# Effect of HMA Surfaces on Rolling Resistance Emission

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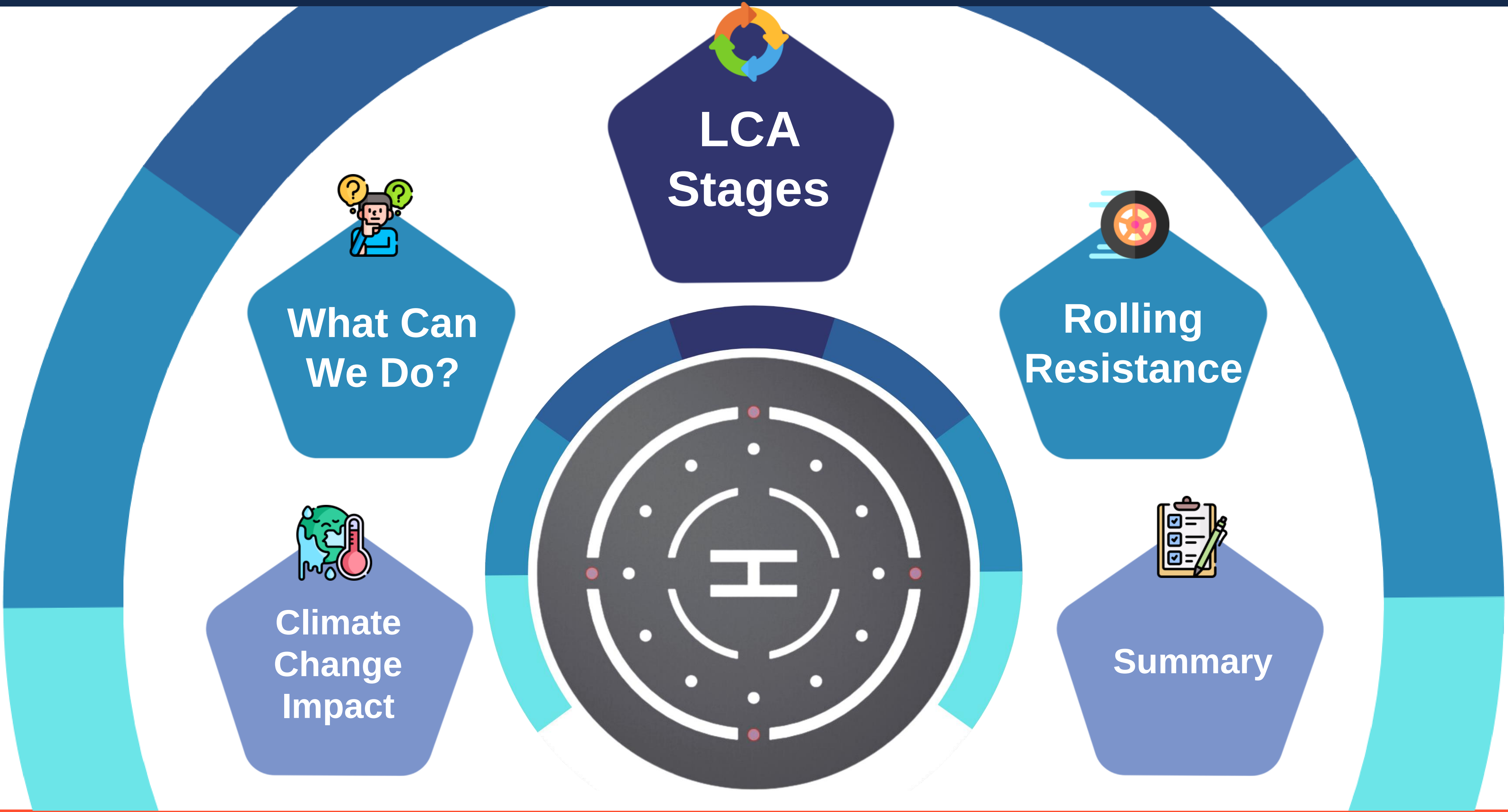
**64th Illinois Bituminous Paving Conference**
**December 6, 2023**

*The support of many students, collaborators, and sponsors are acknowledged*


LCA Stages
What Can We Do?
Rolling Resistance
Climate Change Impact
Summary

# Global Climate Changes

## Present

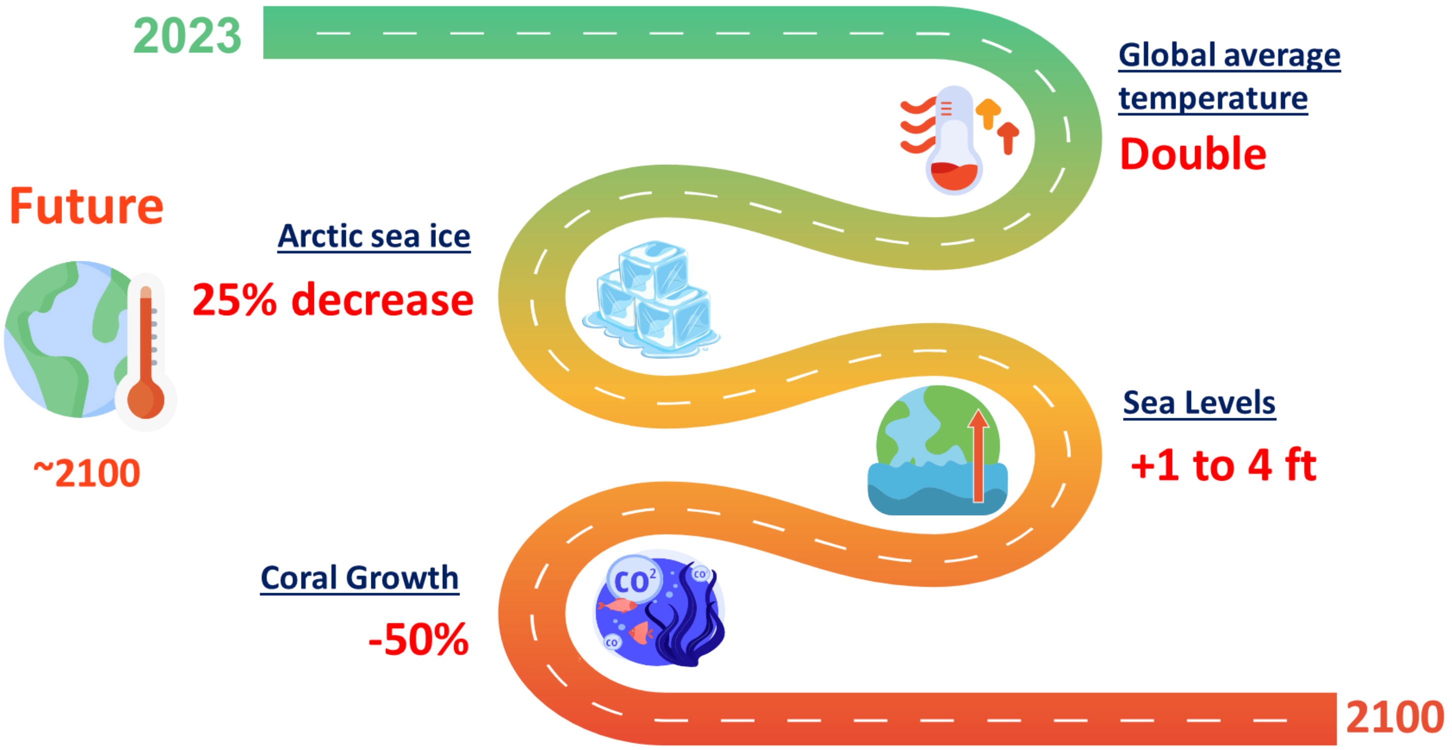
**$CO_2$** ↑
**421** ppm

**Ice Sheets** ↓
**466** billion ton/yr

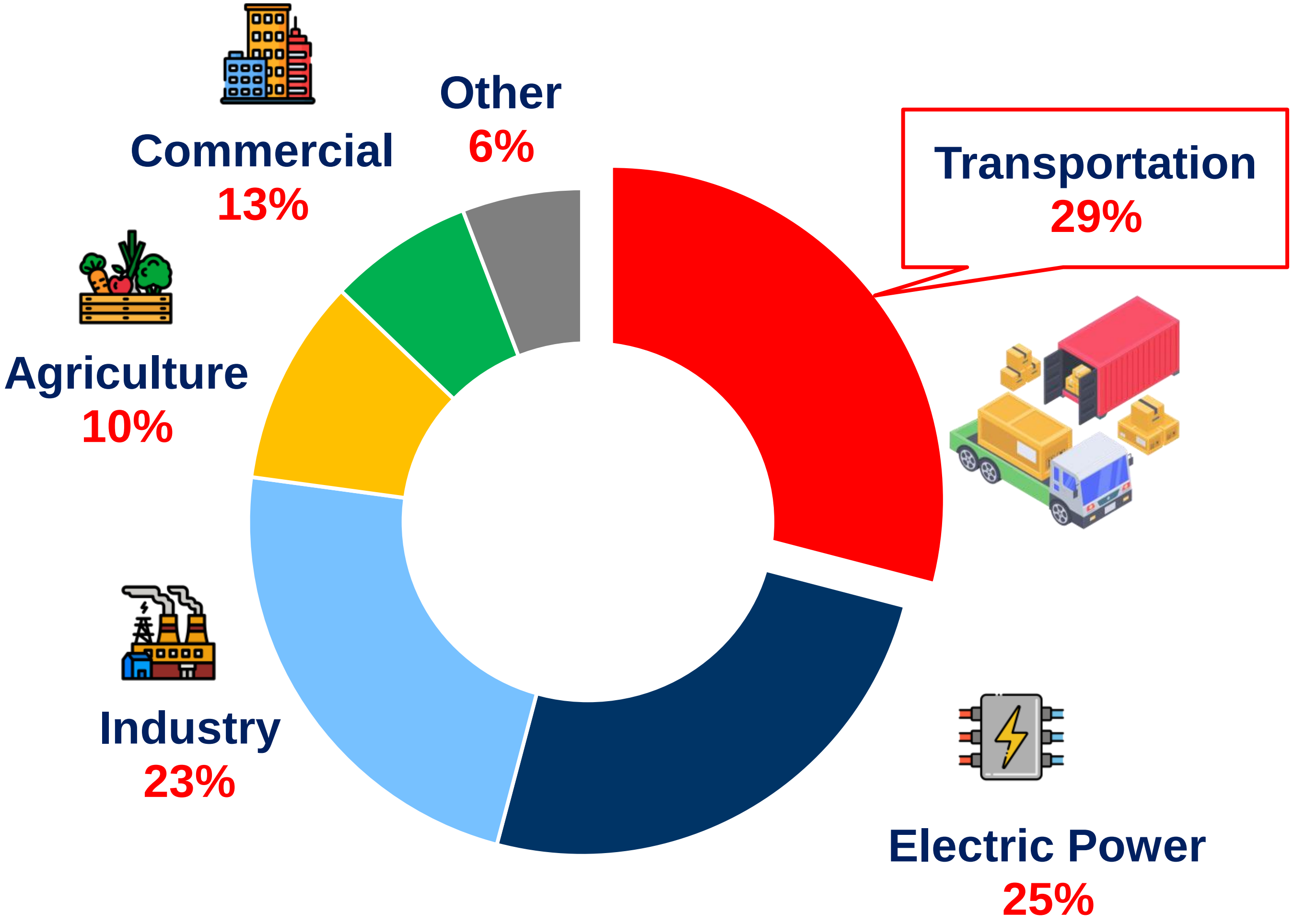
**Sea Level** ↑
**4** in since 1993

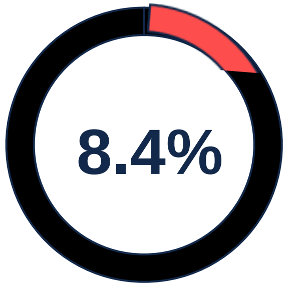
**Global Temperature** ↑
**2.0** $^0$F since preindustrial

