

Environmental Tradeoffs in Transportation Infrastructure Investment



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Image source: Los Angeles Metro.



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A project with UCLA and UC Berkeley



Motivation

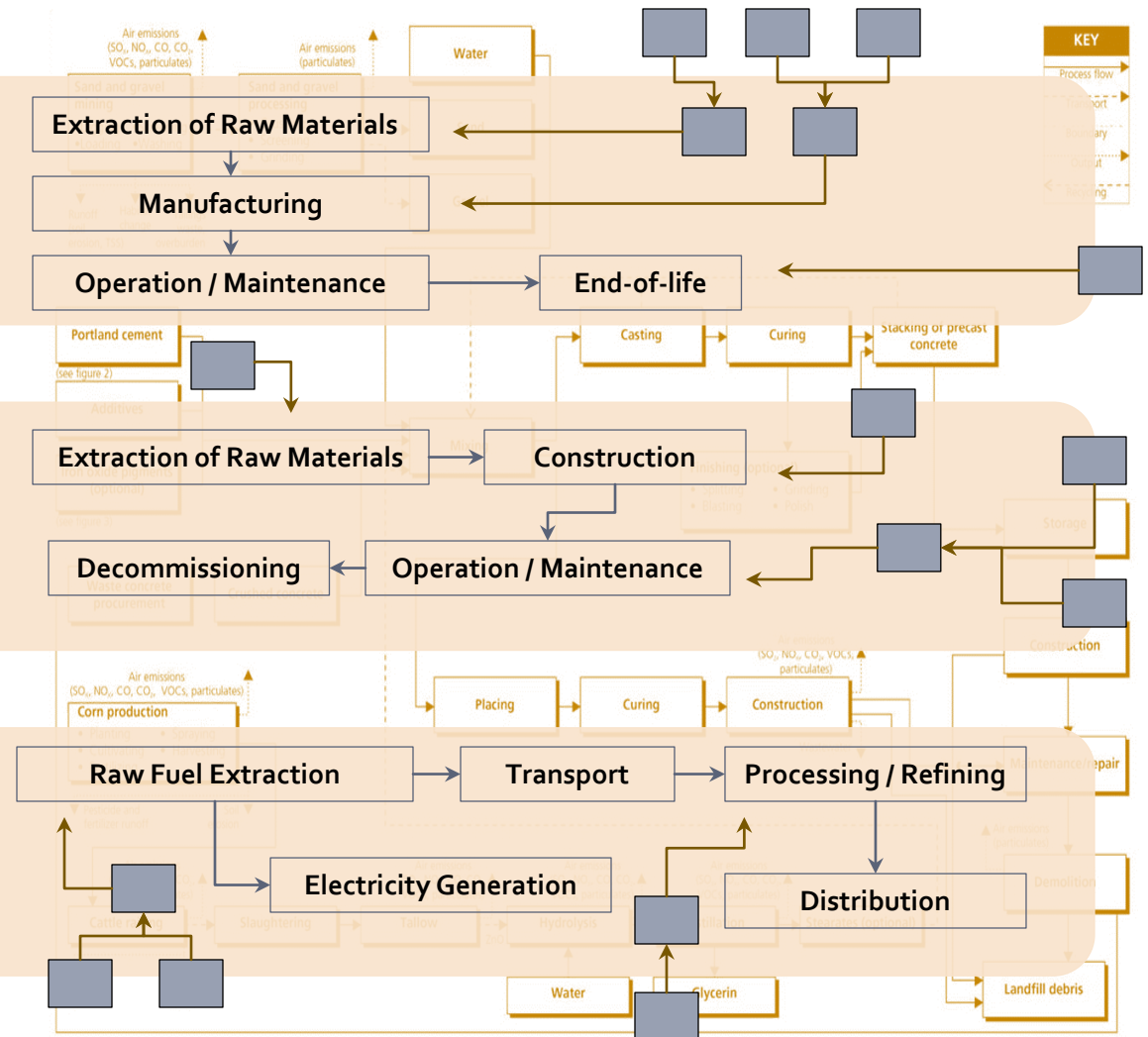
- Transportation decision making often occurs with indicators determined from a subset of system processes:
 - “tailpipe” emissions are the majority of emissions
 - the majority of impacts result from “tailpipe” emissions.
- More and more we are recognizing the shortfalls of this limited view
- Life-cycle assessment affords us an opportunity to evaluate the larger footprint

