Developing Pavement Networks that Save

Jeremy Gregory

Concrete 2015: 15th Annual Concrete Conference for the Maryland Transportation Industry

March 17, 2015

Hello from Boston, record-breaking city

108.6” of snow this winter

We're thinking about pavements – when we can see them!

MIT Concrete Sustainability Hub

Mission

Develop breakthroughs that will lead to more sustainable and durable infrastructure, buildings and homes

Strategy

I. Provide scientific basis for informed decisions

II. Demonstrate the benefits of a life-cycle view

III. Transfer research into practice

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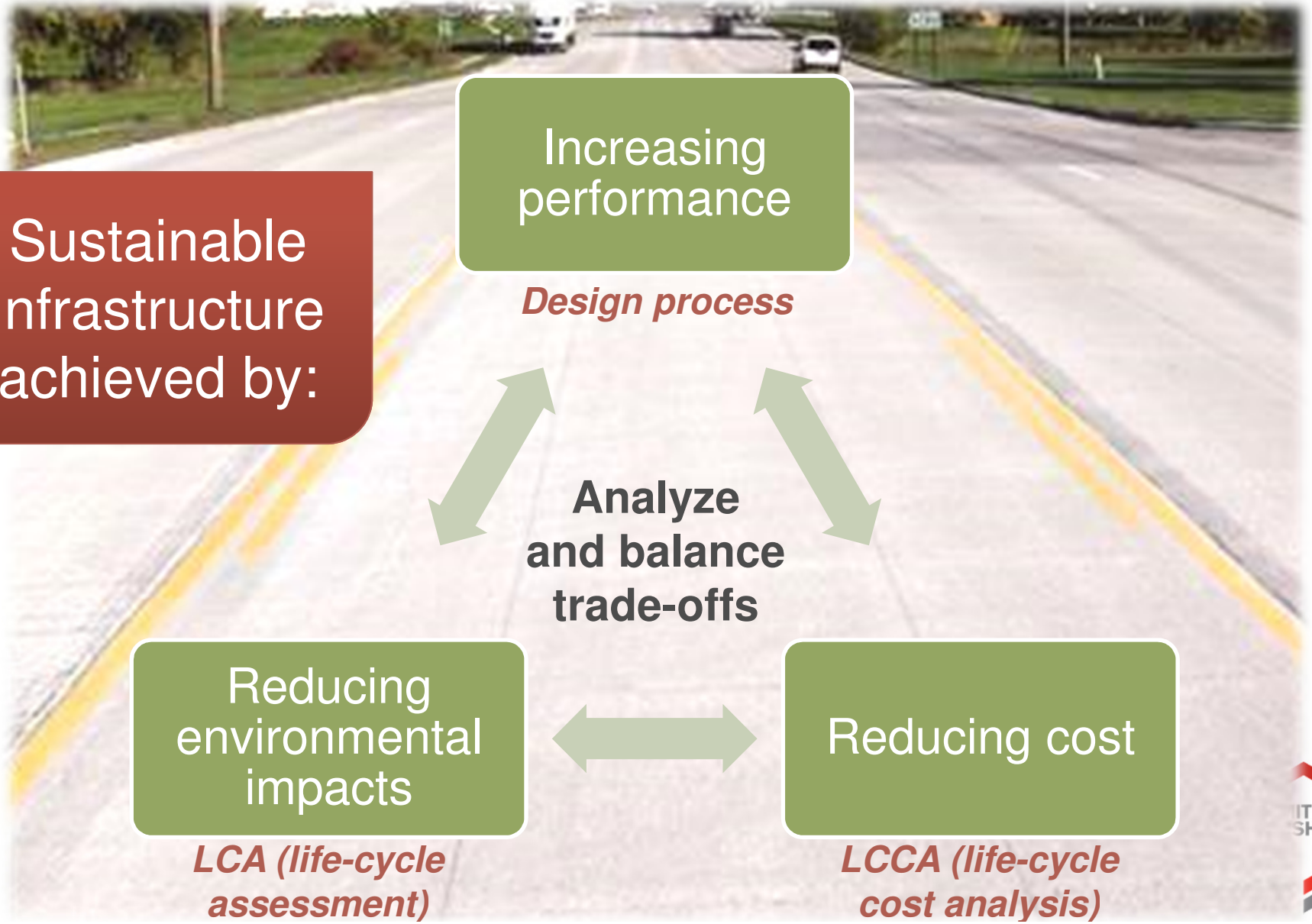
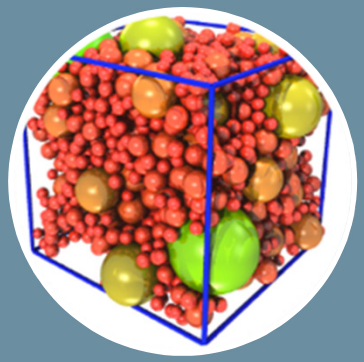
CSHub research supports sustainable infrastructure design decisions



CSHub approach is holistic and multidisciplinary



Science

Engineering

Economics

Environment

The life-cycle perspective frames CSHub work

Multiple mechanisms for reducing environmental impact and cost

Materials Production

- Use recycled
- Reduce energy
- Improve material performance

Design & Construction

- Use less (i.e., stronger) material
- Create longer-lasting designs

Use

- Reduce vehicle fuel consumption
- Reduce heat island effects

End-of-Life

- Enable material recovery

Prioritizing mechanisms requires a trade-off analysis of performance and life-cycle environmental impacts and costs

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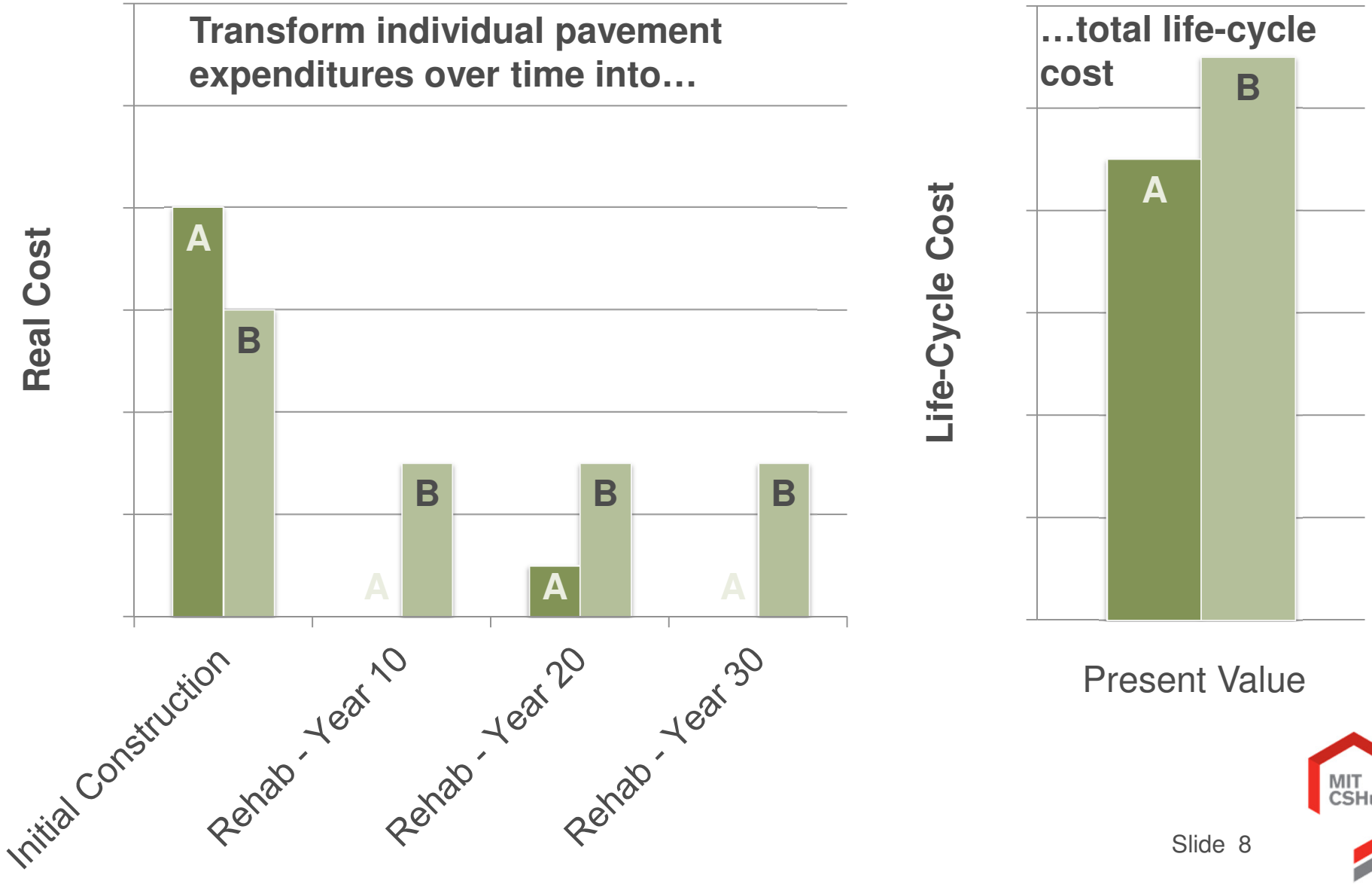
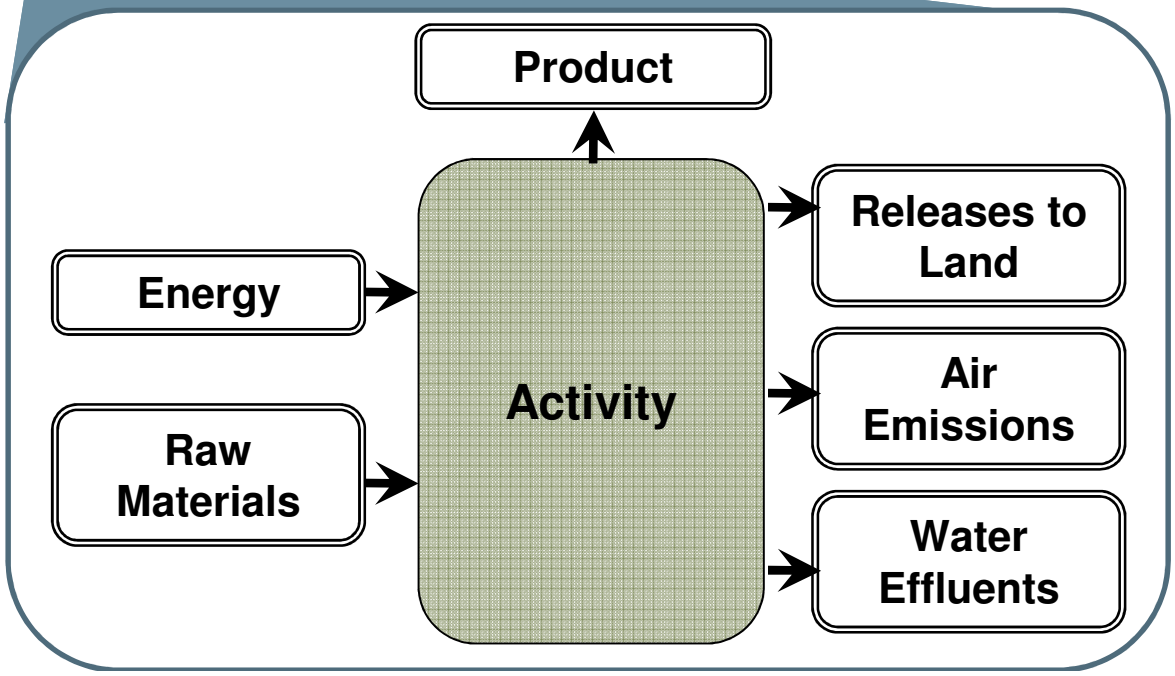
LCCA – Life-cycle cost analysis: Method for evaluating total costs of ownership



LCA – Life-cycle assessment: Method for quantifying environmental impact




Materials Production | Design & Construction | Use | End-of-Life



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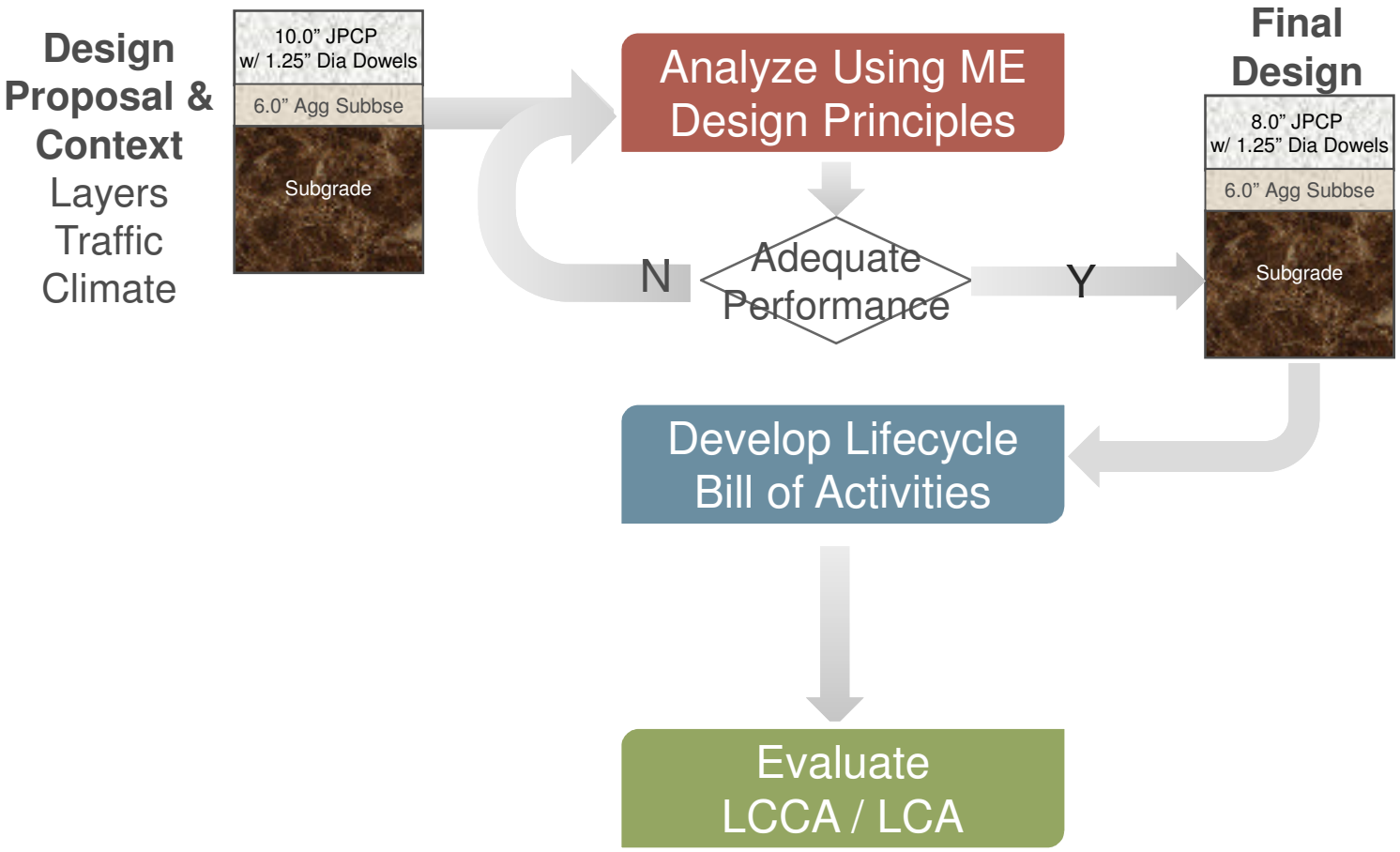
CSHub Pavement LCCA & LCA Goals

