Use-phase and the Life-Cycle

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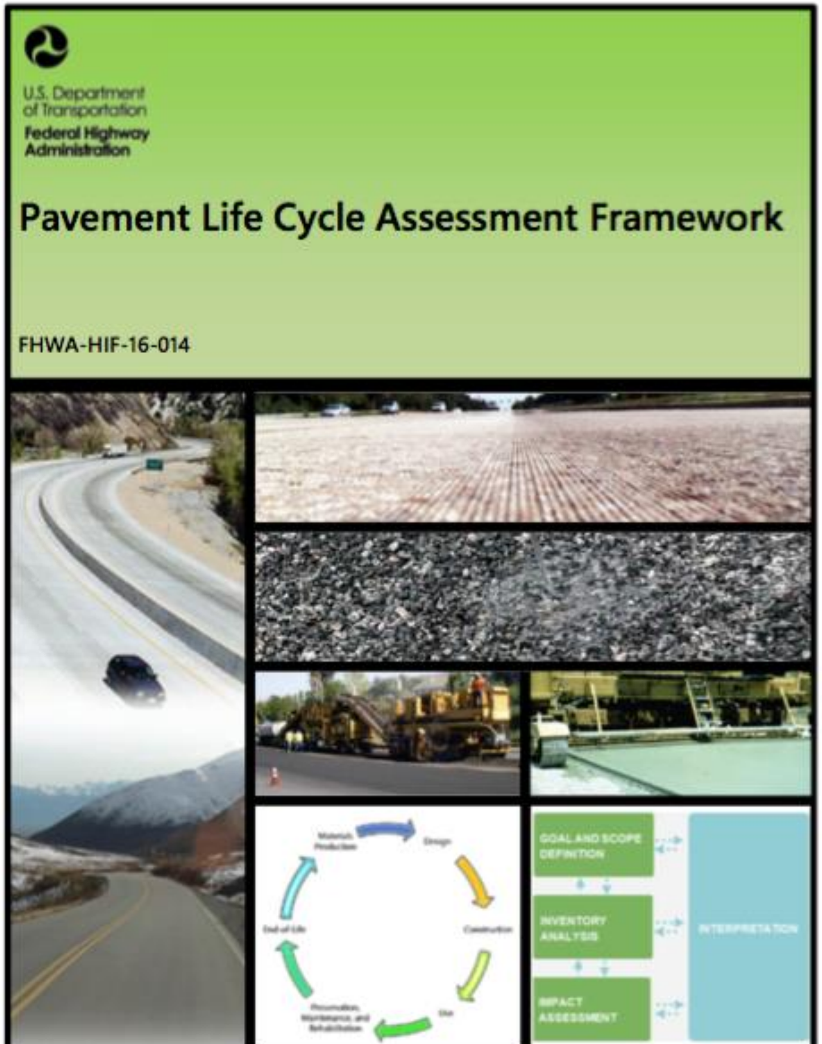
Sustainable Pavements Workshop
March 22, 2017

Pavement Life Cycle Assessment Framework



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16. Abstract

Awareness of the importance of environmental protection, and the possible impacts associated with the production, use, and retirement of products, has generated considerable interest in the use of assessment methods to better understand and address those impacts. Life-cycle assessment (LCA) is one of the techniques developed for this purpose. LCA is a structured evaluation methodology that quantifies environmental impacts over the full life cycle of a product or system, including impacts that occur throughout the supply chain. LCA provides a comprehensive approach for evaluating the total environmental burden of a product by examining all the inputs and outputs over the life cycle, from raw material production to the end-of-life (EOL). For pavements, this cycle includes the material production, design, construction, use, maintenance and rehabilitation (M&R), and EOL stages.

LCA has a commonly accepted standard method (published by the International Organization for Standardization [ISO]), however, specifics within this method vary greatly from one application to another. Additionally, there are no widely accepted standards that focus on pavement-LCA. This pavement LCA framework document is an important first step in the implementation and adoption of LCA principles in the pavement community within the U.S. A framework for performing an LCA specific to pavement systems along with guidance on the overall approach, methodology, system boundaries, and current knowledge gaps are presented in this document.

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life-cycle assessment, sustainability, sustainable pavements, environment, society, economics, asphalt, concrete, materials, design, construction, use phase, maintenance, rehabilitation, recycling	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

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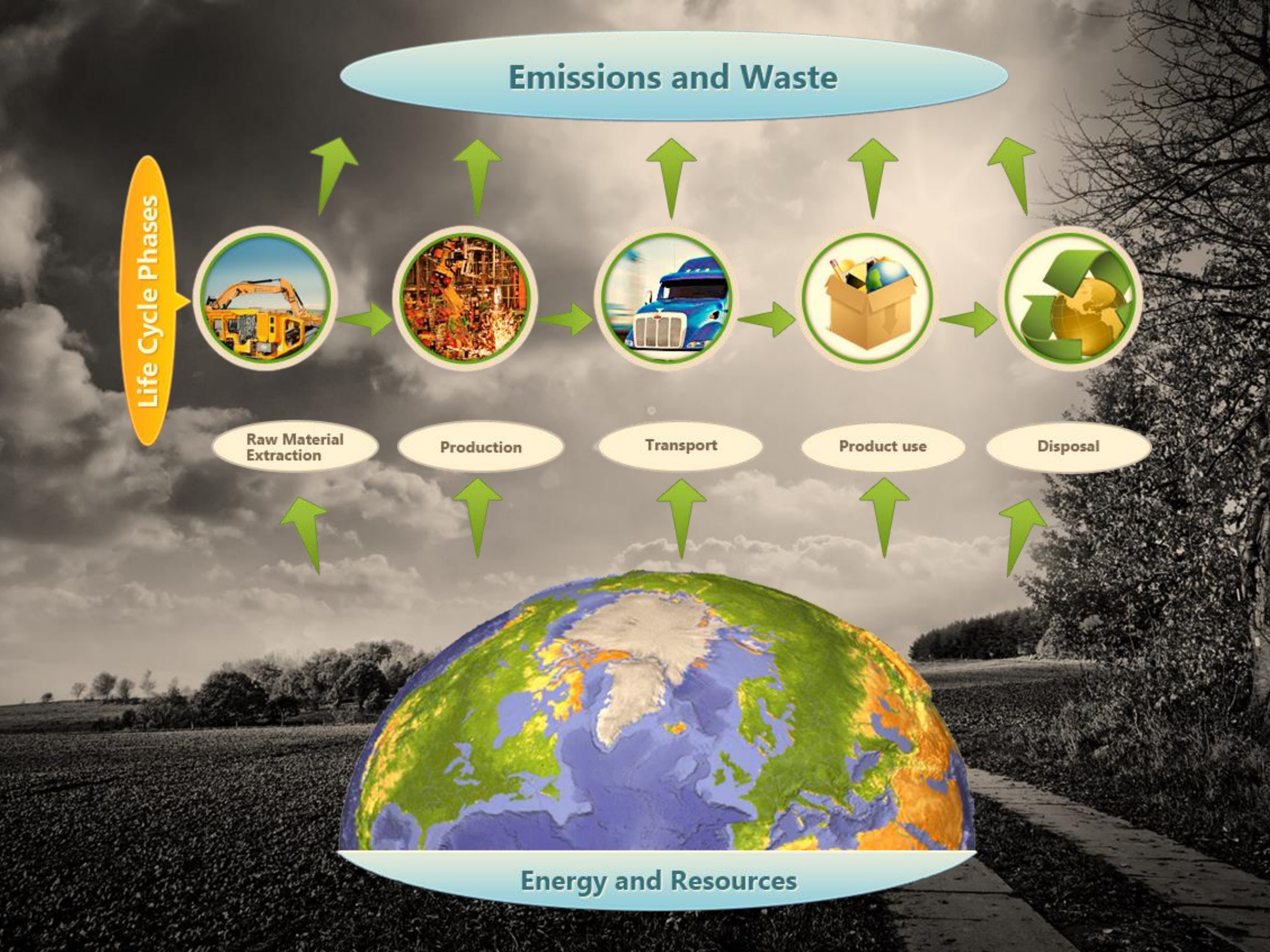
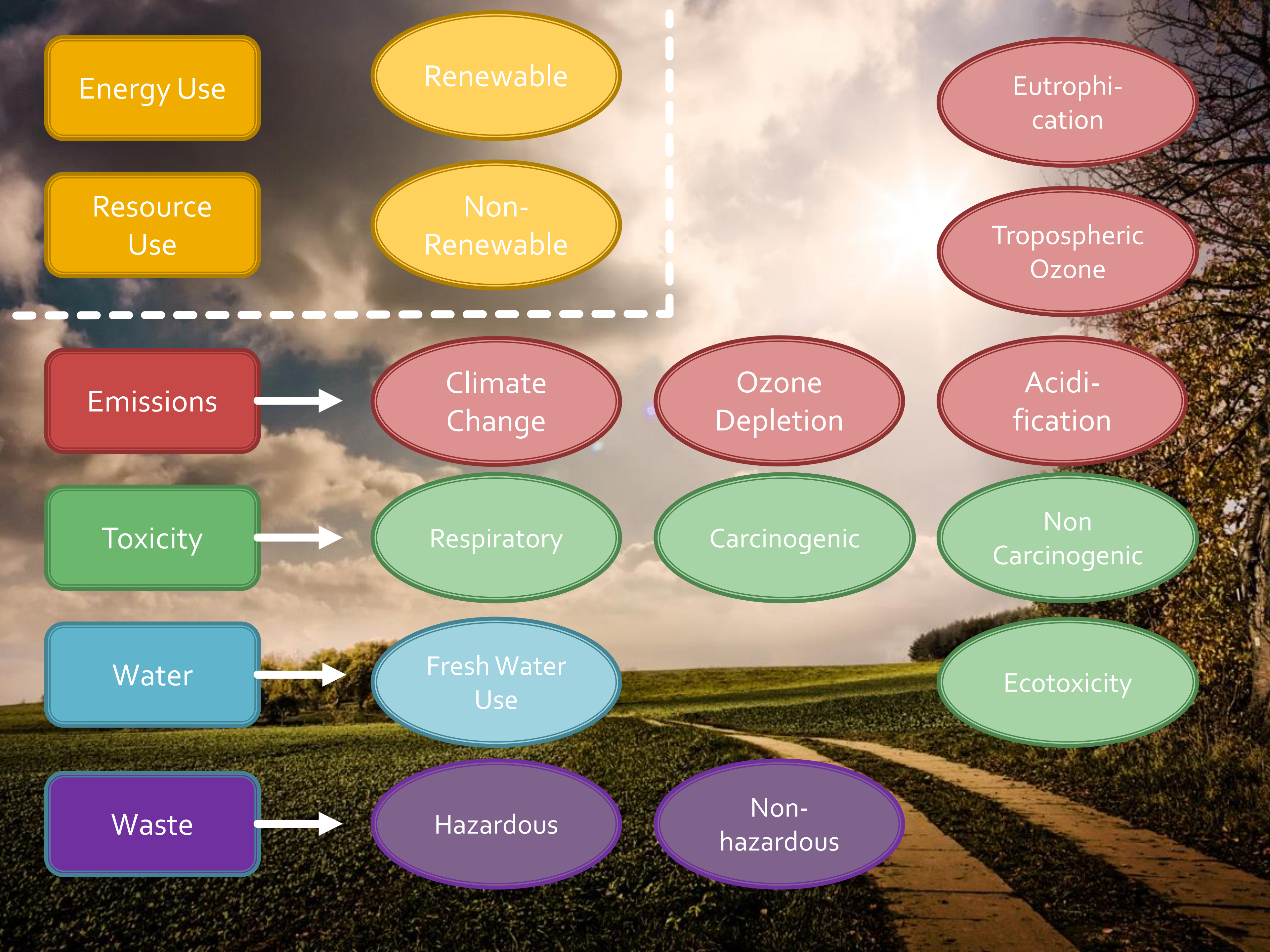
Life-cycle Assessment Purpose

