Flexible Pavement Life Cycle Assessment

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Illinois Bituminous Paving Conference

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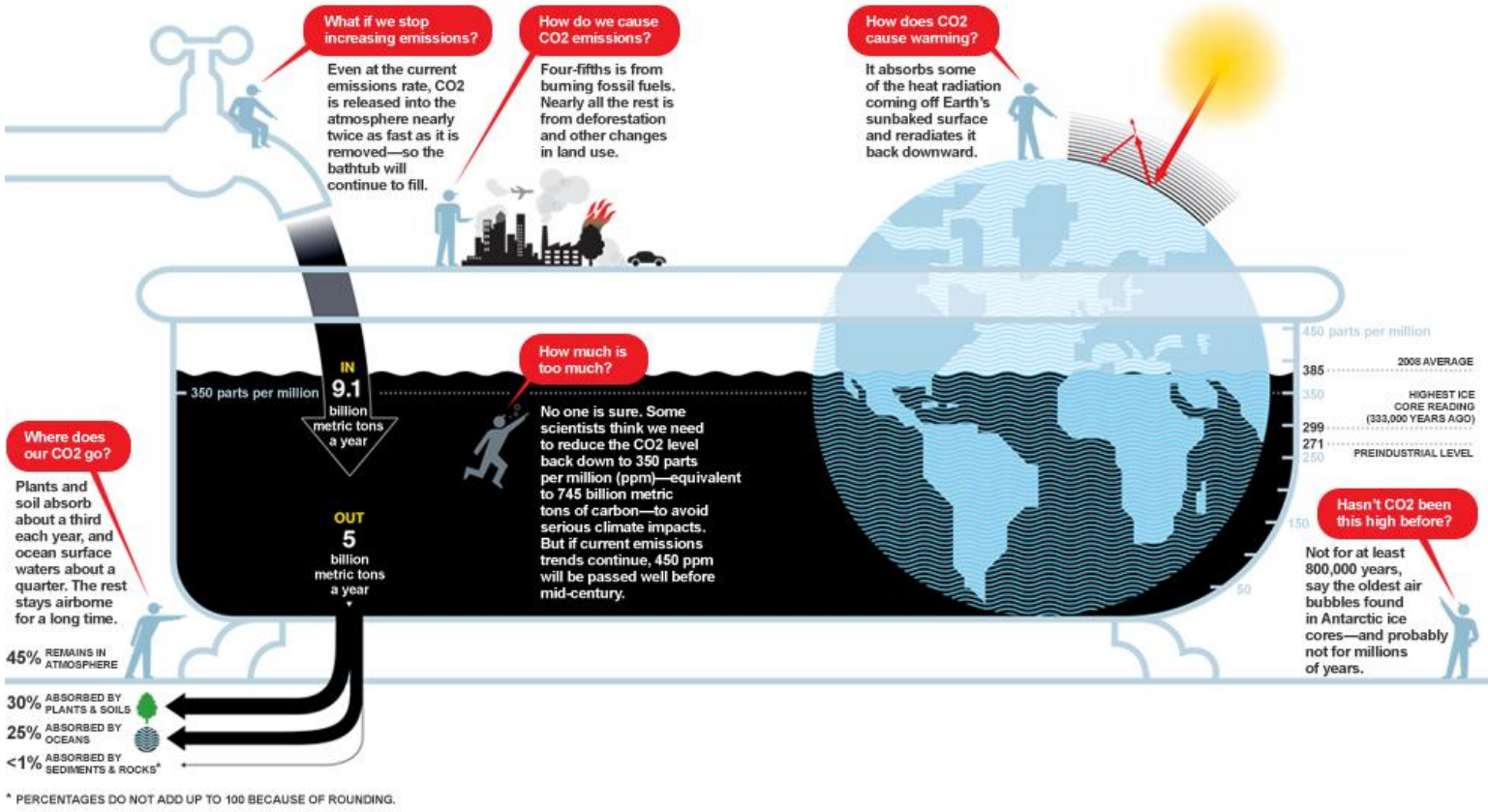
Global Climate Change

1.9°F increase in average global temperature on Earth since 1880

Global average sea level has risen 8-9 in since 1880

Climate disaster events increased from 3 to 20 per year between 1980 & 2023

Antarctica mass decreased at a rate of 142 Bn metric tons/year since 2002



Paris Agreement 2015

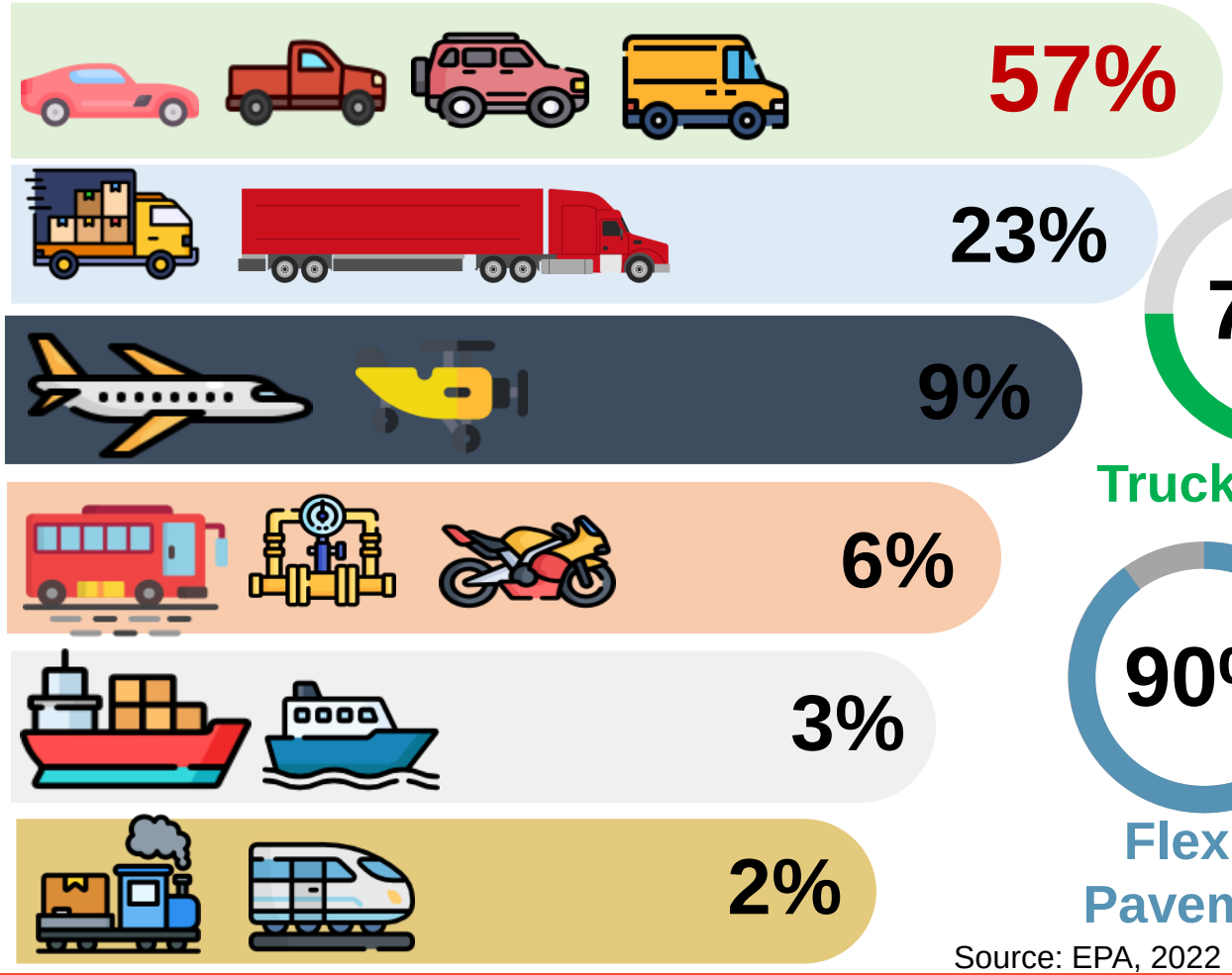
GHG emissions need to be reduced by 45% by 2030 and reach net zero by 2050

US Transportation Sector

Emissions by Economic Sector

- **Transportation (29%)**
- **Electric Power (25%)**
- **Industry (23%)**
- **Commercial & Residential (13%)**
- **Agriculture (10%)**

2022 Transportation GHG Emissions



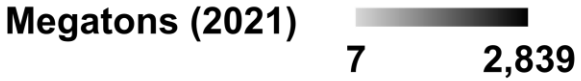
75% Truck Freight

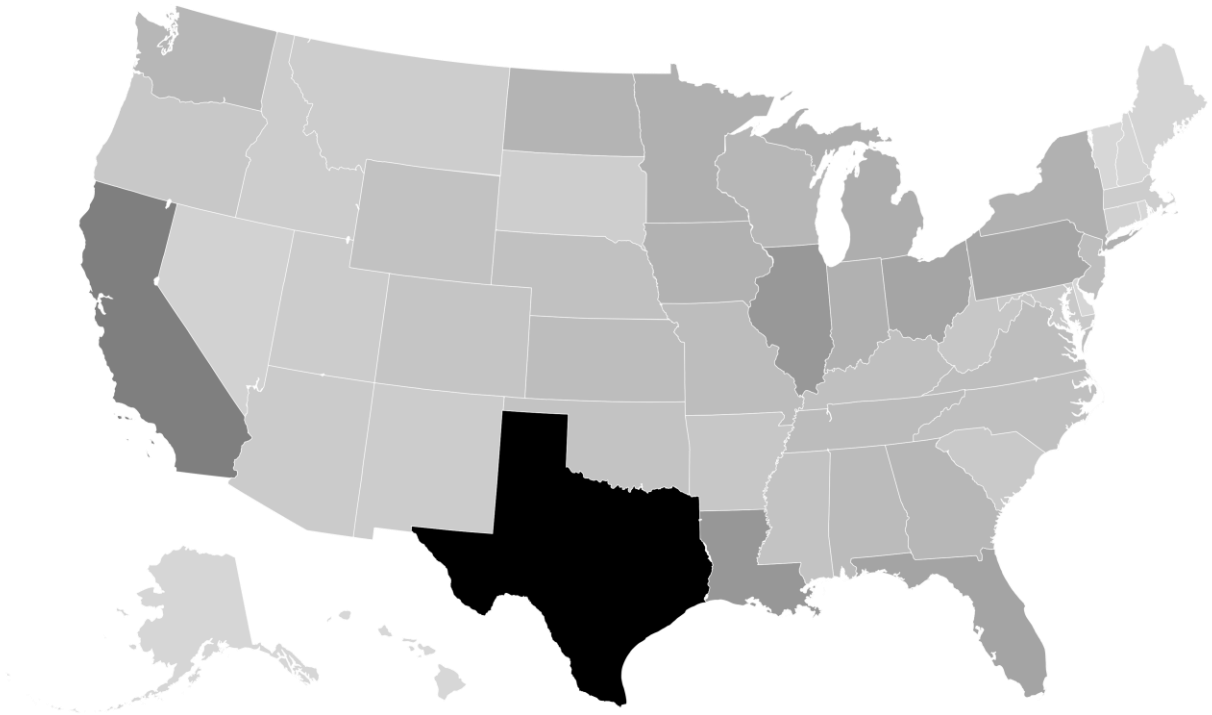
90% Flexible Pavements

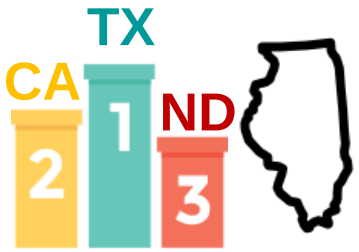
Source: EPA, 2022

Freight Flows by State

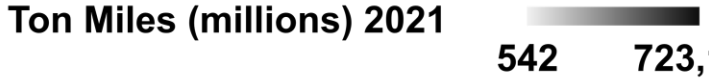
IL - freight flow of 851 megaton (Ranked 4th)