**Methane** ↑
**1923.6** ppb

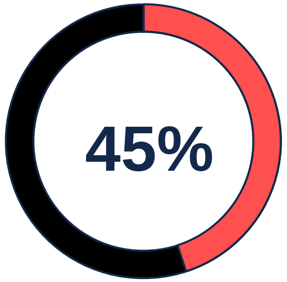


# Transportation Impact in the US



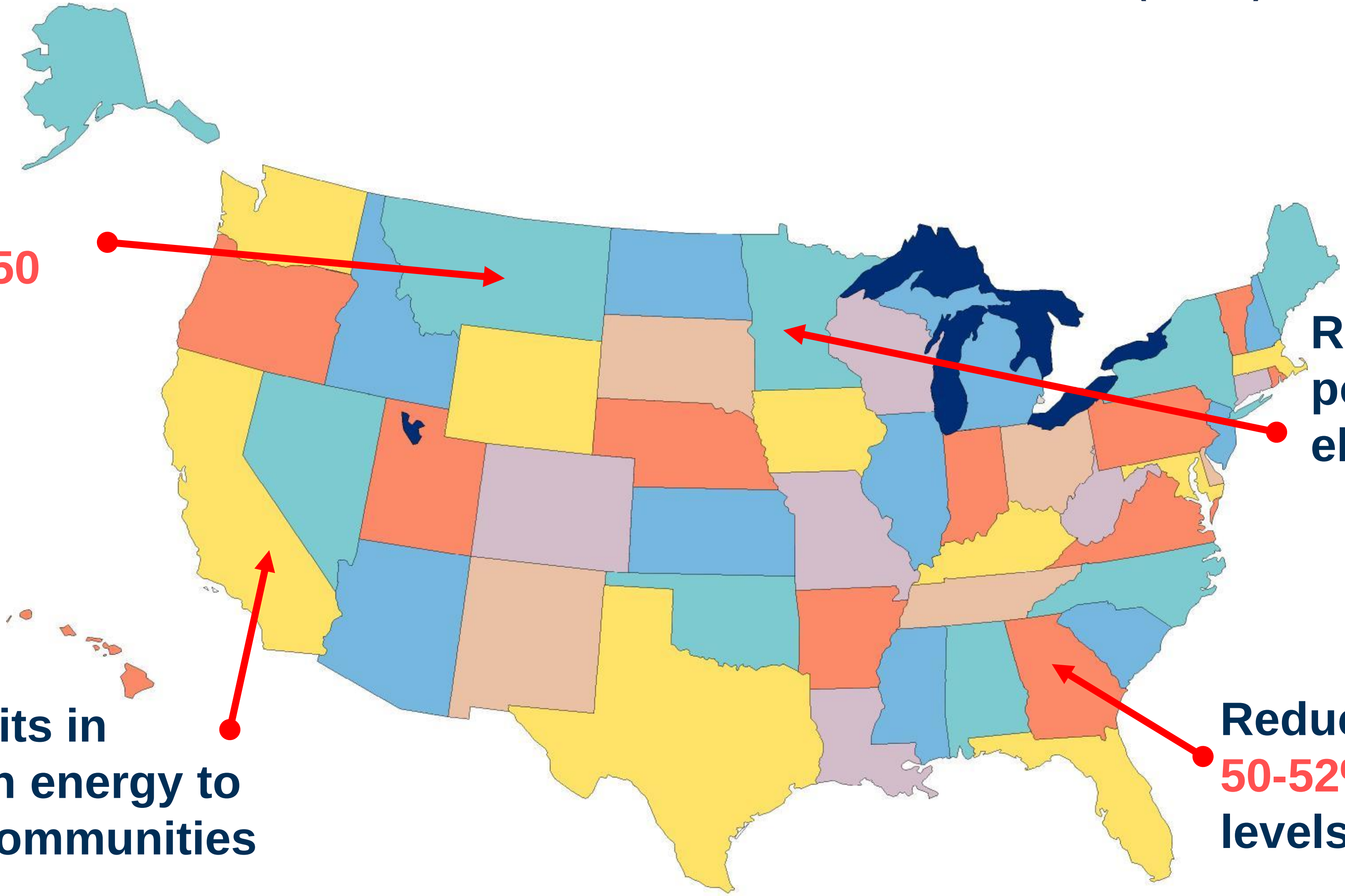

**Transportation Contribution to GDP**




**Transportation Emissions from Roadways**

# US Action Targets

## President's Actions to Tackle Climate Crisis (2021)



**Achieve net-zero emissions by 2050**

**Reach 100% carbon pollution-free electricity by 2035**

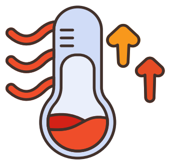
**40% of the benefits in climate and clean energy to disadvantaged communities**

**Reduce GHG emissions 50-52% below 2005 levels by 2030**

# Impact of Climate Changes on Illinois

## Over the Past Century

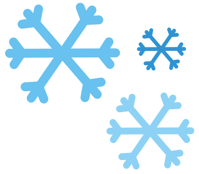
**2** *degrees Fahrenheit* — **increase in average daily temperature**



**15** *percent* — **increase in precipitation**

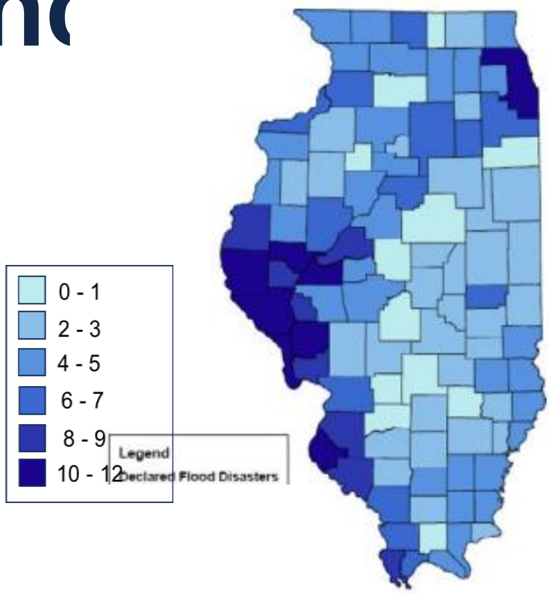
**40** *percent* — **increase in rainfall intensity**

**2** *weeks* — **decrease in snow season duration**

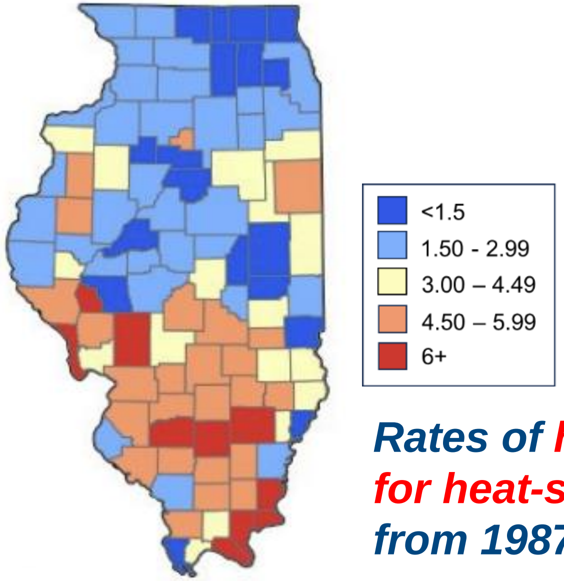


*Illinois State Climatologist (2022)*

**2011 Mississippi River flood caused $360 million of damage to infrastructure, and agriculture**




***Number of federal flood disaster declarations from 1981-2013*** *(EPA, 2016)*




**2012 Illinois drought caused tremendous crop losses reaching $1.2 billion**

***Rates of hospitalization for heat-stress illness from 1987-2014***

*National Weather Service (2012)*

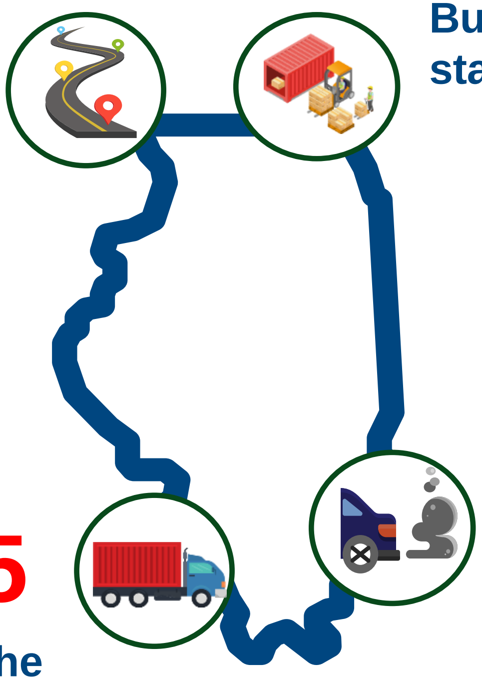
# Transportation in Illinois

**3rd**

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

**3rd**

**Busiest freight state (by value)**



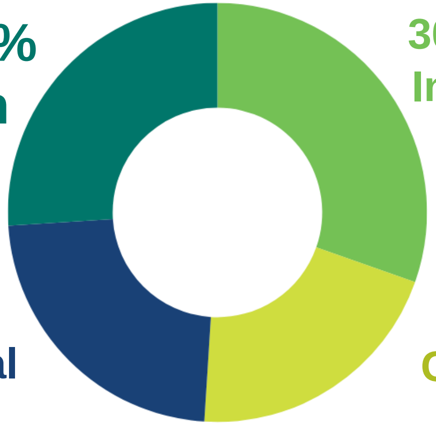
**Top 15**

**State with the highest number of truck drivers**

**5th**

**Contributing state to transportation GHG emissions**

## Energy Use per Sector




*Bureau of Transportation Statistics (2017)*

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

*EIA (2023)*

# Illinois Climate Change Action Targets

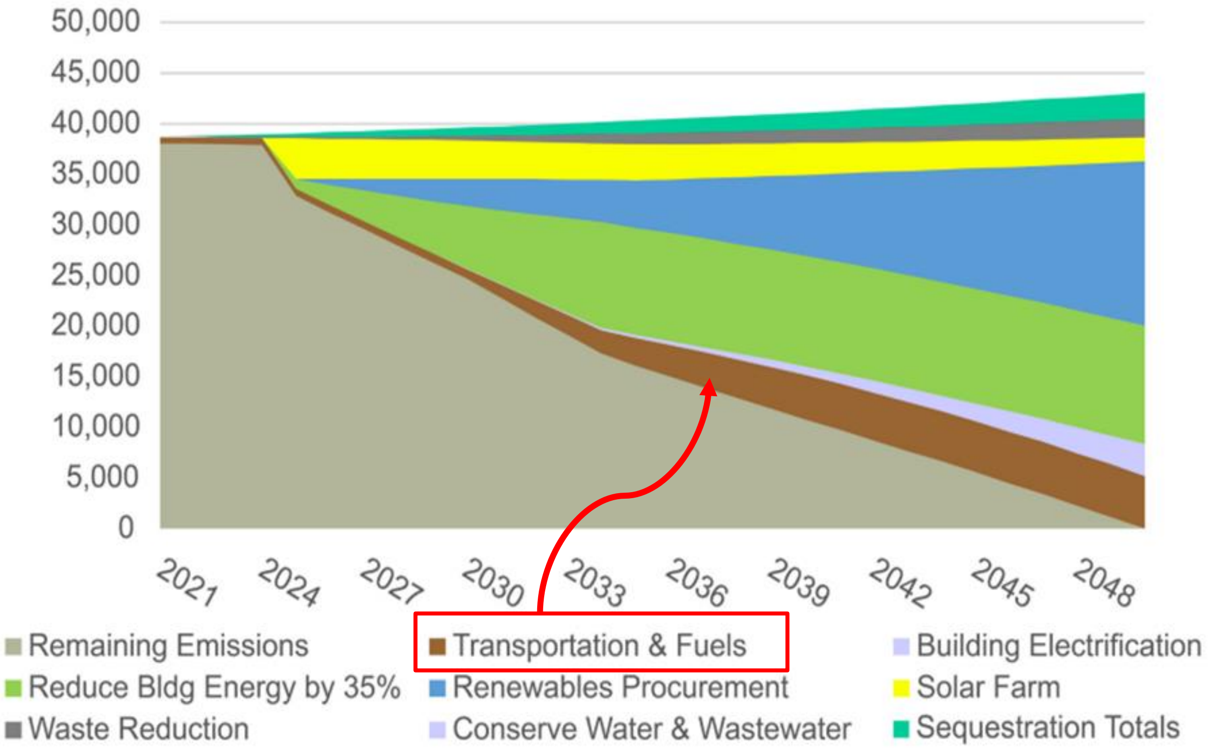
## Illinois Department of Natural Resources Climate Action Plan (2022)