- Identifying opportunities to improve the environmental performance of products and production systems
- Inform and guide decision makers as part of the strategic planning process
- Identify trade-offs in decision making across all life-cycle stages and multiple environmental and other indicators


Emissions and Waste
Life Cycle Phases
Raw Material Extraction
Production
Transport
Product use
Disposal
Energy and Resources



Energy Use
Renewable
Resource Use
Non-Renewable
Eutrophication
Tropospheric Ozone
Emissions
Climate Change
Ozone Depletion
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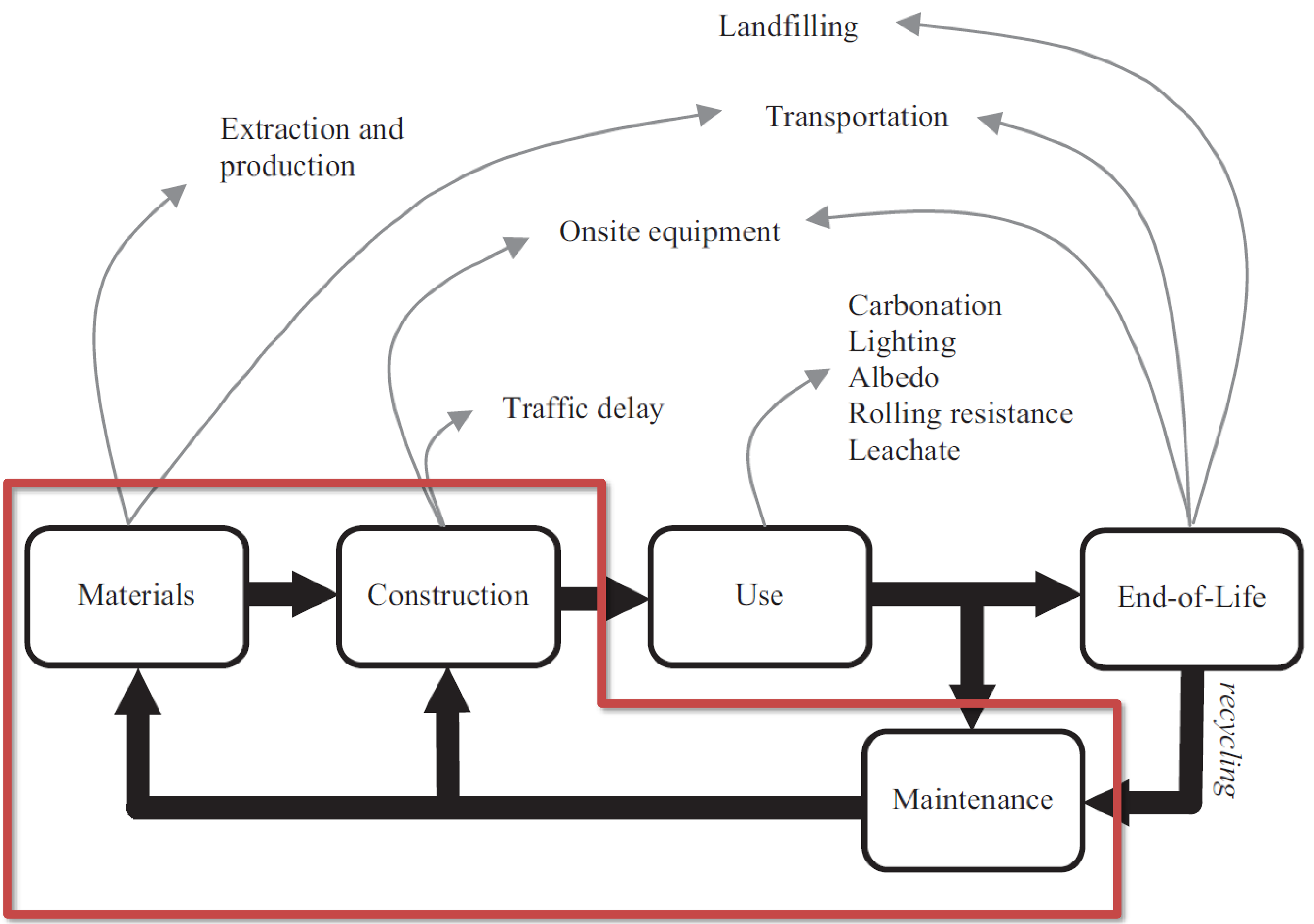
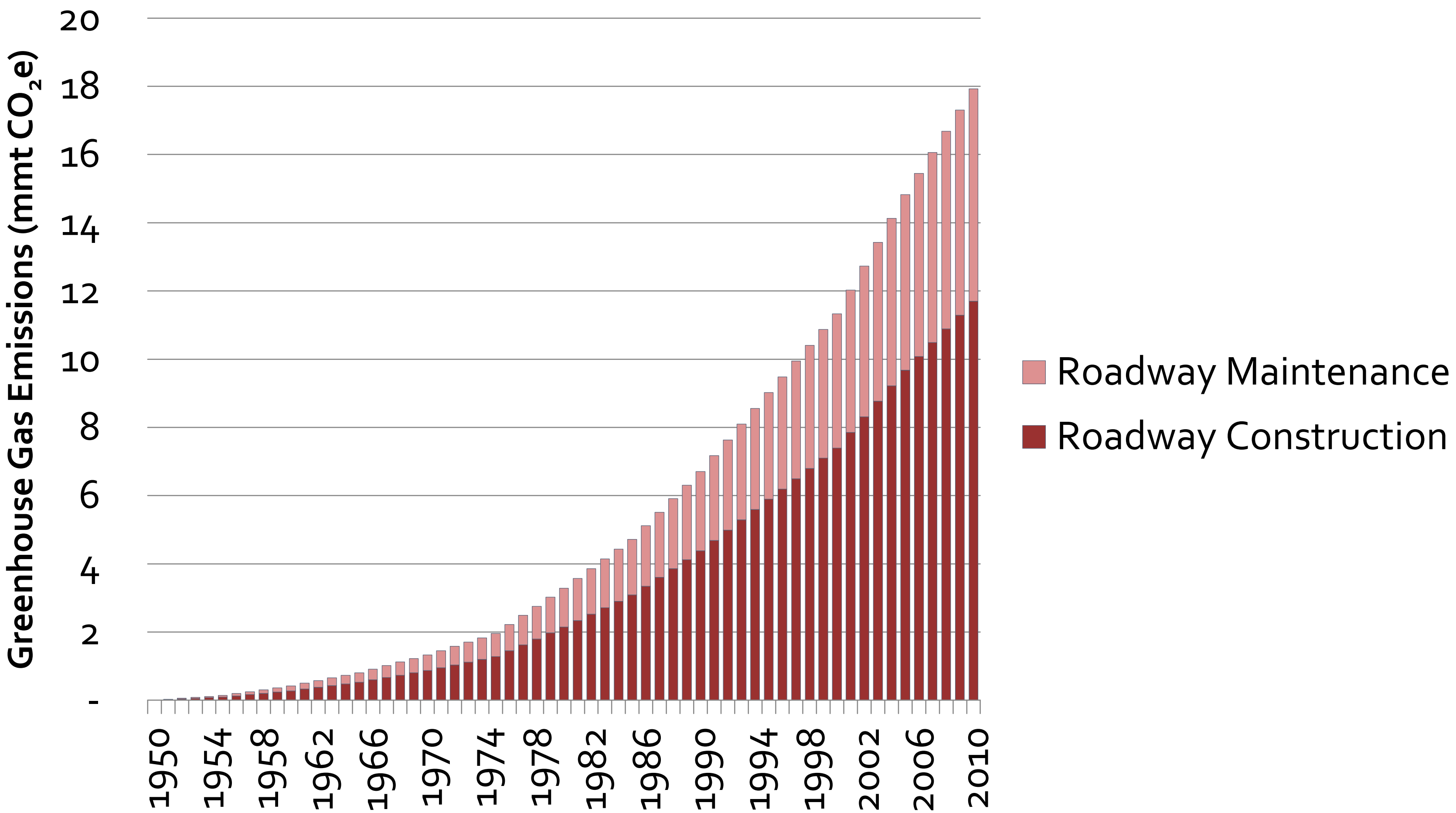
Toxicity
Respiratory
Carcinogenic
Non Carcinogenic
Water
Fresh Water Use
Ecotoxicity
Waste
Hazardous
Non-hazardous