1. Drive the pervasive use of life-cycle costing and life-cycle assessment for:
   - Pavement design
   - Pavement type selection
   - Maintenance decisions
   - Asset management

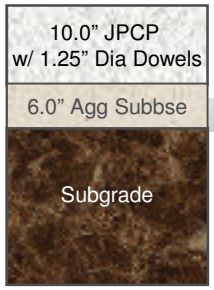
2. Improve the robustness of pavement-related decision-making

Motivation: Pavement design is iterative;
Accelerated feedback → more testing, more improvement



Motivation: Pavement design is iterative;
Accelerated feedback → more testing, more improvement

Design Proposal & Context
Layers
Traffic
Climate



Analyze Using ME Design Principles

Develop Lifecycle Bill of Activities

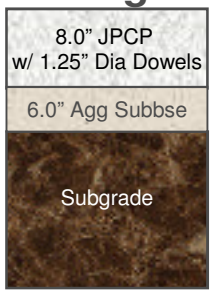
Evaluate LCCA / LCA

Adequate Performance

N

Y

Final Design



MIT research aims to integrate these activities

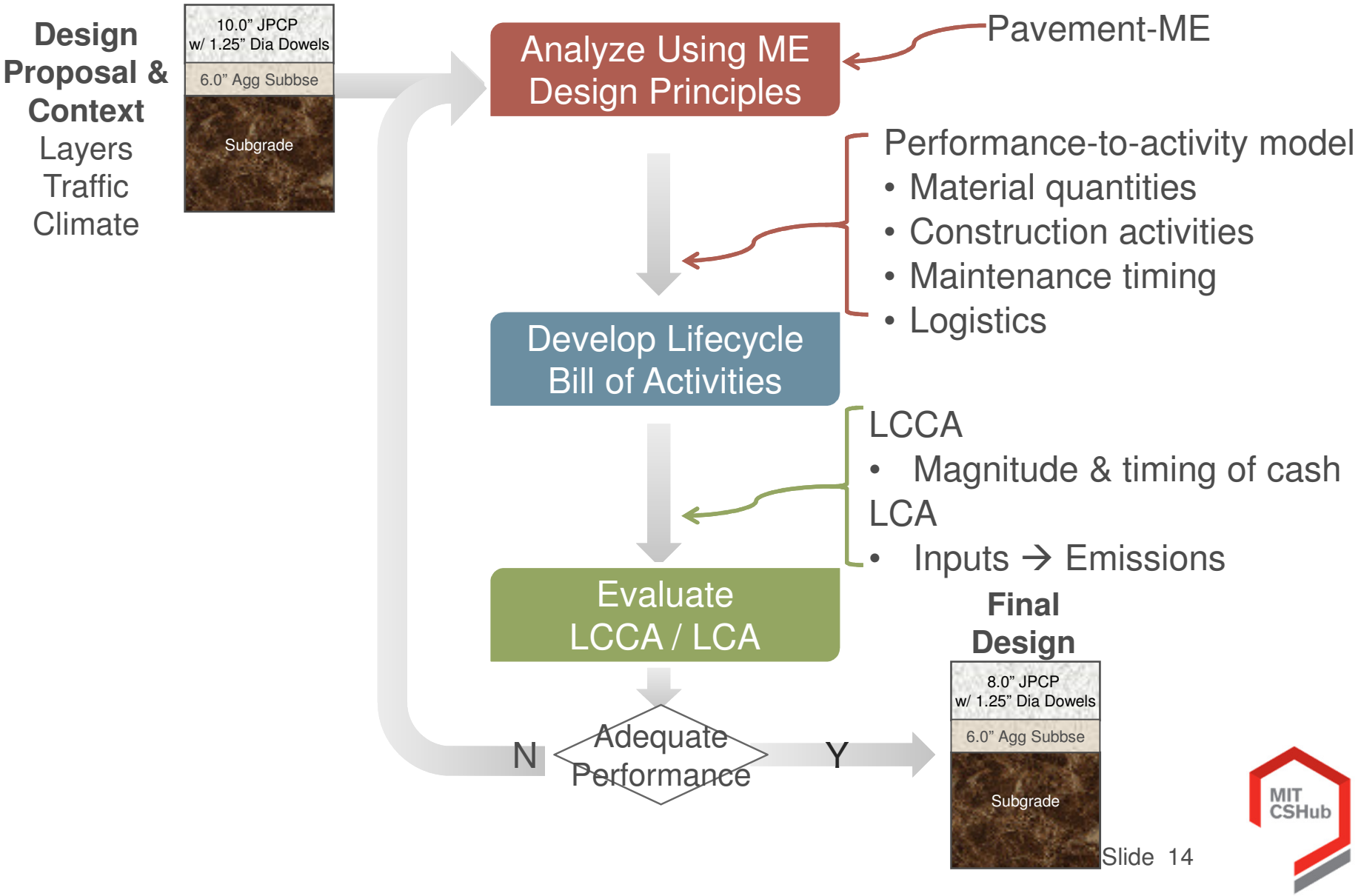
Life-cycle Cost:

Key accomplishments

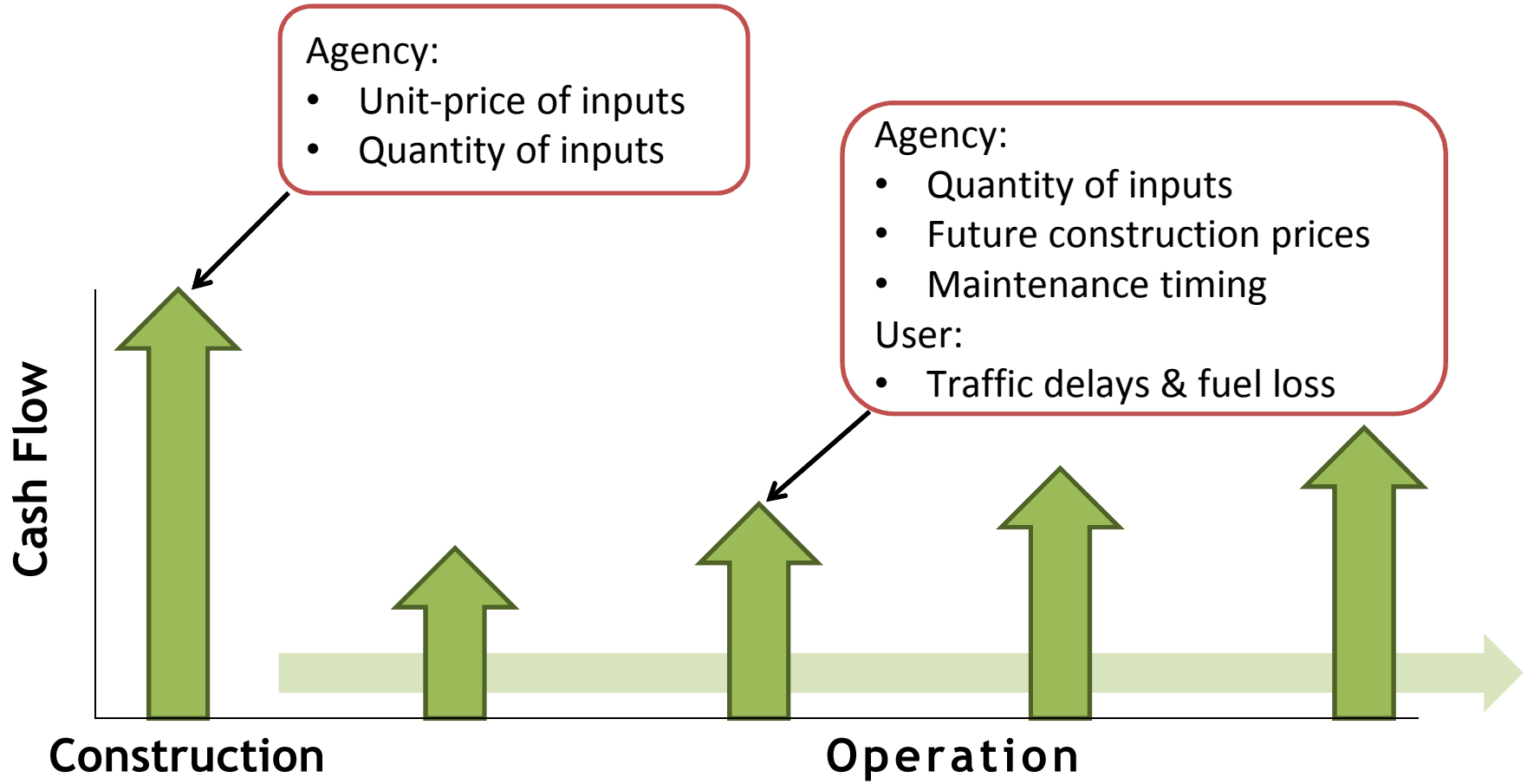
–

Key findings

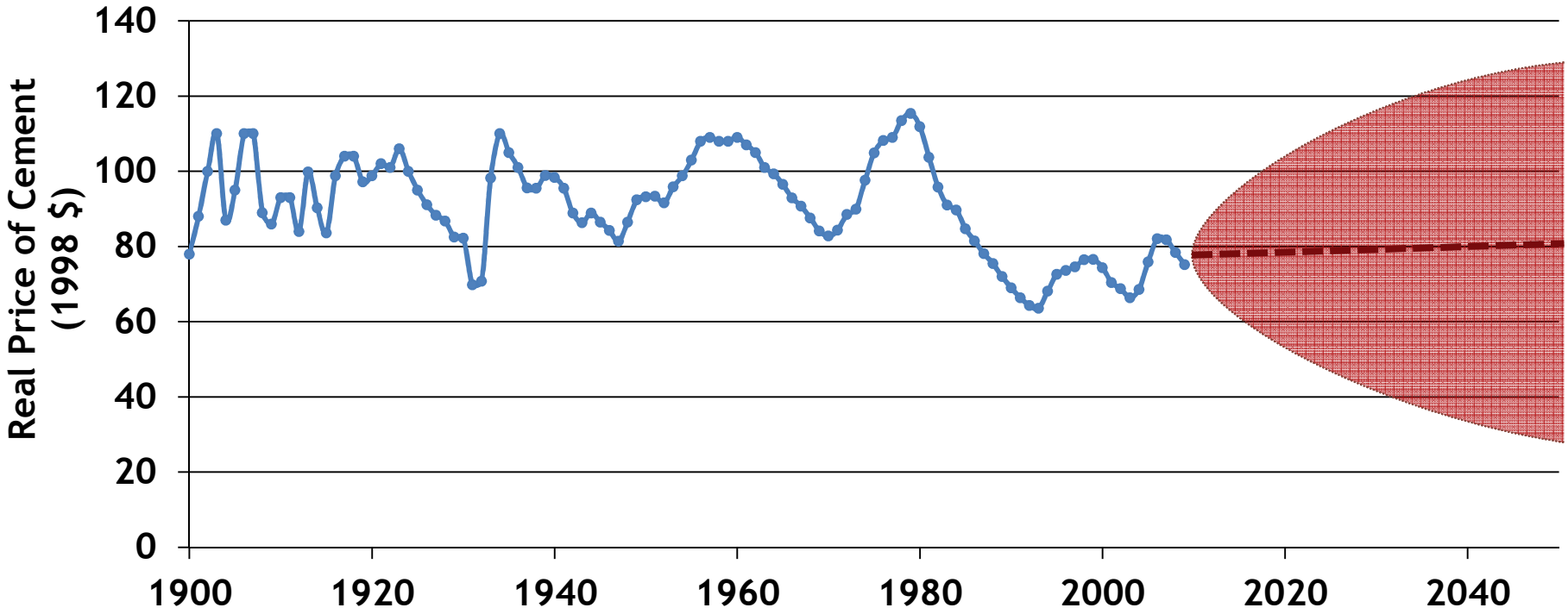
CSHub created linkage between design tools and evaluation