### Main Goals by 2050

- Reach net zero GHG emissions
- Increase Illinois resiliency to climate change impacts
- Ensure climate change actions benefit all Illinois residents
- Partner with and inspire others to act

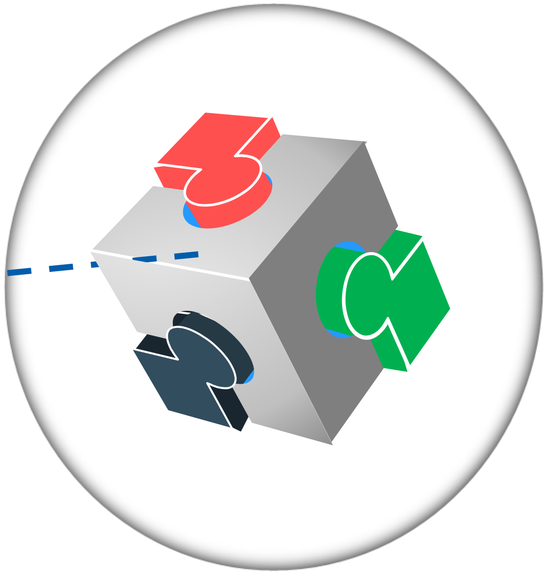
### Impacts of Recommended Measures

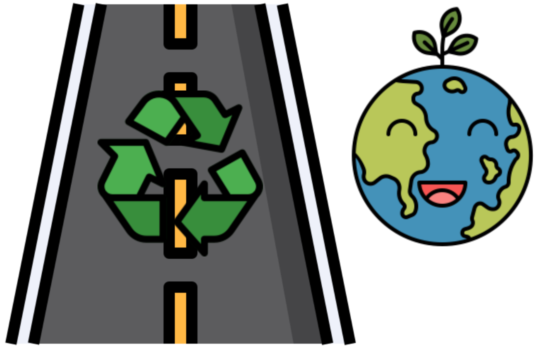
(Currently - 38,700 $MTCO_2e$)



# Resilient Pavements

- Safety/ Comfort
- Durability
- Cost Effectiveness & Climate Impact





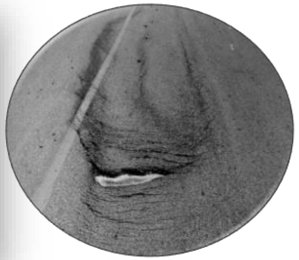
- Achieves its engineering goals
- Is part of a larger system
- Preserves surrounding ecosystems
- Uses resources efficiently
- Reduces energy losses