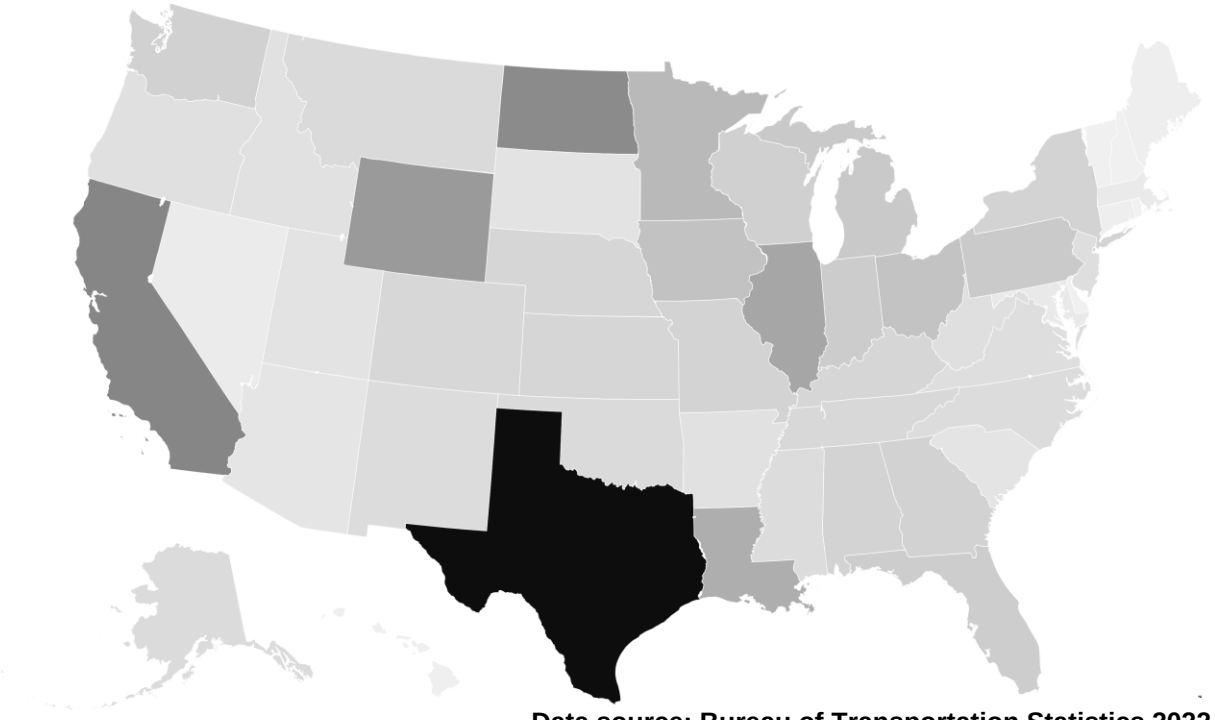






IL – 241,659 Mn ton miles (Ranked 5th)





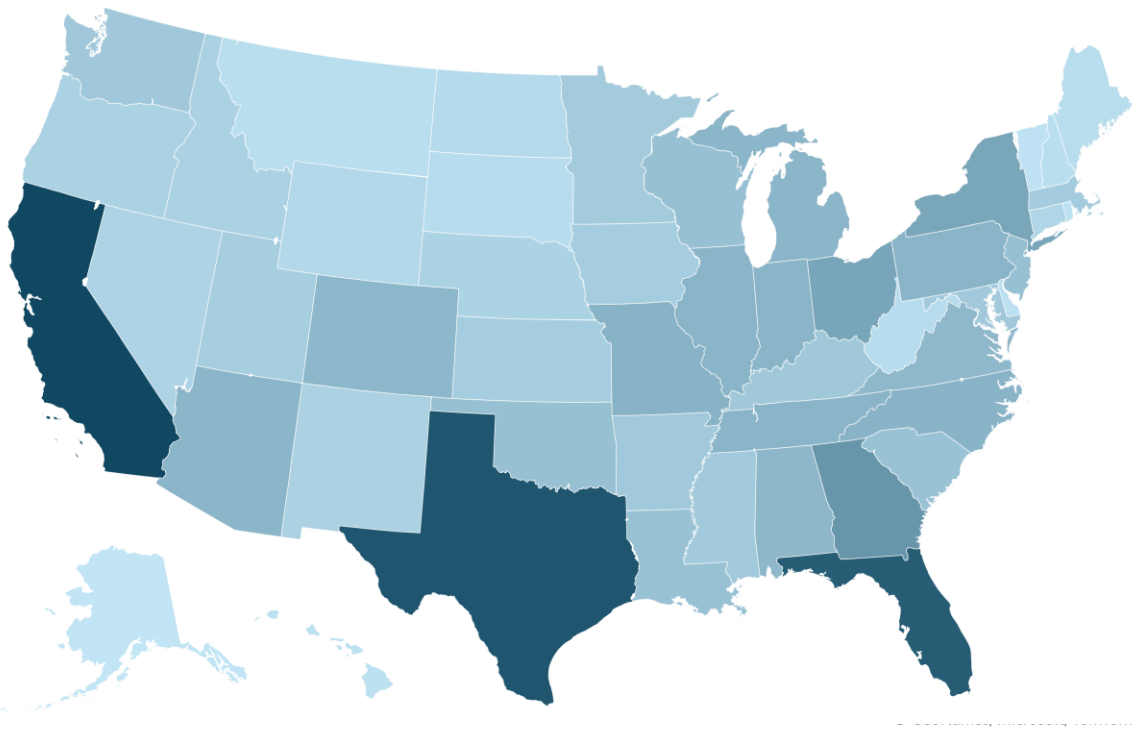
Data source: Bureau of Transportation Statistics 2022

On-road Emissions (2020)

IL emitted 53.2 megatons CO_2
(Ranked 9th)

On Road emissions (megatons)

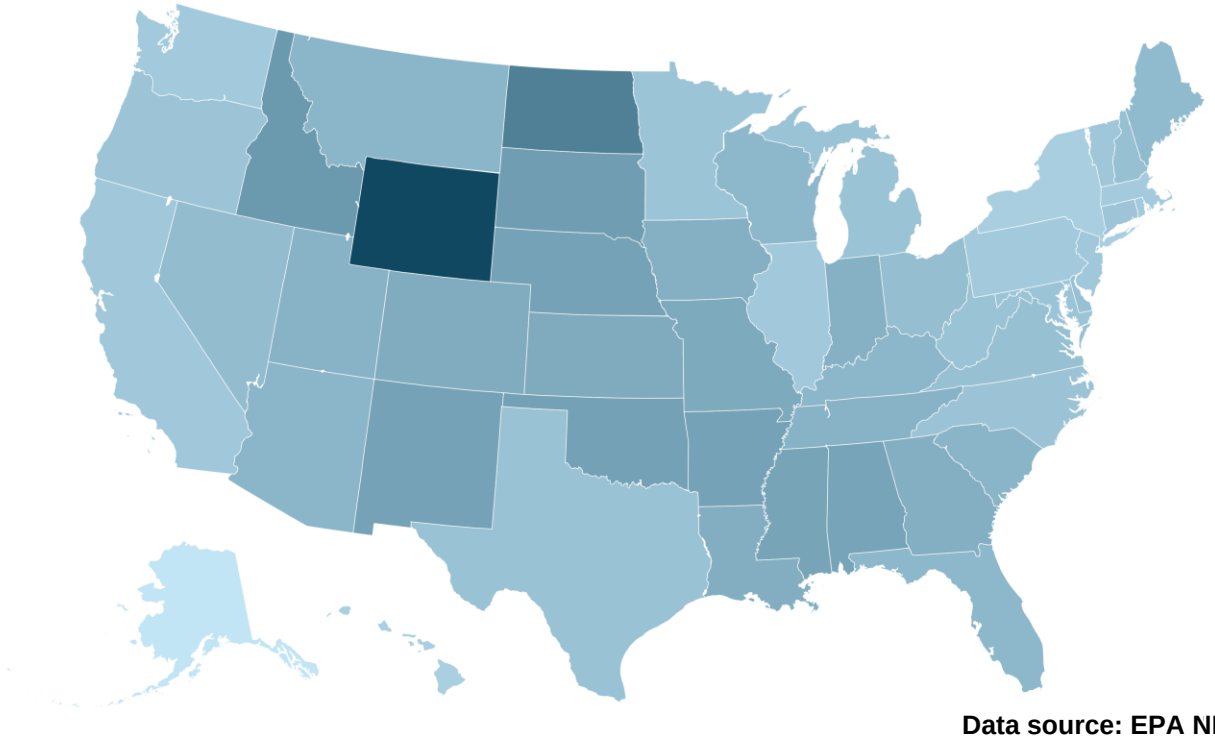
0.0 169.8



IL had 4.2 tons CO_2/capita
(Ranked 43rd)

On Road emissions (ton) / capita

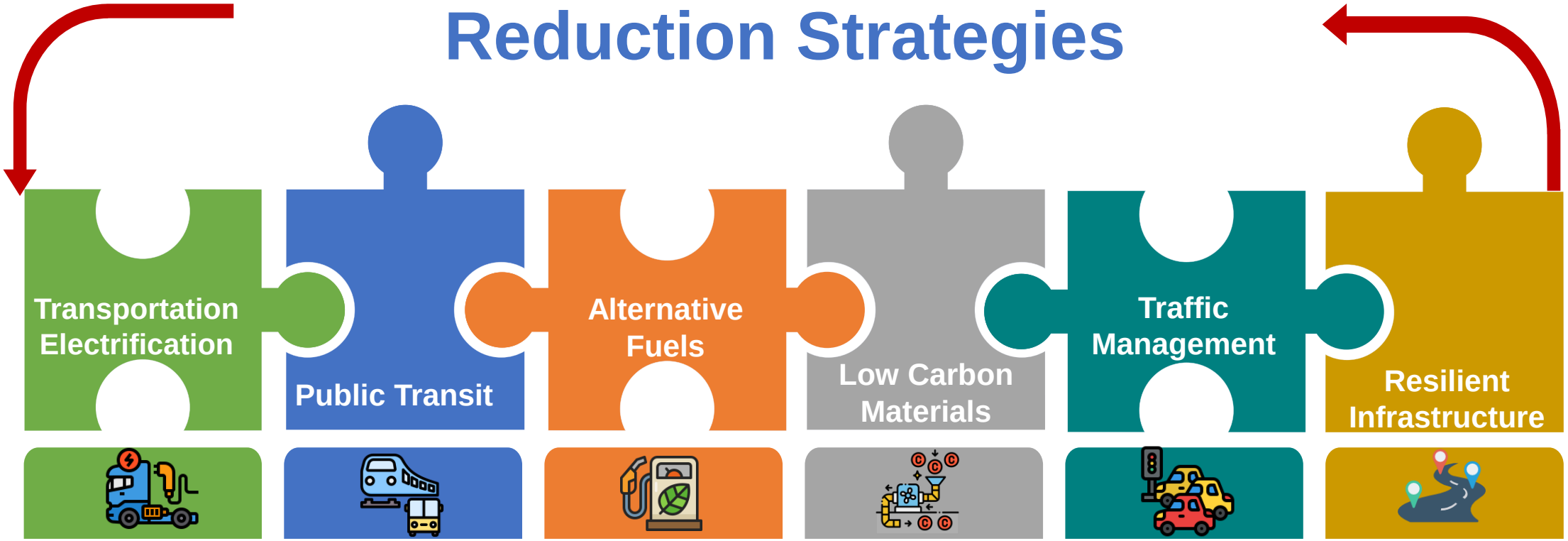
0.01 23.54



Data source: EPA NEI

Net-Zero Goal

National Highway Emission Reduction Strategies



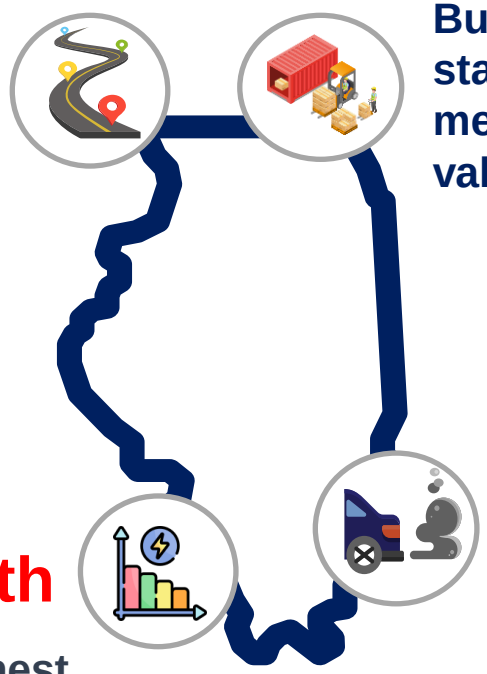
Transportation Sector in Illinois

3rd

State with highest number of total lane miles (306,658 lane mi)

