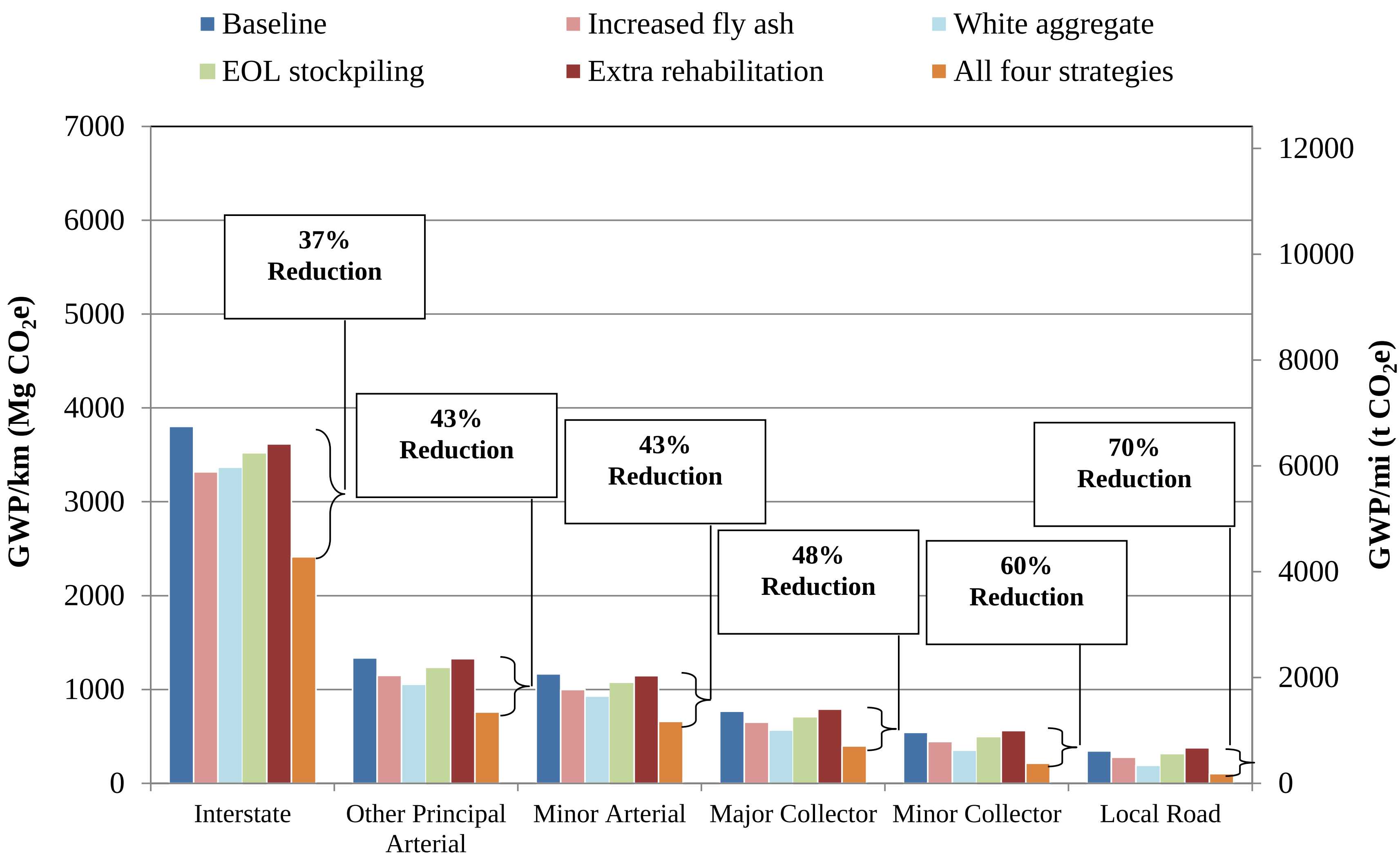
GHG Reduction Opportunities

Example: Urban Roadways



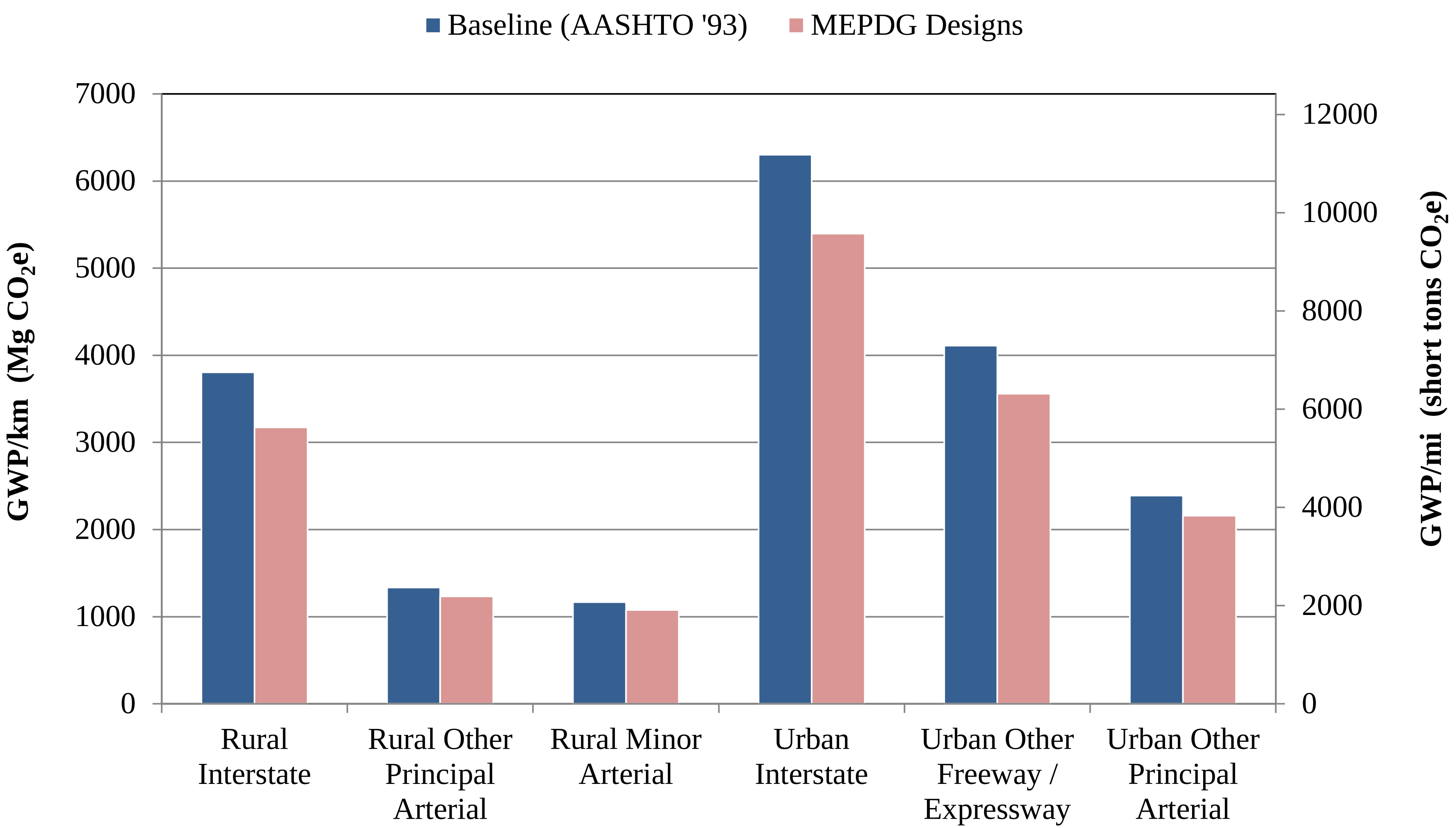
GHG Reduction Opportunities

Example: Rural Roadways



GHG Reduction Opportunities

MEPDG case study in Oxnard, CA



Cost-Effectiveness Analysis

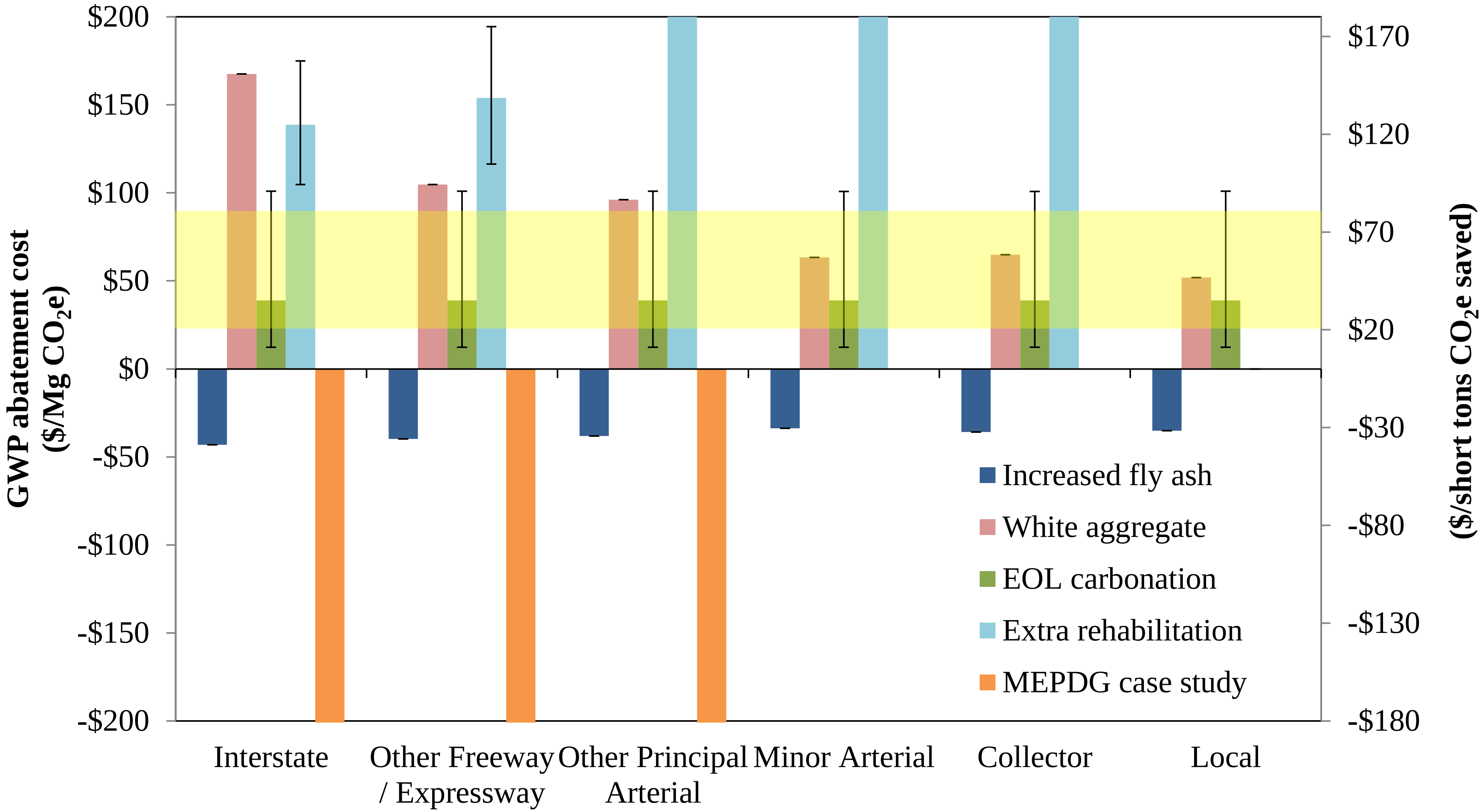
Approach

$$CE_{alt} = \frac{cost_{alt} - cost_{base}}{emmissions_{alt} - emissions_{base}} = \frac{\Delta costs_{alt-base}}{\Delta emissions_{alt-base}}$$

- Evaluate costs of GHG reduction strategies
  - Builds upon LCA research
  - Provides insight into feasibility of reduction strategies
- Price of carbon
  - Fluctuates with market
  - Roughly valued at ~$20/Mg CO_2
  - Large range: $5 – $65 (or higher)
  - 2012 carbon tax in Australia: $25/Mg CO_2
- How does the economic analysis change the approach to reducing emissions?
  - Dismiss (or modify) strategies that are not cost effective
  - Different strategies for different functional classifications

Cost-Effectiveness Analysis