# Impact of New Technologies

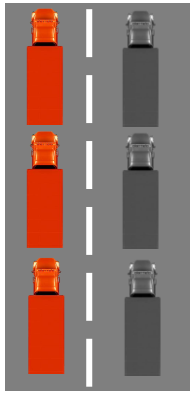
## Truck Electrification

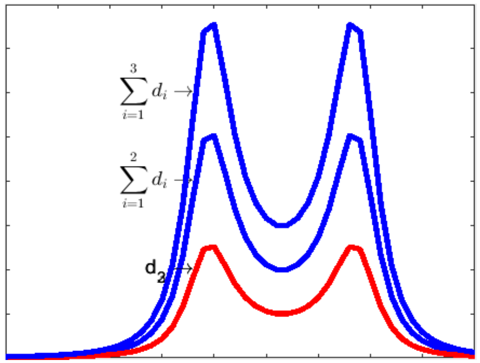
### Increased Axle Loading

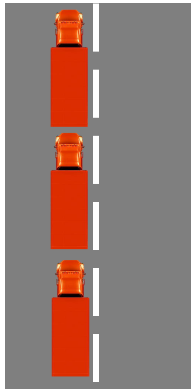

### Increased Torque

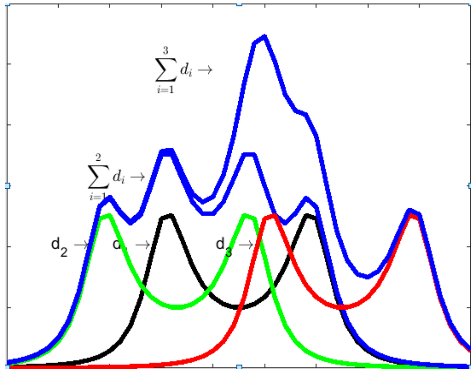


## Platooning

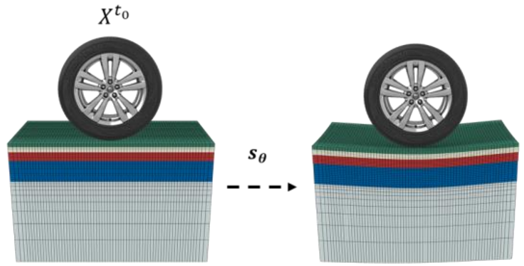


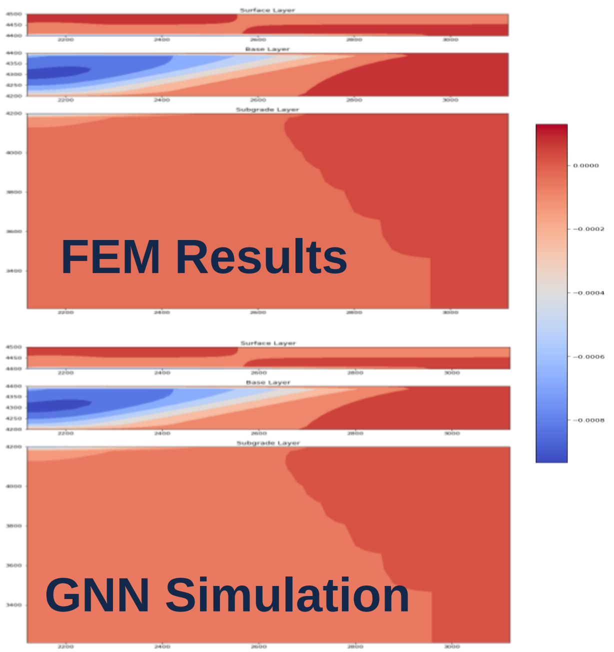






## Advanced Analysis



# Next Steps!

**Creative Construction**
- 3D Printing
- Drone Monitoring
- Real time QA/QC

**Innovative Maintenance**
- Predictive
- Sensor-based
- Computer Vision

**Advanced Design**
- Mechanistic
- Data-Driven (Physics Informed ML)

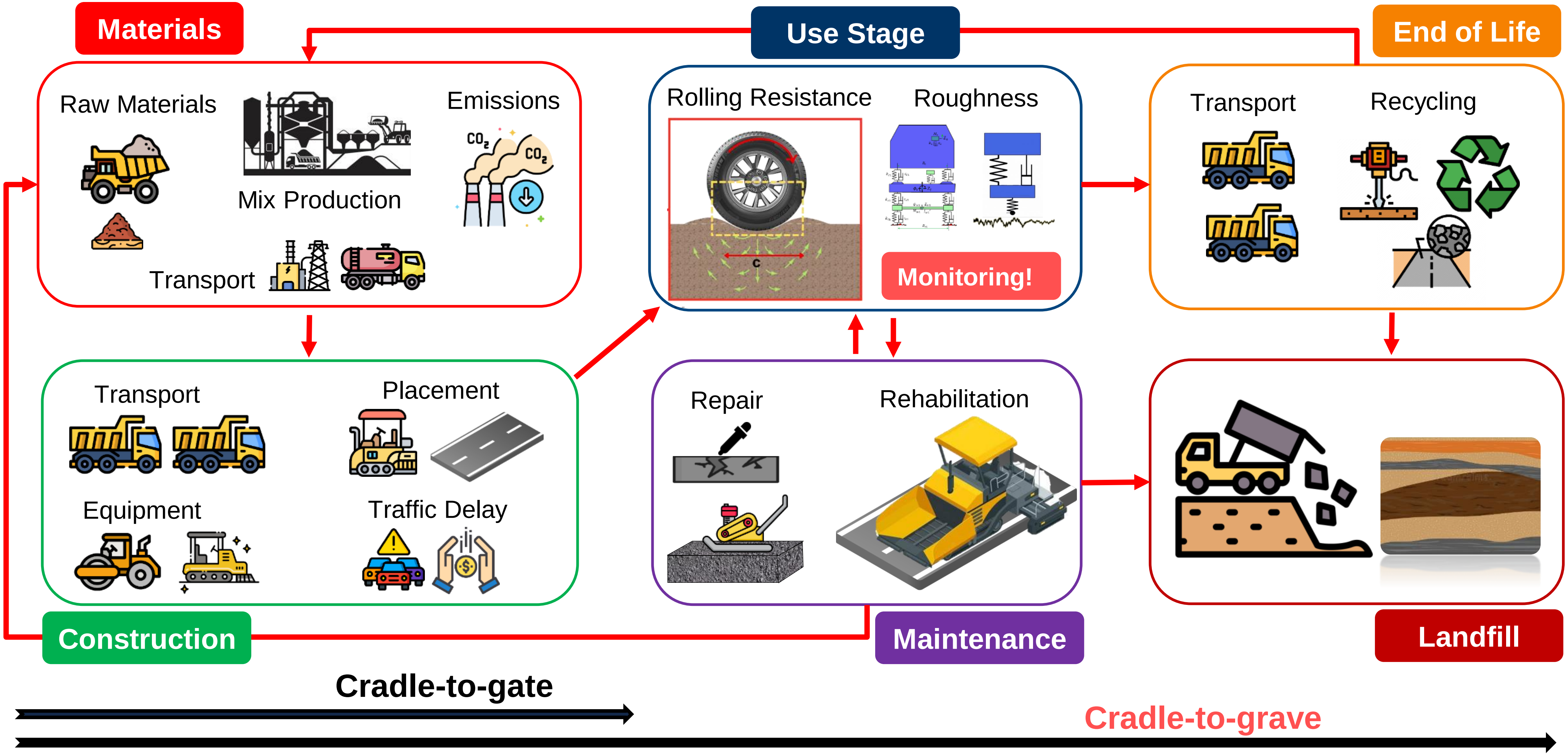
**Recycling**
- RAP
- FDR
- CIR

**Innovative Materials**
- Self-Healing
- Bio-based
- Nanomaterials

**Energy Harvesting**
- EM induction
- Piezoelectric
- Thermoelectric generators

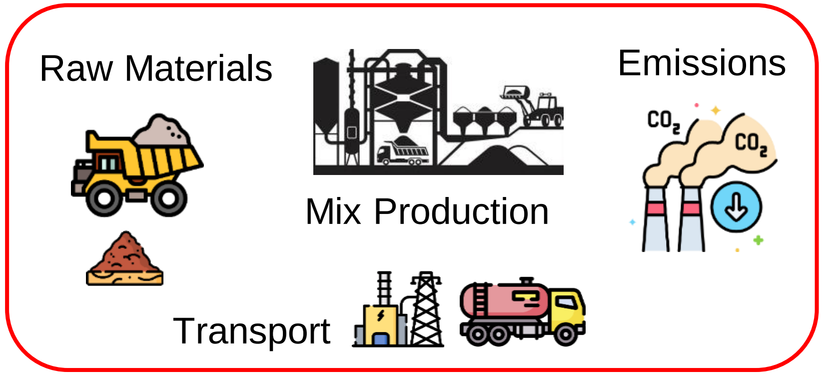
**LCA**

# LCA Stages

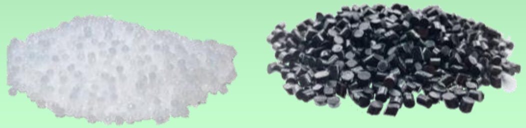

Materials
Raw Materials
Mix Production
Emissions
CO2
CO2
Transport
Use Stage
Rolling Resistance
c
Roughness
Monitoring!
End of Life
Transport
Recycling
Construction
Transport
Placement
Equipment
Traffic Delay
Maintenance
Repair
Rehabilitation
Landfill
Cradle-to-gate
Cradle-to-grave