The Transportation "System"

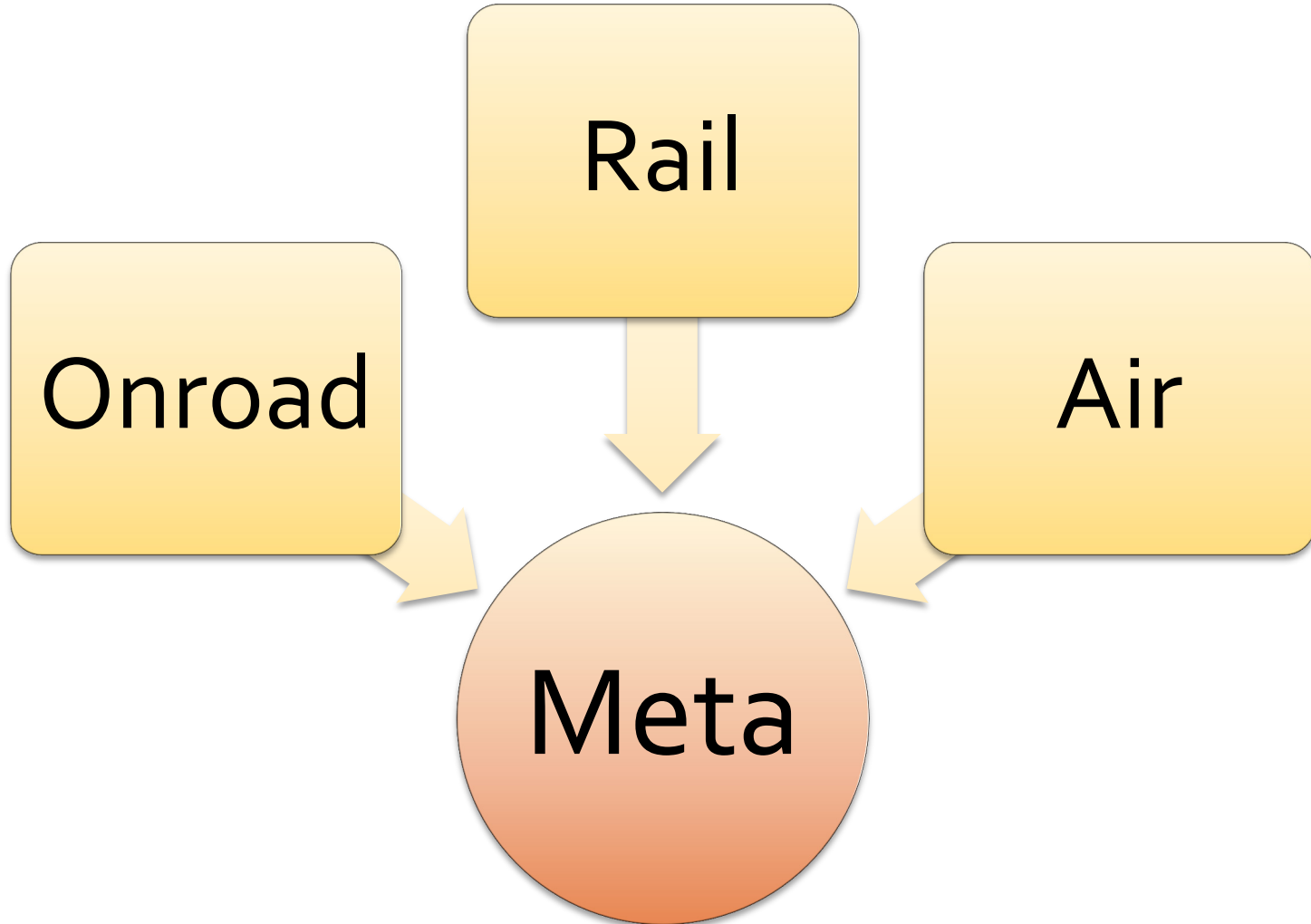
Vehicle

Infrastructure

Energy Production



Modeling Structure



Past Work

- Average US modes
 - Sedan, pickup, SUV
 - Peak and off-peak buses
 - Light rail, metro rail, commuter rail
 - Aircraft: short, medium, and long-haul flights
- Cities
 - San Francisco, Chicago, New York City
- Infrastructure
 - Parking
- Regions
 - California Corridor & High-speed Rail