CSHub created probabilistic cost estimates for entire life-cycle



CSHub created effective long-term, probabilistic price projections



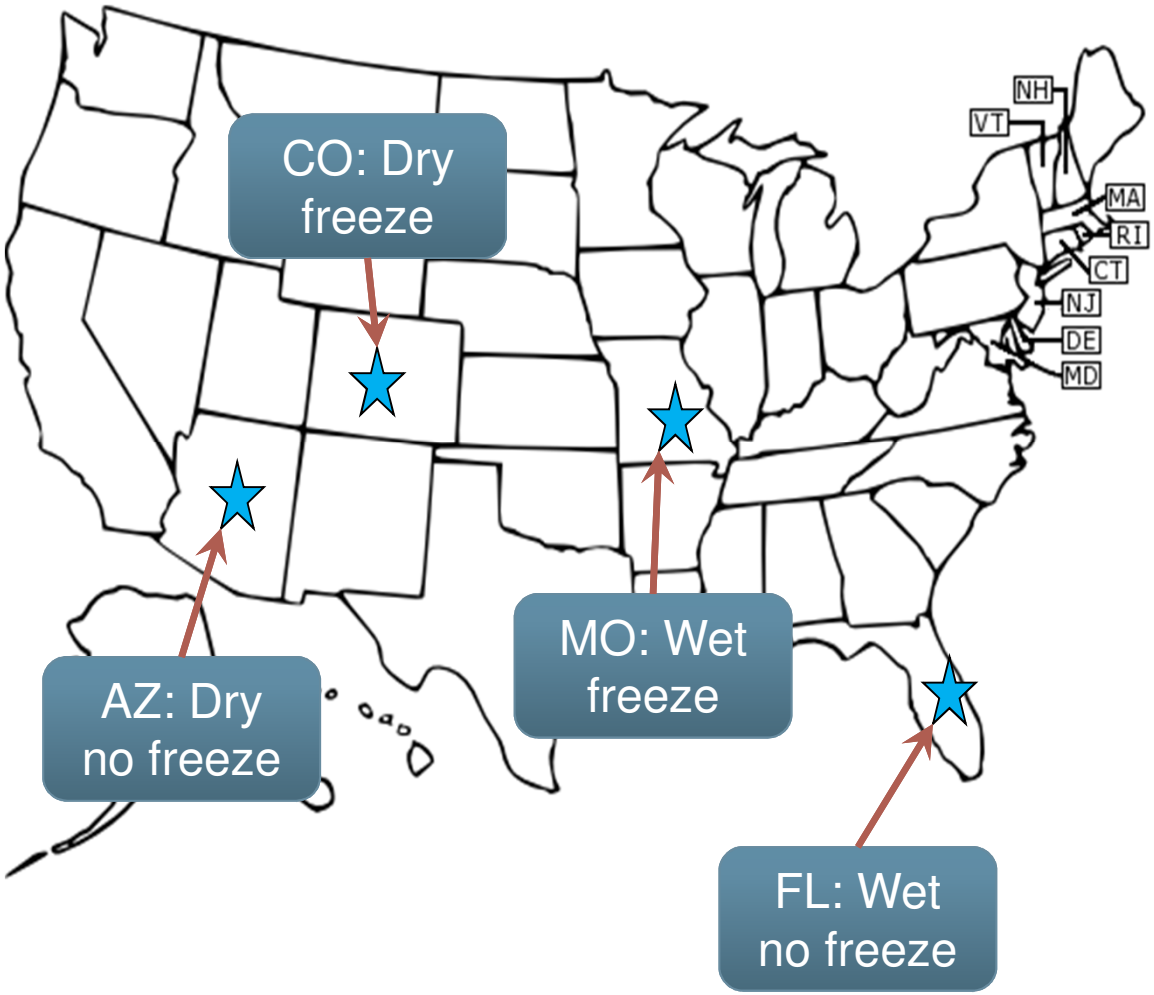
Source: USGS

Effective price projections:

- Must be built from significant sets of data
- Must be viewed as probabilistic in nature

CSHub conducted LCCAs for a wide range of scenarios

4 Locations



3 Traffic Levels

- Rural local street/highway
- Rural state highway
- Urban interstate

Several framing conditions

- Pavement designs
- Maintenance schedules
- Design life
- Analysis period

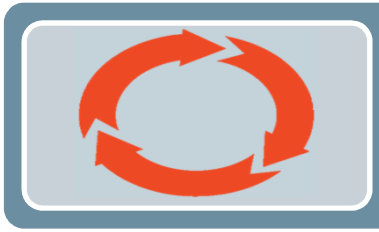
Life-cycle Cost:

Key accomplishments

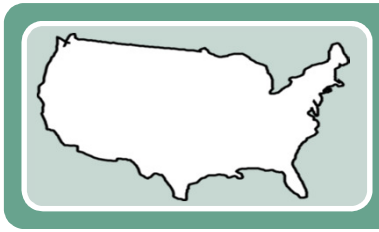
–

Key findings

Key findings from CSHub LCCA research

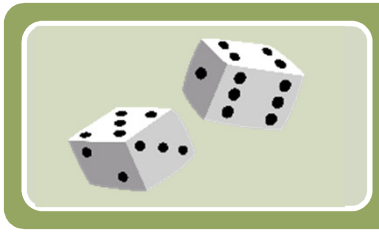


Life cycle matters



Context matters

The future is worth considering

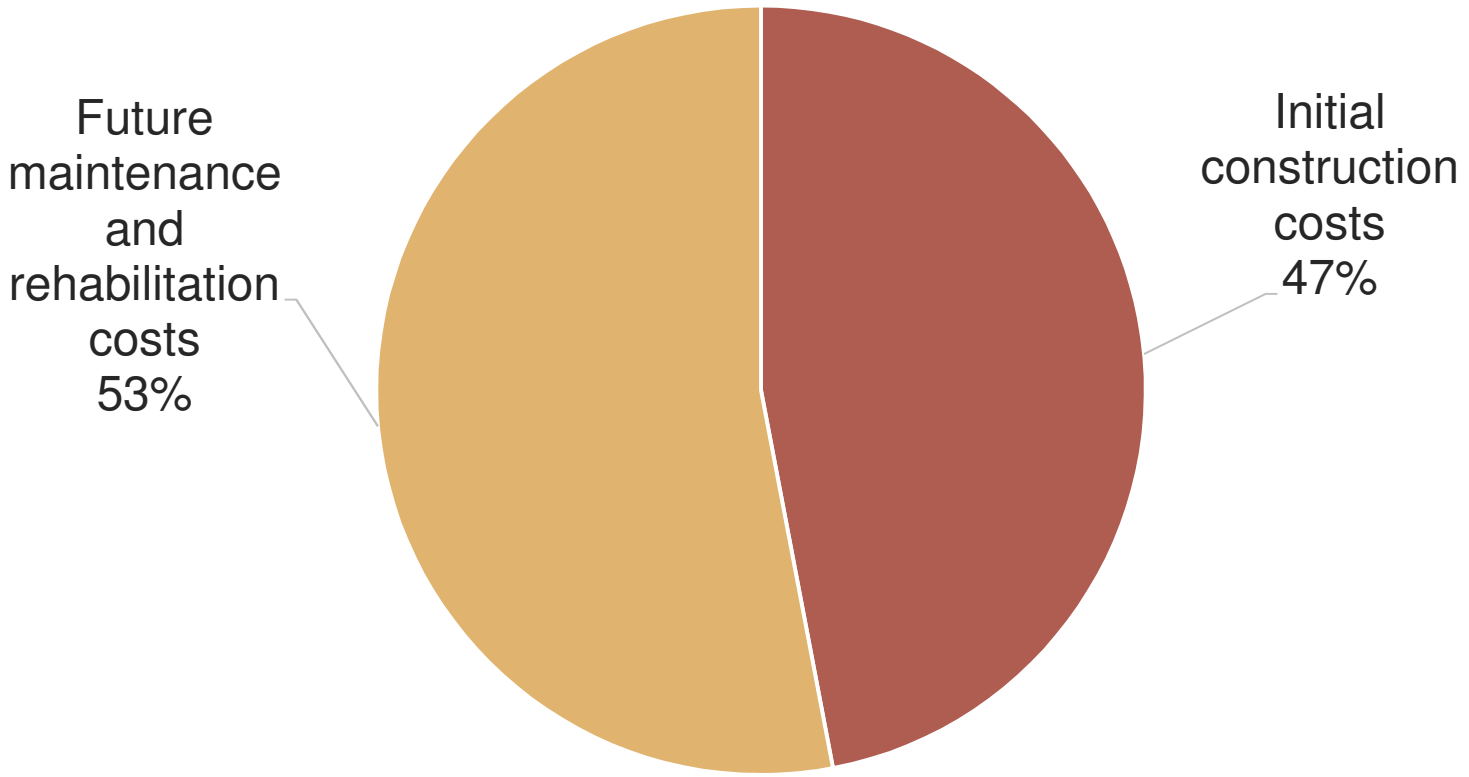


Risk matters

Life cycle matters

Future costs can be significant

Total life-cycle costs for a state highway in Florida



Flexible pavement design developed by Applied Research Associates (ARA), Inc,: AADTT 1k/day; 4 lanes; Wet-no-freeze-FL; FDOT-based rehabilitation schedule; Analysis period = 50 years.

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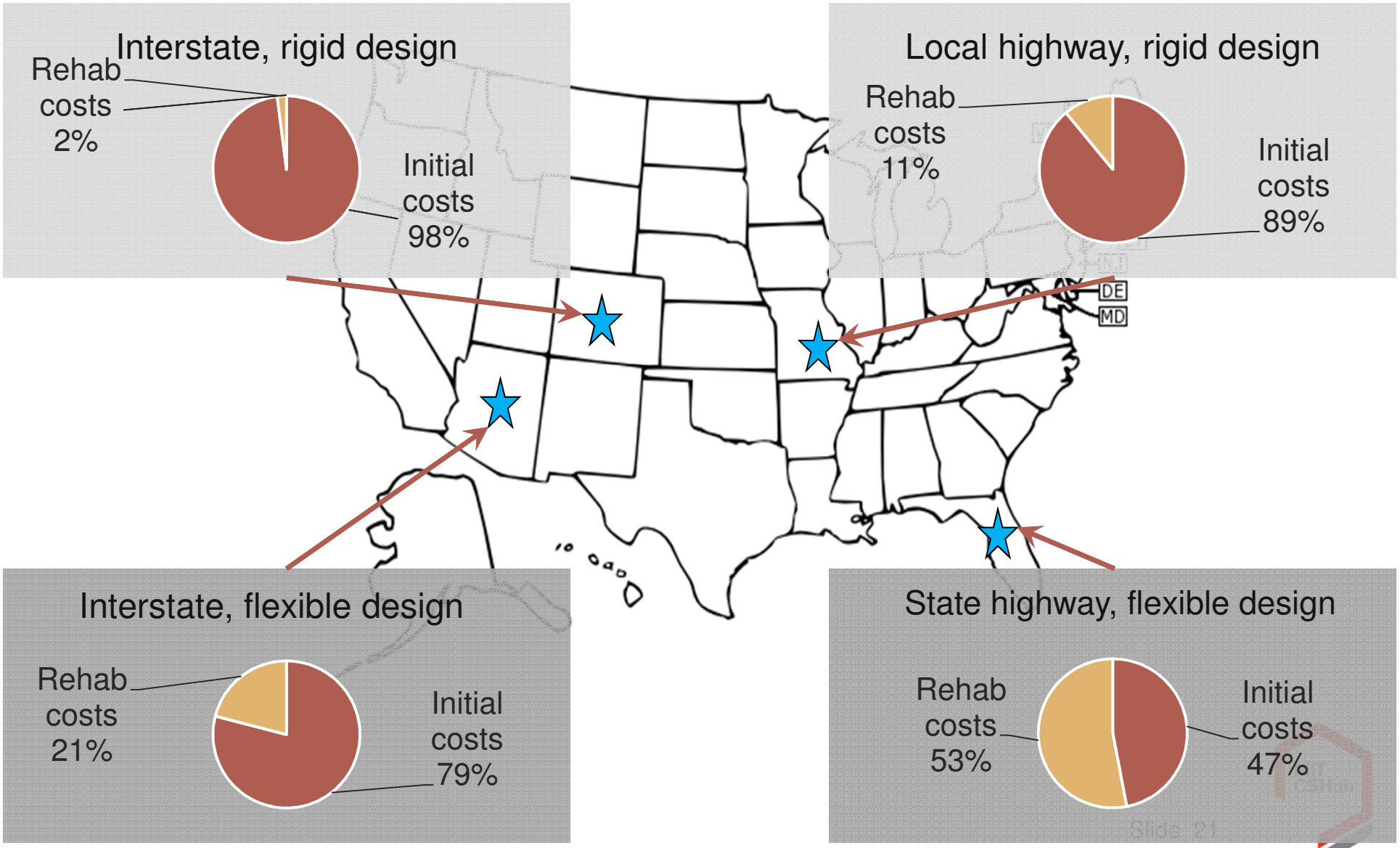
Context matters

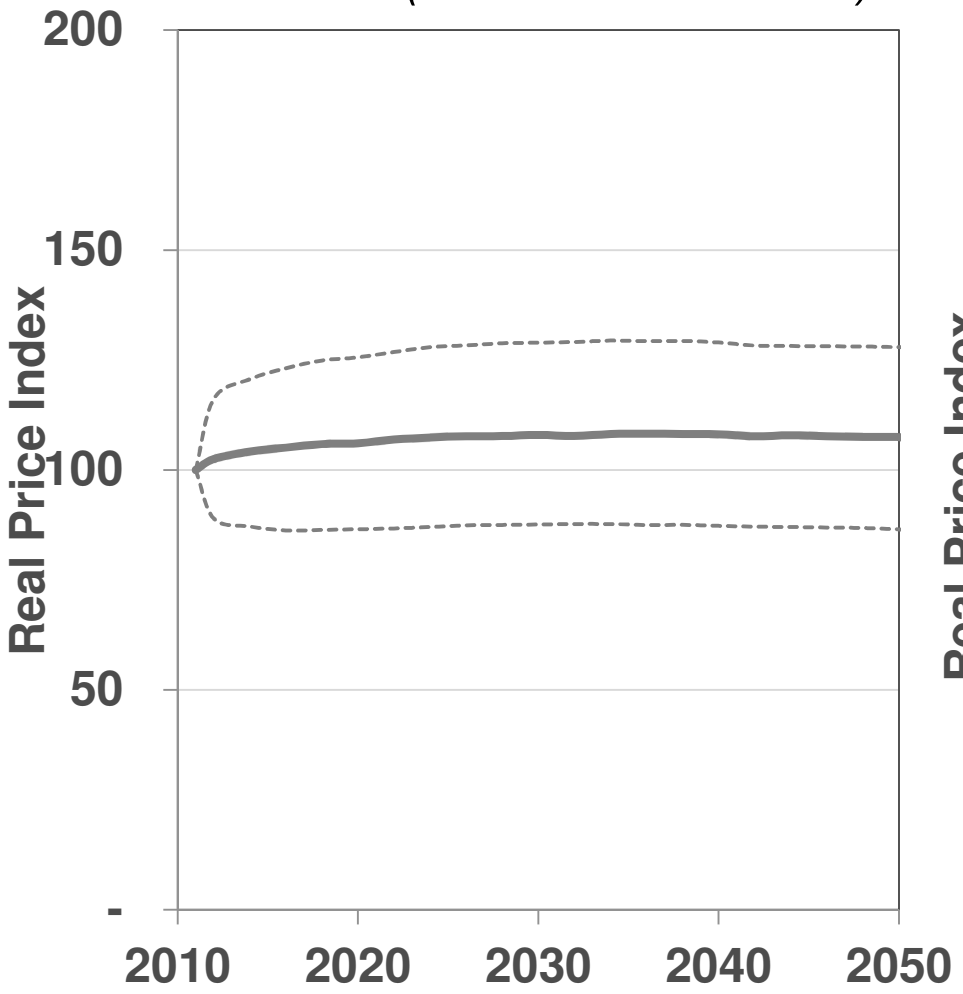
Costs vary with location, traffic level, & pavement design