# LCA: Materials

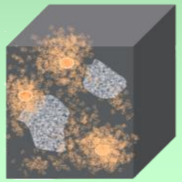
**Materials**




## Recycled Materials

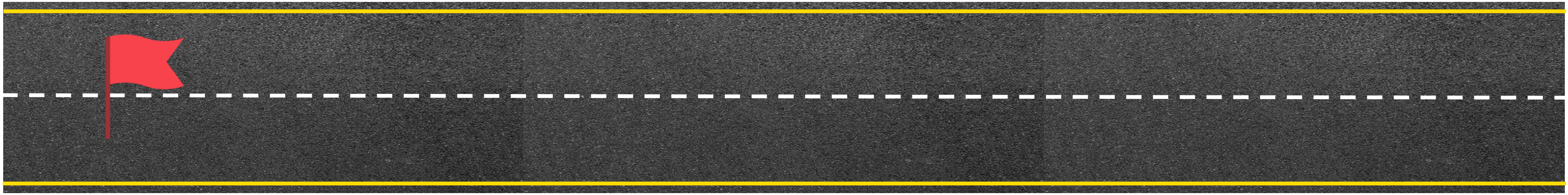


## Self-Healing Materials



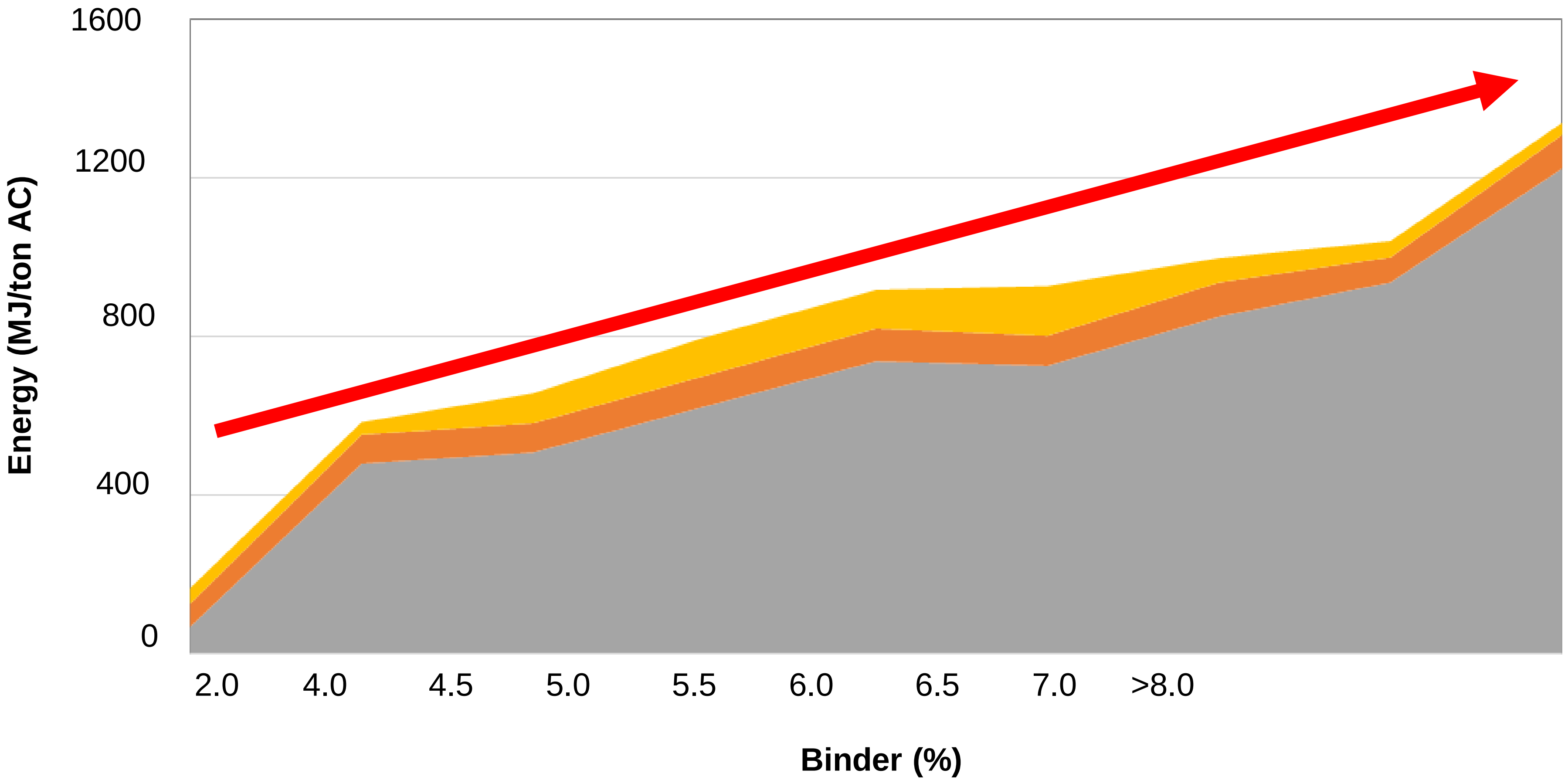
## Local Materials

## Bio-Based Materials



# Contribution of Binder of HMA

## Energy Consumption with Increasing Binder

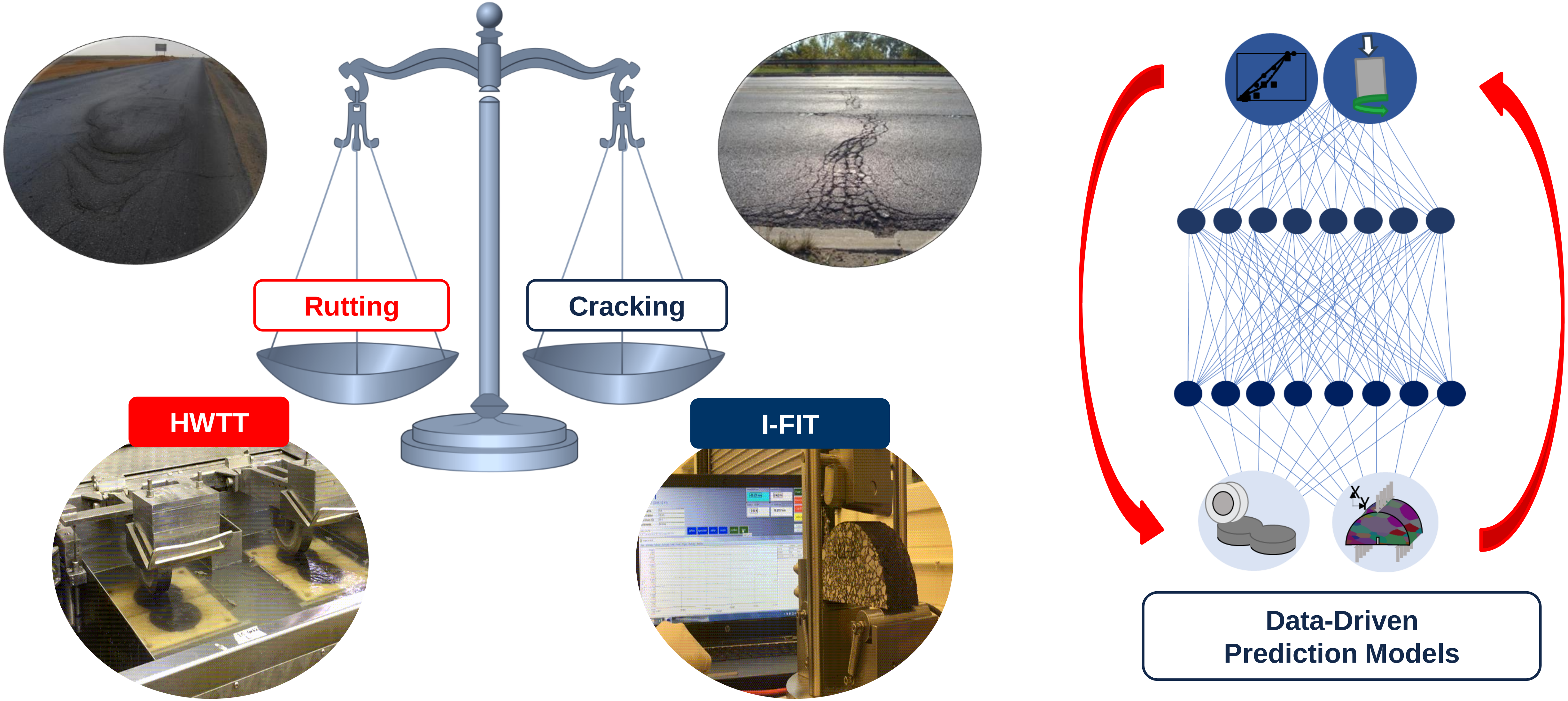



**Transportation**

**Other Materials**

**Binder (40-91%)**

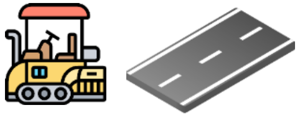
# Balanced Mix Design



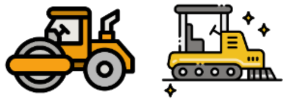
# LCA: Construction

Transport

Placement



Equipment



Traffic Delay

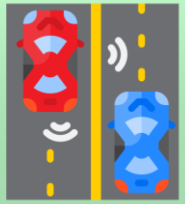
**Construction**

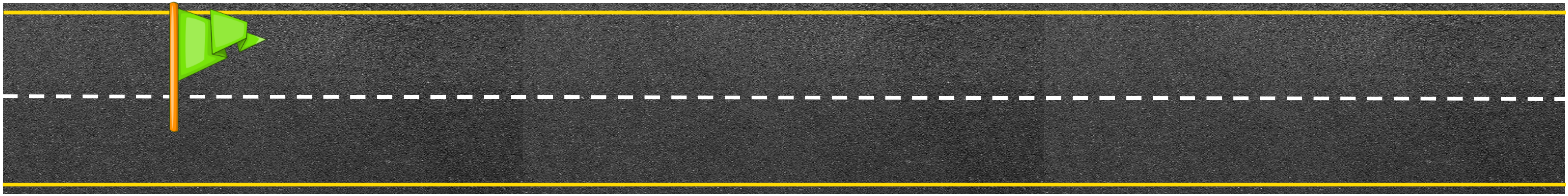
## Real-Time Construction Density

## Sustainable Construction Practices

## QA/QC


## Passive Sensing/ Wireless Charging





# LCA: Maintenance/ Rehabilitation

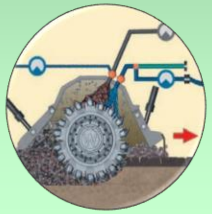
Repair

Rehabilitation

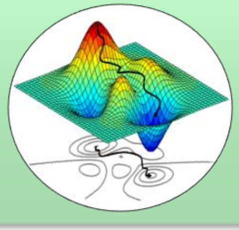
Maintenance

## SMA

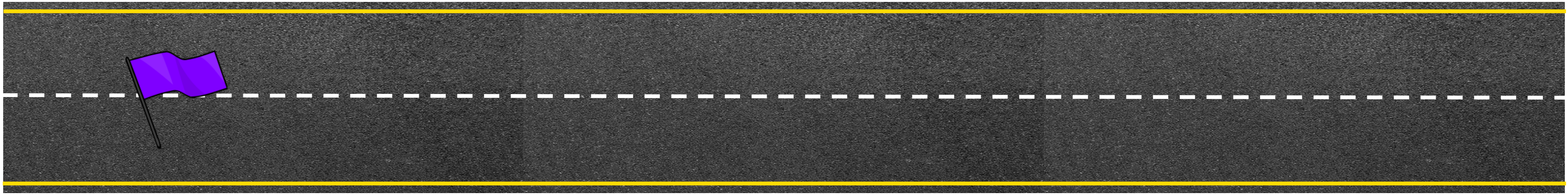
## In-Place Recycling

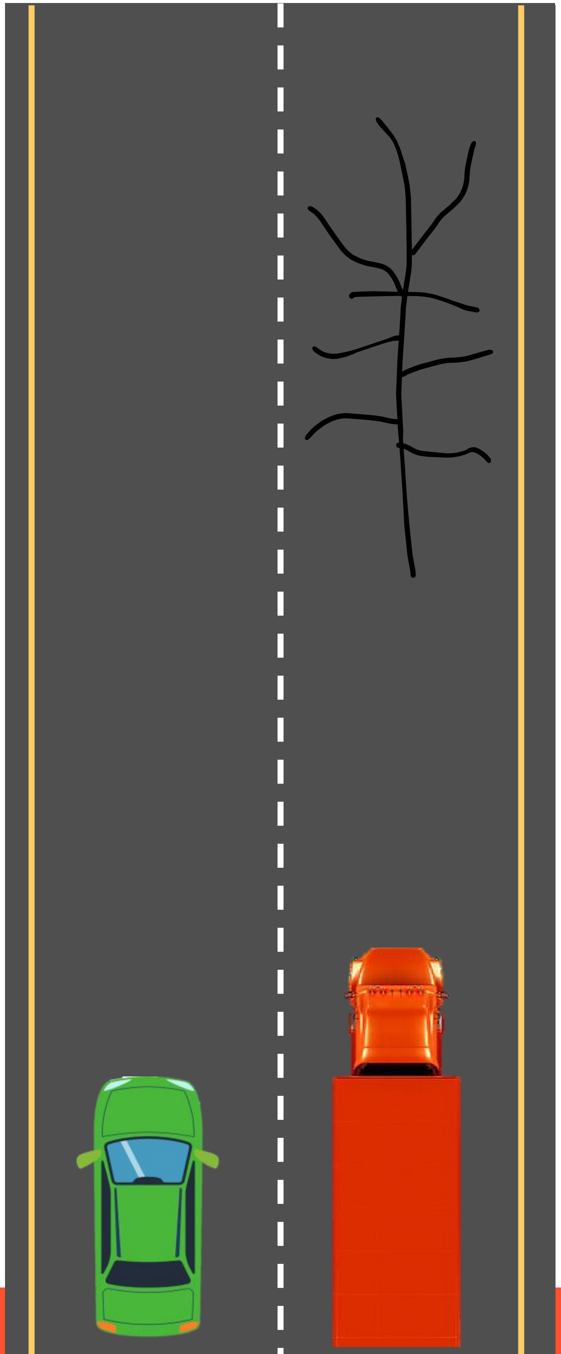


## Optimization



## Recycle Materials

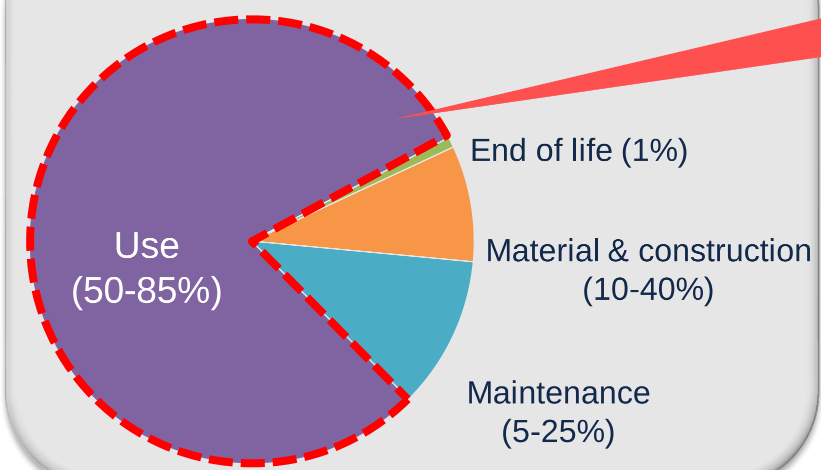


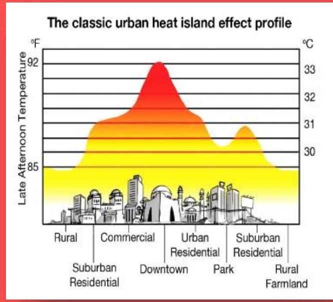


# Use-Stage

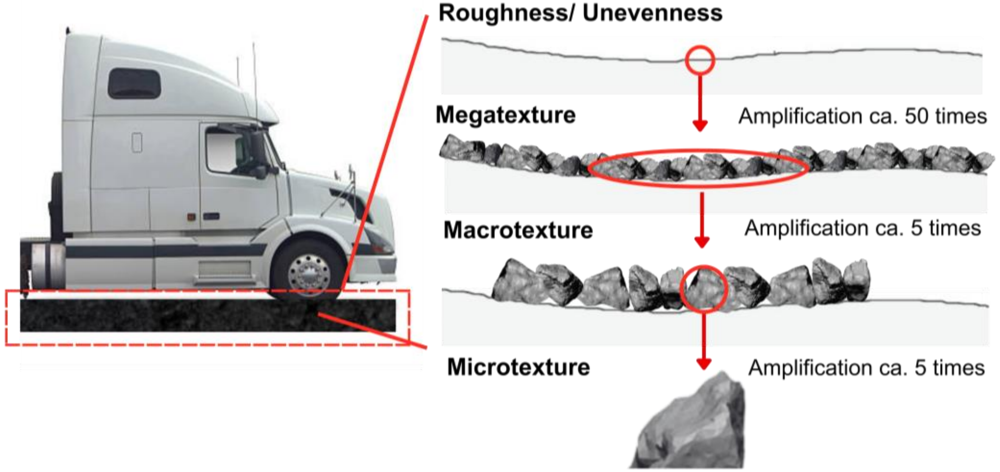
## For a single project

### Typical Energy Consumption

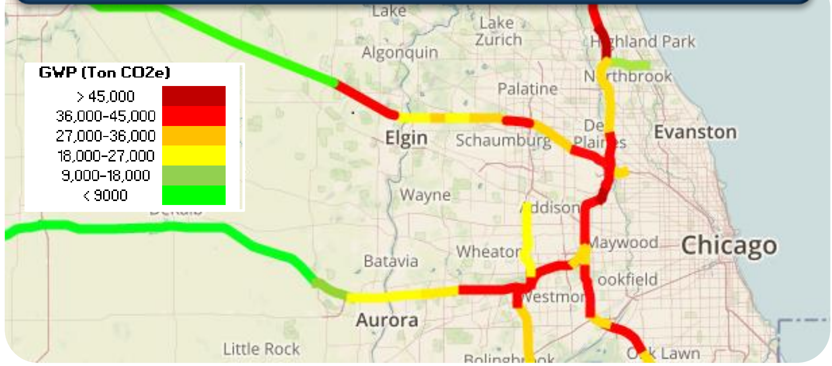



## Roughness, Texture, & Deflection




## For a roadway network



# Truck Fuel Consumption!

**Aerodynamic Drag**

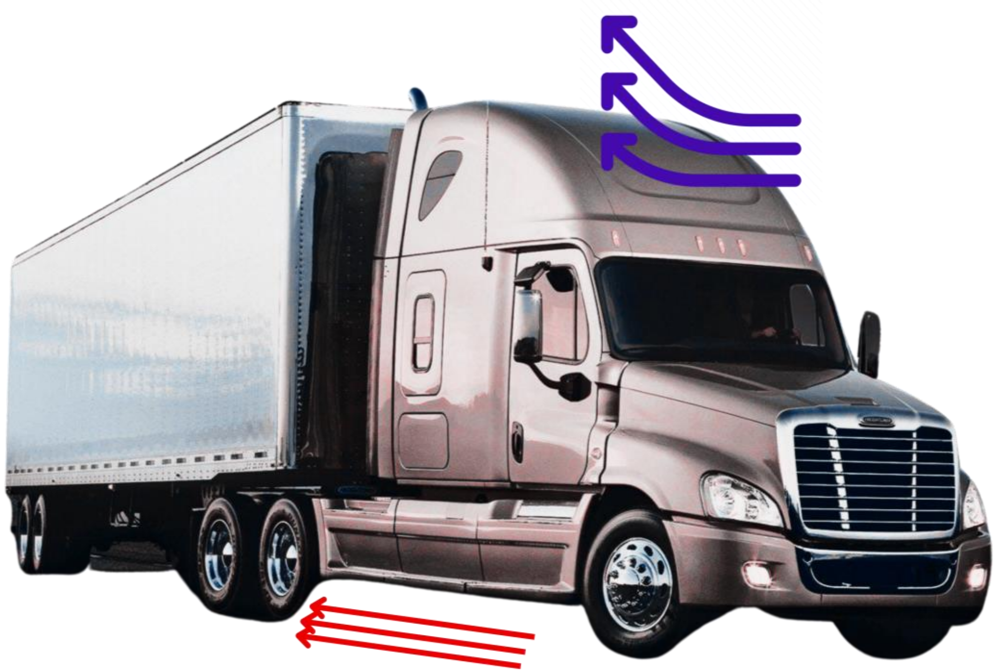
At 60 mph (100 km/h), aerodynamic drag consumes approximately 40% of the fuel