3rd

Busiest freight state when measured by value



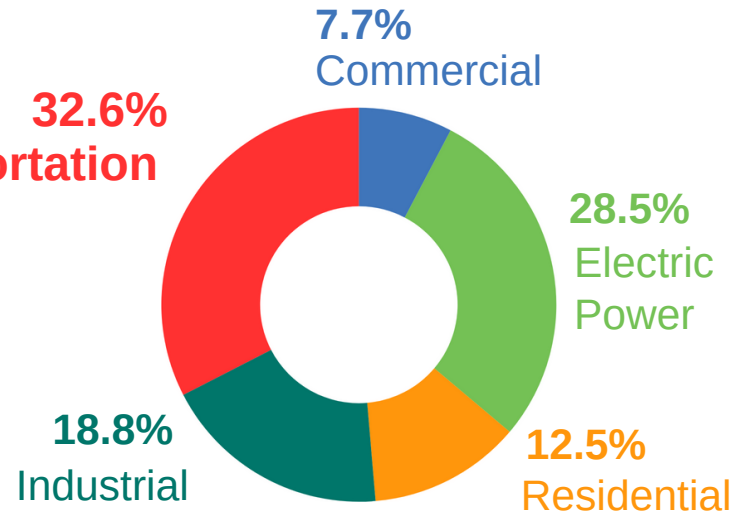
5th

State with highest amount of total energy consumption in the transportation sector

28th

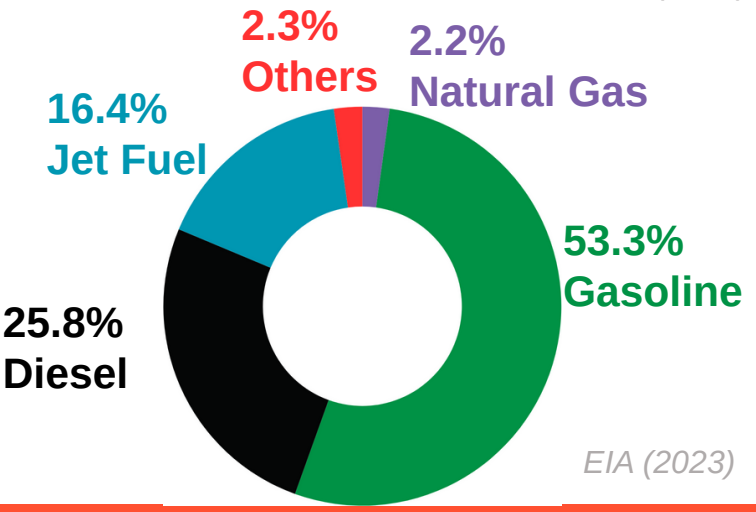
Highest per capita energy-related carbon dioxide emissions by state

Energy Use per Sector



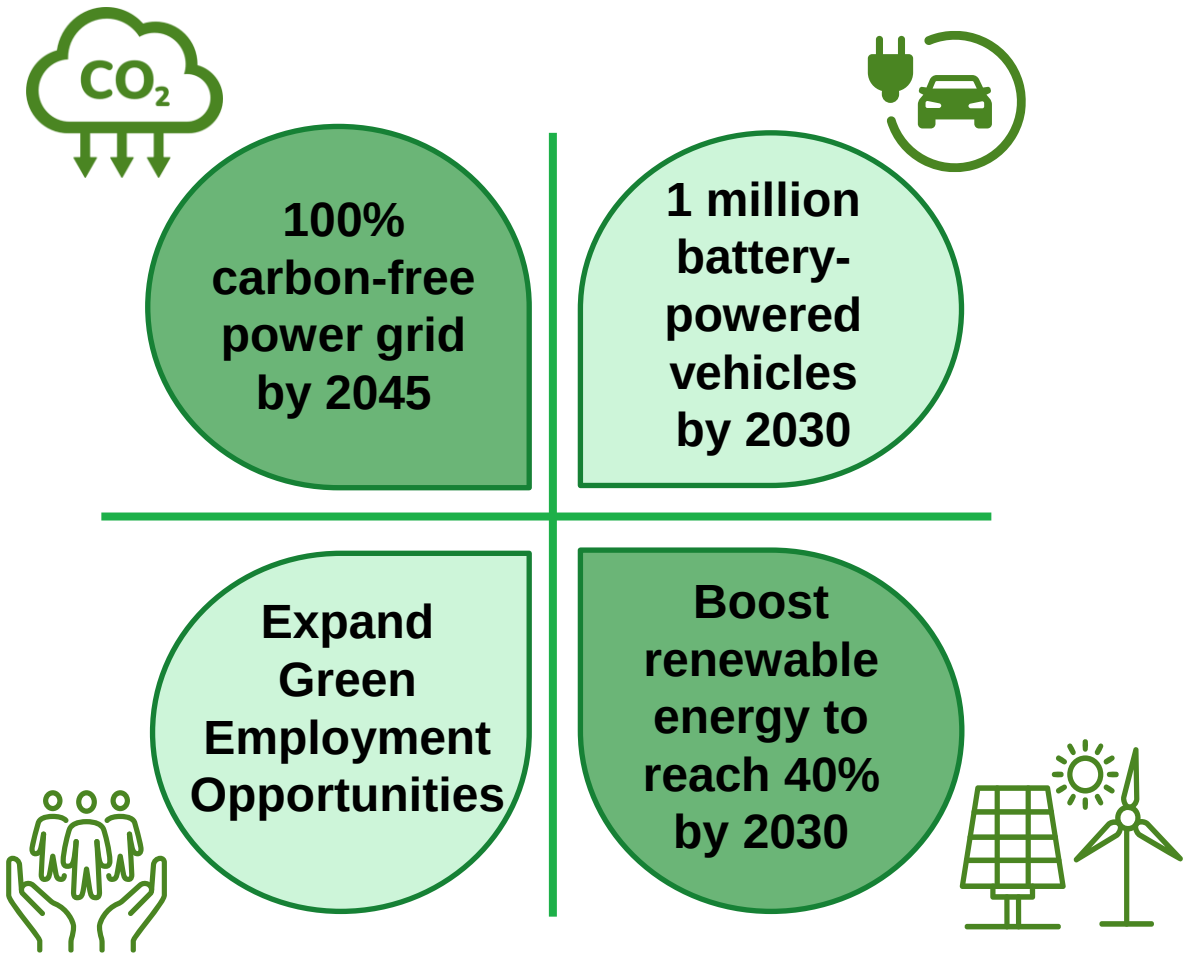
EIA (2023)

Transportation Sector Energy Consumption

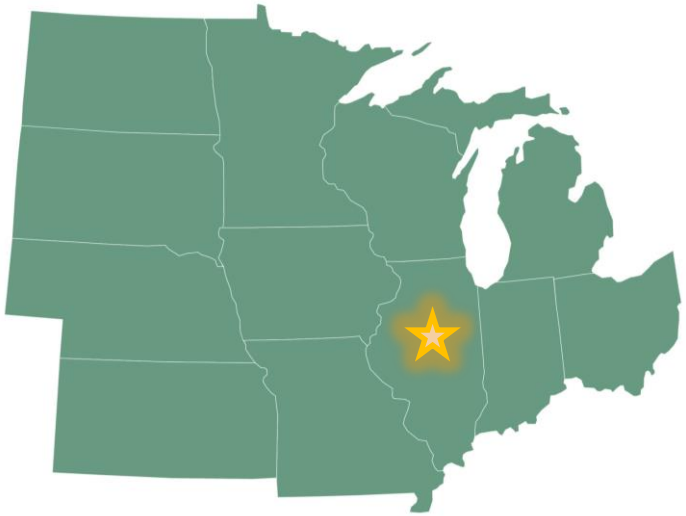


EIA (2023)

Carbon Reduction Strategy – Illinois



Illinois is the first Midwest state to mandate carbon-free power

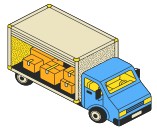


Up to $4,000 rebates for customers who buy electric vehicles

$148.6 Mn NEVI funding

Pavement Sustainability:
Life Cycle Assessment

A Look into the Future (2050)