Los Angeles Metro Orange & Gold Lines

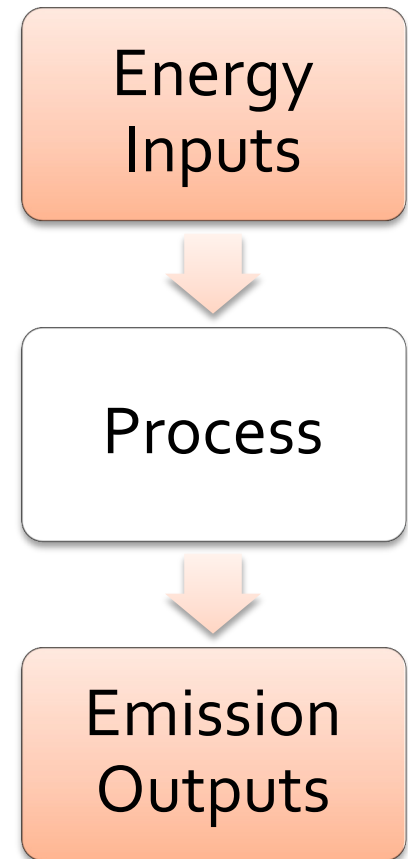


System Boundary

Life Cycle Grouping	Sedan	Orange Line	Gold Line
Vehicle			
Manufacturing	<ul style="list-style-type: none"> ▪ Sedan ▪ Transport to Point of Sale 	<ul style="list-style-type: none"> ▪ Bus ▪ Transport to Point of Sale 	<ul style="list-style-type: none"> ▪ Train ▪ Transport to Point of Sale
Operation	<ul style="list-style-type: none"> ▪ Propulsion ▪ Idling 	<ul style="list-style-type: none"> ▪ Propulsion ▪ Idling 	<ul style="list-style-type: none"> ▪ Propulsion ▪ Idling
Maintenance	<ul style="list-style-type: none"> ▪ Typical Sedan Maintenance ▪ Tire Replacement ▪ Battery Replacement 	<ul style="list-style-type: none"> ▪ Typical Bus Maintenance ▪ Tire Replacement ▪ Battery Replacement 	<ul style="list-style-type: none"> ▪ Typical Train Maintenance ▪ Train Cleaning ▪ Flooring Replacement
Insurance	<ul style="list-style-type: none"> ▪ Sedan Liability 	<ul style="list-style-type: none"> ▪ Bus Liability ▪ Operator Fringe Benefits 	<ul style="list-style-type: none"> ▪ Train Liability ▪ Operator Fringe Benefits
Infrastructure			
Construction	<ul style="list-style-type: none"> ▪ Roadway Construction 	<ul style="list-style-type: none"> ▪ Roadway Construction ▪ Station Construction 	<ul style="list-style-type: none"> ▪ Track Construction ▪ Station Construction
Operation	<ul style="list-style-type: none"> ▪ Roadway Lighting ▪ Herbicide Use 	<ul style="list-style-type: none"> ▪ Road and Station Lighting ▪ Herbicide Use ▪ Control and Signaling 	<ul style="list-style-type: none"> ▪ Track, Station, and Parking Lighting ▪ Herbicide Use ▪ Train Control ▪ Miscellaneous (Escalators, Equipment)
Maintenance	Roadway maintenance is the result of heavy duty vehicles and thus not charged to the sedan.	<ul style="list-style-type: none"> ▪ Road and Station Maintenance 	<ul style="list-style-type: none"> ▪ Track and Station Maintenance
Parking	<ul style="list-style-type: none"> ▪ Curbside Parking 	<ul style="list-style-type: none"> ▪ Dedicated Parking 	<ul style="list-style-type: none"> ▪ Dedicated Parking
Insurance	<ul style="list-style-type: none"> ▪ Road Workers Fringe Benefits 	<ul style="list-style-type: none"> ▪ Non-vehicle Workers Fringe Benefits ▪ Infrastructure Liability 	<ul style="list-style-type: none"> ▪ Non-vehicle Workers Fringe Benefits ▪ Infrastructure Liability
Energy Production			
Extraction, Processing, & Distribution	<ul style="list-style-type: none"> ▪ Gasoline Extraction, Processing, & Distribution 	<ul style="list-style-type: none"> ▪ Natural Gas Extraction, Processing, Distribution, & Compression 	<ul style="list-style-type: none"> ▪ Raw Fuel Extraction and Processing, Electricity Generation, Transmission & Distribution