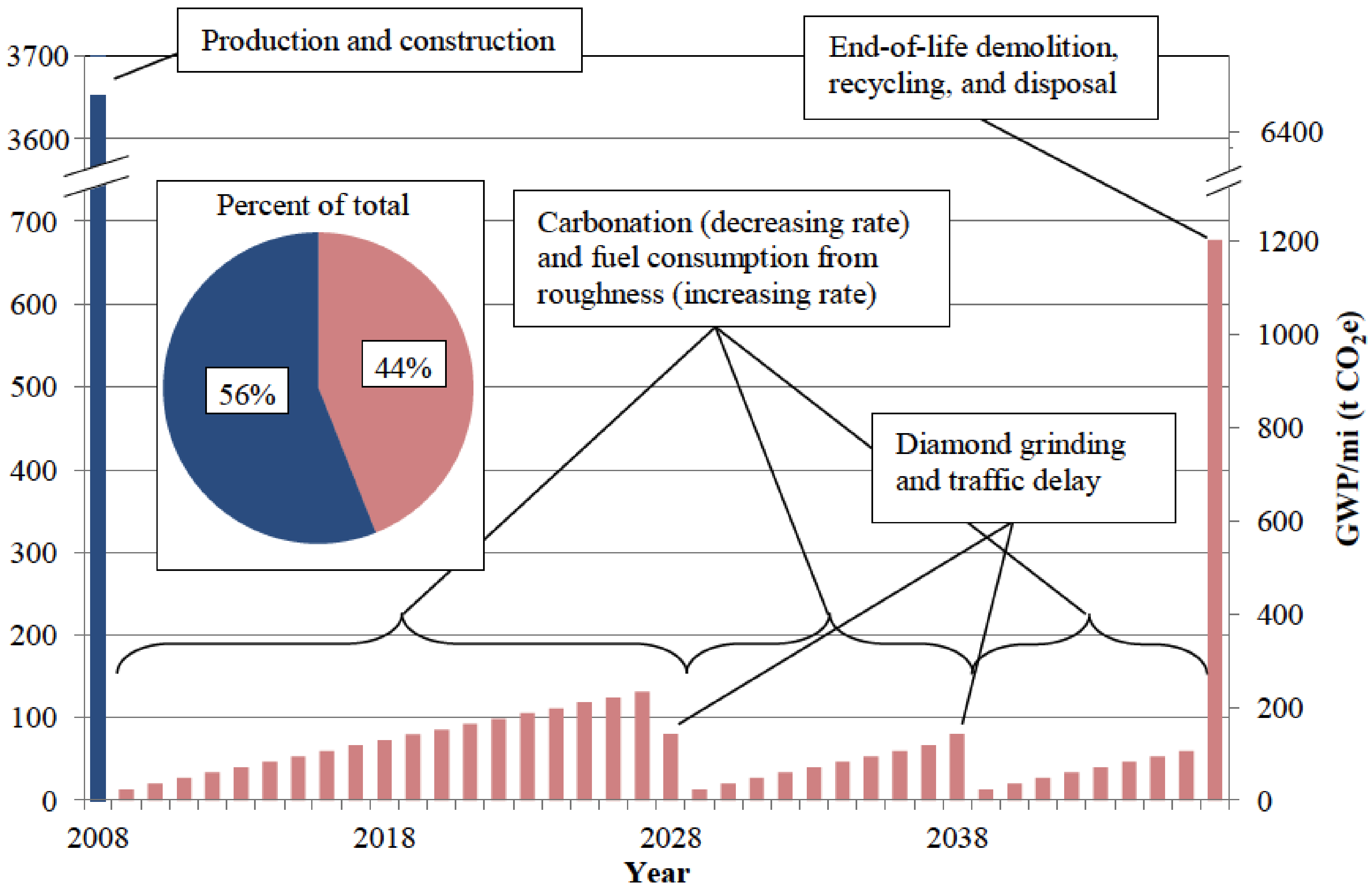


Landfilling
Transportation
Extraction and
production
Onsite equipment
Carbonation
Lighting
Albedo
Rolling resistance
Leachate
Traffic delay
Materials
Construction
Use
End-of-Life
Maintenance
recycling

Maricopa GHG Investment

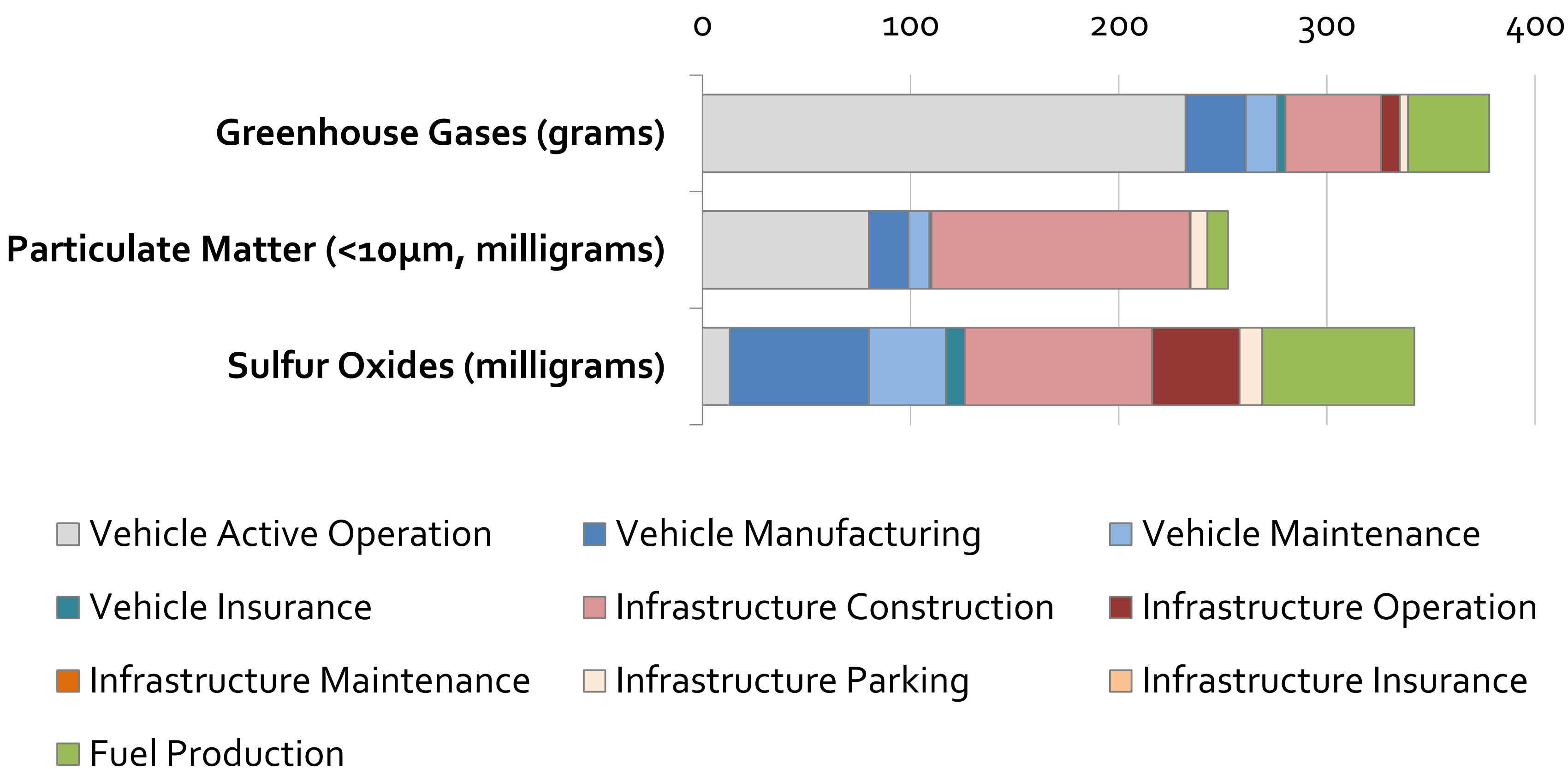


Life-cycle GHG Effects

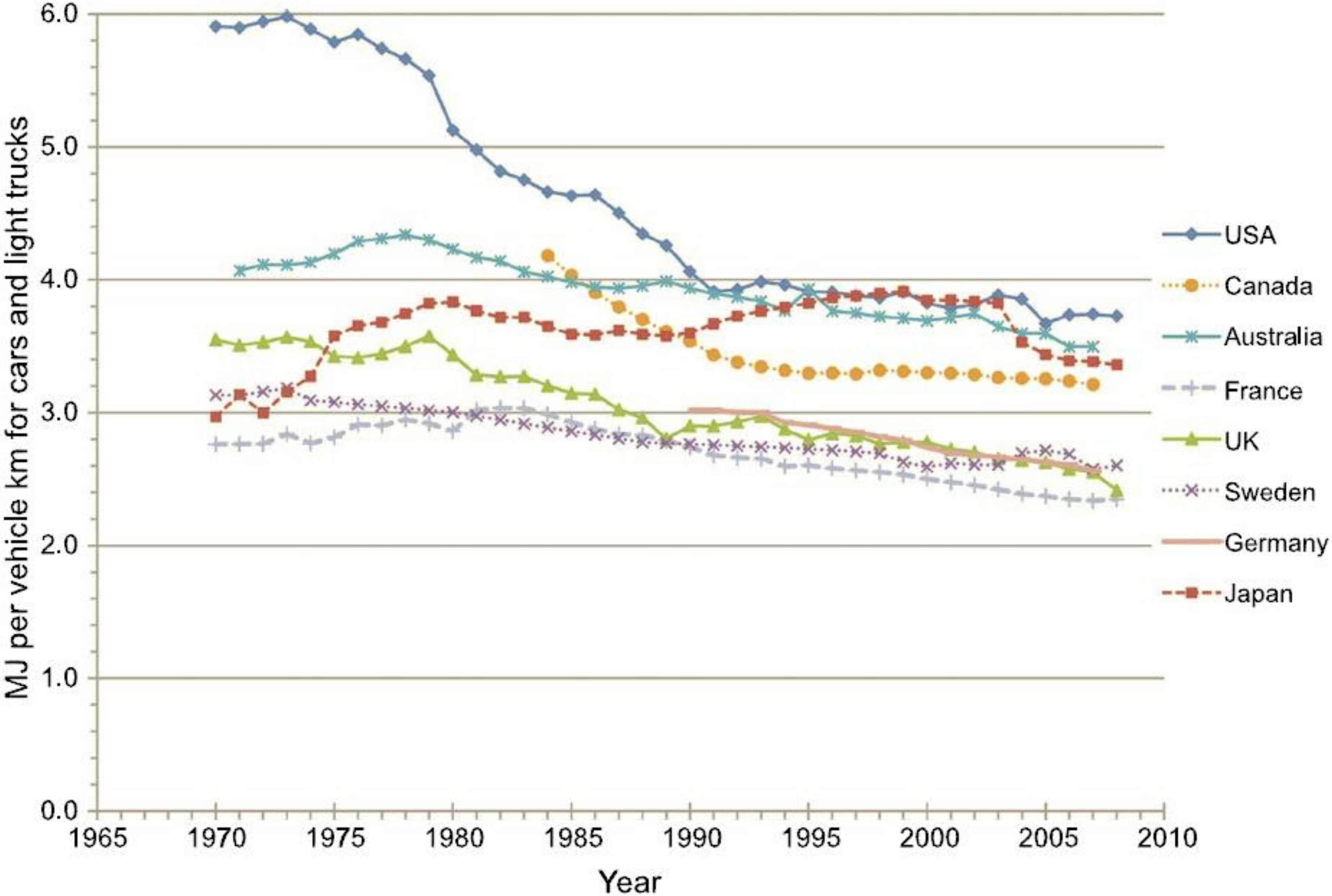


Roadway Impacts in the Auto Life-cycle

Automobile Life-cycle Emissions per Passenger Mile Traveled



Chester and Horvath, 2009, Environmental assessment of passenger transportation should include infrastructure and supply chains, Environmental Research Letters 4(2), doi:10.1088/1748-9326/4/2/024008