50% 

increase in freight weight

15% 

increase in total vehicle mile travelled

125% 

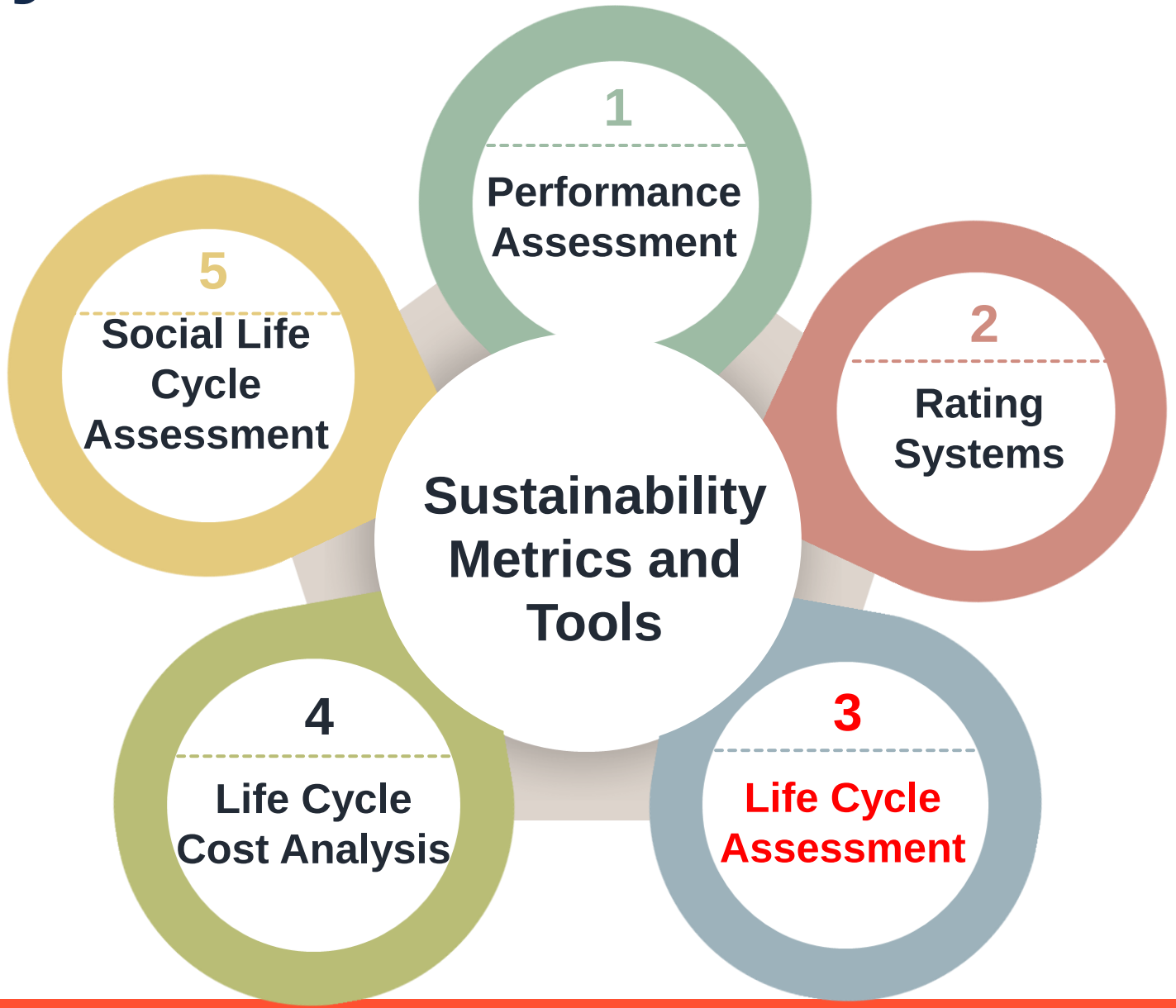
increase in airport operations

12%

increase in population

Sustainability Metrics and Tools

The Three Pillars of Sustainability



Pavement Life Cycle Stages

Material

- Raw material extraction
- Material production

Construction

- Equipment activities
- Traffic delay

Use

- Roughness
- Texture
- Deflection

Maintenance

- Material extraction
- Material production
- Construction activities

End-of-Life

- Onsite/Offsite Recycling
- Landfilling

Asphalt Binder

Crude Oil → **Oil Extraction** → **Flaring** → **Refining** → **Transportation** → **Blending and Storage** → **Asphalt Pavement**

Asphalt Binder in the U.S.

2.8 *million miles* **paved roads in the U.S.**

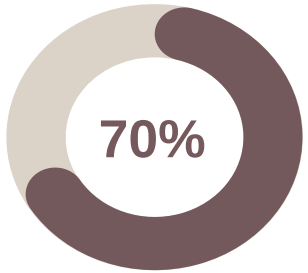
94 *percent* **are surfaced with AC**

420 *million tons* **of AC mixtures produced in 2019**

Asphalt Binder Environmental Impacts

Binder Content (% by wt.)

Contribution to GWP in material stage



Al-Qadi et al., 2015

1 kg virgin asphalt binder: **0.637 kg** CO_2-eq

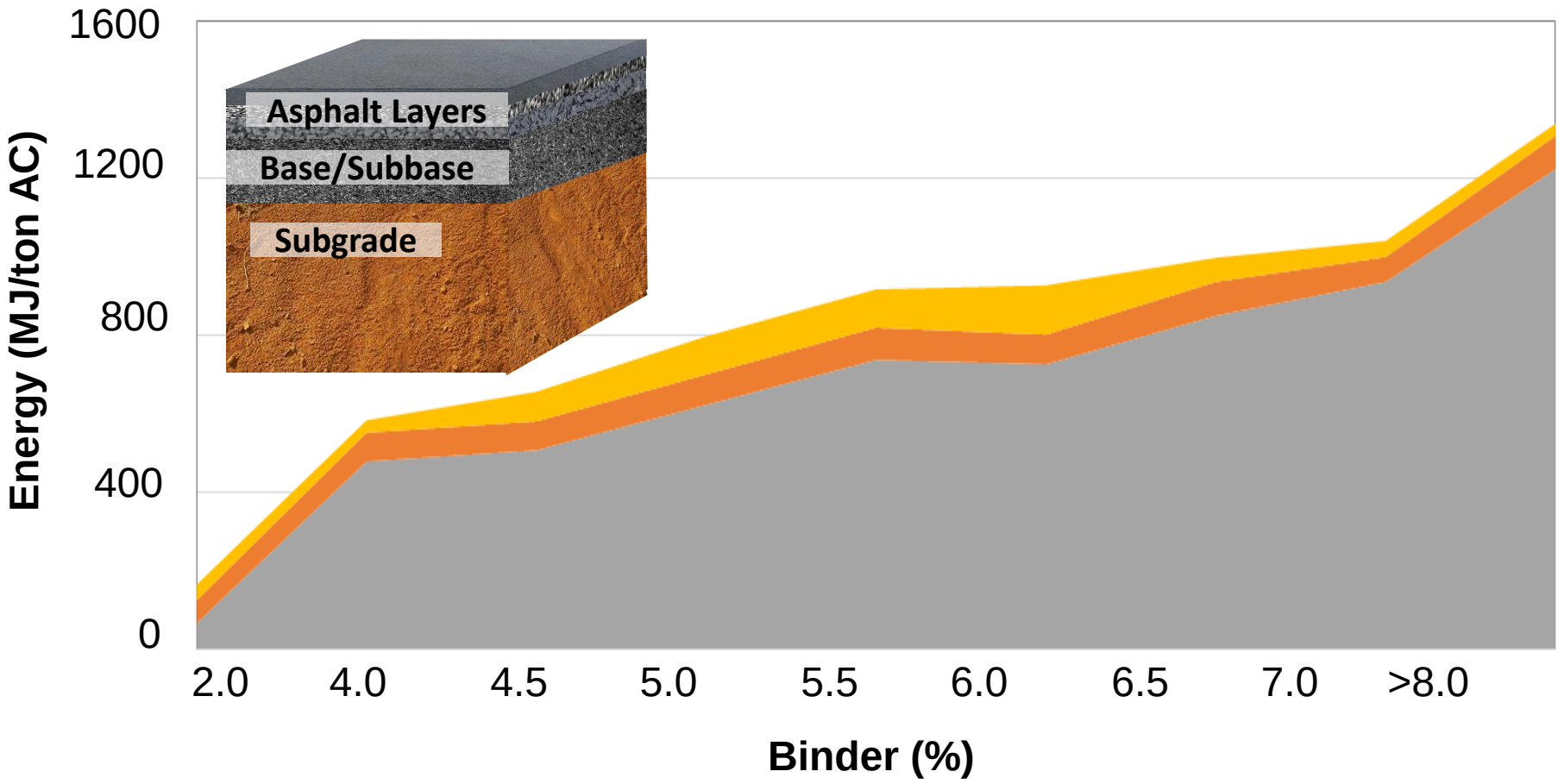
2019 asphalt binder production: **16 million tons** CO_2-eq

Significant contribution to GWP

Wildnauer et al. 2019

Contribution of Binder in HMA

Energy Consumption with Increasing Binder



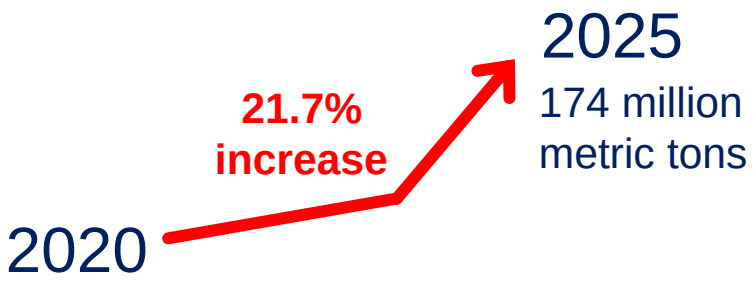
Transportation

Other Materials

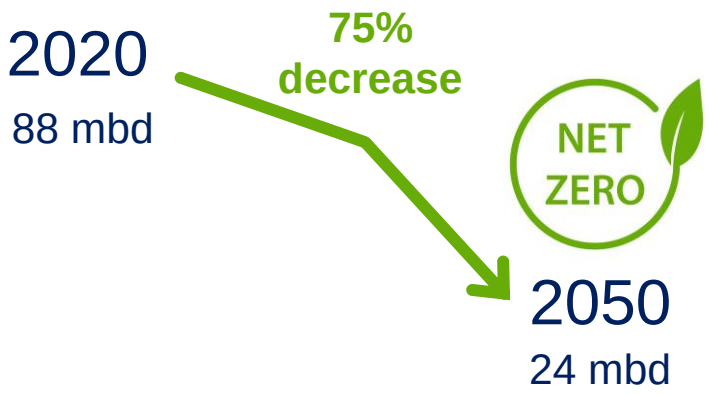
Binder (40-91%)