Example results for urban roadways, with discounting



Key Findings: Concrete Pavement LCA

1. Quantified emissions for typical concrete structures across different classifications using a comprehensive LCA approach
   – All FHWA roadway classifications, from urban interstates to rural local roads
   – Identified sources of emissions in the life cycle
   – Materials phase is dominant, especially for low-volume roads
   – Cement is the highest emission source for every roadway classification

Key Findings: Concrete Pavement LCA

2. Potential for significant GWP reductions
   - Reductions over 50% possible
   - Many other opportunities exist and should be evaluated, for example:
     - Slag
     - Two-lift pavements
     - Increase processing efficiency/reduced emissions

Key Findings: Concrete Pavement LCA

3. Many strategies are (or can be) cost effective
   - Reducing natural resources lowers emissions and costs
   - Reduced overdesign (through MEPDG) and increased use of SCMs are most cost-effective
   - Other strategies are competitive with carbon prices, but need to be evaluated on a project scale.
   - Framework is established – needs to be expanded to additional strategies

3. Summary

Contributions and Findings

- **Methodology**
  - Identified and described key transparency requirements for pavement LCA and LCCA
  - Established comprehensive system boundaries

- **Concrete Pavement LCA**
  - Quantified GHG emissions for a range of FHWA roadway classifications
  - Identified and quantified GHG emission reduction strategies
  - Evaluated cost effectiveness of these strategies through LCCA
  - Established an LCA and cost effectiveness process for others to follow

Recommended Future Work

- **LCA Modeling**
  - Complement the presented results by including asphalt and composite pavements
  - Consider more detailed representative structures for the U.S. pavement network
  - Consider multiple impact categories
  - Consider other reduction strategies

Thank You

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