Millard-Ball and Schipper, 2010, Are We Reaching Peak Travel? Trends in Passenger Transport in Eight Industrialized Countries, Transport Reviews, doi:10.1080/01441647.2010.518291

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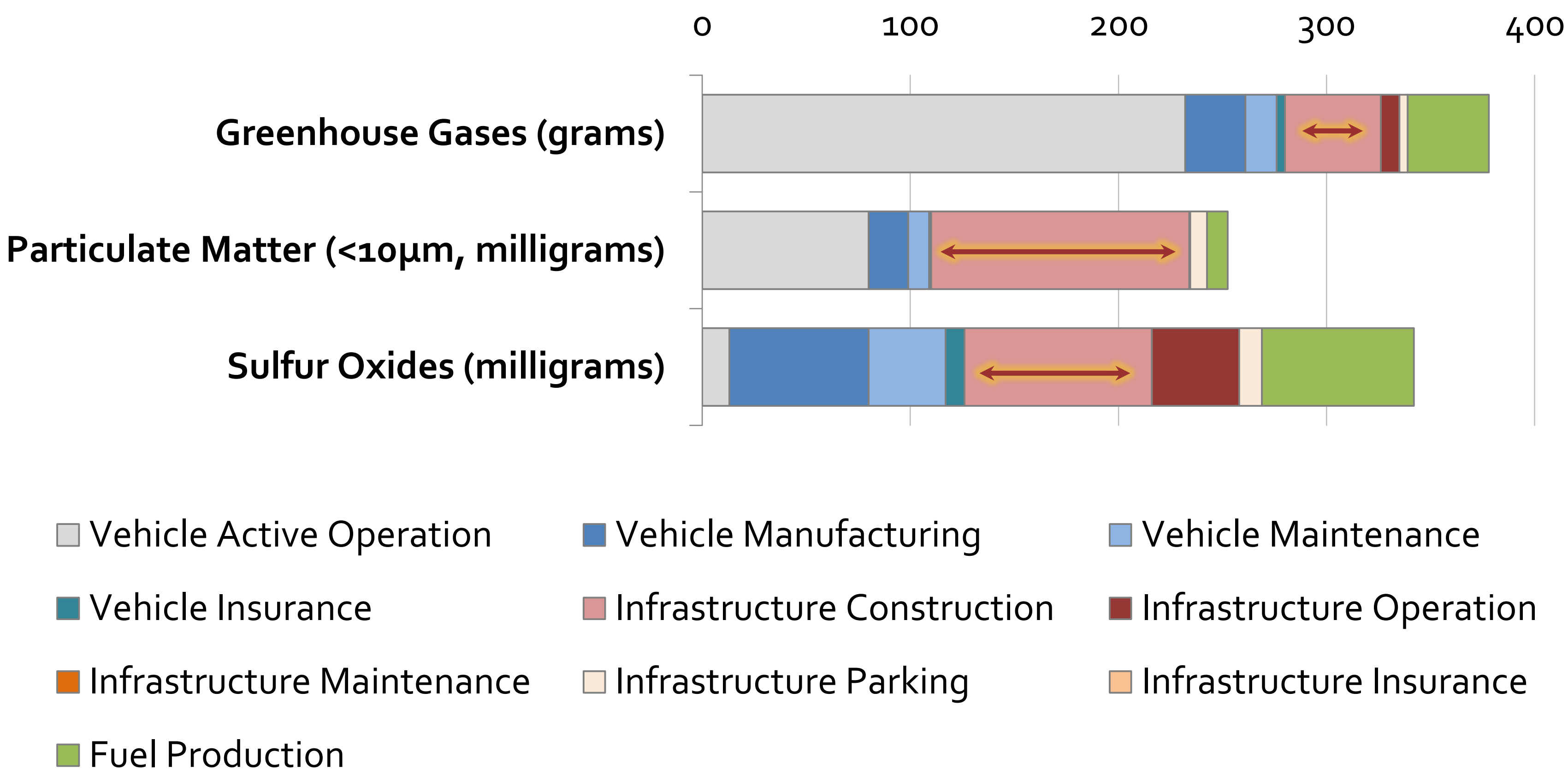

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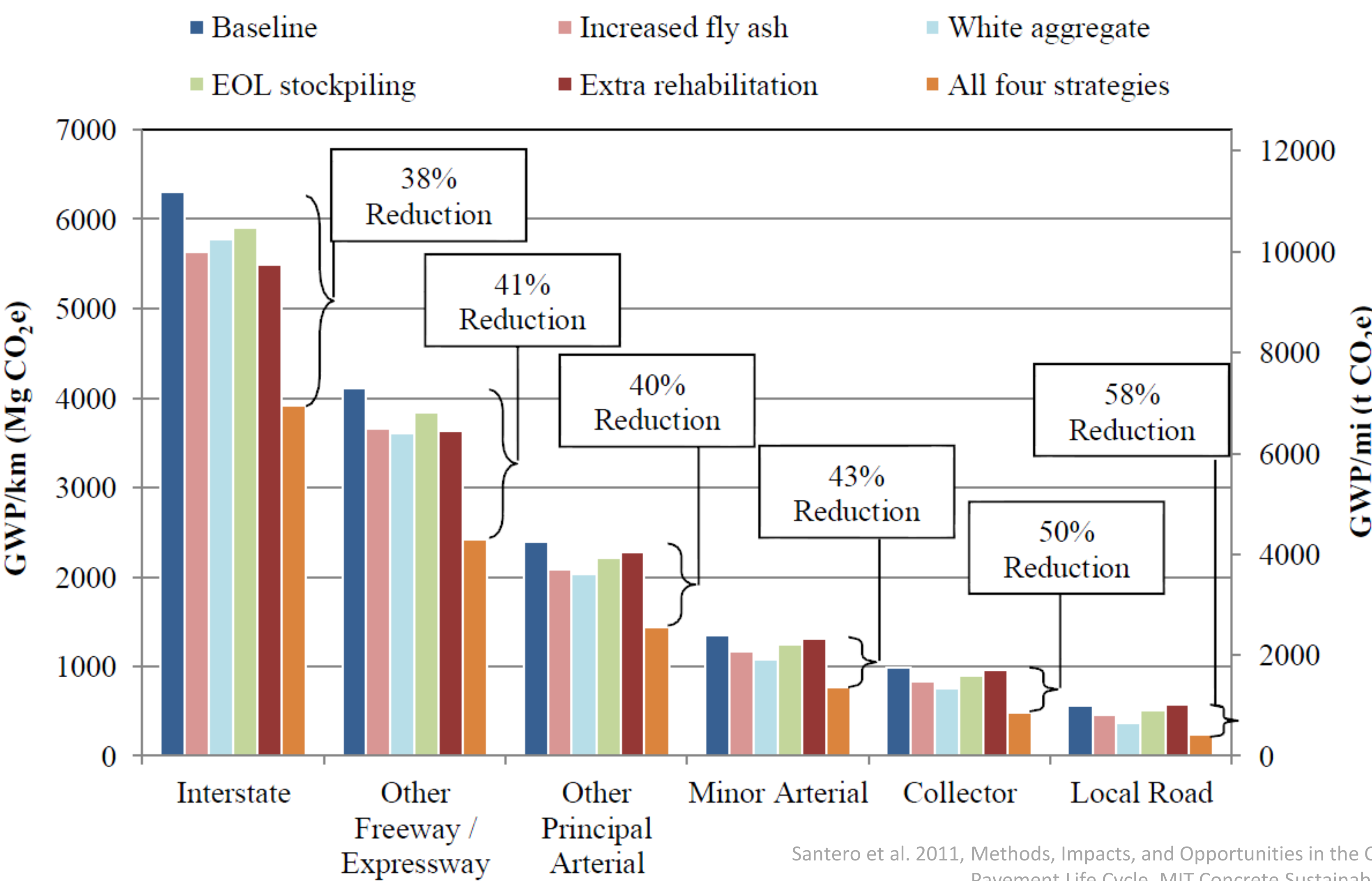
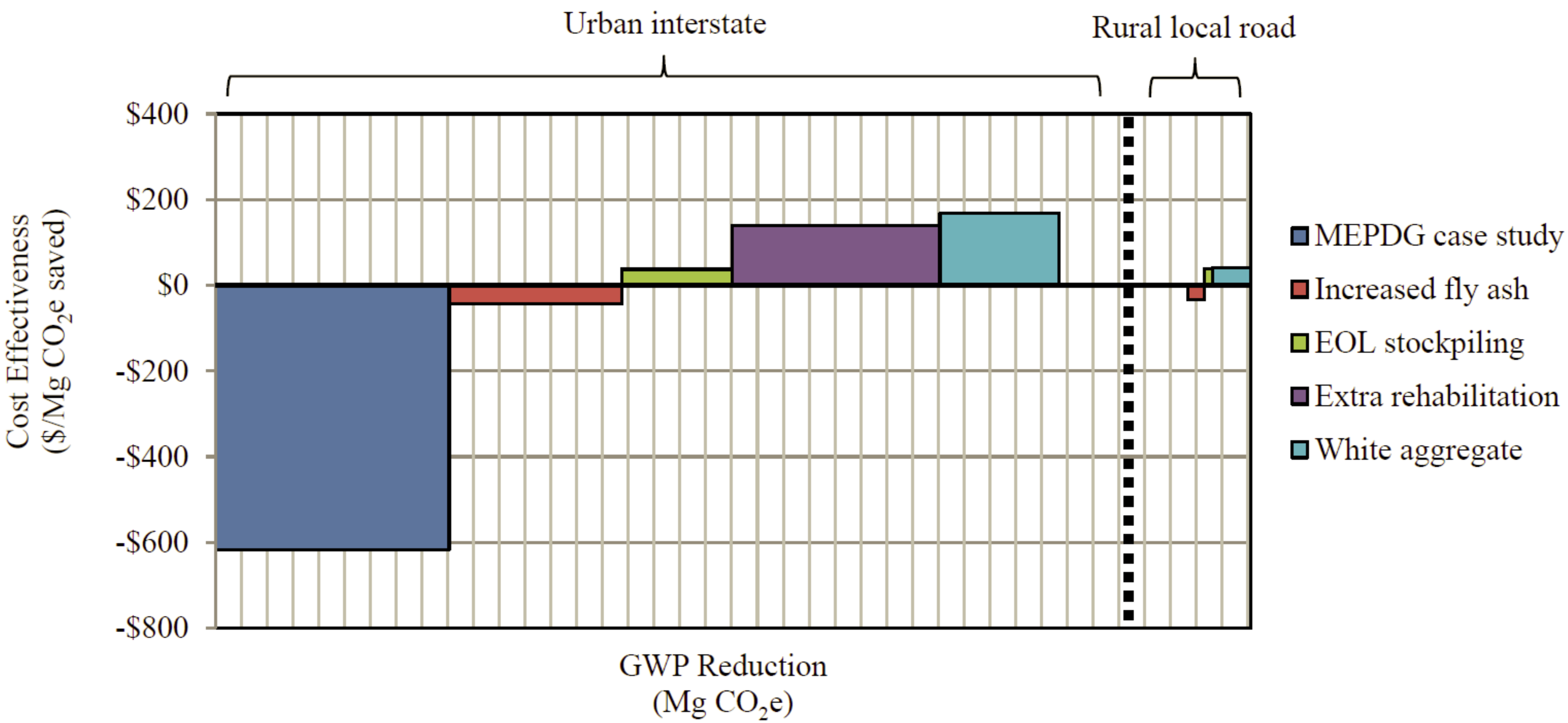
Reduction Opportunities