Current Challenges

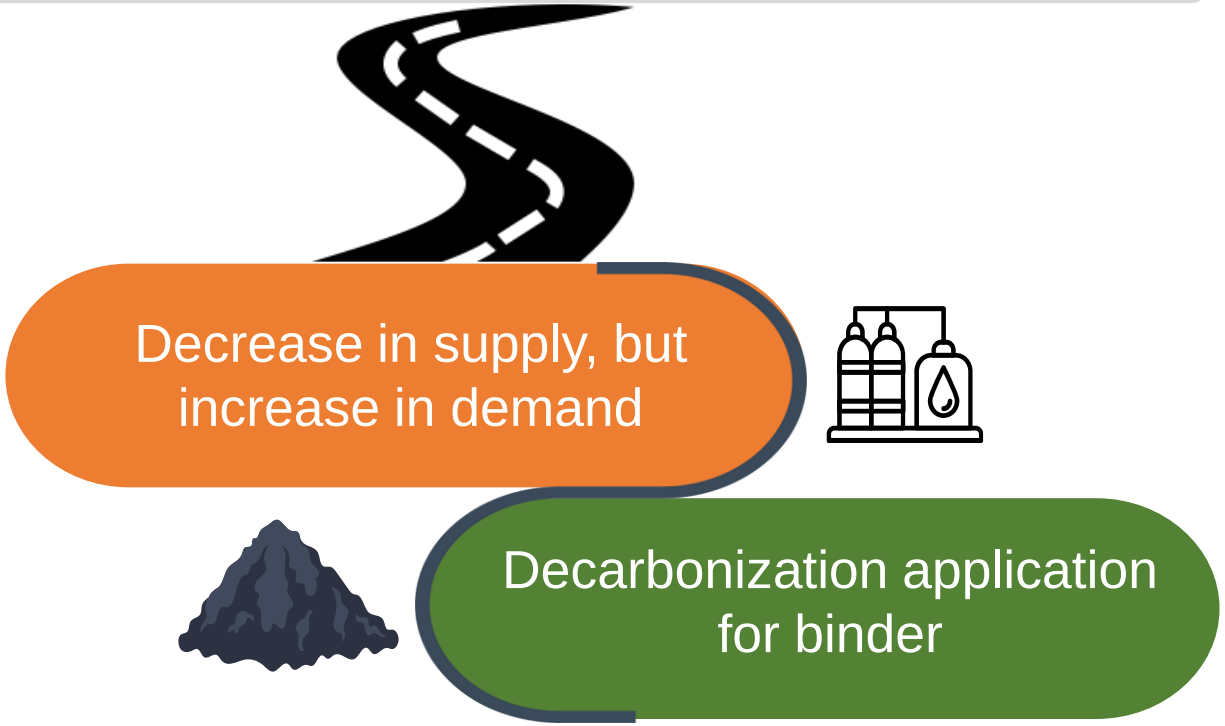
Asphalt Binder Annual Consumption



Petroleum Demand



Shift in Asphalt Binder Supply Chain

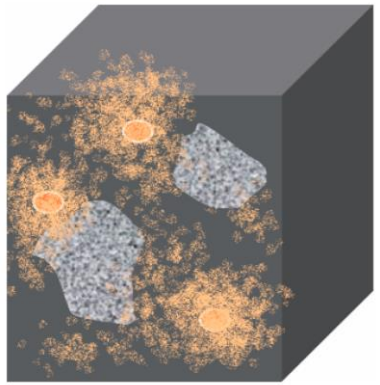


Pavement Life Cycle

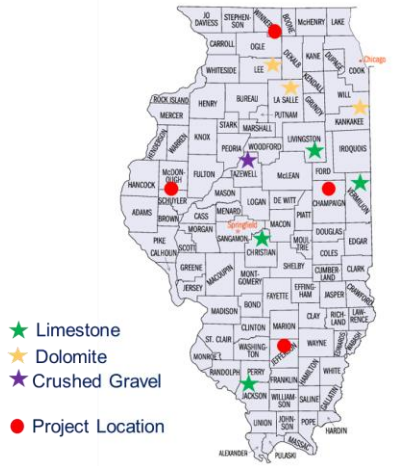
Material

Recycled Materials

Self-healing Materials

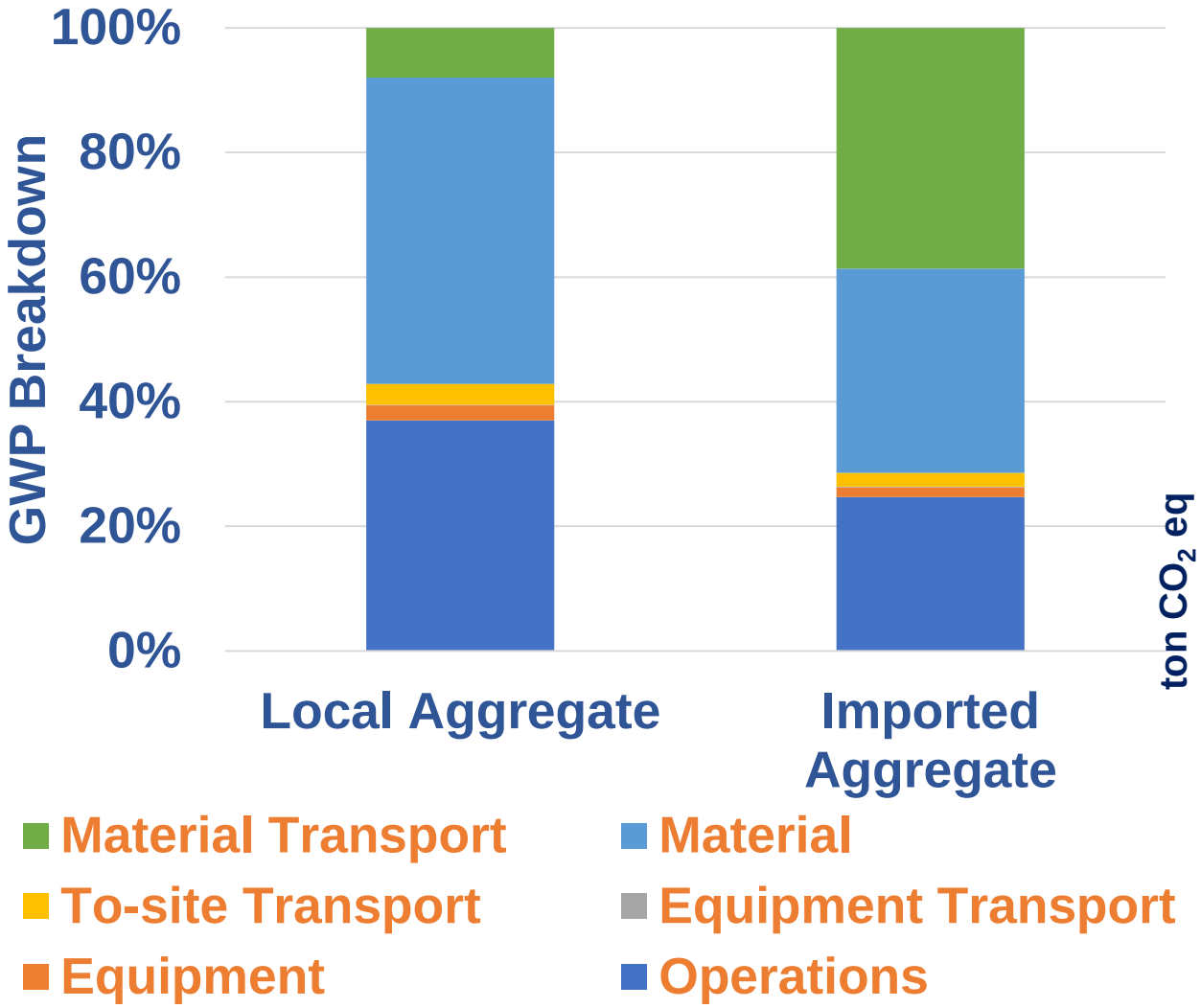


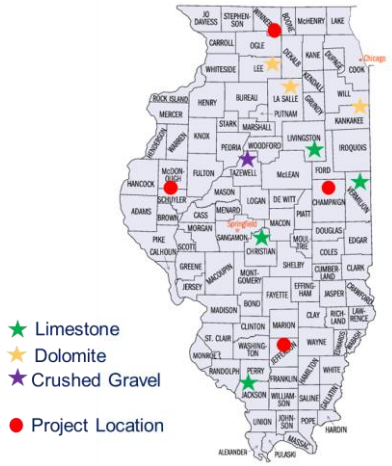
Local Materials

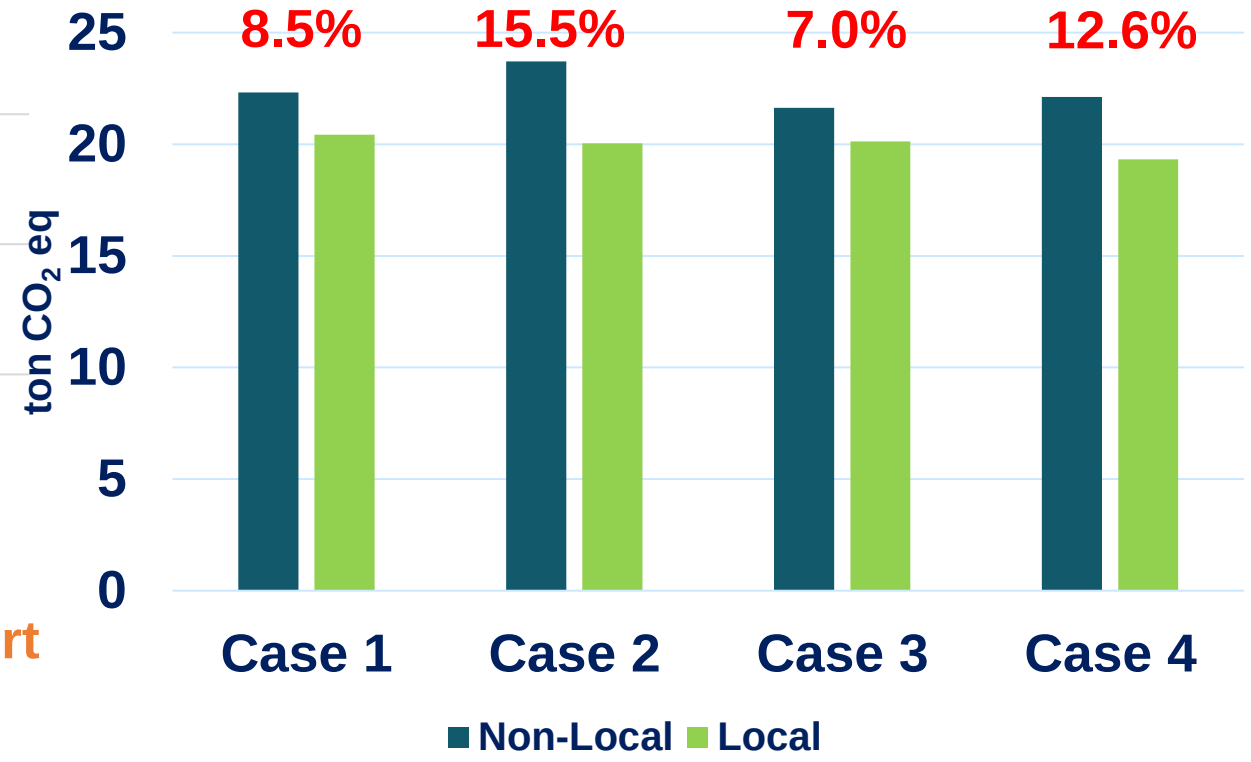


Bio-Based Materials

SMA with Local Aggregates





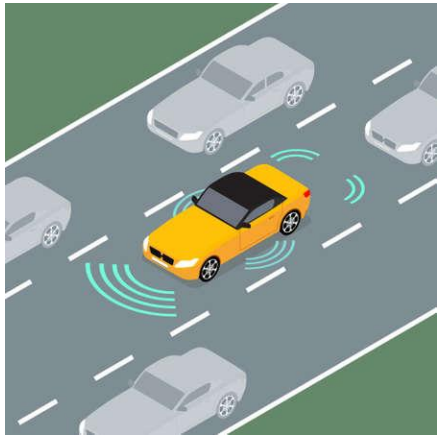


Pavement Life Cycle

Real-time Construction Density