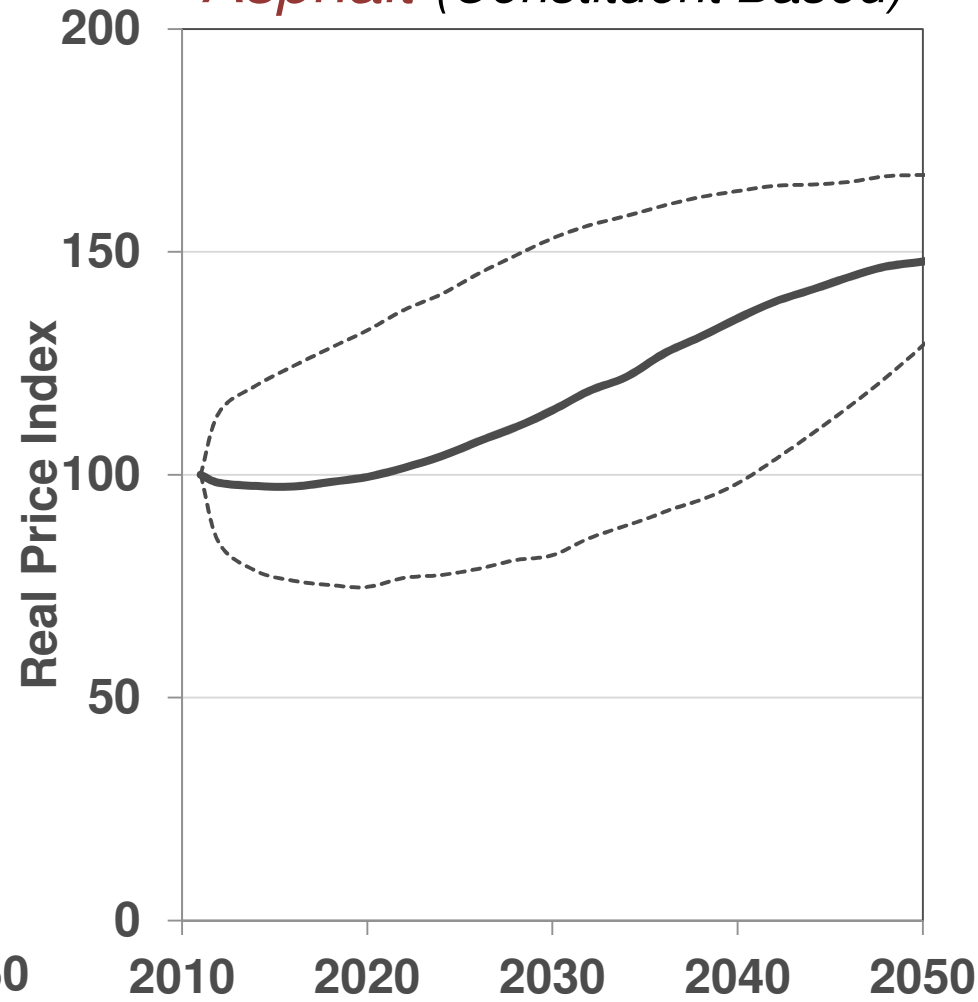
The future is worth considering

Effective price projections are plausible

Concrete *(Constituent Based)*

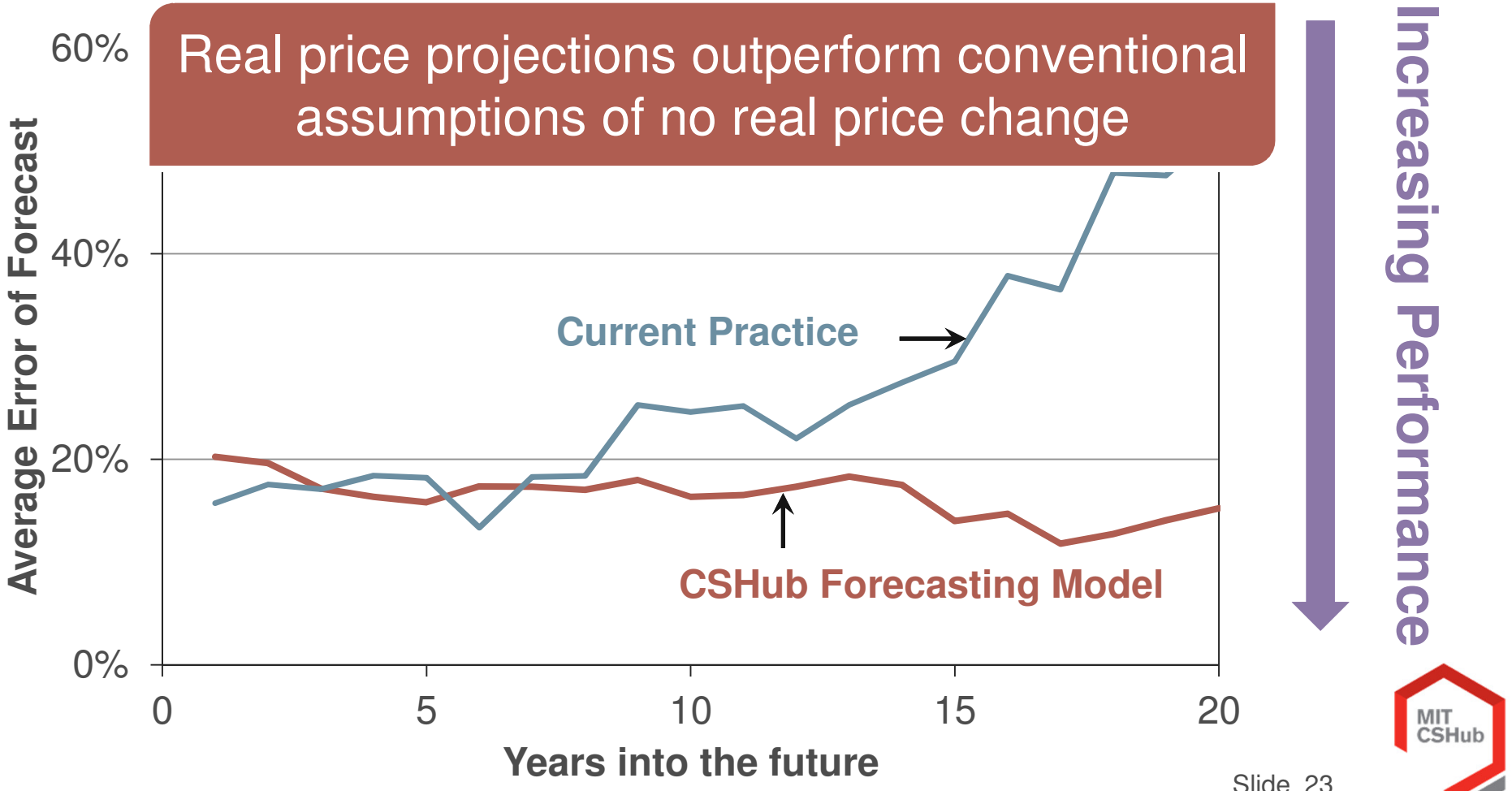


Asphalt *(Constituent Based)*



CSHub forecasts have been shown to be more effective than current assumptions

Testing the effectiveness of the model for the state of Colorado



Life-cycle Environmental Performance:

Key accomplishments

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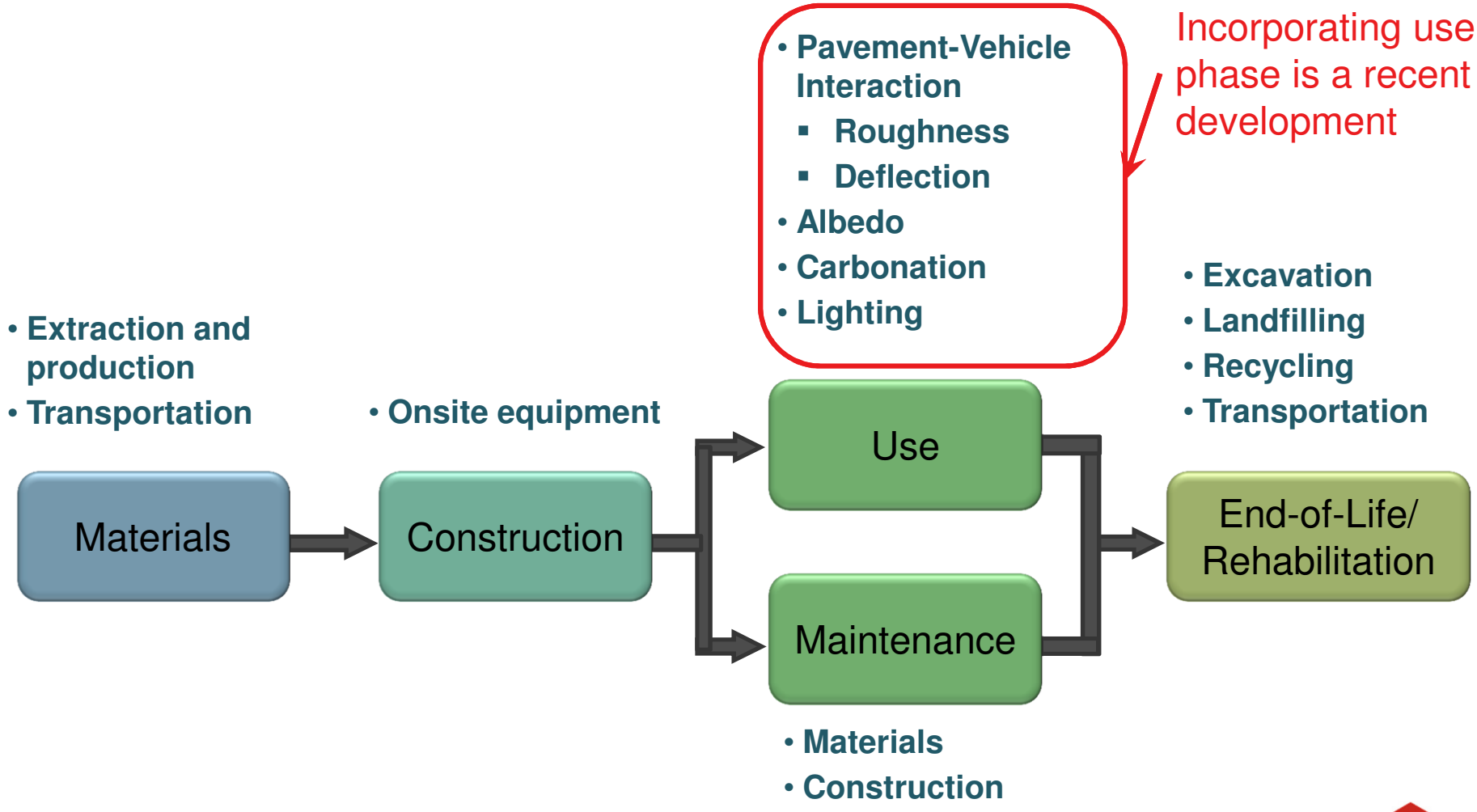
Key findings

CSHub created probabilistic life-cycle assessment model including use phase

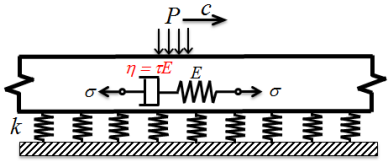


CSHub implemented model-based assessment of PVI using new deflection model

Pavement Deflection

Pavement Roughness

MIT Model



MEPDG+HDM4

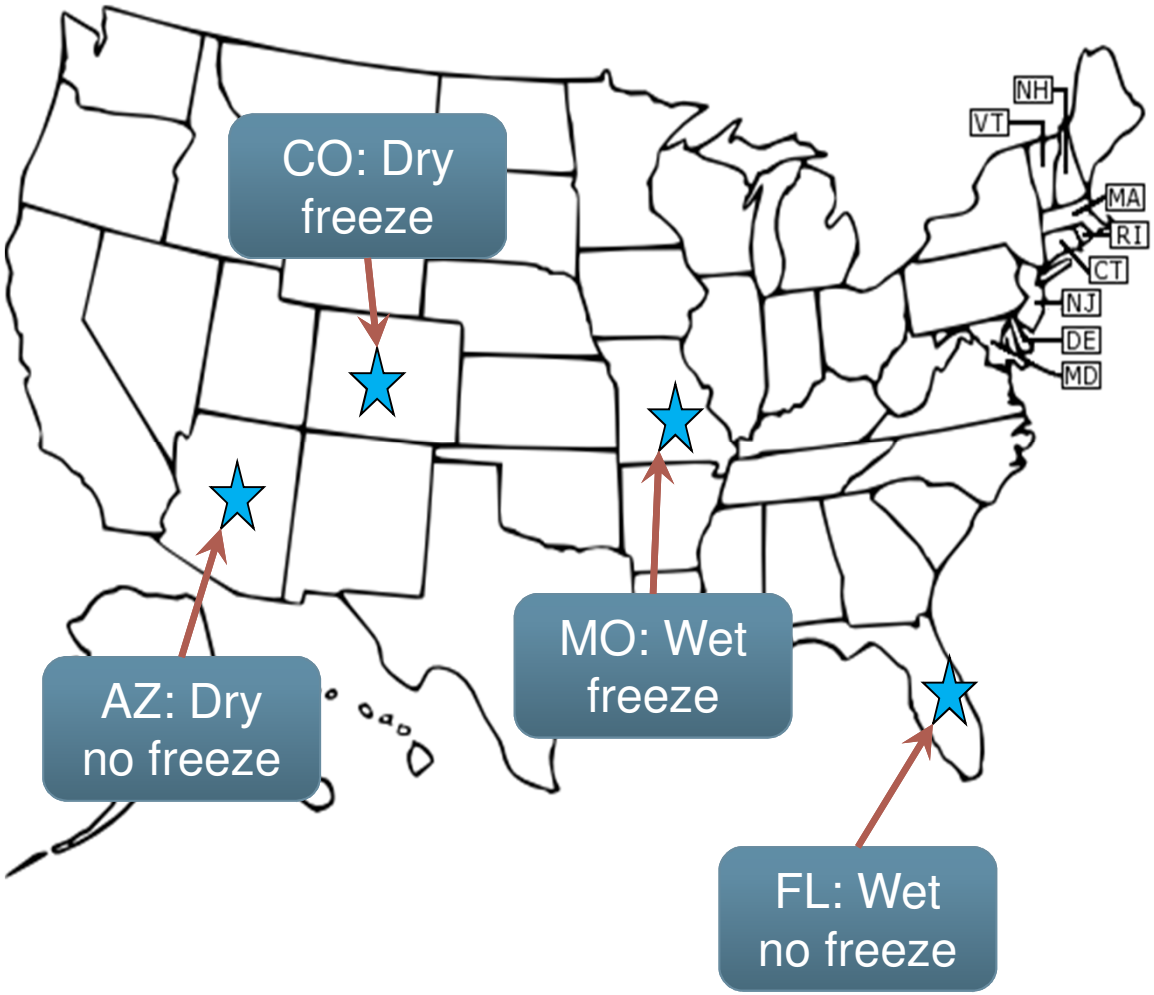
Structure and Material

Calculation Method:

Deflection & Roughness → **Excess Fuel Consumption** → **Environmental Impact**

CSHub conducted LCAs for a wide range of scenarios

4 Locations



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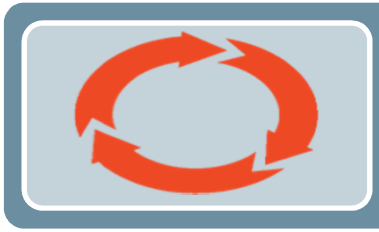
Key findings from CSHub LCA research



Life cycle matters

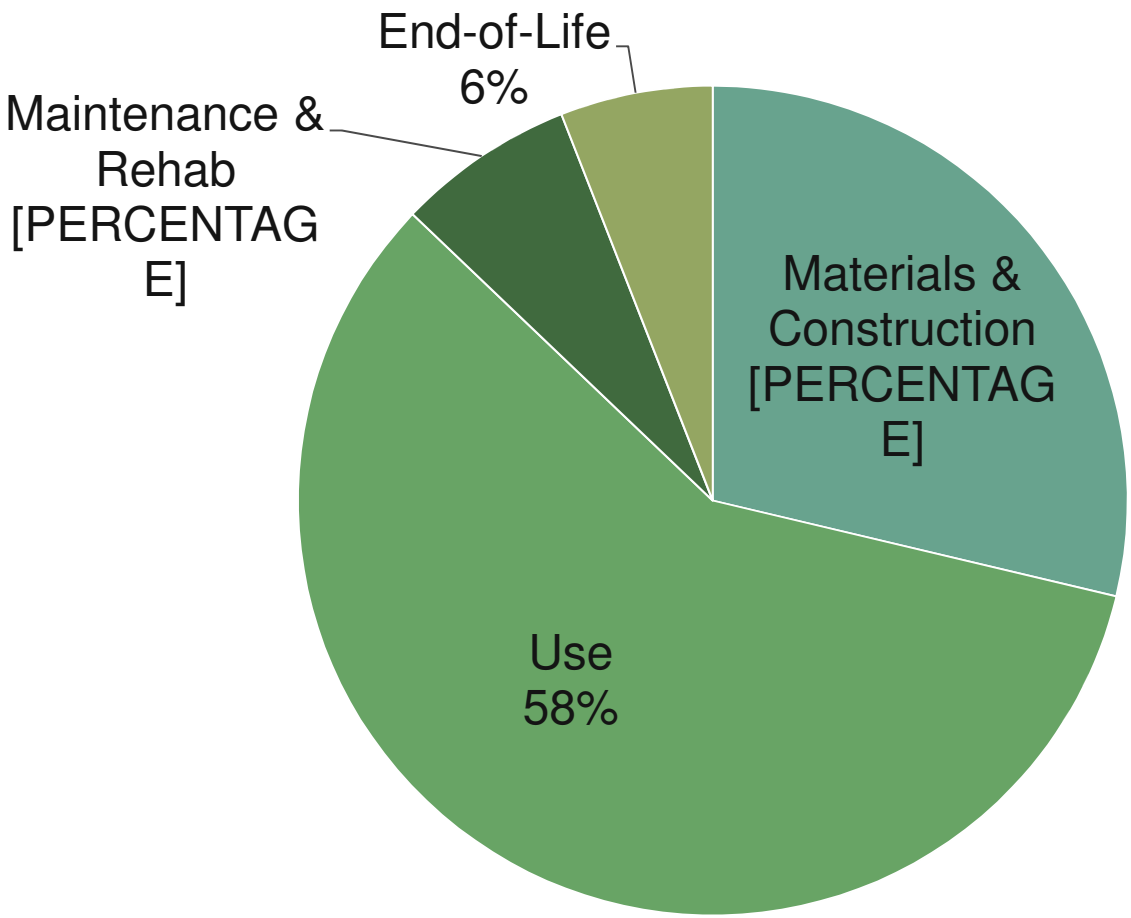
Pavement-vehicle interaction (PVI) matters

Context matters

Large opportunities to improve exist

Life-cycle matters

Use phase can be a significant fraction of pavement environmental impact



Example:
Life-cycle GHG (greenhouse gas) emissions of an urban interstate pavement in Missouri

Flexible pavement design developed by Applied Research Associates (ARA), Inc,: AADTT 8k/day; 6 lanes; Wet-freeze-MO; MEPDG-based rehabilitation schedule.

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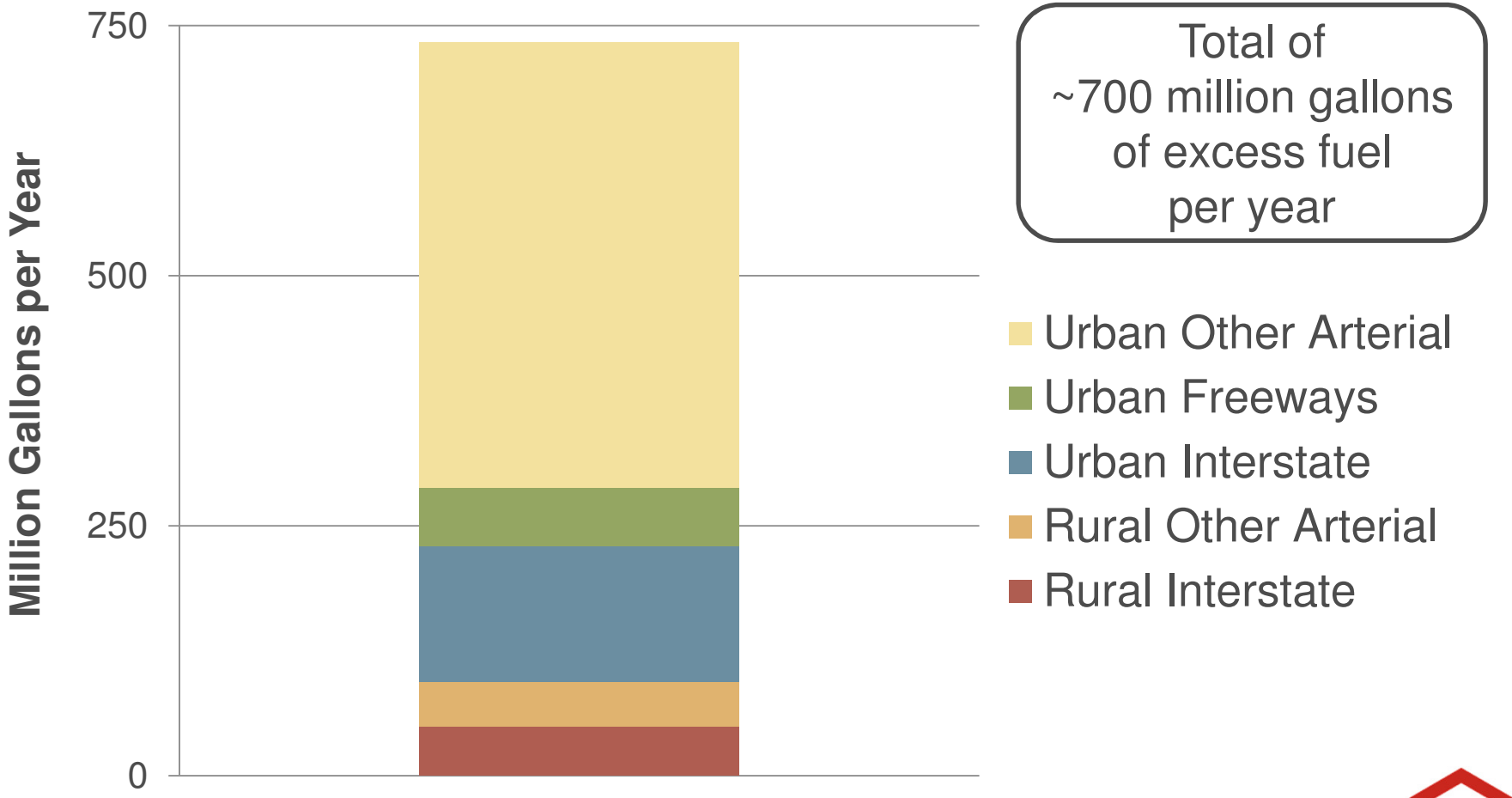
PVI matters

Excess fuel consumption from PVI is significant

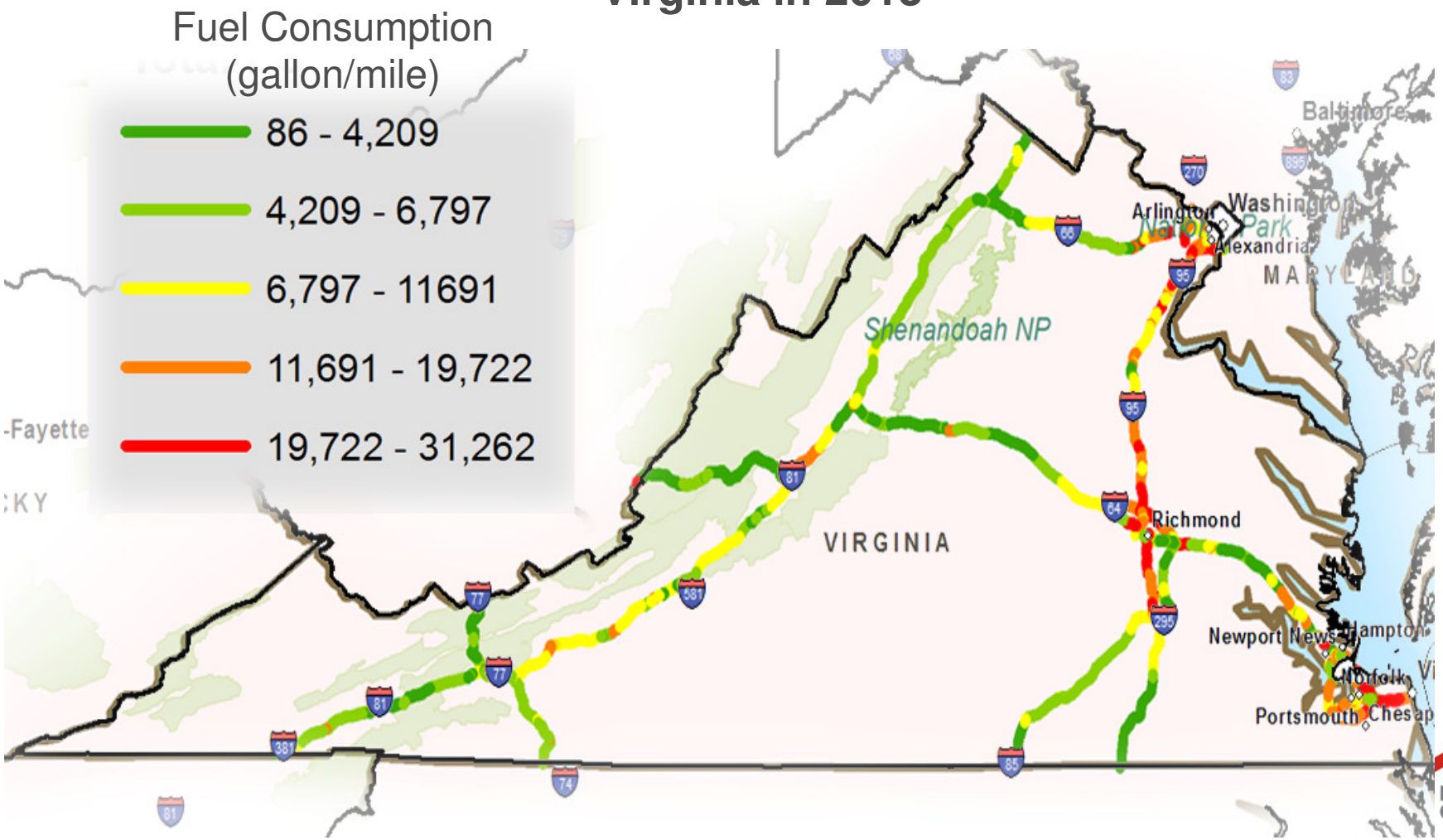
Estimate of extra fuel consumption from PVI in US pavement test sections



PVI matters

PVI data can be used in network pavement management

Excess fuel consumption due to PVI for cars & trucks on interstates in Virginia in 2013



Assumed speed= 100 km/h=62.6 mph; assumed temperature= 16 C/61 F

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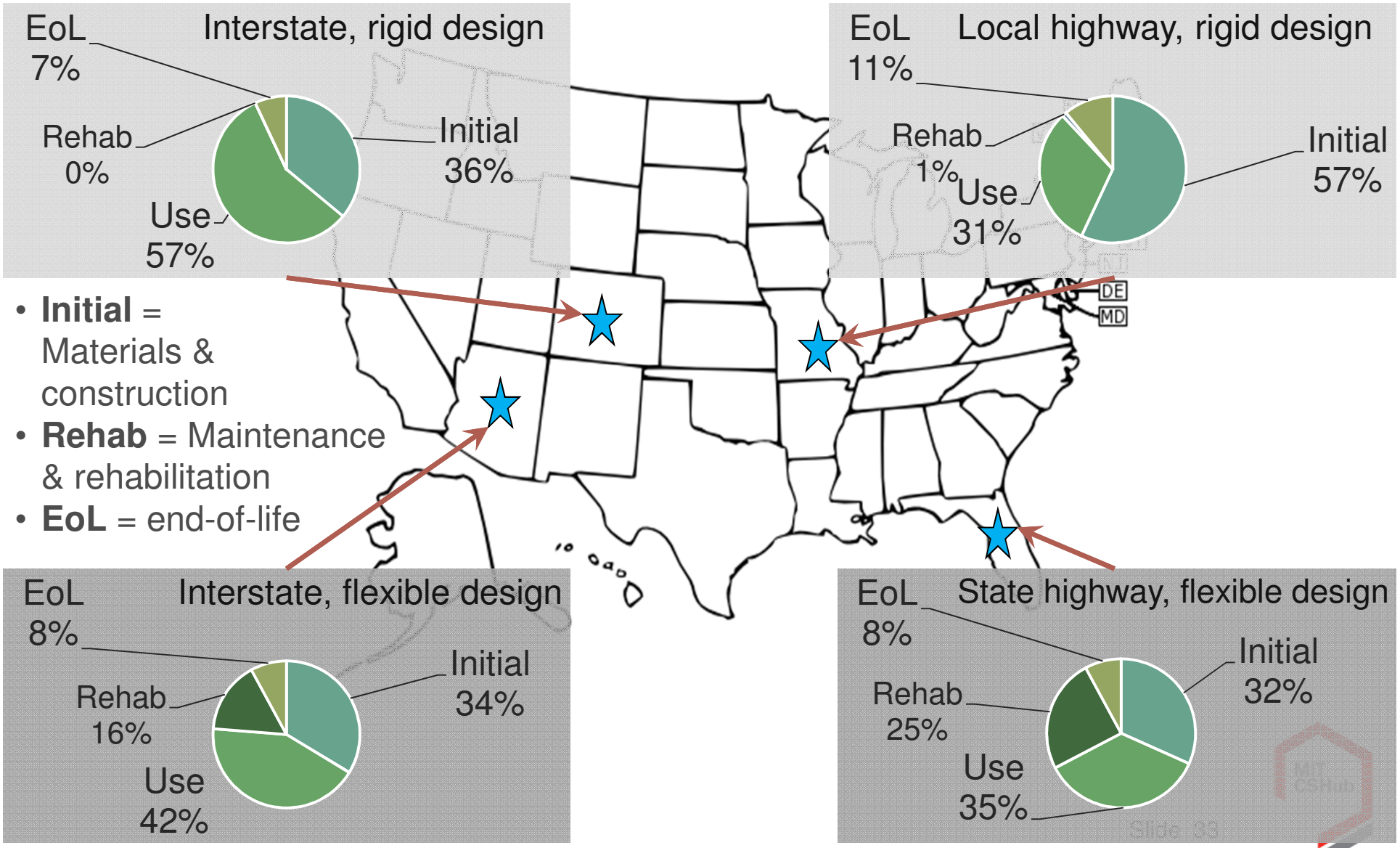
Context matters