**Mechanical Loss**

Mechanical losses consume approximately 25% of the fuel

**Rolling Resistance**

Rolling resistance accounts for approximately 35% of the fuel consumed

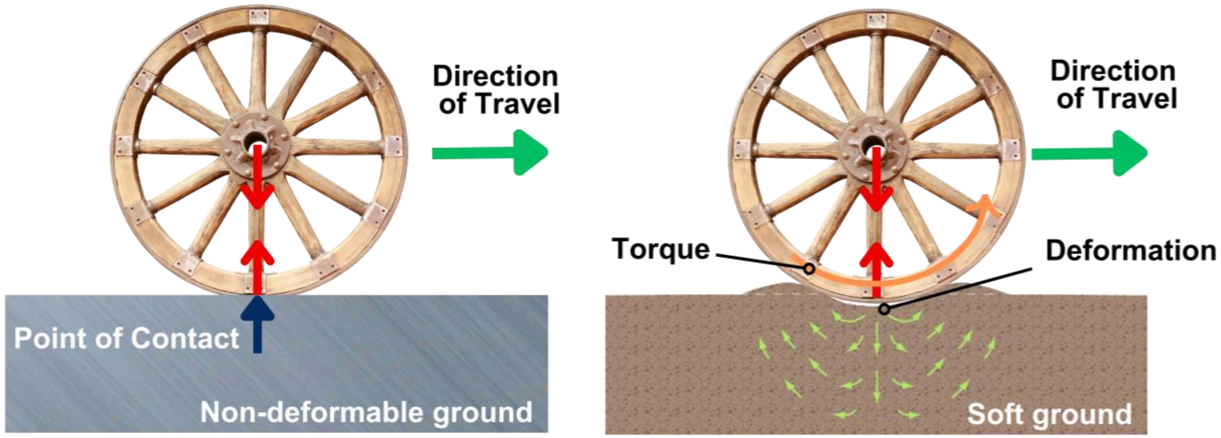


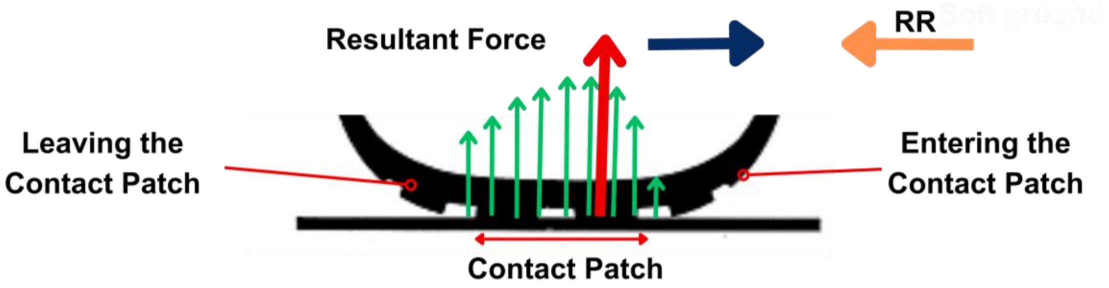
# Deflection

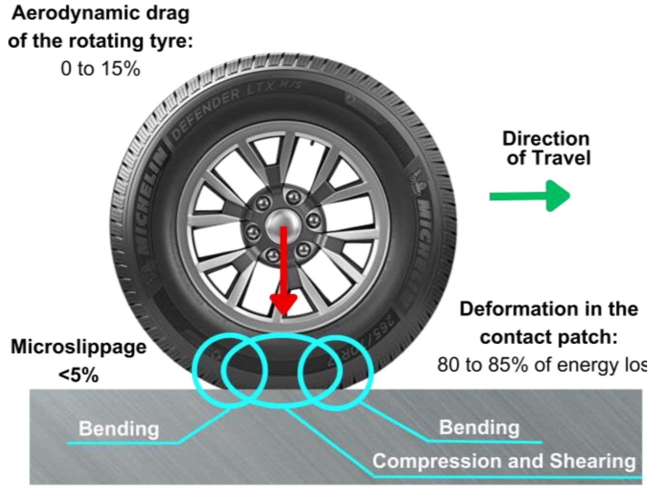
## Definition

Rolling resistance is the energy consumed by a tire per unit of distance covered.

**Roughness** > **Texture** > **Deflection**




a) **Deformation of a tire when it flattens out in the contact patch (80-95%)**

b) **Aerodynamic drag of the rotating tire (0-15%)**

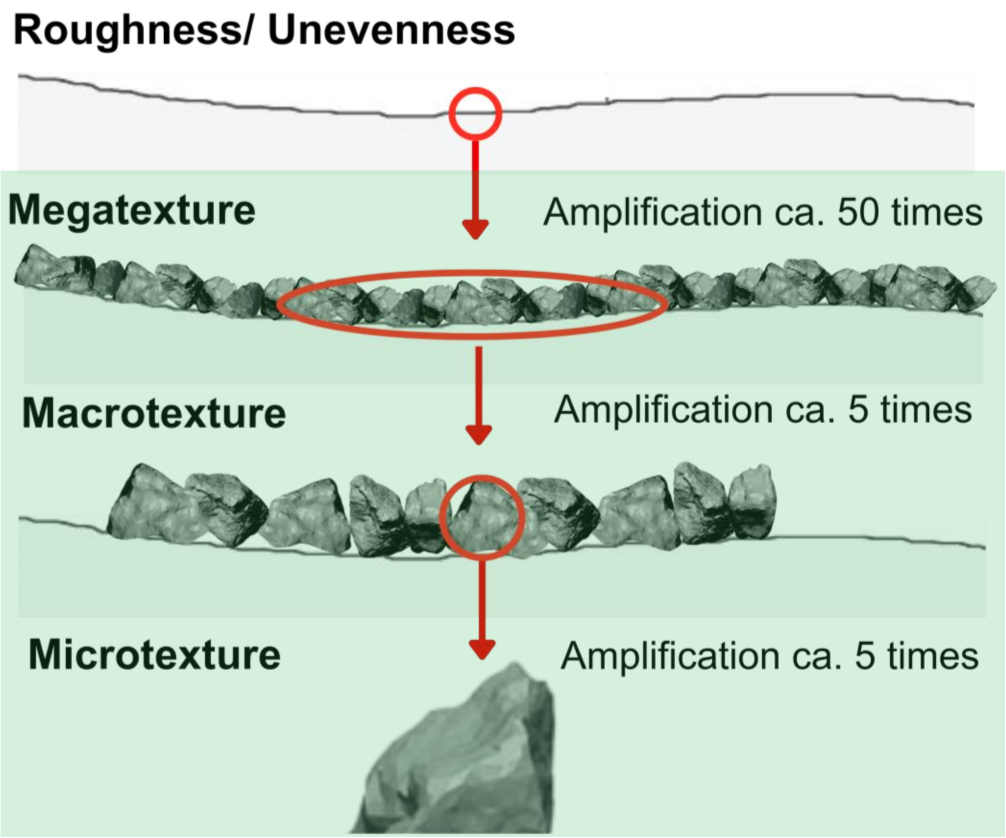
c) **Micro-slippage between the tread and the road surface or between the tire and the wheel rim (<5%)**



(Rolling resistance and fuel savings, Michelin)

# Texture

Roughness > **Texture** > Deflection




- **Induces lower-frequency vibrations compared to roughness**
- **Impacts the contact area between the tire and pavement**
- **Impacts grip at the tire-pavement interface**

# Low-RR Pavements: Case Study

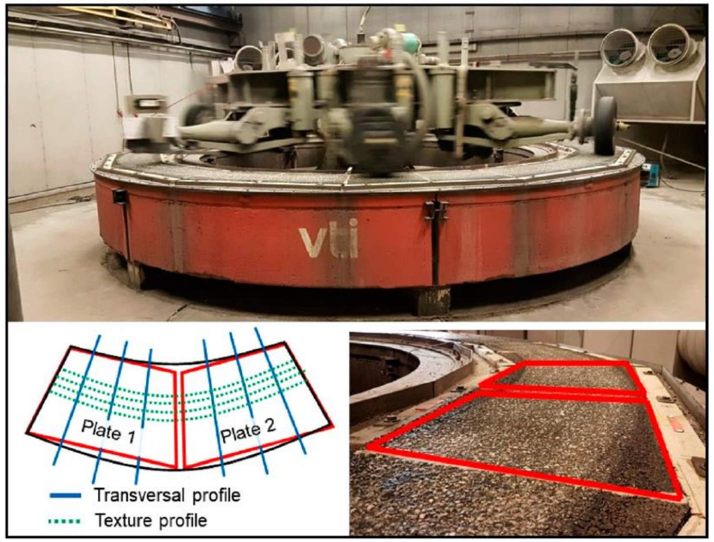
## Denmark

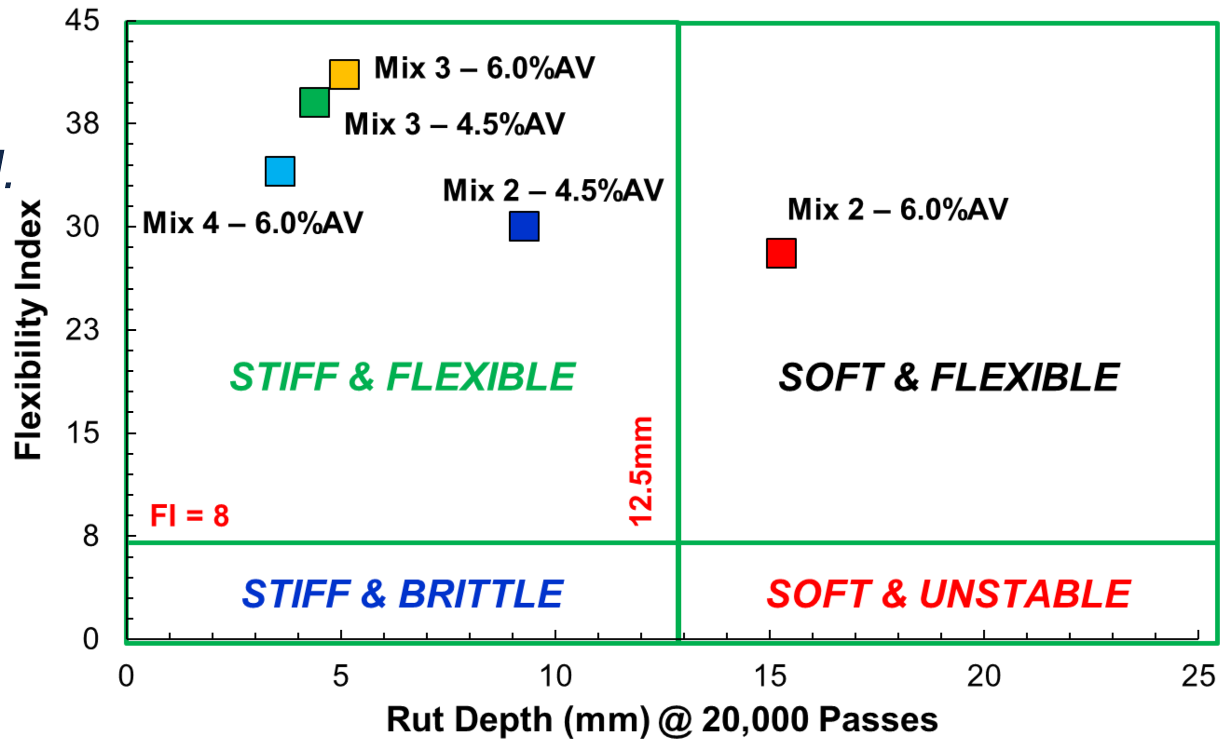
**Going from IRI = 80 in/mi, and MPD=1.0 mm
to IRI = 57 in/mi, and MPD=0.6 mm**