Construction

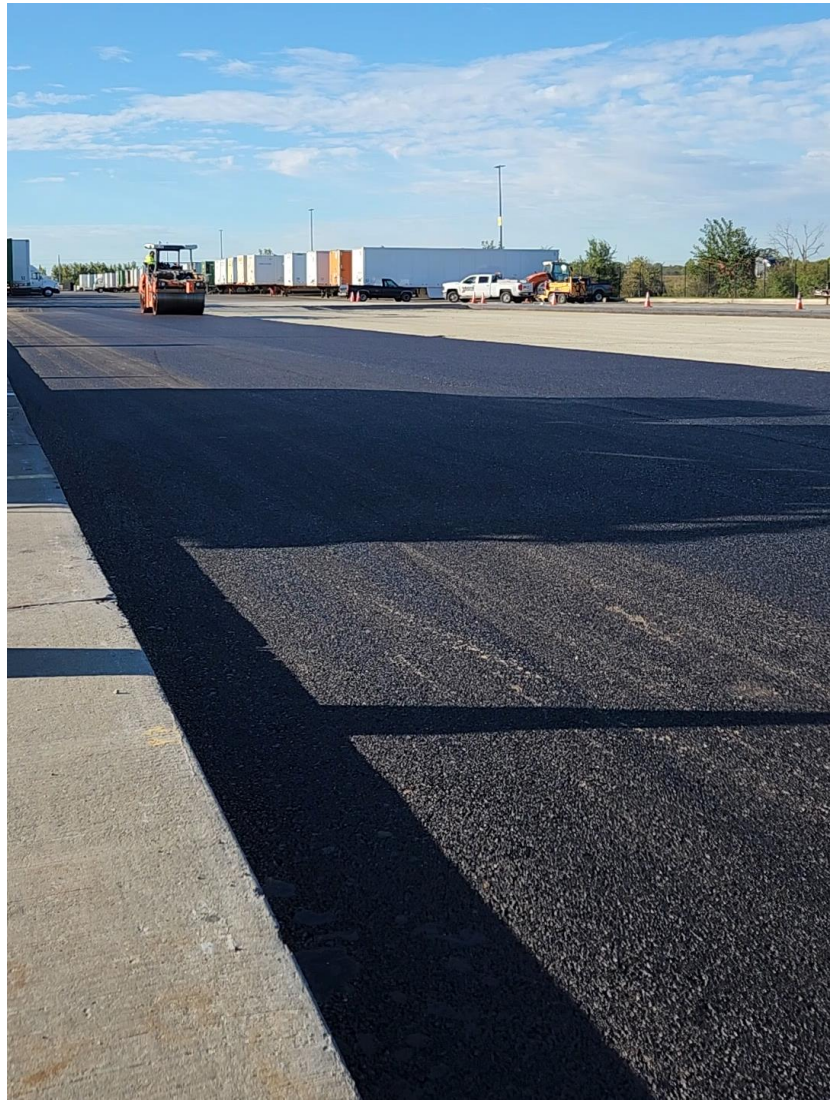
Passive Sensing

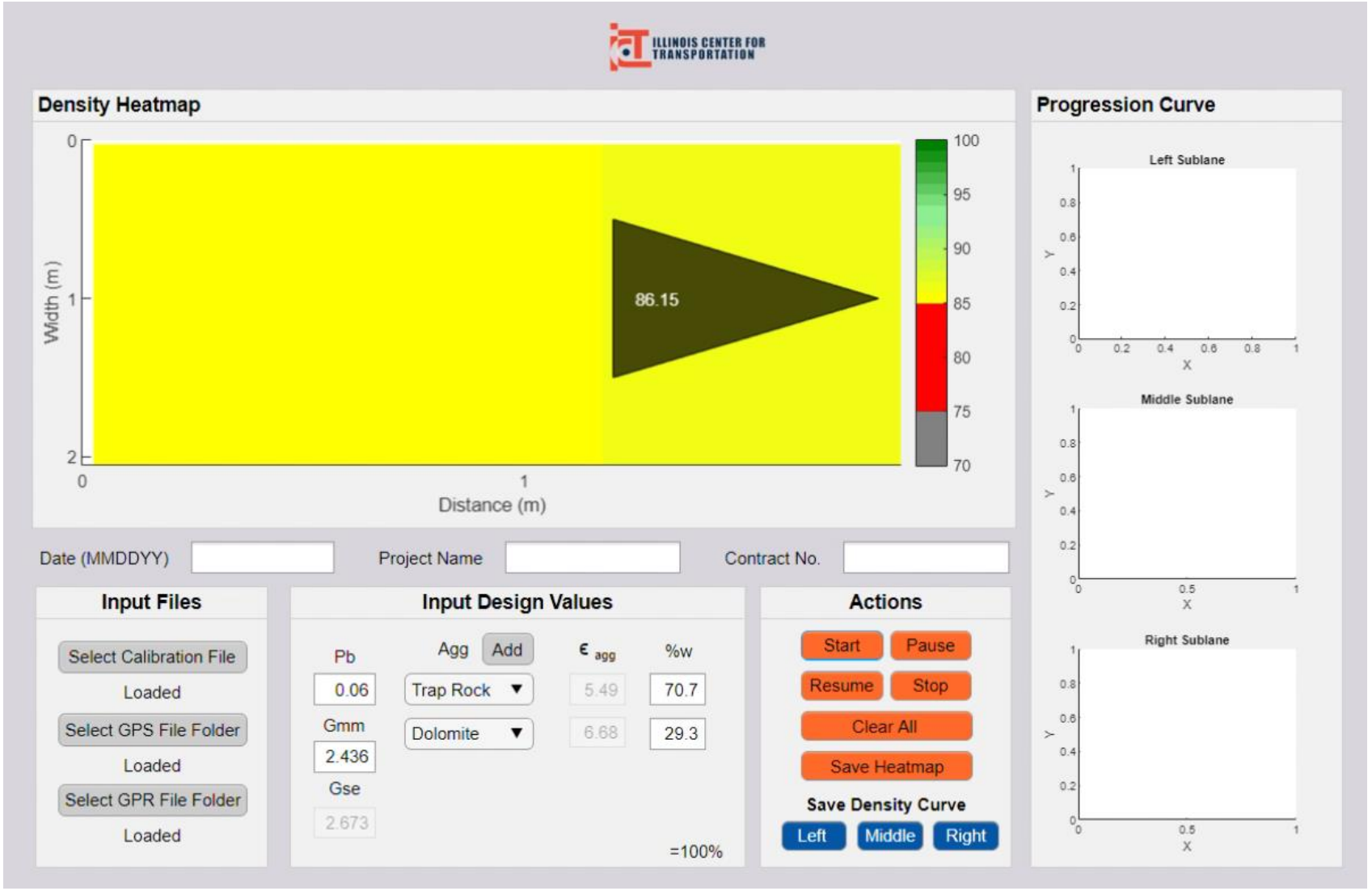


Quality Assurance

Sustainable Construction Practices

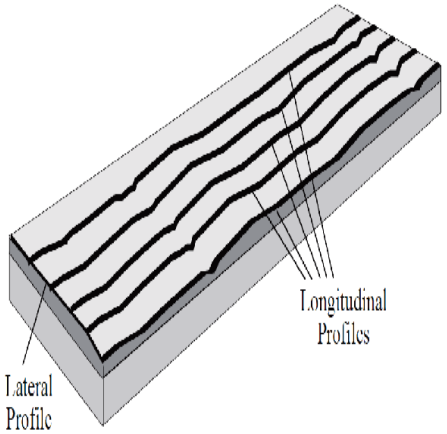
Real-Time Density during Construction





Pavement Life Cycle

Roughness and Texture



Truck Platooning

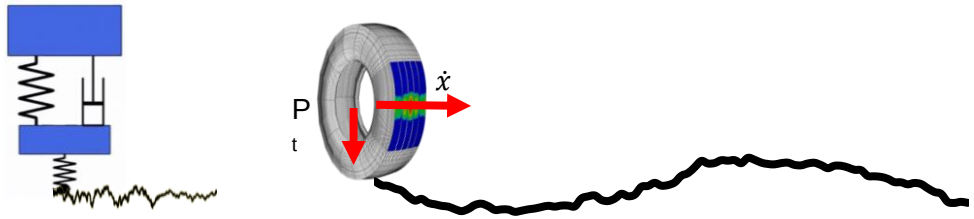
Use

Electric Trucks

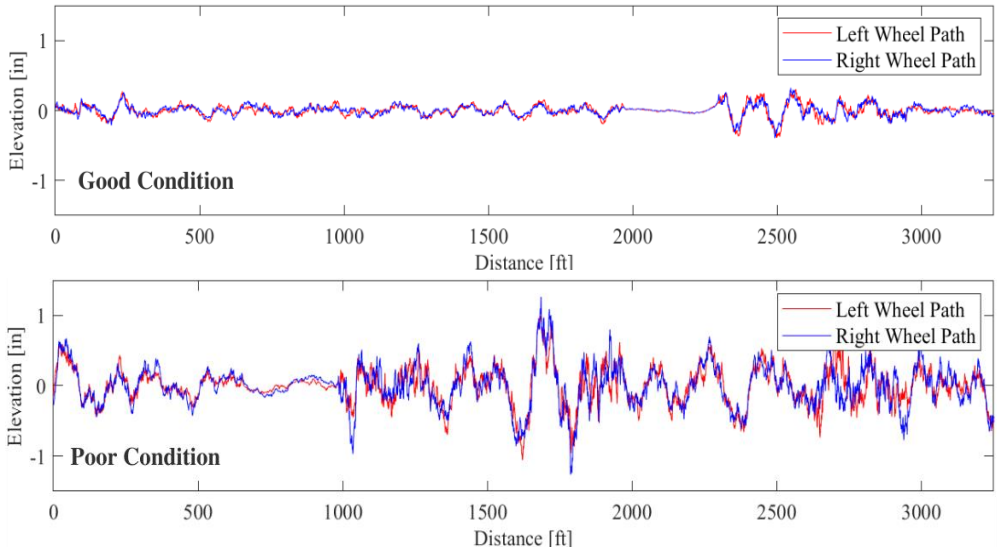
Use of Alternative Fuels

Impact of Road Roughness

Roughness

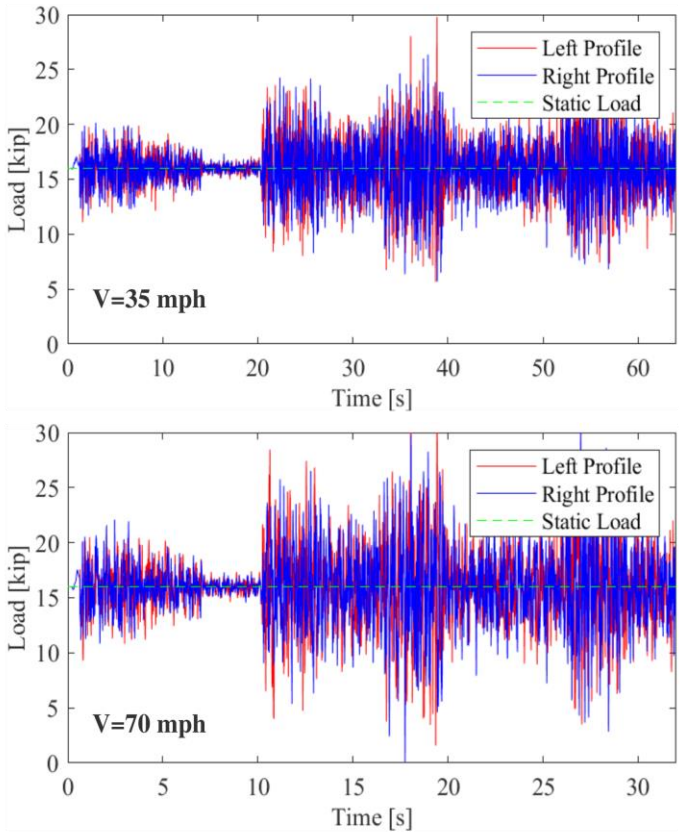


Roughness impact **cumulative deformation** of suspension/tires.