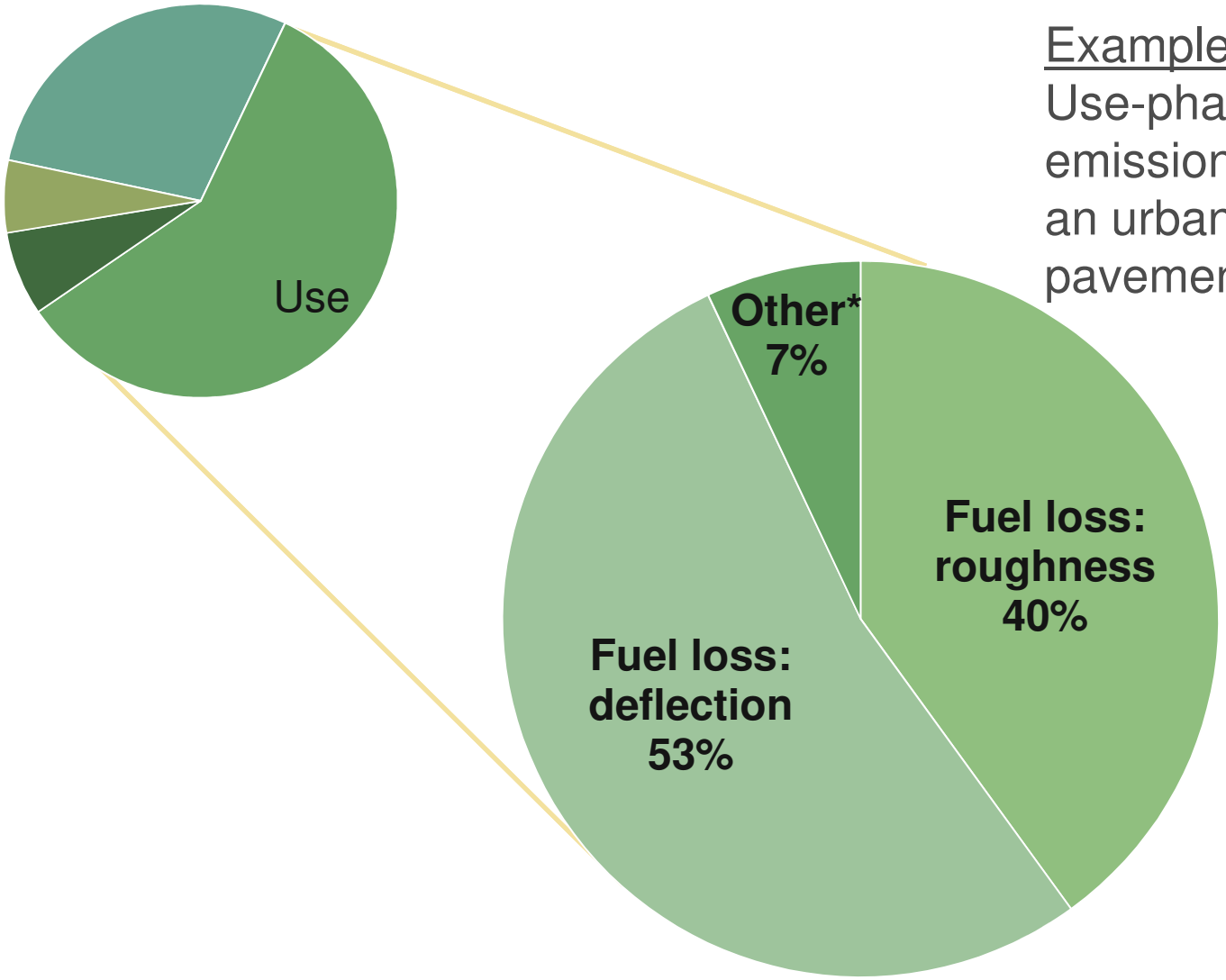
Burdens vary with location, traffic level, & pavement design



- **Initial** = Materials & construction
- **Rehab** = Maintenance & rehabilitation
- **EoL** = end-of-life

Deflection matters

In some contexts, deflection causes the majority of fuel lost to PVI



Example:
Use-phase GHG emissions by source for an urban interstate pavement in Missouri

*Other: carbonation & lighting

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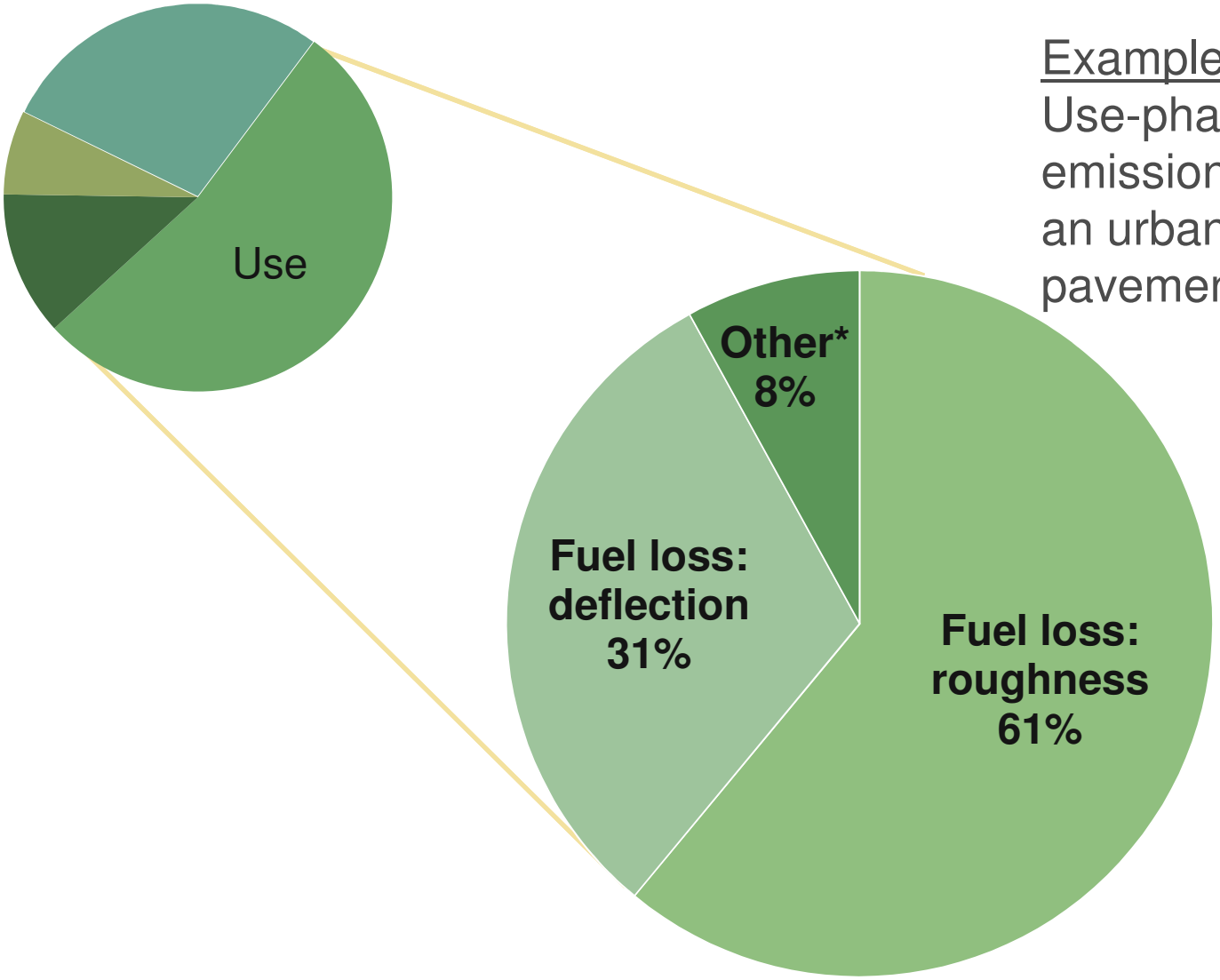
Roughness matters

In some contexts, however, roughness causes most of the fuel lost to PVI



Example:
Use-phase GHG emissions by source for an urban interstate pavement in Colorado

*Other: carbonation & lighting

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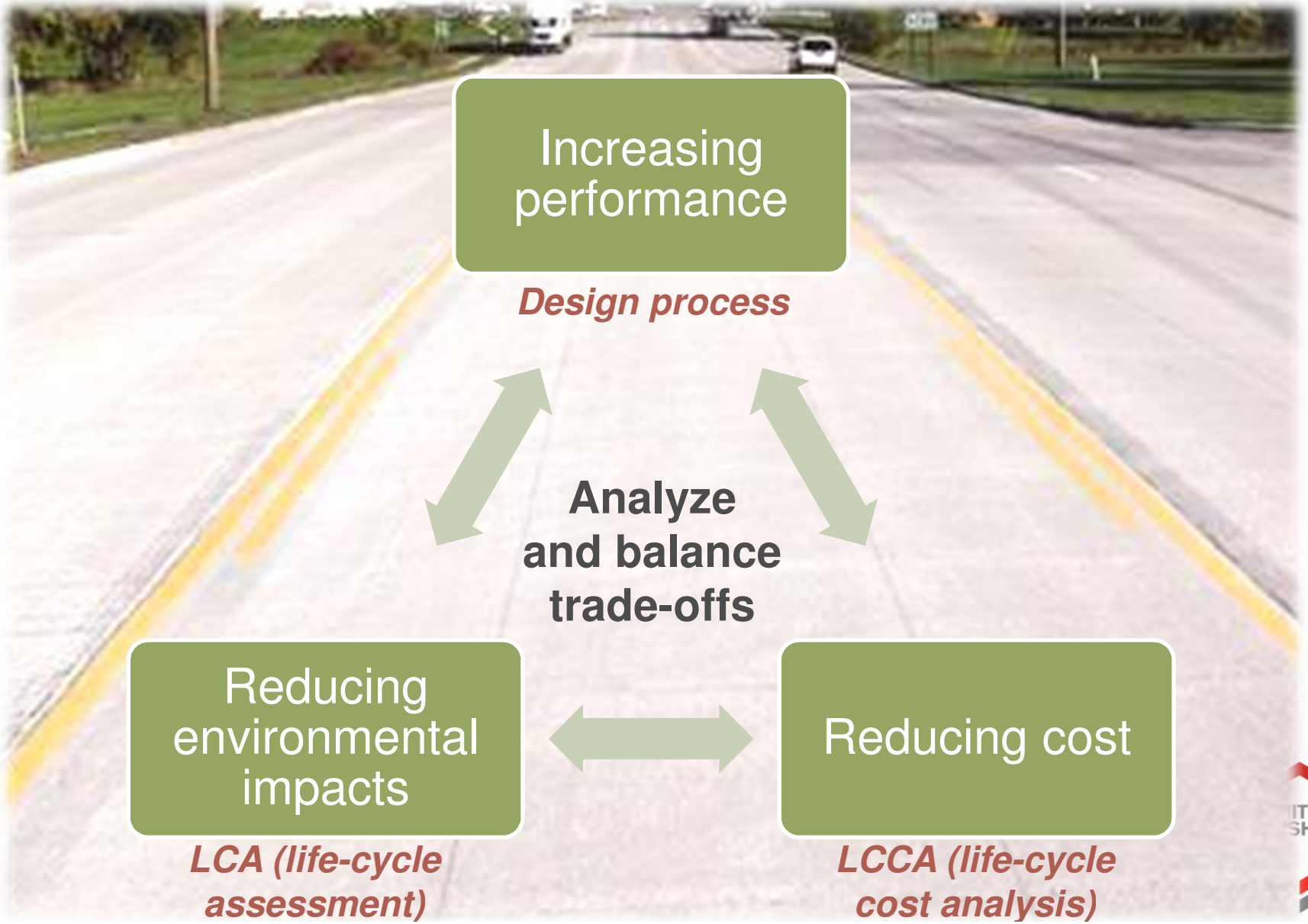
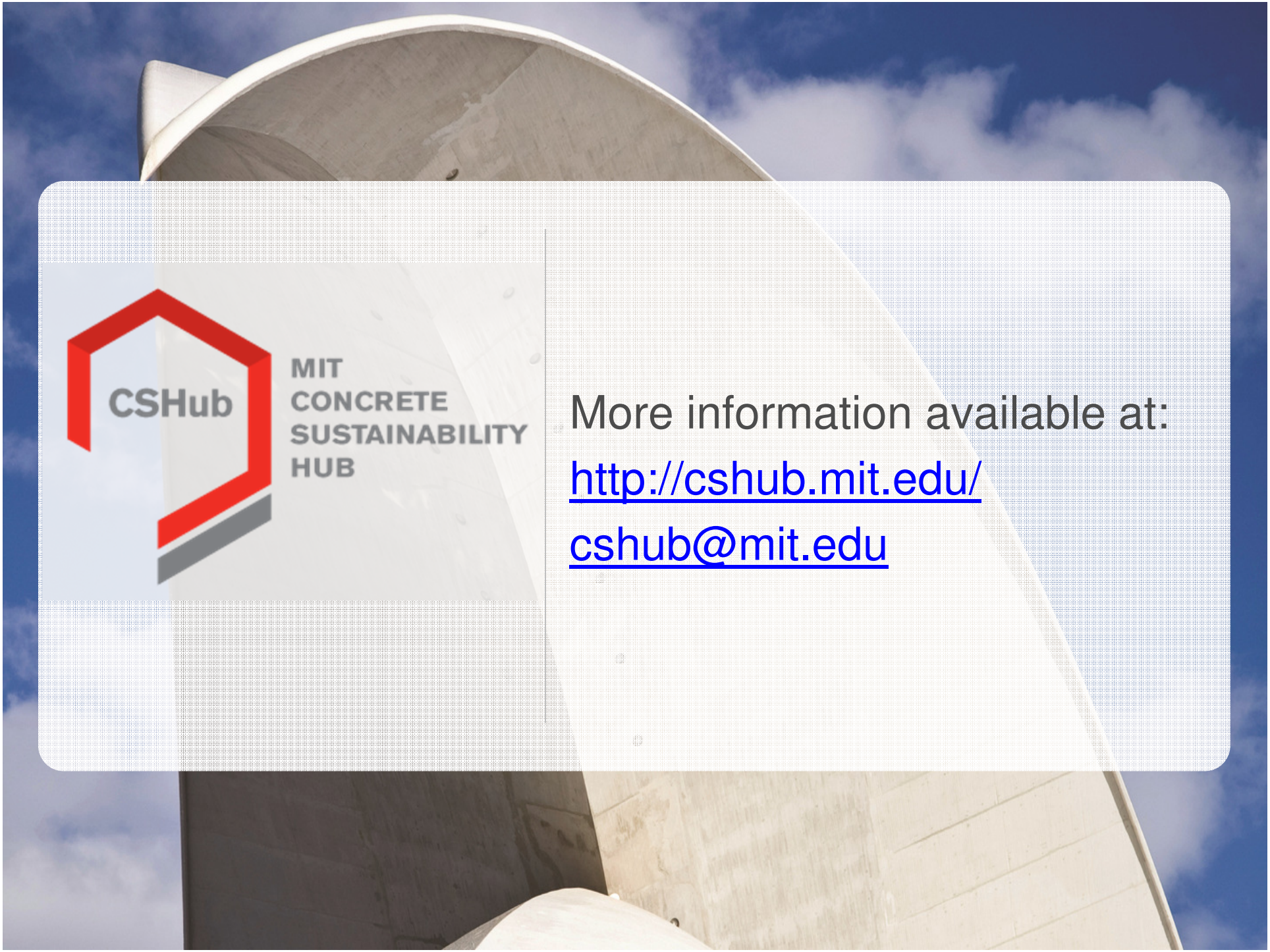
Designing sustainable infrastructure requires a life-cycle perspective