Environmental Indicators

- Energy
- Air Emissions
 - SO₂ Respiratory irritant, acid deposition
 - CO Asphyxiant
 - NO_x Respiratory irritant, smog
 - VOC Photochemical smog, cancerous
 - PM Respiratory and cardiovascular damage
- Greenhouse Gases
 - CO₂, CH₄, N₂O
- Others
 - Water, labor, costs, toxics, hazardous, etc.

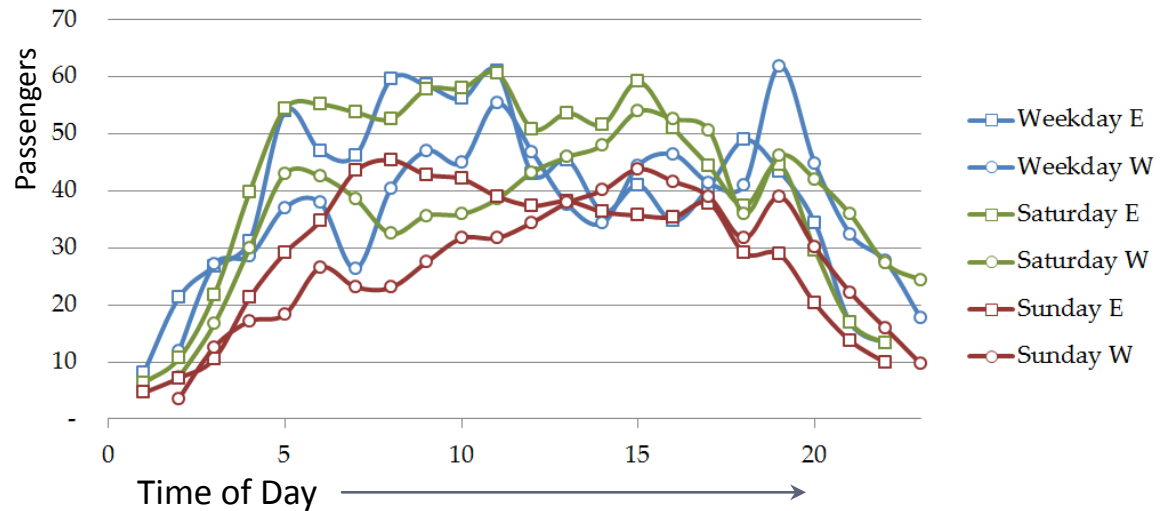


Occupancy

■ Orange line

■ 57 seats

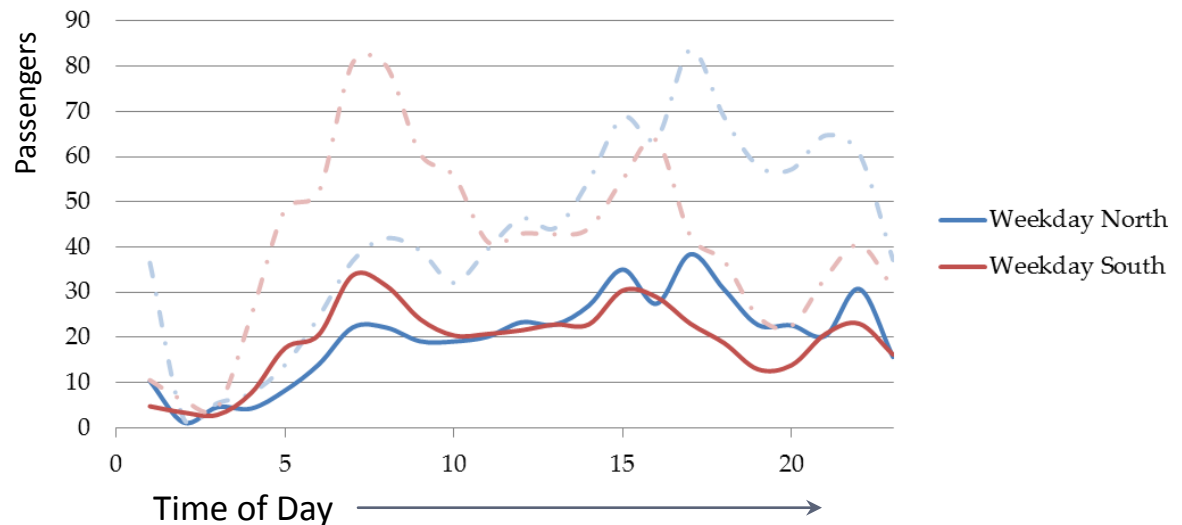