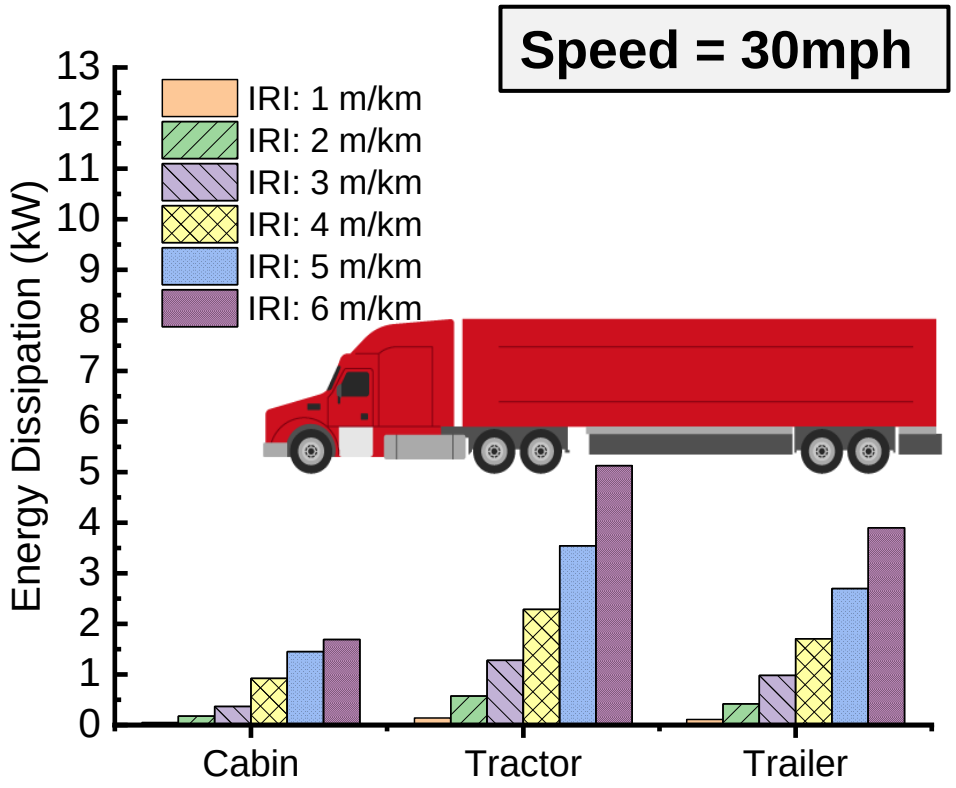


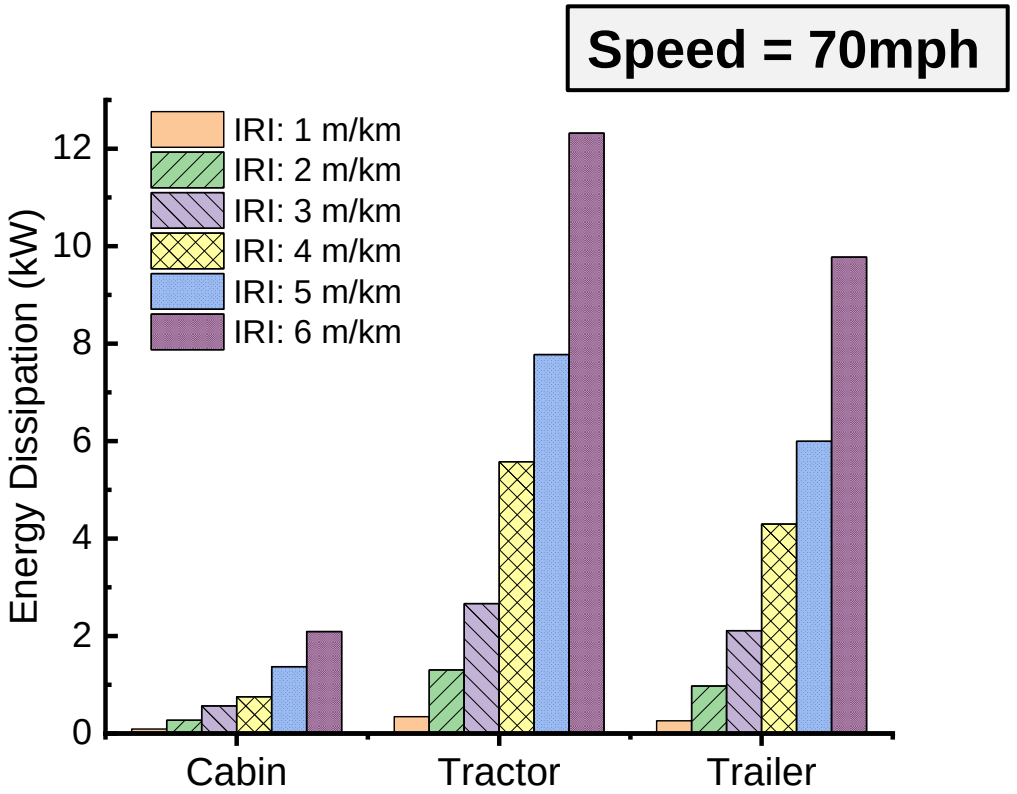
Dynamic Loading

Load amplification, increased w/ speed



Impact of Road Roughness



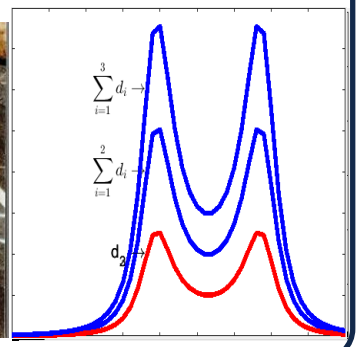


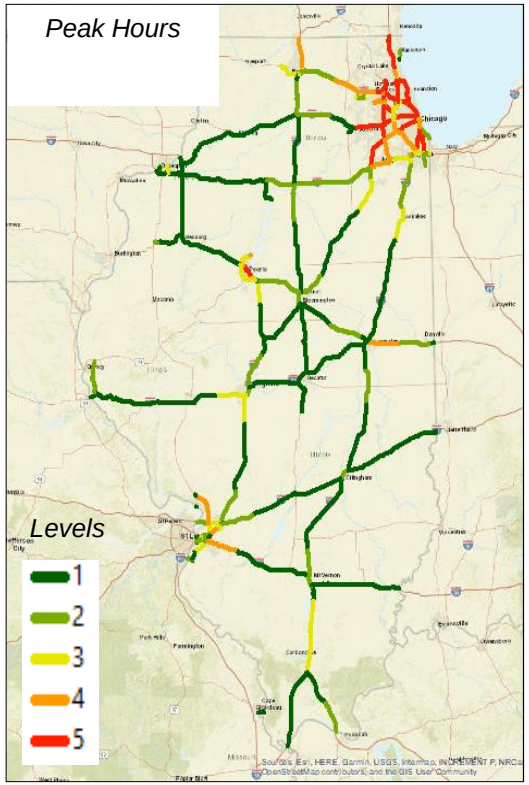
Liu, X., & Al-Qadi, I. L. (2021). Development of a Simulated Three-Dimensional Truck Model to Predict Excess Fuel Consumption Resulting from Pavement Roughness. *Transportation Research Record*, *2675*(9), 1444–1456. https://doi.org/10.1177/03611981211007849

Platoons: Leveraging Communication

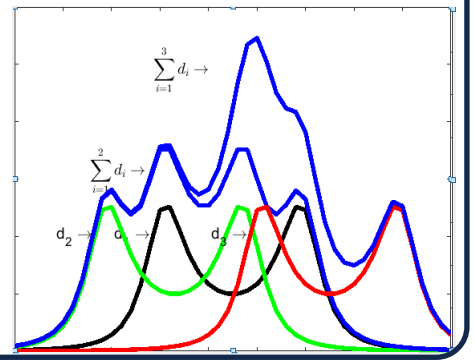
To minimize damages of truck platoons to pavement

Channelized





Optimized



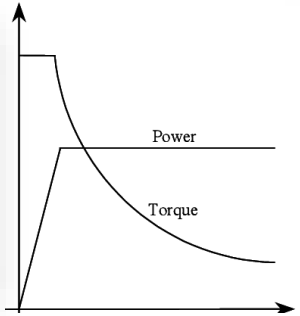
Impact of E-Trucks on Pavements

Increased Axle Loading

Increased Torque

Electric Battery Pack

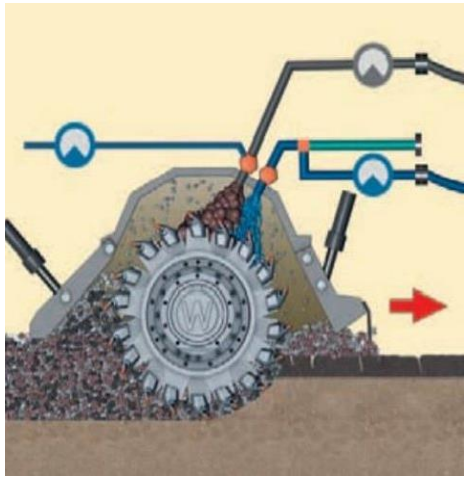
Torque at 0 RPM!