More information available at:

http://cshub.mit.edu/

cshub@mit.edu

Backup slides

Context: the US is not sufficiently investing in its ailing road system

The U.S. road system is in poor condition

Significant funding is required to fix the system

$170 billion in annual capital investment needed to improve road system
(source: FHWA)

Insufficient investments are being made

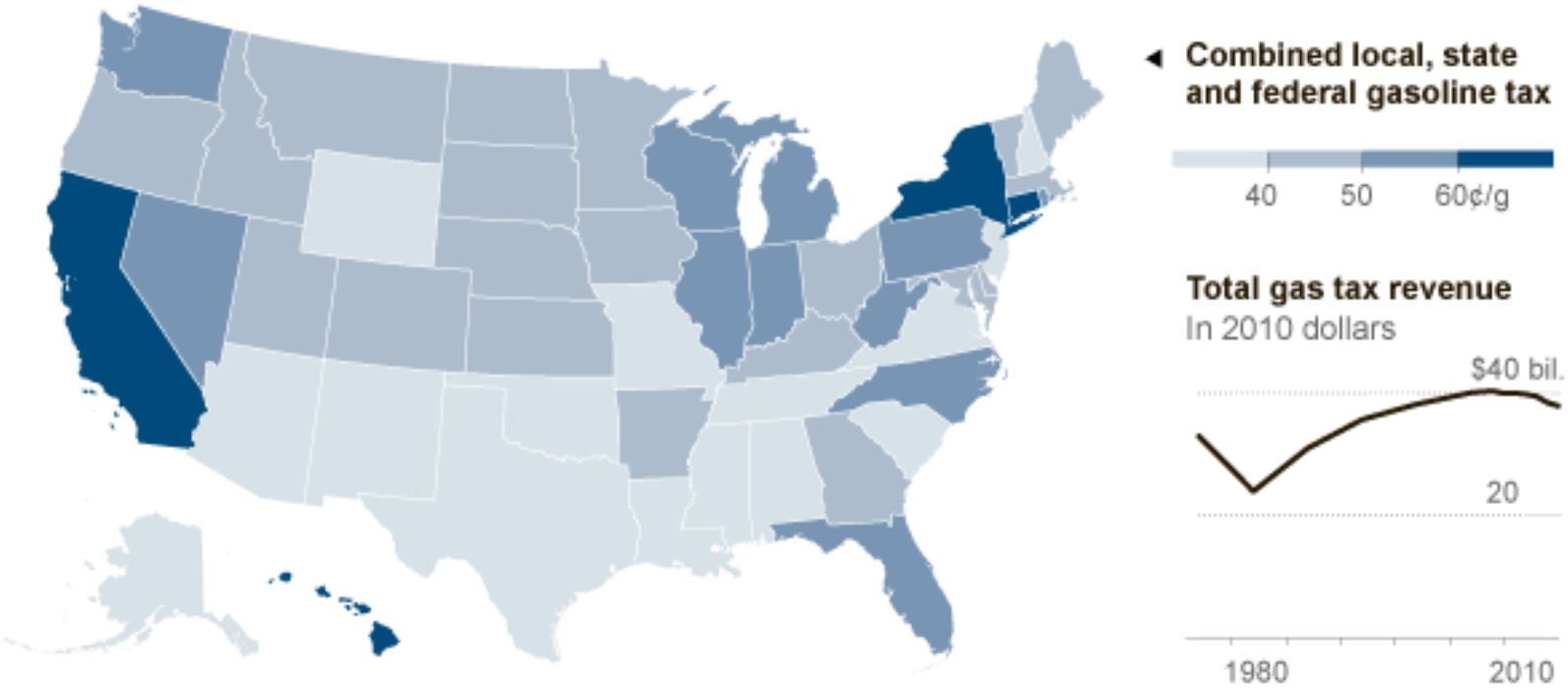
- The Highway Trust Fund is nearly bankrupt
- Funding for roads will remain constrained for the foreseeable future

Governments are being forced to do more with less

The New York Times

Feb 14, 2013

Governments Look for New Ways to Pay for Roads and Bridges



Gas Taxes Fail to Keep Up Because most states do not tie their gasoline tax to inflation, taxes are worth less over time. Increased fuel efficiency also means consumers are using less gas.

Sources: American Petroleum Institute; Tax Policy Center

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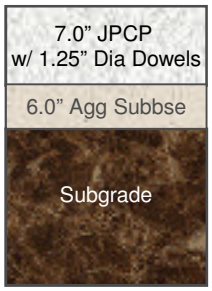
Our actions today affect the financial health of future generations

Our actions today affect the environmental health of future generations

We urgently need cost-effective solutions that maximize performance while minimizing environmental impact

CSHub created linkage between design tools and evaluation

Pavement has associated activities;
…activities translate to cost & impact



Pavement Design & Context

Pavement Performance

MEPDG

Performance-to-activity modeling

Bill – of – activities

- Material quantities
- Construction activities
- Maintenance timing
- Logistics

LCCA Model

LCA Model

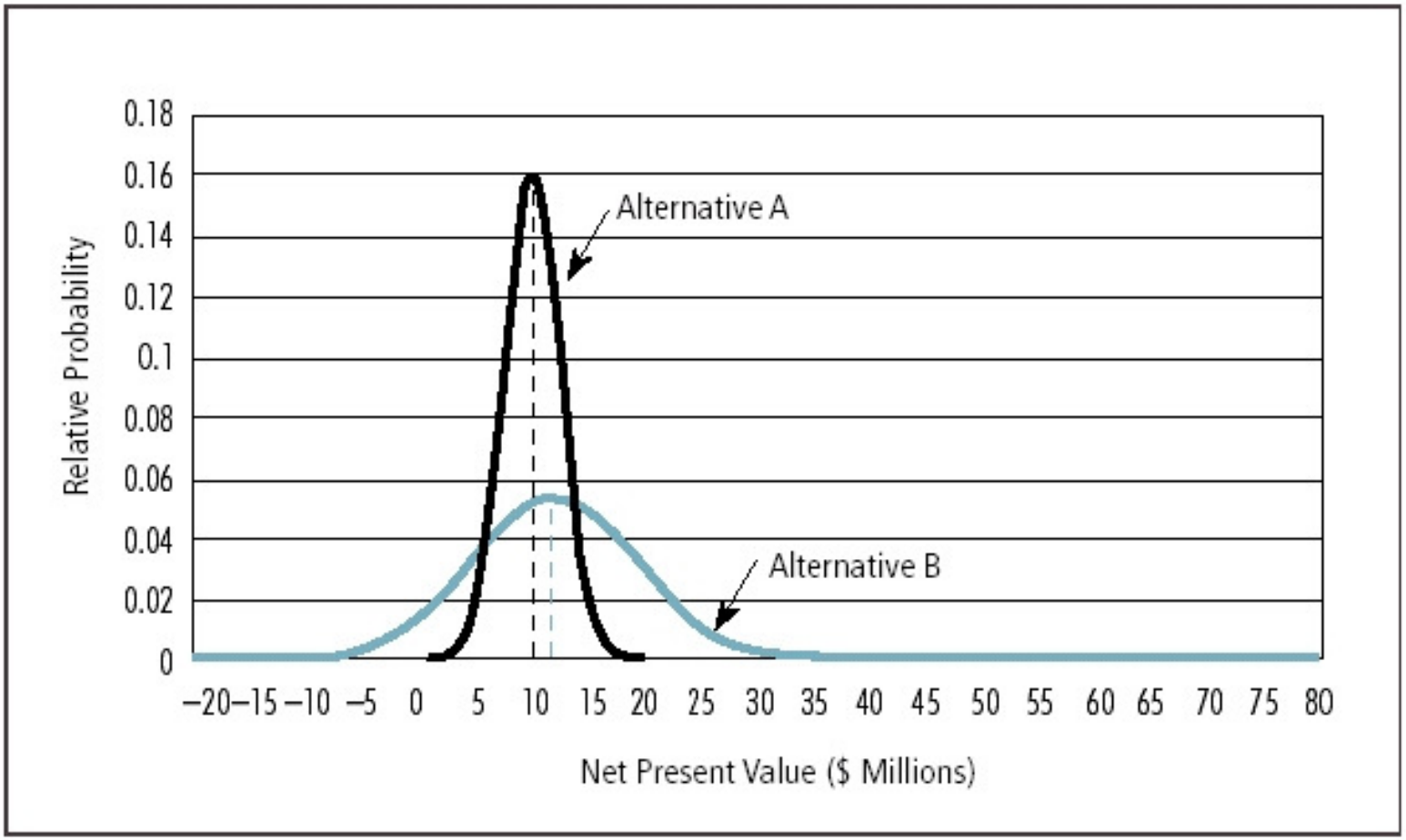
Cash flows

- Magnitude
- Timing

Life-cycle inventory

- Material & energy inflows
- Emissions outflows

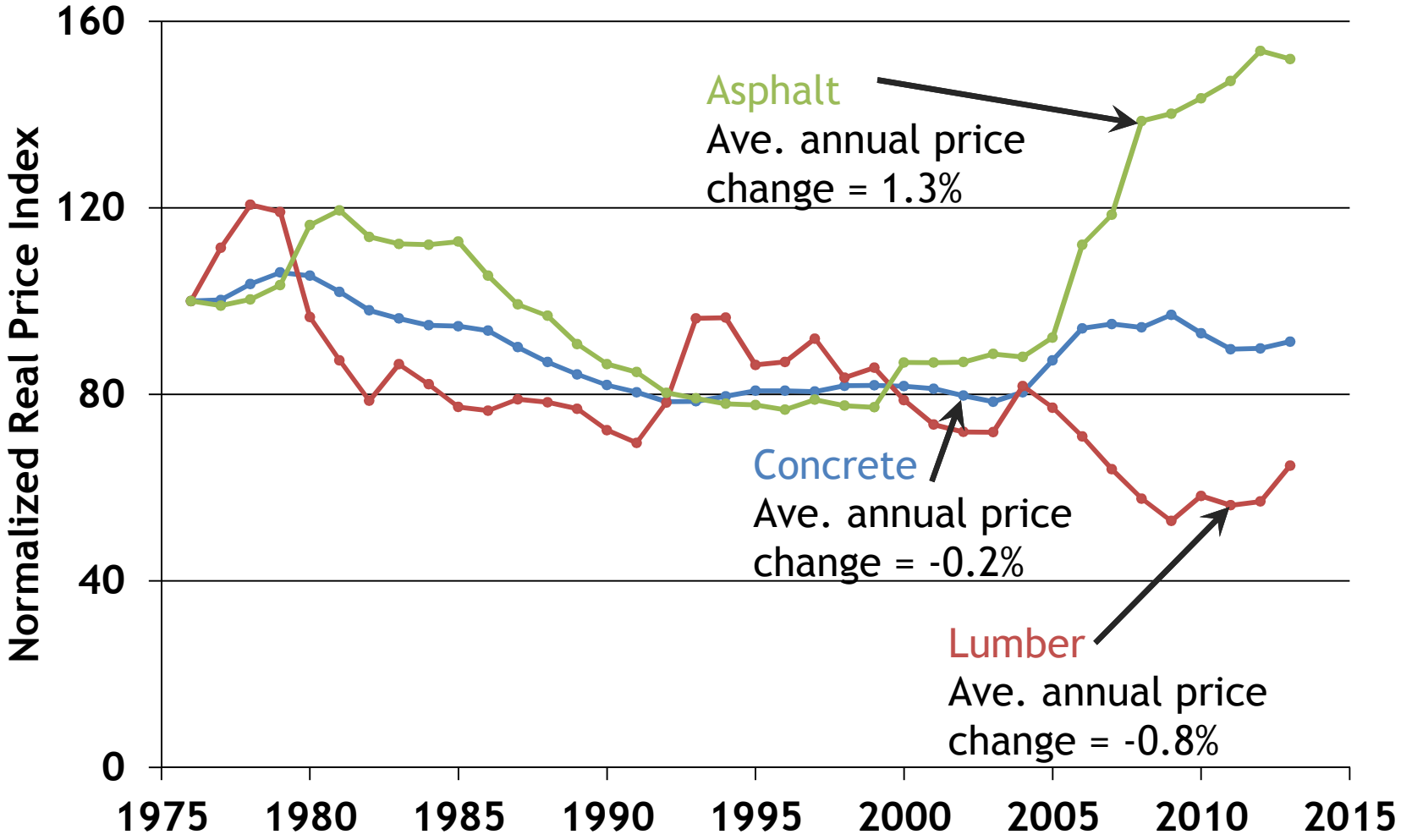
CSHub models are probabilistic



Probabilistic models incorporate uncertainty. The figure shows a range of cost outcomes for two competing project alternatives. Source: FHWA