**Expected Reduction in Fuel Consumption of 1%**

## Design Requirements

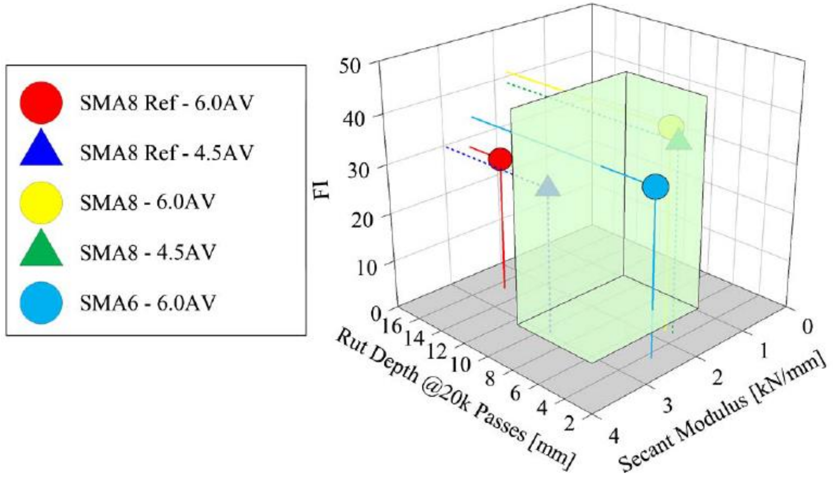
- **Fine gradation**
- **High Polymer-Modified Binder Content** *to ensure long-lasting texture level.*

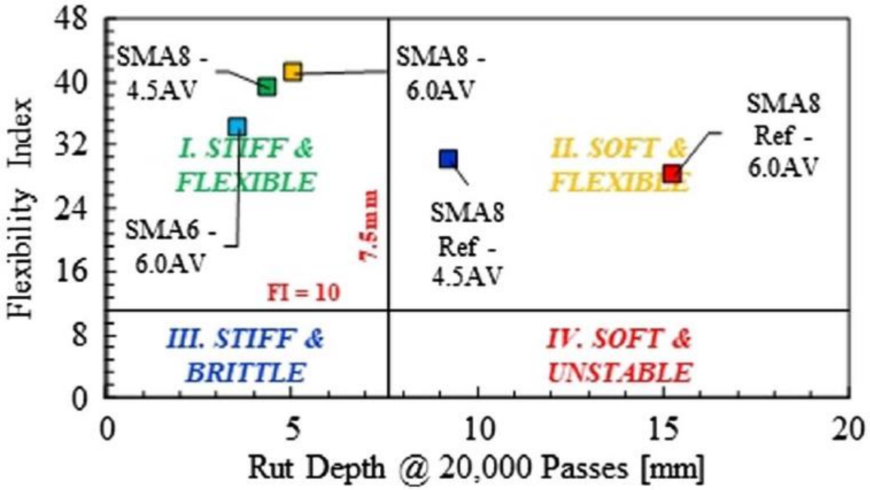


# Low-RR Pavements

- Dynamic Modulus
  - Lower than reference mixes at low T°
  - Higher than reference mixes at high T°
- High Flexibility Index (I-FIT)
- Low Permanent Deformation (HWTT
- BMD Category: Stiff & Flexible

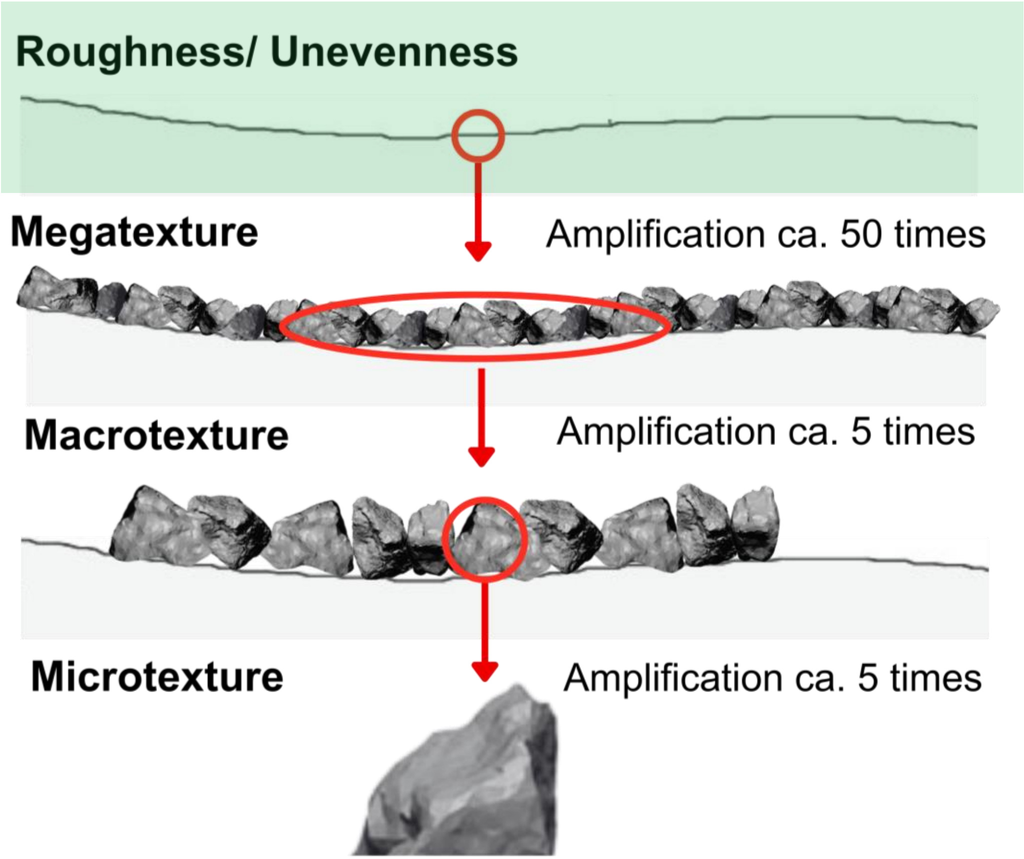



Espinoza-Luque et al. (2017)

# Roughness

**Roughness** > **Deflection** > **Texture**



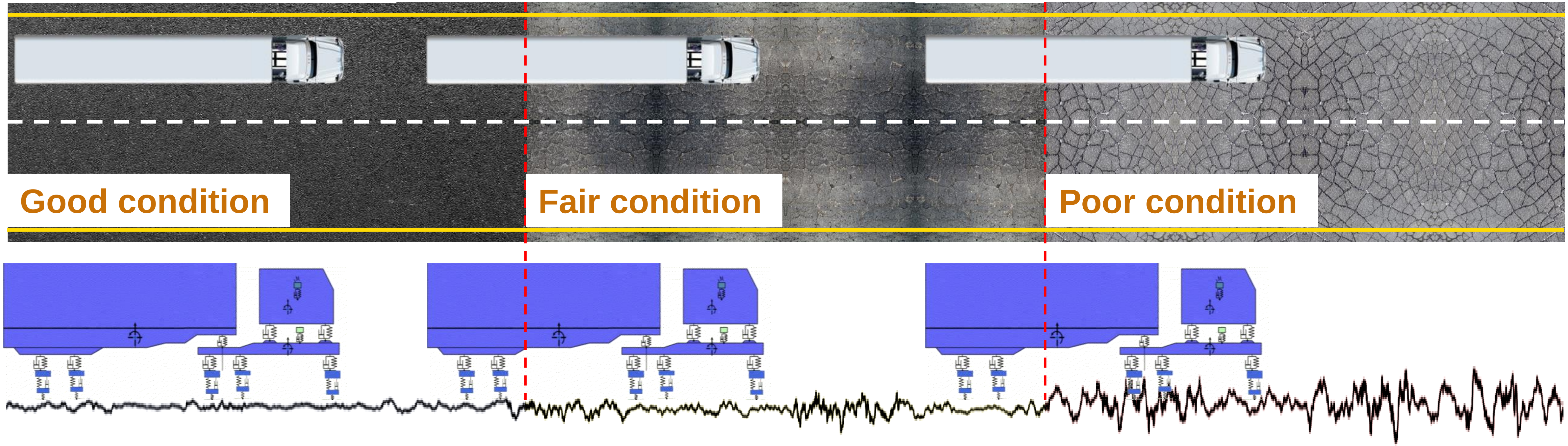

a) Affects vertical dynamics of the vehicle (energy losses).

b) Induces higher tire deformation due to increased static load.

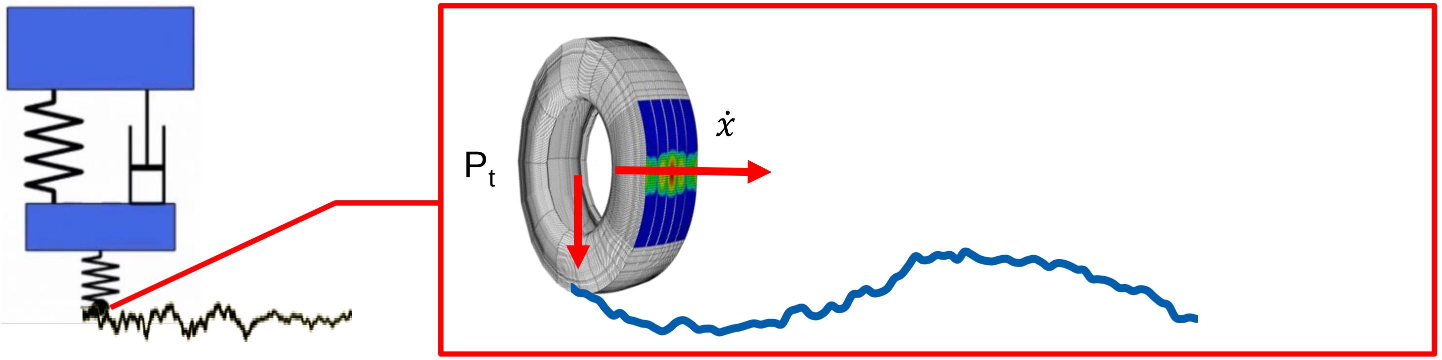
c) Increases tire and wear of tires.

d) Its effect is compounded at higher speeds or higher loads.