■ 38 pax

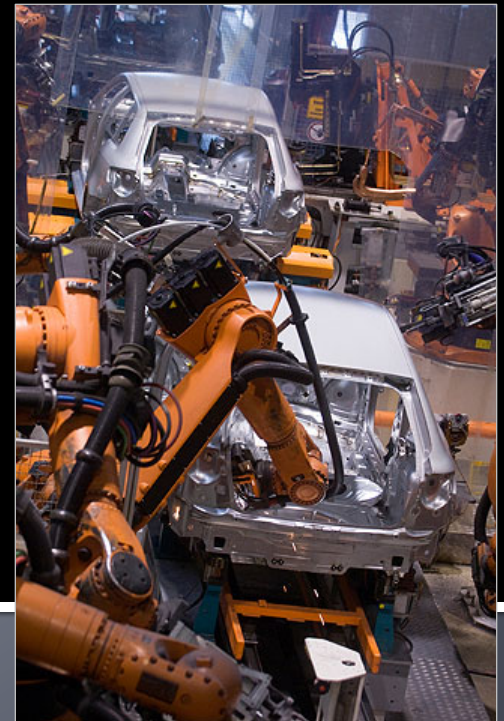


■ Gold line

■ 152 seats

■ 43 pax

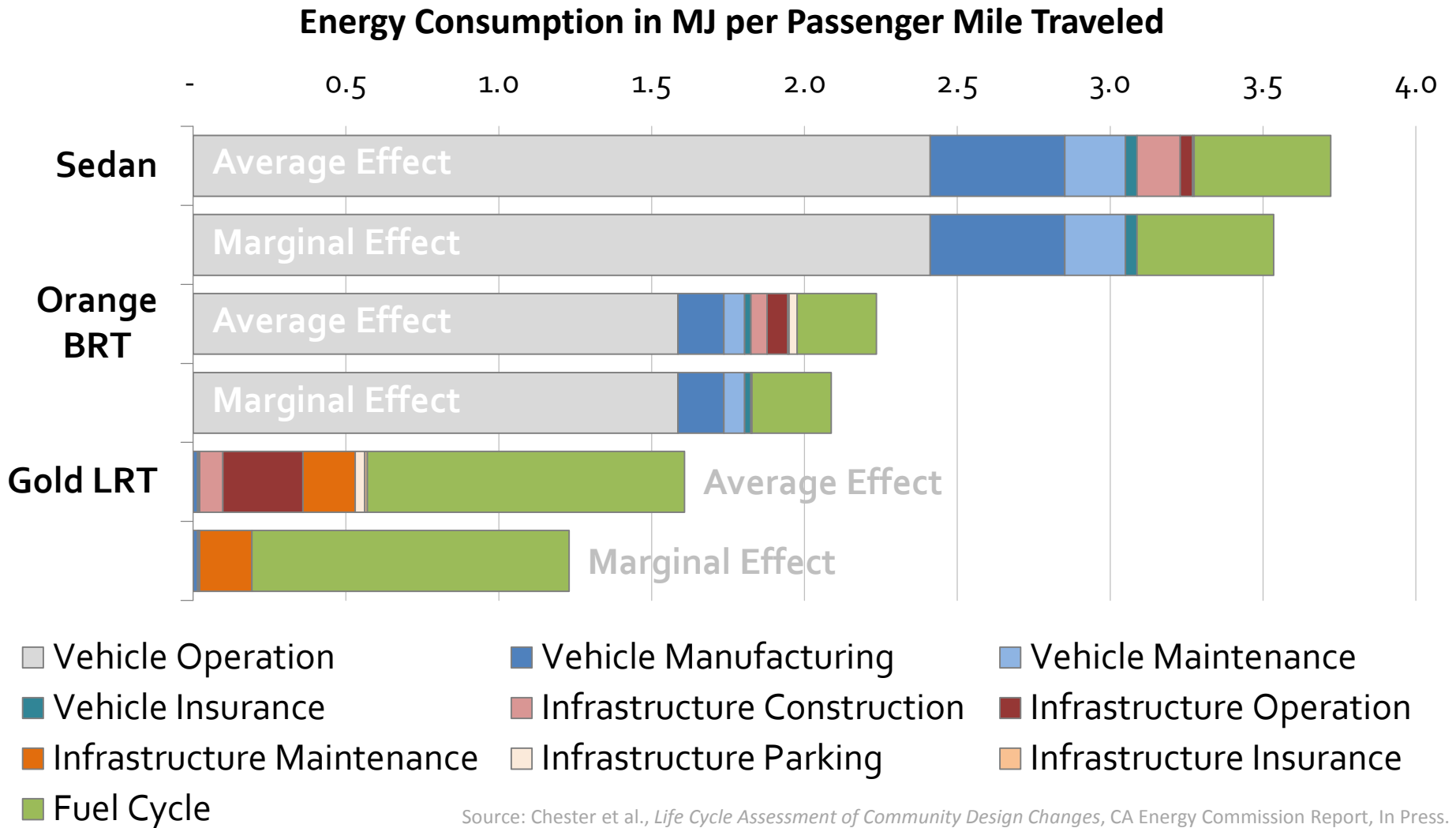




Phase ① Preliminary Results

Preliminary Results

Energy Consumption Inventories

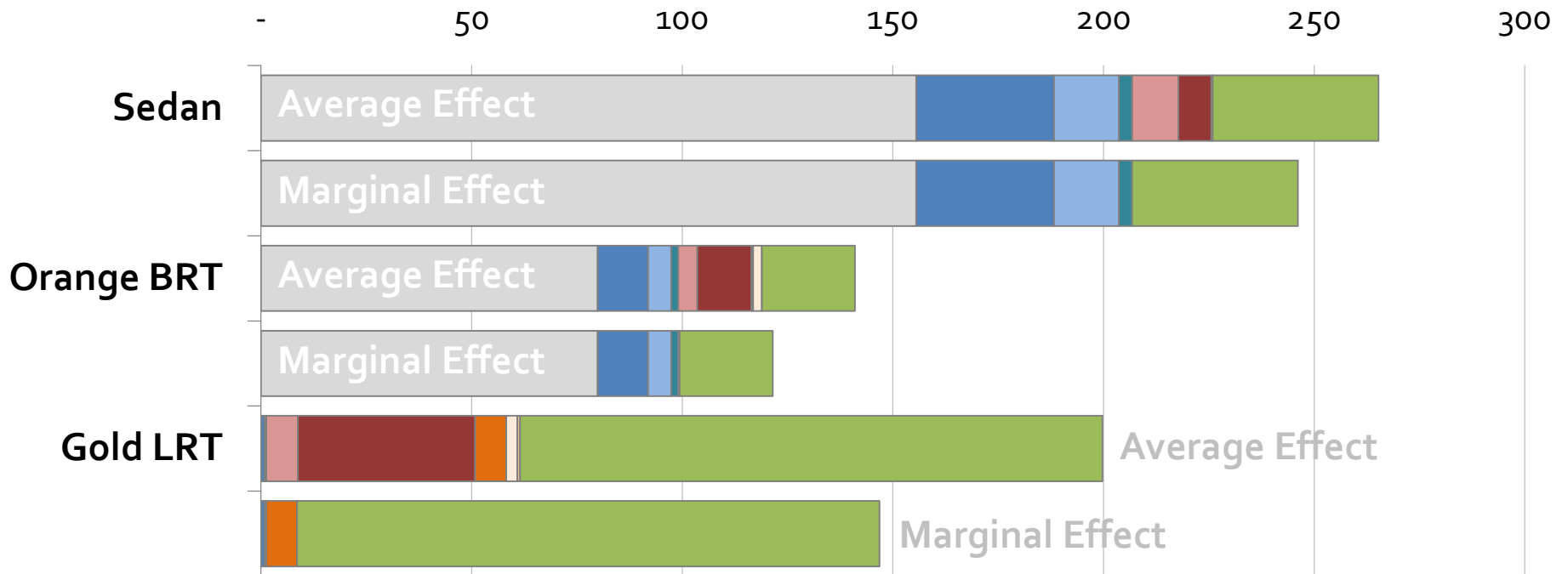


Source: Chester et al., *Life Cycle Assessment of Community Design Changes*, CA Energy Commission Report, In Press.

Preliminary Results

Greenhouse Gas Inventories