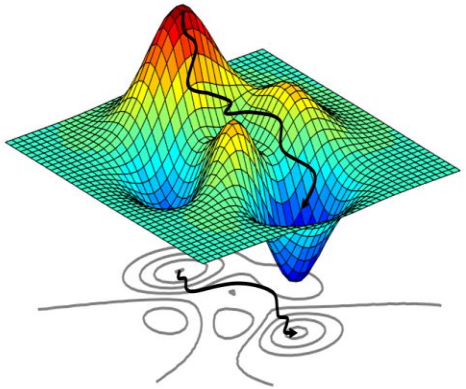
Pavement Life Cycle

SMA Application

In-Place Recycling



Maintenance Optimization

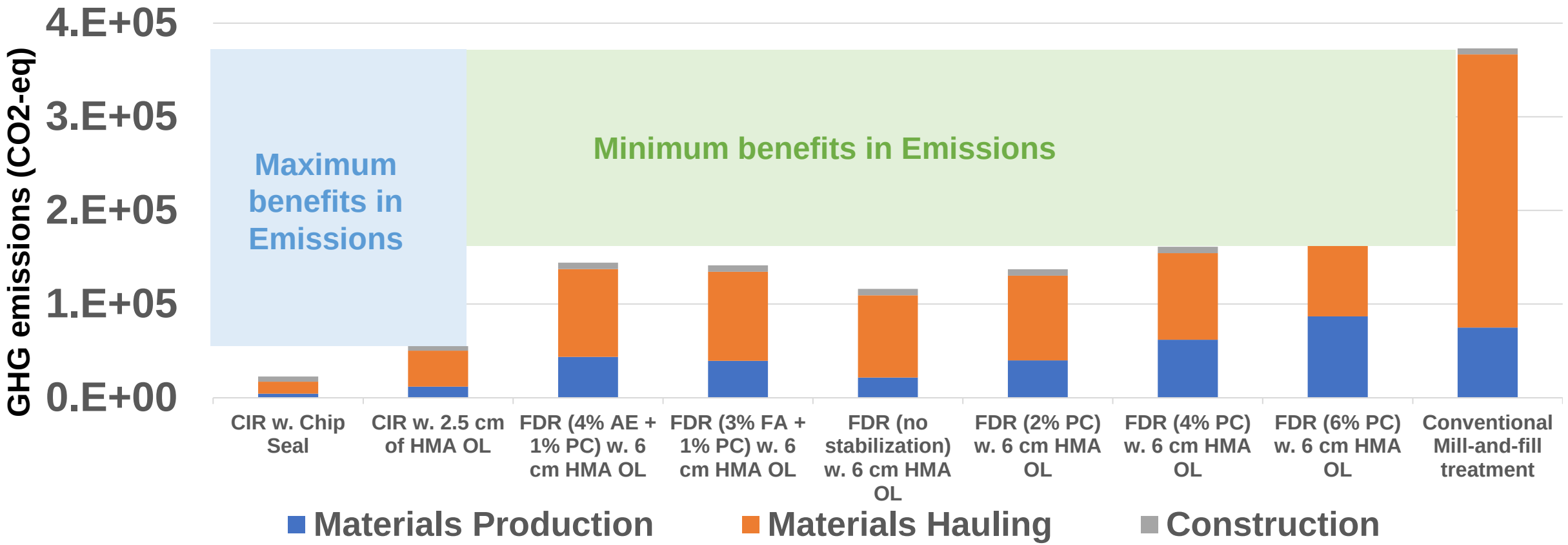


Maintenance

Recycled Materials in Maintenance

GHG Benefits of CIR and FDR

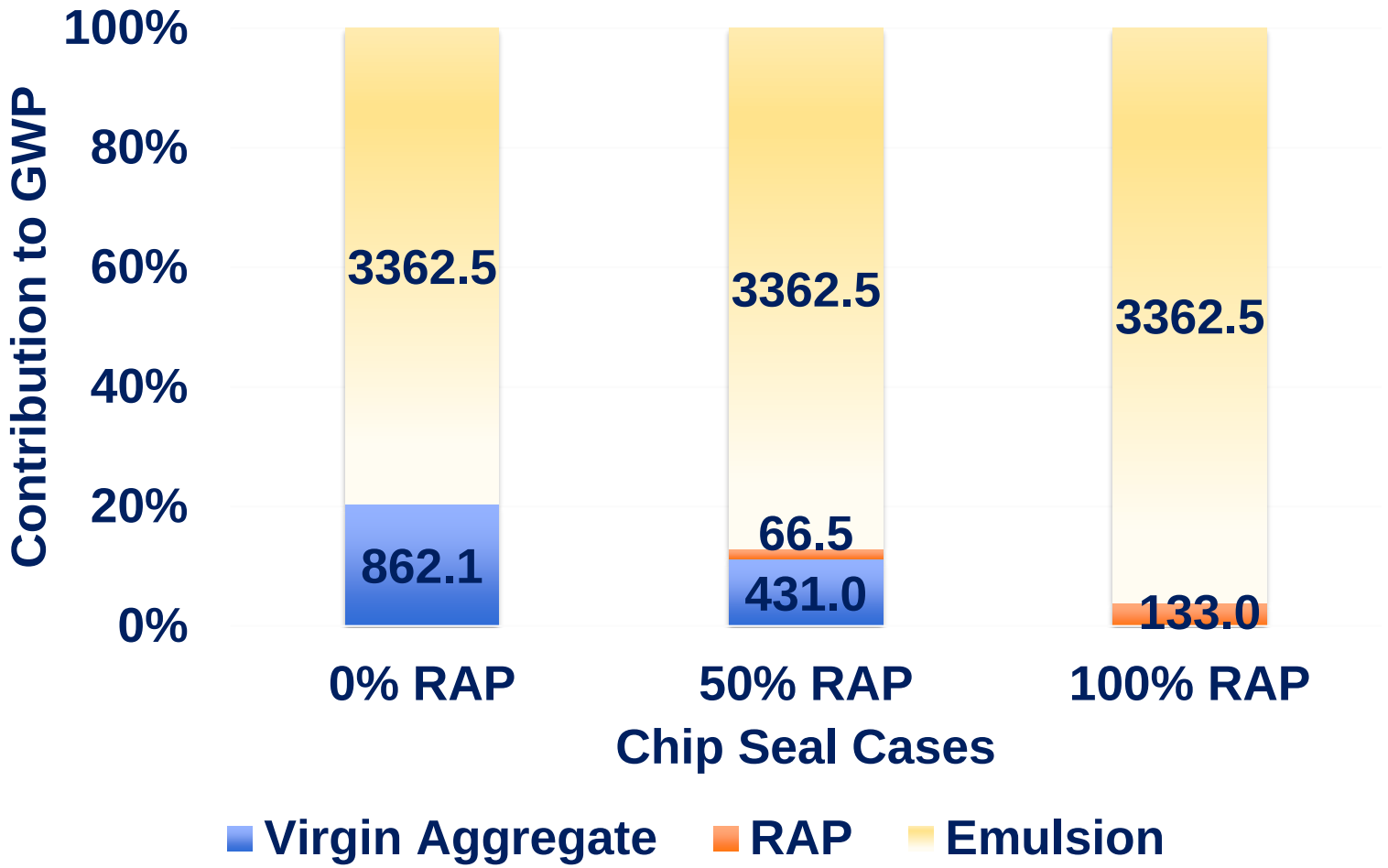
GHG emissions of CIR, FDR, and conventional maintenance



Al-Qadi et al. (2017). Final Report for A Life-Cycle Methodology for Energy Use by In-Place Pavement Recycle Techniques

Use of RAP in Preservation Treatment

Contribution of chip seal materials to GWP



Pavement Life Cycle

Landfilling

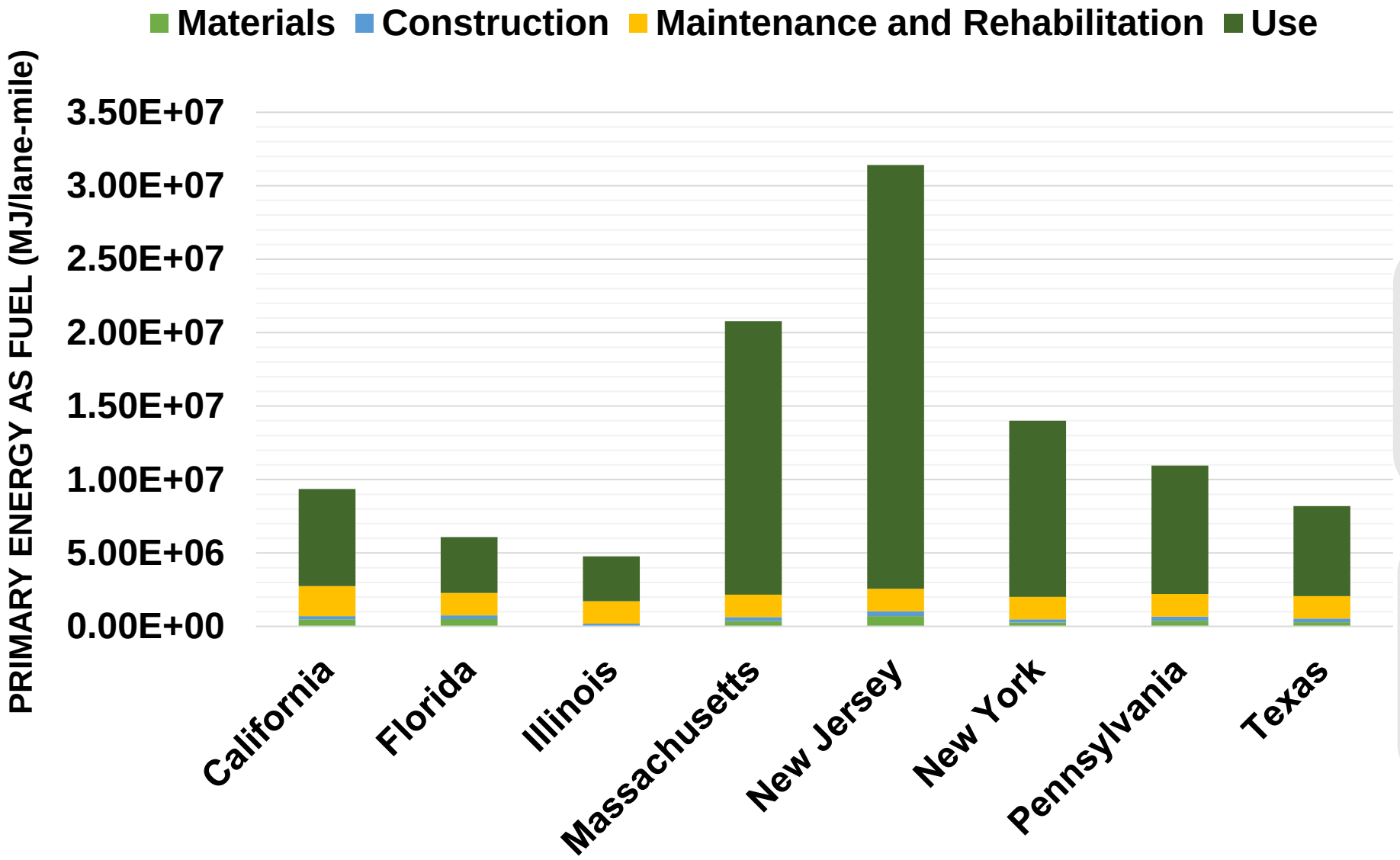
On-site Recycling

Off-Site Recycling

Materials Reuse in Pavements

End-of-Life

AC Pavement LCA Results



Use stage has the highest emission contribution

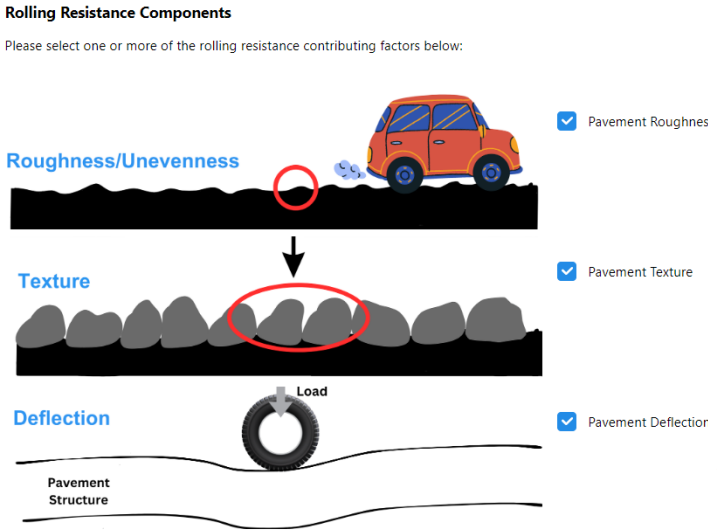
Overlooking emissions from pavements underestimates transportation GHG emissions

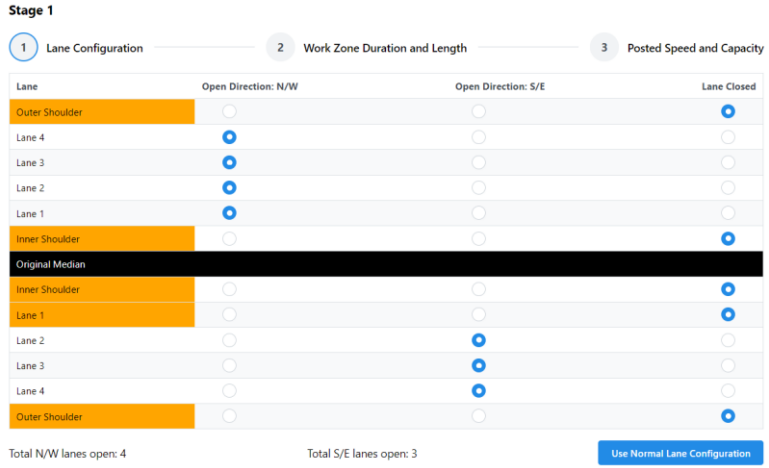
Flexible pavement contribution to transportation emissions differs between states

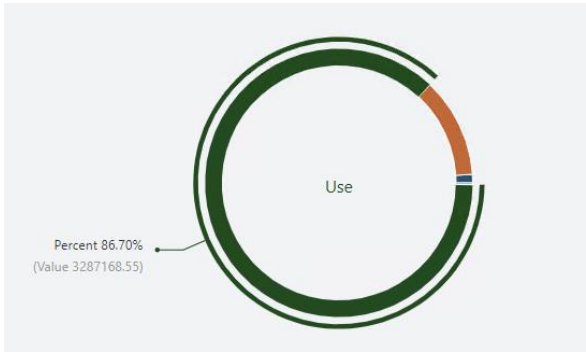
State of the Art/ Practice Web Application

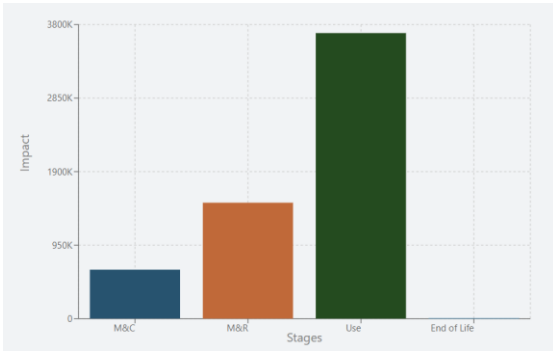
Quantify sustainability performance of pavements

- Free access
- Detailed traffic analysis
- Electric vehicles
- Vehicle-road interaction
- Probabilistic cost
- Road work zone









Summary

- **By 2050, Flexible Pavement Won't Be the Same!**
- **Pavement must reach net-zero emissions**
  - Harmonizing government, industry, and academia is a vital step towards minimizing flexible pavement GHG emissions
- **Must consider alternative materials, construction and rehabilitation technologies, and monitoring methods**
- **Building resilient and smooth pavement is crucial to reduce CO_2!**
- **A balanced LCA and LCCA (S-LCA in the future) is an important approach to quantify emissions and track progress towards net-zero emissions**

Acknowledgments

- Illinois Department of Transportation (IDOT)
- Federal Highway Administration (FHWA)
- Federal Aviation Administration/ NAPA
- ICT engineers and students
- Students helping in slides (A. Khan, M. Hafeez, L. Diab, J. Cardenas Huaman, and L. Abufares).

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THANK YOU

Any Questions?

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