# Roughness-Induced EFC and DWL

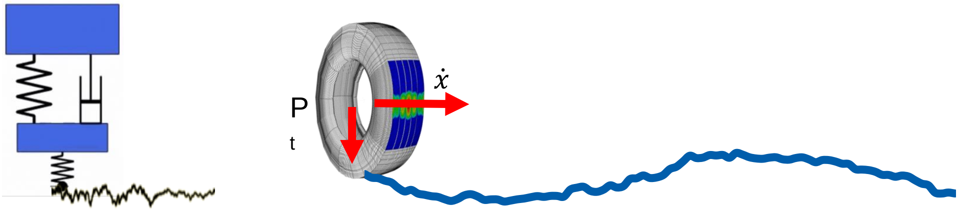



- **Truck suspension system**
- **Tire characteristics**
- **Pavement profiles**

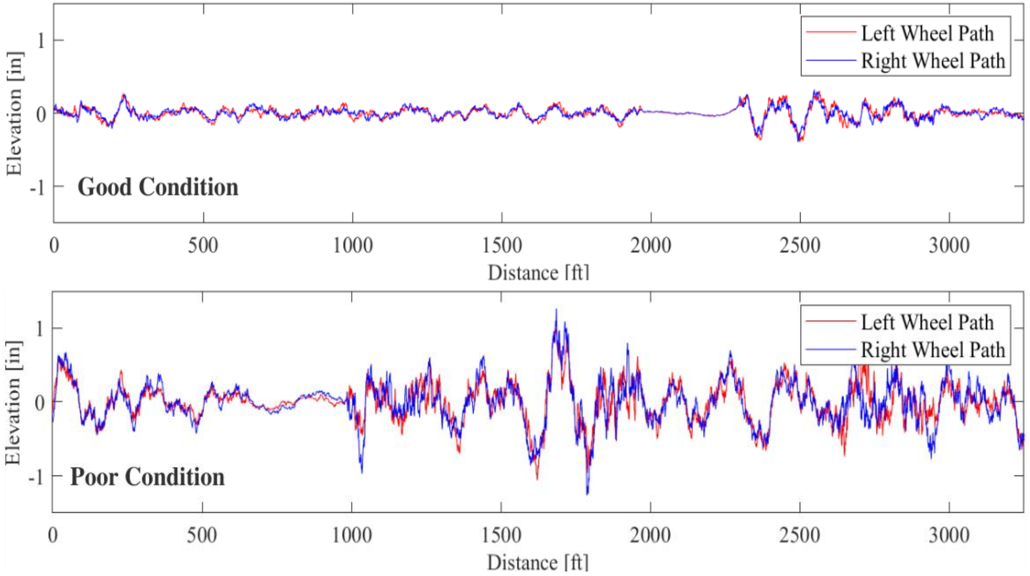


# Impact of Roughness

## Roughness

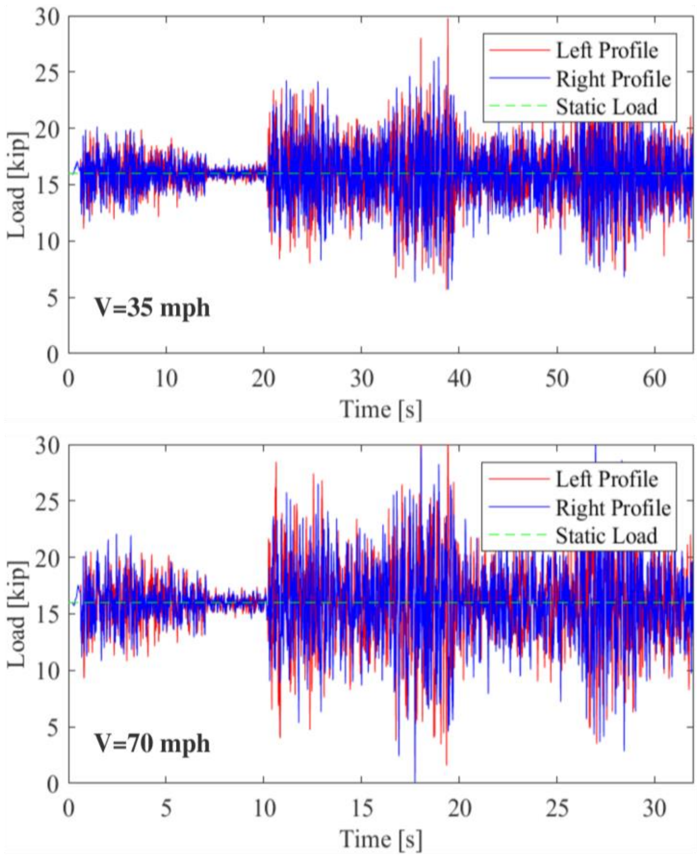



**Roughness impact cumulative deformation of suspension systems.**



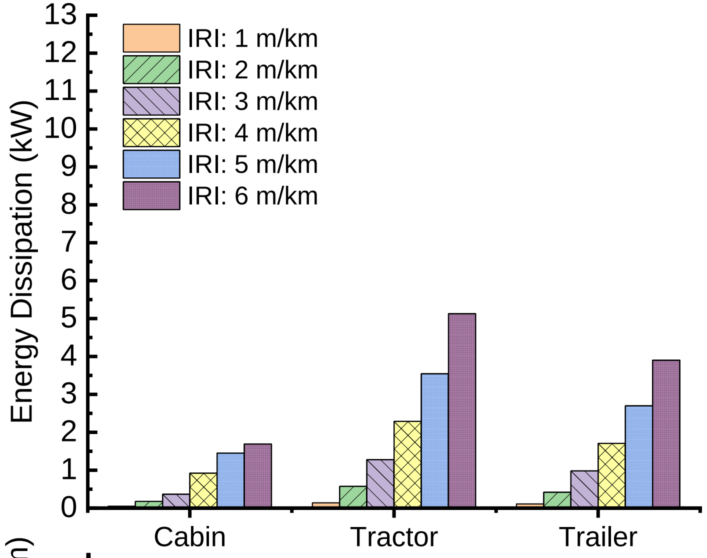

## Dynamic Loading

**Load amplification, increased w/ speed**

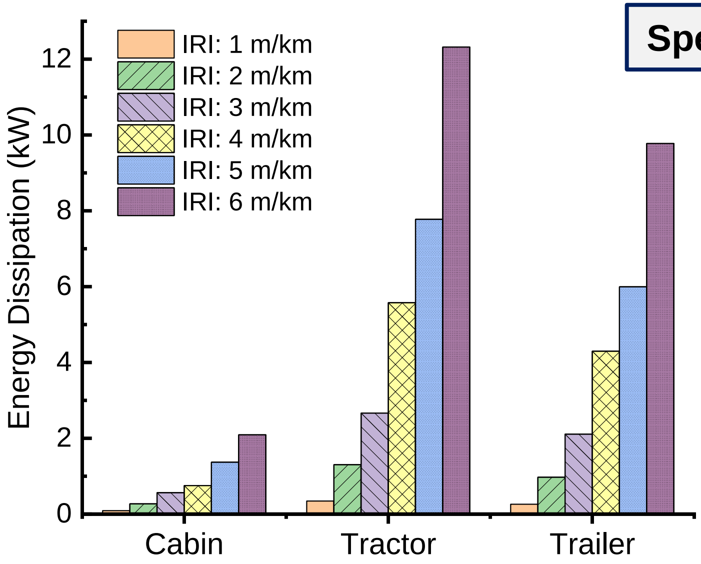


# Excessive Energy Consumption

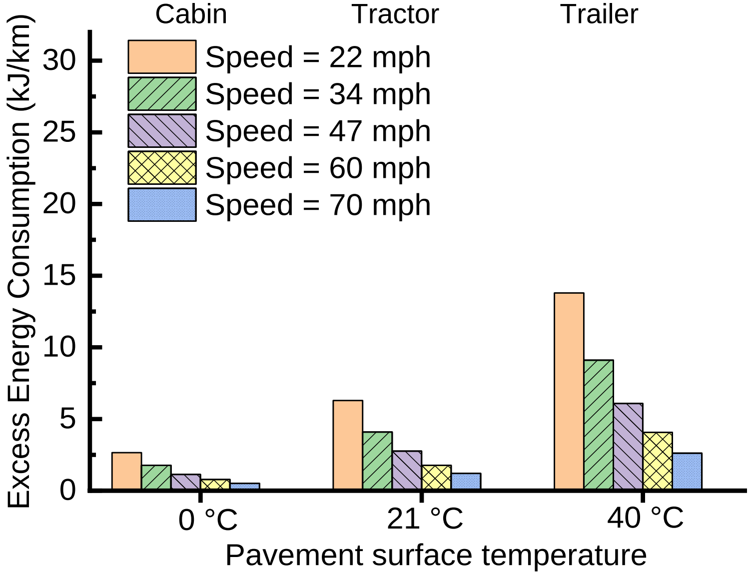
**Speed = 30mph**



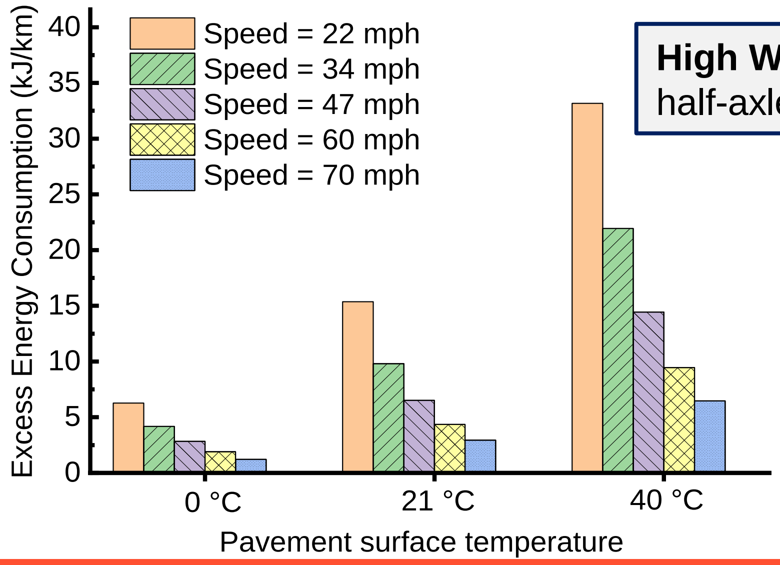

**Speed = 70mph**




**Low Wheel Load**: half-axle load of 6 kips




**High Wheel Load**: half-axle load of 12 kips

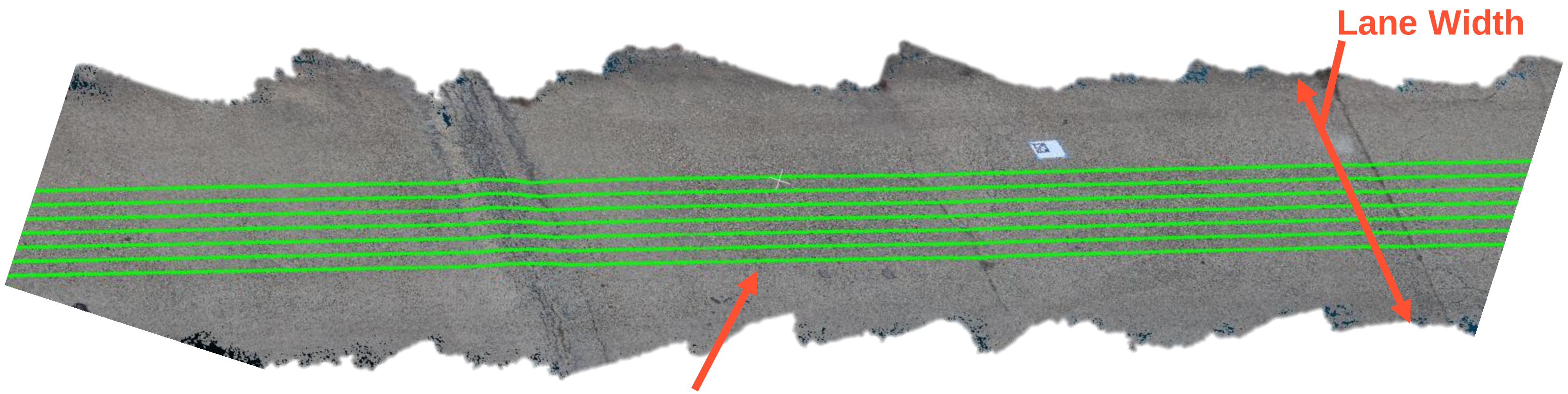


# Using Computer Vision Techniques to Quantify Pavement Rolling Resistance

## Acquire Overlapping Images




## Reconstruct Pavement Surface in 3D




**Extract Profile Data**

Roughness · Megatexture · Macrotexture · Microtexture

**Rolling Resistance** ← [Vehicle Energy Losses trough suspension system | Tire energy losses through deformation]

[Grip at tire-pavement interface] → **Friction**

# Summary

- Transportation is responsible for 26% of the GHG emissions in IL.
  - Significant part comes from roadways.
- Pavement sustainability should be assessed from cradle to grave.
  - Innovation across LCA stages is needed.
- Roughness and pavement texture influence rolling resistance.
  - Higher roughness levels and higher texture depths lead to higher energy loss.
- Reducing rolling resistance leads to considerable energy savings.
  - *Can be achieved through proper mix design and construction.*


# THANK YOU

*Any Questions?*

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