The future is worth considering

Prices change differently for different materials

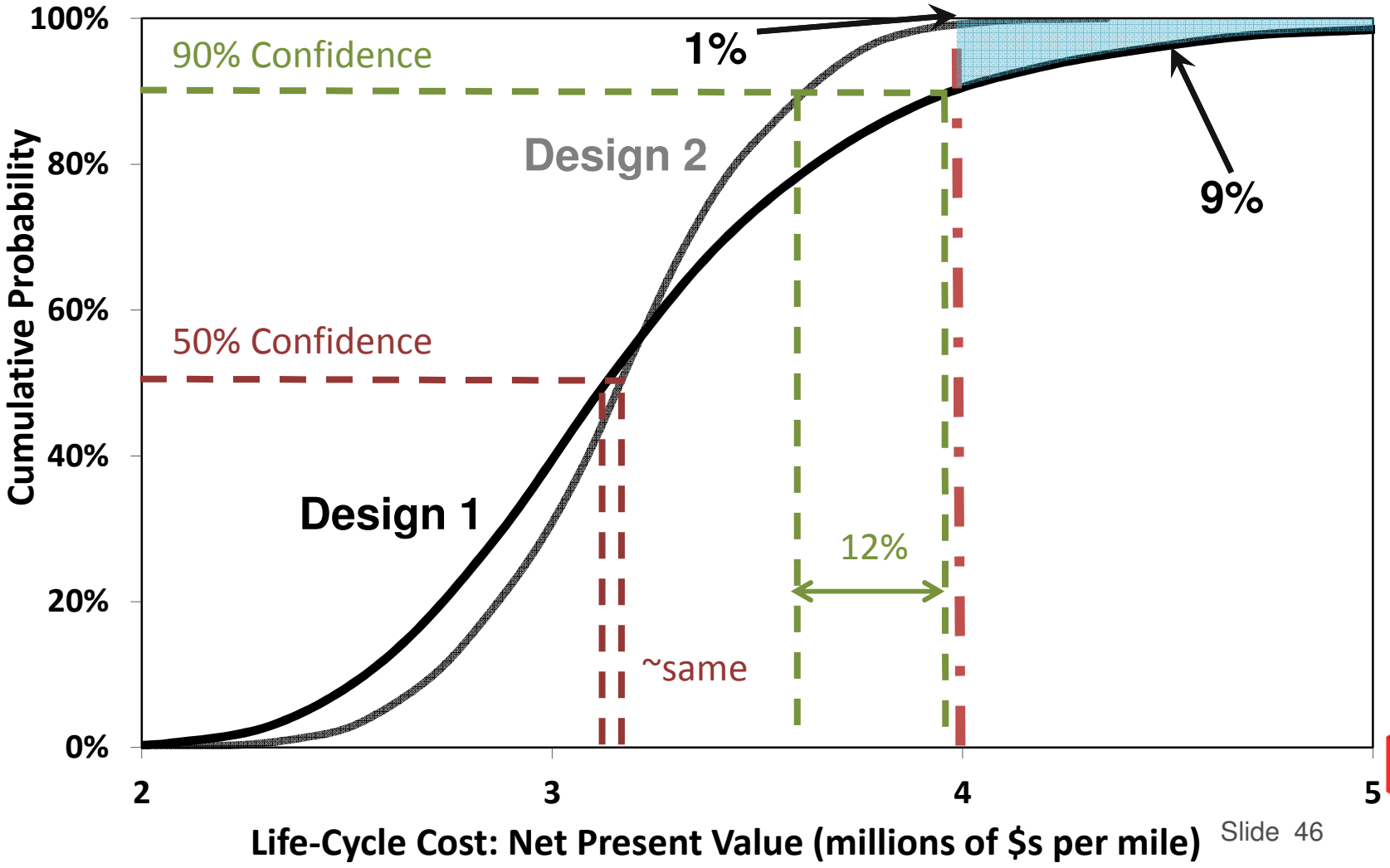


Risk matters

Higher uncertainty means higher risk

Difference between alternatives depends on risk profiles

Risk of exceeding a particular cost can be calculated



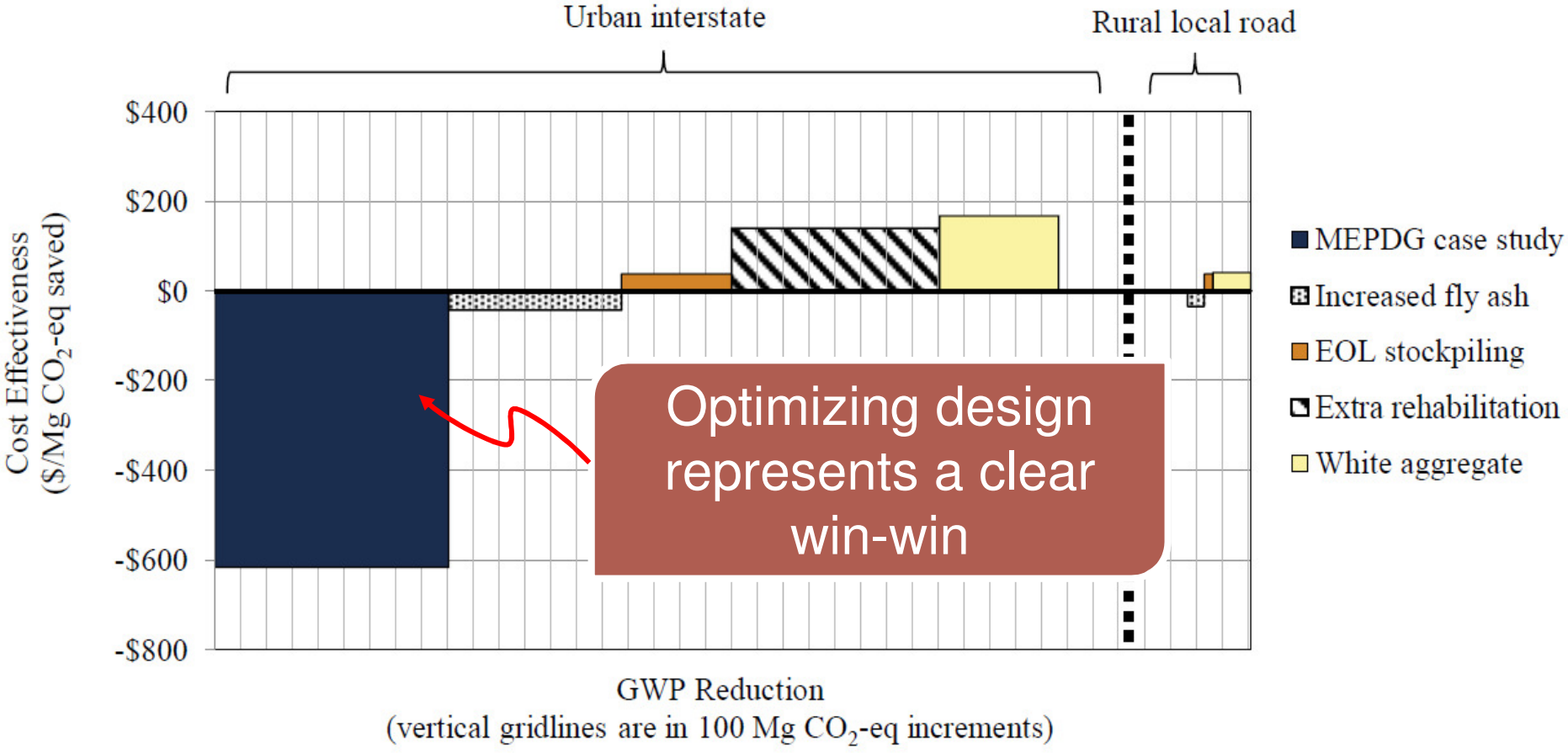
There are several opportunities for future research

- Improve models for estimating initial construction cost

- Incorporate life-cycle cost considerations into asset management programs

Large opportunities to improve exist

Pavement design optimization saves GHGs & $

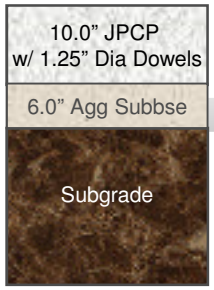


There are several opportunities for future research

- Develop context-specific models of albedo
- Explore impacts of using recycled content in pavement materials
- Identify opportunities to reduce impact using optimized designs

Opportunities for collaboration

Design Proposal & Context
Layers
Traffic
Climate



Analyze Using ME Design Principles

Develop Lifecycle Bill of Activities

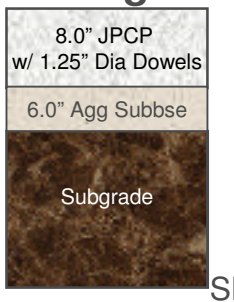
Evaluate LCCA / LCA

Adequate Performance

N

Y

Final Design



Theme of collaborative projects: Integration of LCCA and LCA into pavement and asset management decisions

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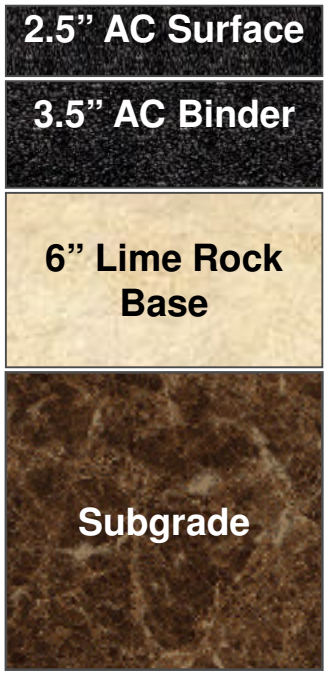
Potential collaborative research topics

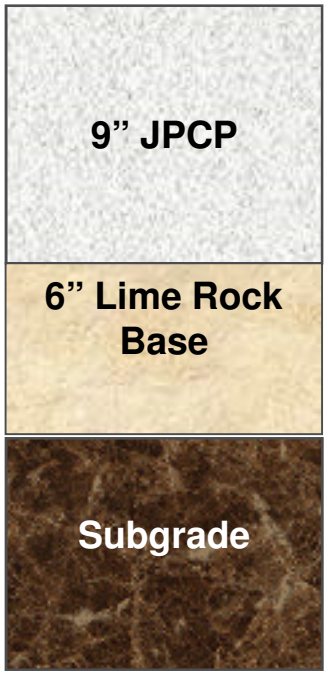
- LCCA
  - Integrating probabilistic LCCA and ME design
  - Improving cost estimation methods
- LCA
  - Integrating probabilistic LCA and ME design
  - Improving data and models used in LCA
- PVI
  - Network-level assessments of excess fuel consumption due to PVI

Case study: wet no-freeze state HW in Florida

Flexible



Rigid



Parameter	Value
AADTT two Directions	1,000 vehicles/day
Number of Total Lanes-two Directions	4
AADTT Linear Annual Increase	3%
Climate	Wet No Freeze – FL
Soil Type	A-2-4

Functional Unit:
1 center-lane mile over a 50-year analysis period

FDOT Rehabilitation Schedule

- Year 14: 2” Mill, 2.5” AC overlay
- Year 28: 2” Mill, 2.5” AC overlay
- Year 40: 2” Mill, 2,5” AC overlay
- Year 50: end of life

MEPDG Rehabilitation Schedule

- Year 20: 2” Mill, 2.5” AC overlay
- Year 37: 2” Mill, 2.5” AC overlay
- Year 50: end of life

FDOT Rehabilitation Schedule

- Year 20: Diamond Grinding, 3% Patching
- Year 35: Diamond Grinding, 5% Patching
- Year 50: end of life

MEPDG Rehabilitation Schedule

- Year 30: Diamond Grinding, 1% Patching
- Year 50: 7 years salvage

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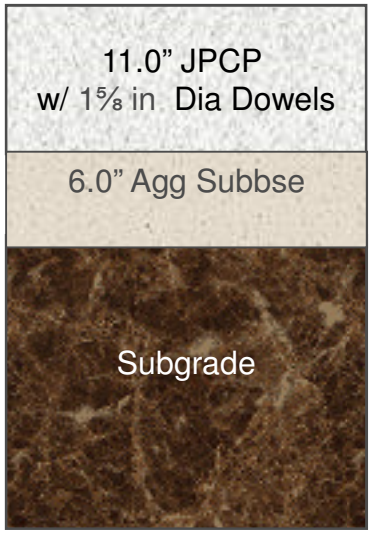
Case study: wet freeze urban interstate HW in Missouri

Flexible

Rigid



Parameter	Value
AADTT two Directions	8,000 vehicles/day
Number of Total Lanes-two Directions	6
AADTT Linear Annual Increase	3%
Climate	Wet Freeze - MO
Soil Type	A-7-6

Functional Unit:
1 center-lane mile over a 50-year analysis period

MODOT Rehabilitation Schedule

- Year 25: 2” Mill, 2” AC overlay
- Year 35: 2” Mill, 2” AC overlay
- Year 50: end of life

MODOT Rehabilitation Schedule

- Year 25: Diamond grinding & full depth patching
- Year 50: End of life

MEPDG Rehabilitation Schedule

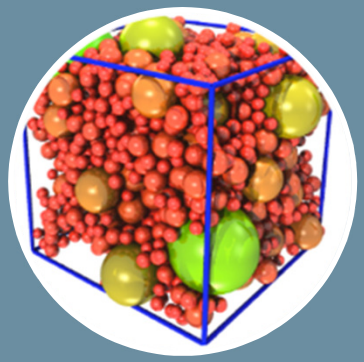
- Year 12: 2” Mill, 2” AC overlay
- Year 33: 2” Mill, 3” AC overlay
- Year 50: end of life

MEPDG Rehabilitation Schedule

- Year 30: Diamond grinding & full depth patching
- Year 50: 7 years salvage

MIT CSHub

CSHub approach is holistic and multidisciplinary



Science

Engineering

Economics

Environment

CSHub research supports pavement decisions

LCA (life-cycle assessment)

Environmental Impact

Factors in decisions

Cost

Performance

LCCA (life-cycle cost analysis)

Pavement design process