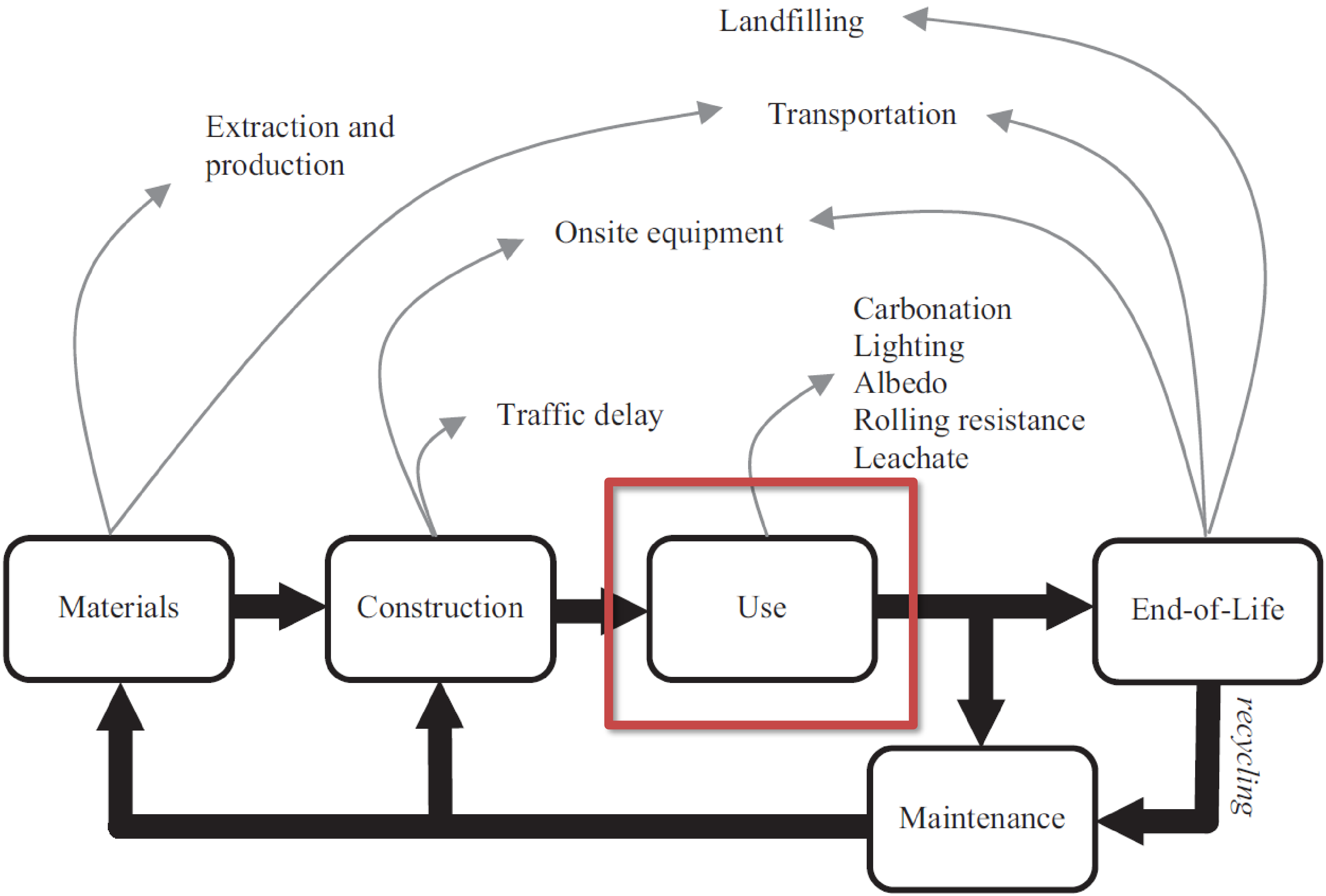
Santero et al. 2011, Methods, Impacts, and Opportunities in the Concrete Pavement Life Cycle, MIT Concrete Sustainability Hub

Cost of Conserved GHG Emissions



Mechanistic Empirical Pavement Design Guide (MEPDG) model. Advanced designs tools, such as MEPDG, can help to define when M&R trigger levels are reached.

Santero et al. 2011, Methods, Impacts, and Opportunities in the Concrete Pavement Life Cycle, MIT Concrete Sustainability Hub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Rolling resistance
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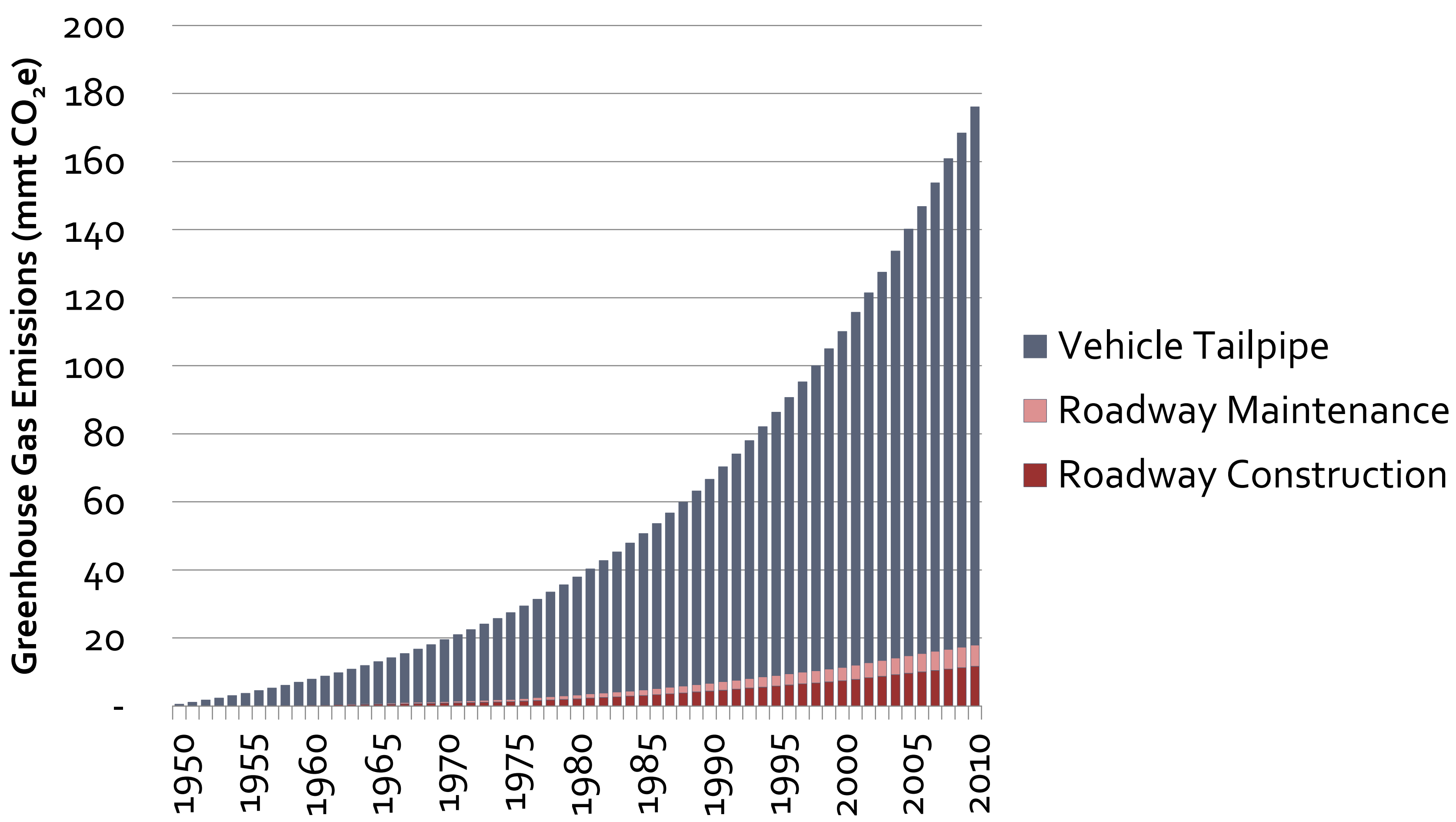
Traffic delay
Materials
Construction
Use
End-of-Life
Maintenance
recycling

Use Phase and Tailpipe Emissions



Use Phase and Tailpipe Emissions

- Vehicle emissions resulting from the use of the infrastructure are potentially an order(s) of magnitude greater than the cumulative construction and maintenance emissions burden
- A portion of these emissions can be attributed to pavement attributes and construction and maintenance activities

Use Phase and Tailpipe Emissions

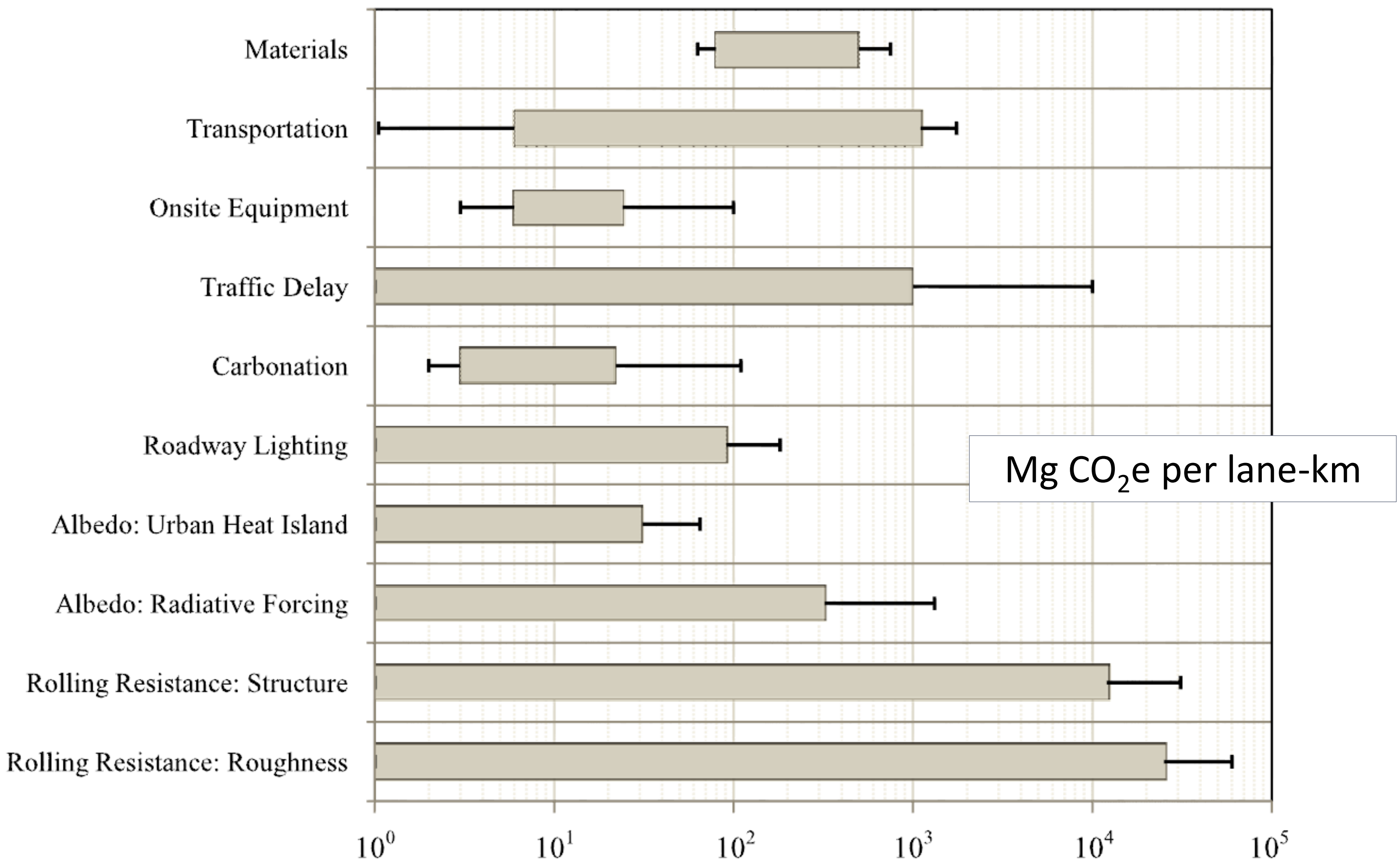
Work Zone Congestion

- Construction, maintenance, and rehabilitation activities will cause changes to traffic flow, traffic speed, delay, and potentially increase VMT due to diversions
- Off-peak activities can reduce these impacts but may be partially offset by emissions associated with lighting for nighttime construction.

Rolling Resistance

- Pavement roughness, macro texture, and structural response affect vehicle fuel economy and have a significant environmental impact
- In some cases rough pavement texture can function as a safety feature. In such instances, a tradeoff is made between safety and vehicle emissions.

Greenhouse Gas Process Sensitivity



Santero and Horvath, 2009, Global Warming Potential of Pavements, Environmental Research Letters 4, doi:10.1088/1748-9326/4/3/034011

Greenhouse Gas Priority Ranks

Priority rank	Life-cycle component	Ideal GWP scenario	Worst GWP scenario
①	Rolling resistance: roughness	Smooth pavements with low vehicle traffic.	Rough pavements with high vehicle traffic.
	Rolling resistance: structure	High stiffness pavement structures on low-traffic sections. Low truck traffic (AADTT).	Low stiffness pavement structures on high-traffic sections. High AADTT.
②	Traffic delay	Pavement sections with low traffic or where capacity is much higher than demand. Sections with readily available detours. Use of lane closures during off-peak traffic periods.	Pavement sections with high traffic or where capacity is comparable to demand. Sections where detours are not readily available. Lane closures occur during peak traffic periods.
	Transportation	Low overall material demand. Locally available materials, especially aggregates. Use of *in situ* recycling strategies. Any long-distance travel utilizes efficient transportation modes.	High overall material demand. Materials need to be shipped over long distances, especially aggregates. Long-distance travel using inefficient modes. Use of virgin materials for each process.
	Materials	Pavements with low structural demands (e.g., low AADTT, temperate climate) that require less material. Use of recycled or other low-impact materials. High quality construction practices that facilitate longer service lives.	Pavements with high structural demands (e.g., high AADTT, extreme climate) that require more material. Use of virgin materials. Low quality construction practices that decrease pavement service lives.
	Albedo: radiative forcing	High albedo pavements (e.g., fresh concrete).	Low albedo pavements (e.g., fresh asphalt).

Greenhouse Gas Priority Ranks

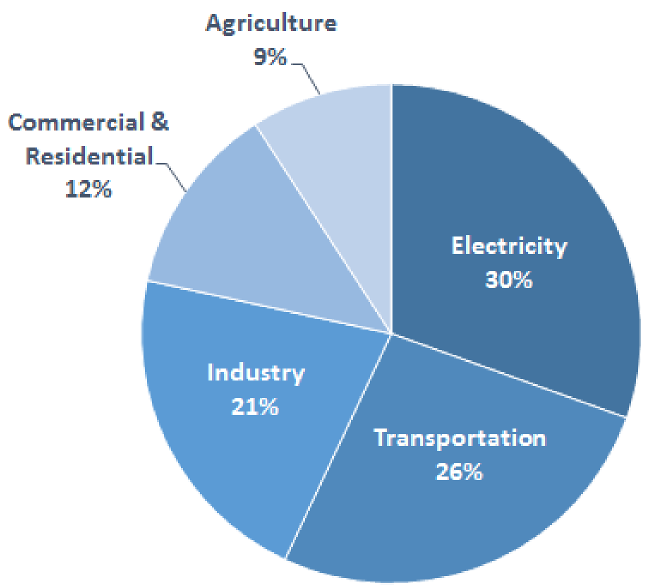
Priority rank	Life-cycle component	Ideal GWP scenario	Worst GWP scenario
③	Roadway lighting	Light colored pavements on freeway or other roadway classifications with low lighting requirements.	Dark colored pavements on arterials or other roadway classifications with high lighting requirements.
	Albedo: urban heat island	High albedo (e.g., fresh concrete) pavements in sparsely populated areas. Temperate climates with low air conditioning demand.	Low albedo pavements (e.g., fresh asphalt) in dense urban environments. Hot weather climates with high air conditioning demand.
	Carbonation	High surface area of exposed concrete. Concrete with high cement content and porosity. High humidity and temperature climates. Concrete rubblized and exposed at the end of its life.	Concrete surface is buried under other pavement layers. Concrete has a low cement content and porosity. Low humidity and cold temperature climates. Left intact at its end of life.
	Onsite equipment	Projects with few construction activities over the life cycle. Use of off-site processes (allocated to 'materials') to manufacture materials. Small projects that utilize short and straightforward construction processes.	Projects with many construction activities over the life cycle. Heavy use of *in situ* recycling processes which require onsite materials production. Large projects requiring multiple layers and lifts.

Do improvements to infrastructure lead to emissions benefits for vehicles?

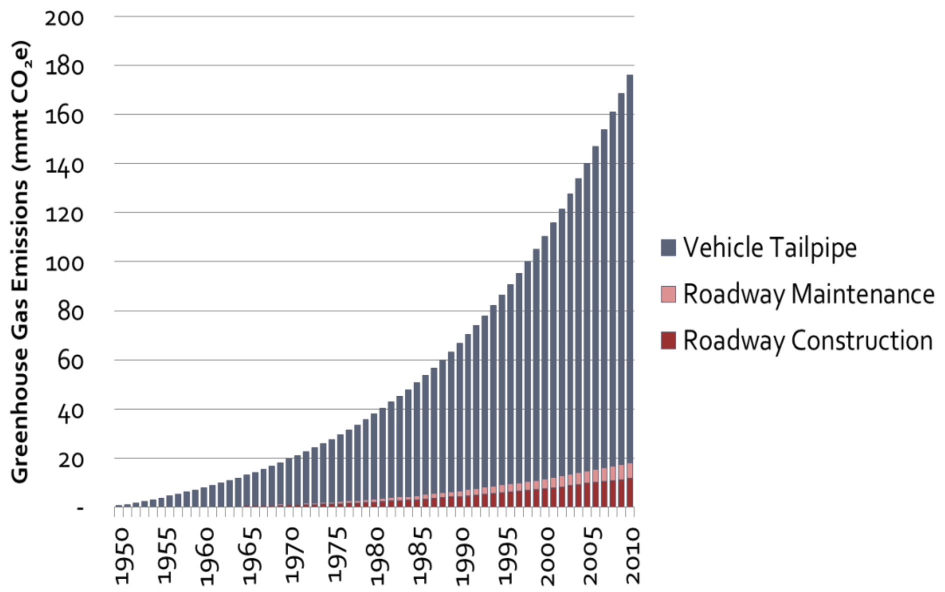
Texas A&M Transportation Institute

Arizona State University

Total U.S. Greenhouse Gas Emissions by Economic Sector in 2014



U.S. Environmental Protection Agency (2014).
U.S. Greenhouse Gas Inventory Report: 1990-2014.



Do improvements to infrastructure lead to emissions benefits for vehicles?

Texas A&M Transportation Institute

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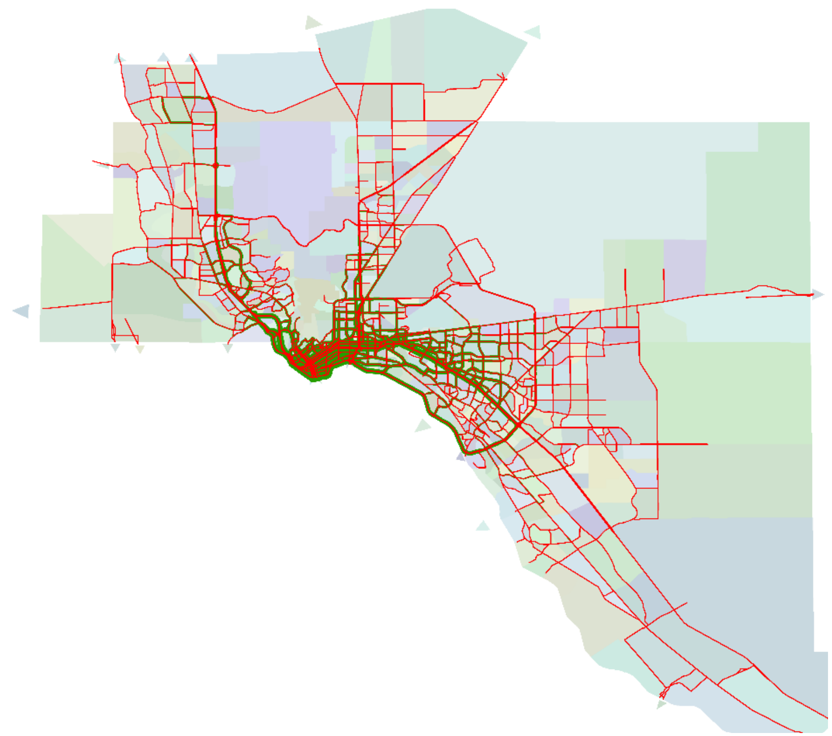


Life Cycle Assessment

Step 0: Demolition and Removal of Existing Infrastructure

What are the existing conditions and what equipment is required?

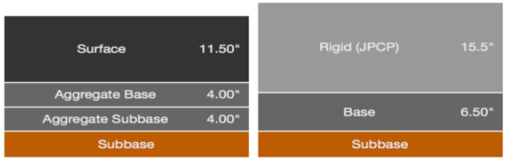
What is done with old material? How far is it transported?

Step 1: Construction of New Infrastructure

Infrastructure Design

1) Material Selection
Flexible vs. Rigid Pavement

2) Cross Sectional Design
Expected Traffic Loadings and Design Life



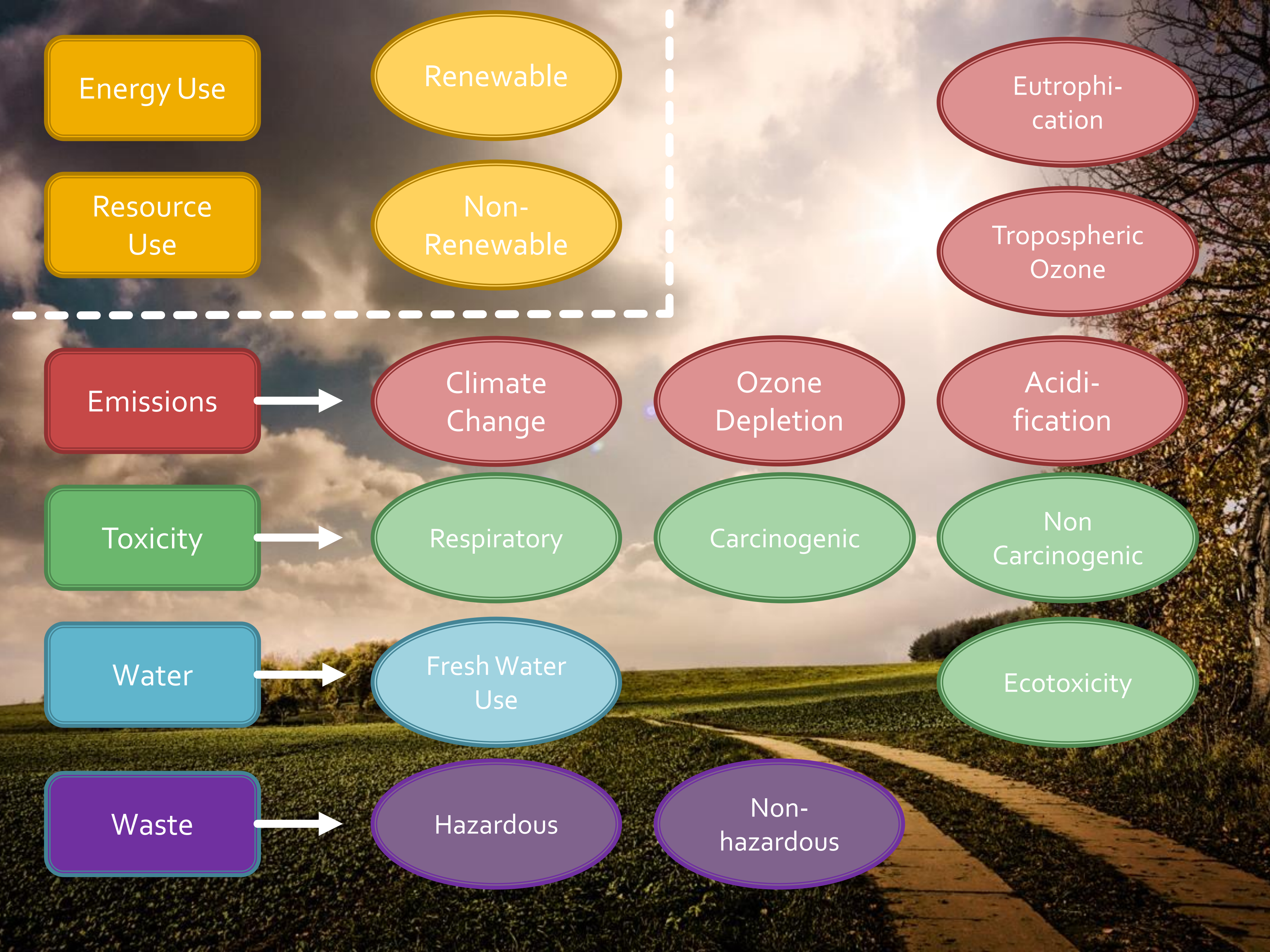
vs.

- Does Texas DOT and City of El Paso use recycled materials in pavements?
- What is the source of the materials? How far is it transported?
- Are there any design elements unique to El Paso or Texas?

Step 2: Maintenance of Infrastructure

What are the maintenance practices of TX-DOT and the City of El Paso?

How does the maintenance requirement change from the old infrastructure to the new?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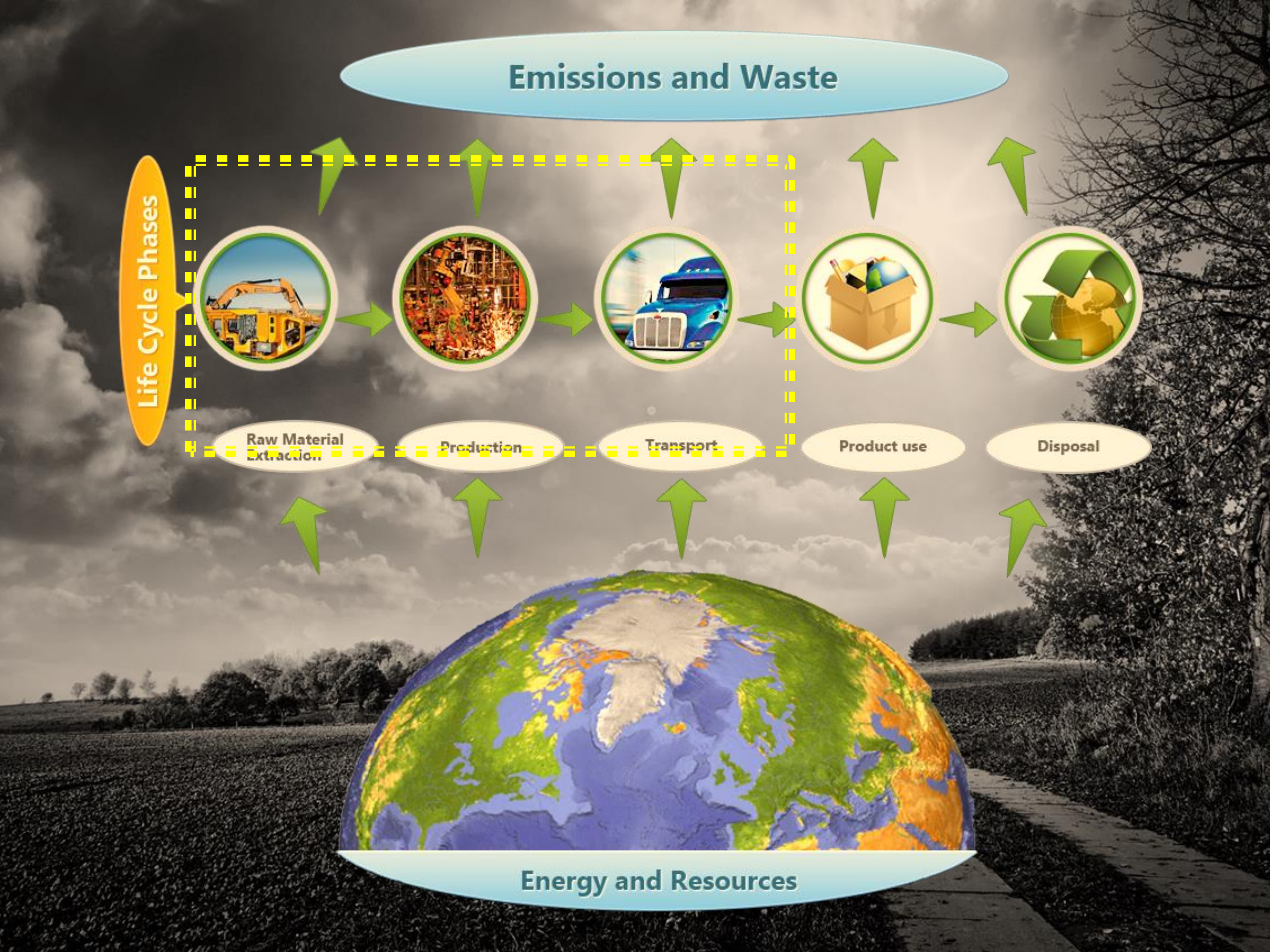

Emissions and Waste
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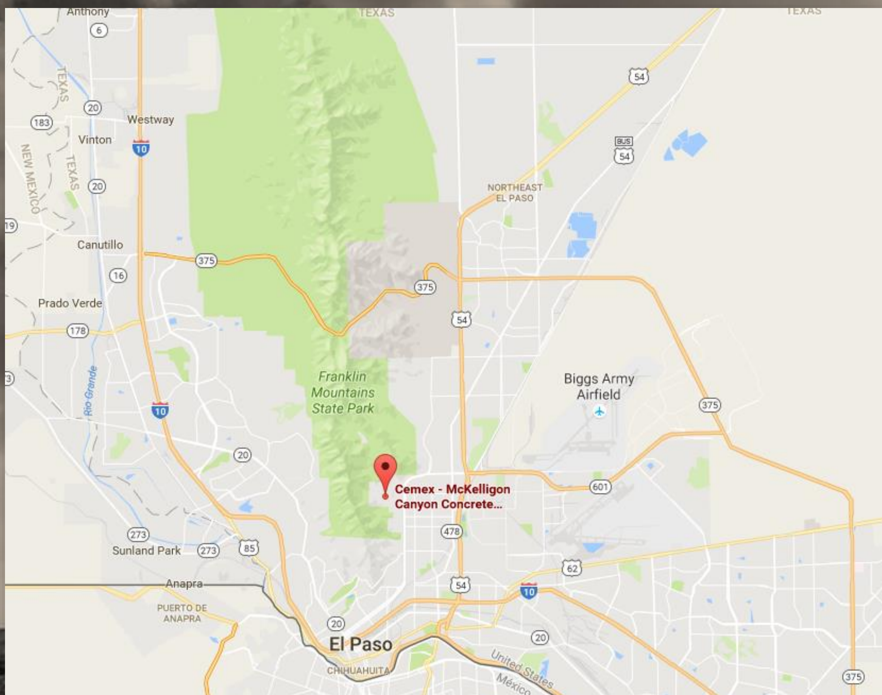
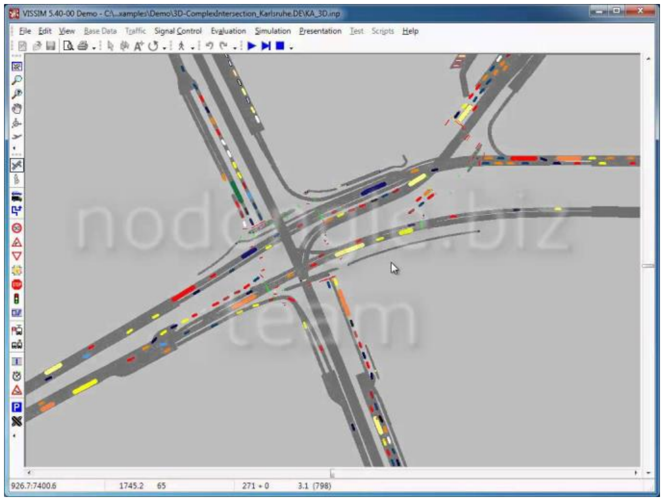
Some impacts are global – Climate Change



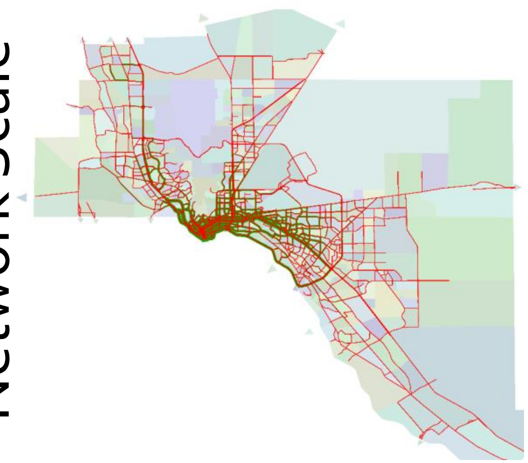
Other impacts are Local- Respiratory

Vehicle Travel and Emissions

Project Scale



Network Scale



Vehicle Activity X Emission Factors = Emissions

MOVES

Link-Level Average Speed → MOVES → Speed-Based EF

Link-Level VMT X Speed-Based EF = Total Emissions

Use Phase and Tailpipe Emissions

Induced Demand
“Field of Dreams” Principle

Do improvements to infrastructure lead to emissions benefits for vehicles?

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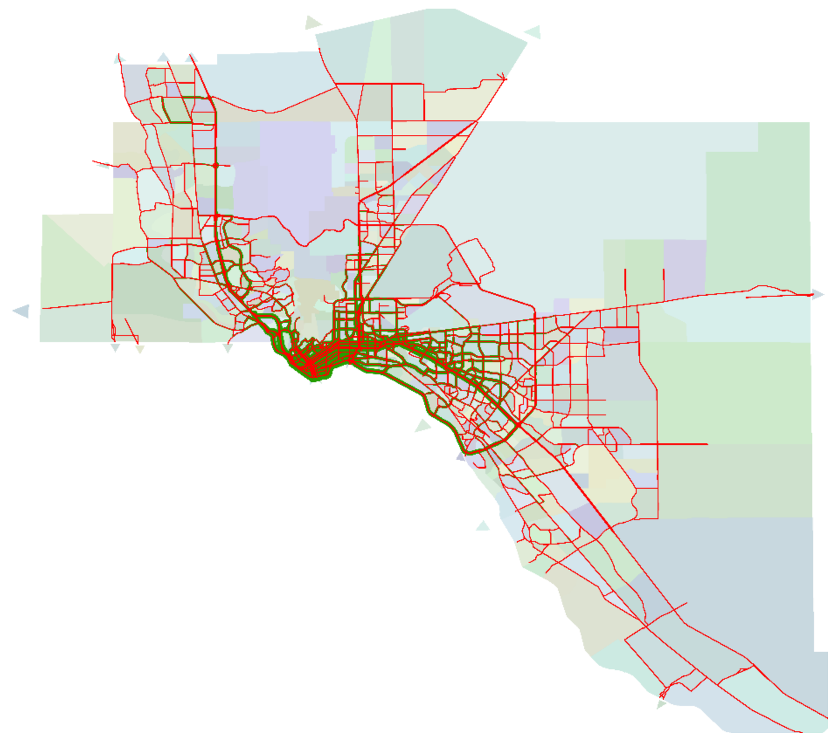
- Preliminary findings suggest that traffic flow improvements at the project level do not necessarily translate into emission benefits across a larger network
  - Combination of induced demand, downstream network capacity constraints, and UE vehicle rerouting lead to additional congestion and increased VMT → Increased Emissions



Conclusions

- Changing pavement systems to improve environmental sustainability is a complex process
- LCA can help guide the decision making process regarding changes to policies and practices to reduce impacts of pavements
- LCA as a method is data driven and there are currently limited tools available.
- FHWA Tech Brief – Life Cycle Assessment of Pavements (FHWA-HIF-15-001 , October 2014)
- FHWA Full Report - Pavement Life Cycle Assessment Framework (FHWA-HIF-16-014, July 2016)

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Questions?

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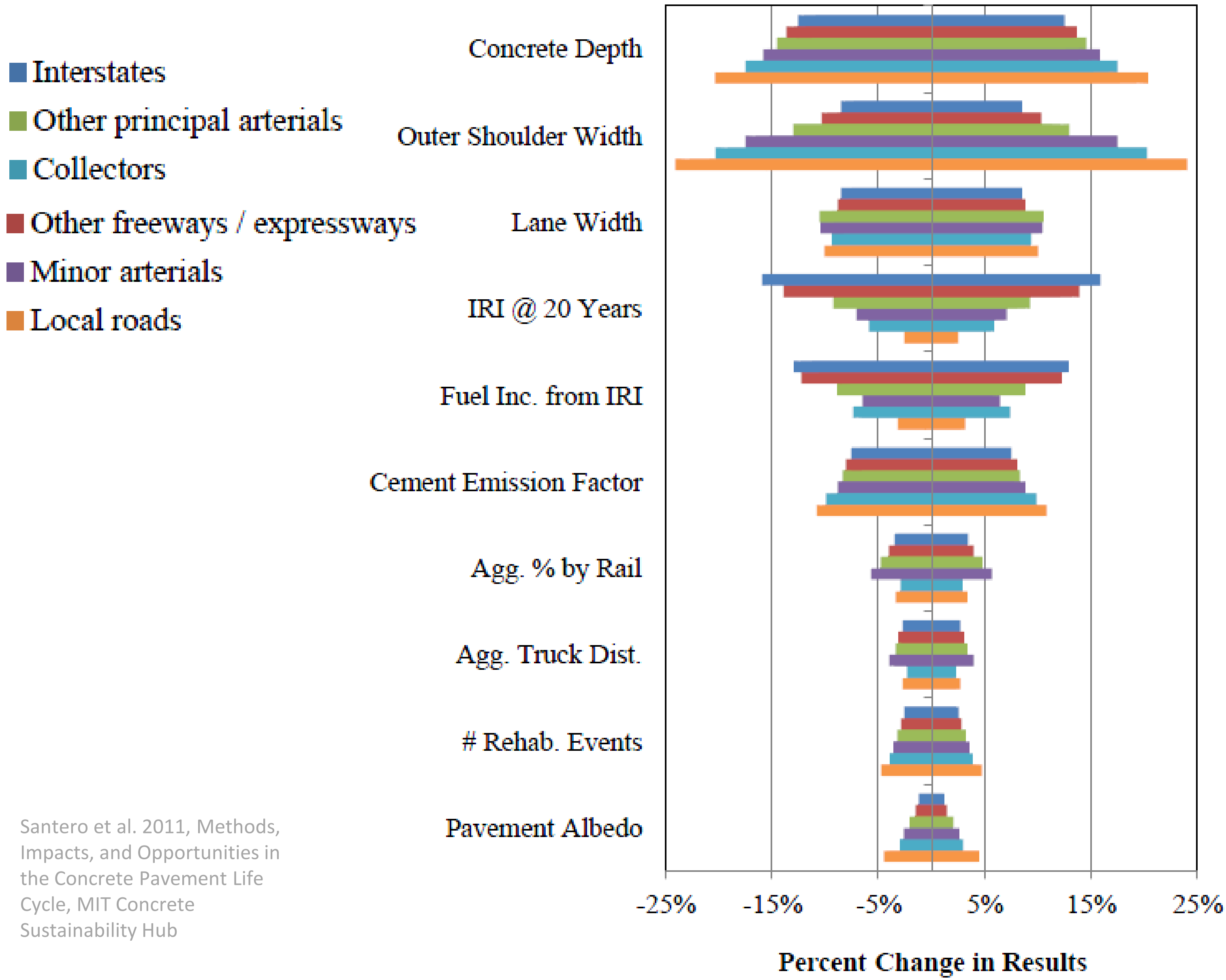
Concrete Pavements

Greenhouse Gas sensitivity to ten most influential parameters on six urban roadway classifications



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Comprehensive Approaches

- Clear need for life-cycle assessment
  - Materials
  - Construction
  - Use
  - End-of-life
- Traveled way makes up only a fraction of surface area

Upfront investments can lead to massive societal economic and environmental gains.

Modeling Advances

- Materials & Methods
  - Wearing Course
  - Subbase
  - Shoulders
  - Embankments
- Roughly 90 life-cycle components
- Indicators
  - Costs
  - Energy
  - Water
  - CO_2
  - NO_x
  - VOC
  - PM
  - SO_2
  - CO