Greenhouse Gas Emissions in g CO₂e per Passenger Mile Traveled



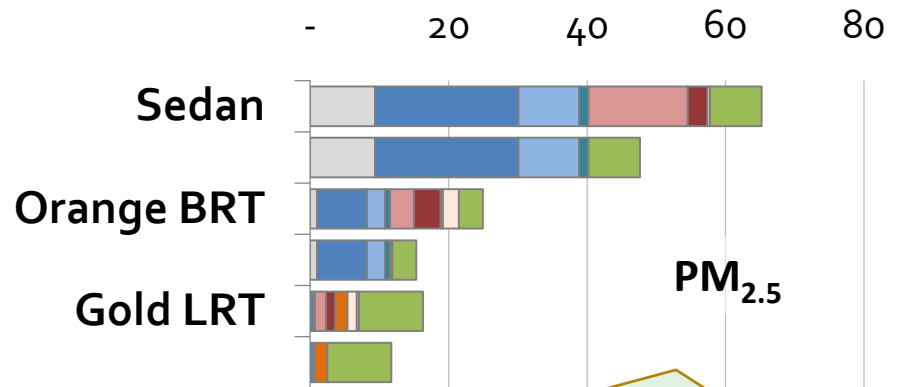
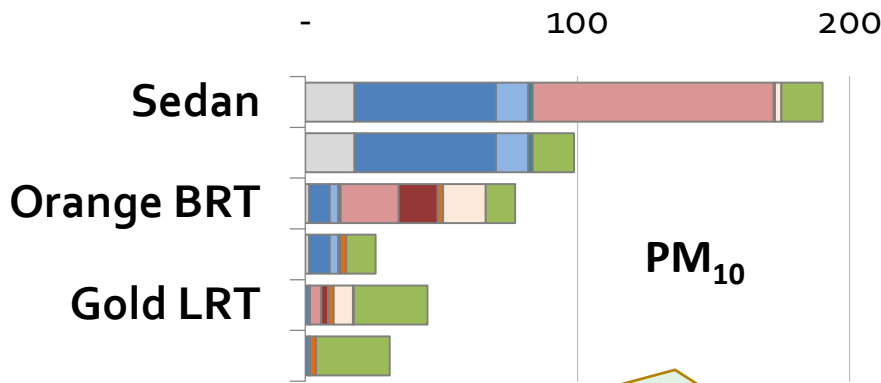
- Vehicle Operation
- Vehicle Manufacturing
- Vehicle Maintenance
- Vehicle Insurance
- Infrastructure Construction
- Infrastructure Operation
- Infrastructure Maintenance
- Infrastructure Parking
- Infrastructure Insurance
- Fuel Cycle

Source: Chester et al., *Life Cycle Assessment of Community Design Changes*, CA Energy Commission Report, In Press.

Preliminary Results

Particulate Matter Inventories

PM Emissions in mg per Passenger Mile Traveled



Life cycle **PM₁₀** emissions are dominated by:

- 1) Asphalt aggregate production for sedan and Orange line infrastructure.
- 2) Steel, iron, and aluminum for vehicle manufacturing.

Life cycle **PM_{2.5}** emissions are dominated by:

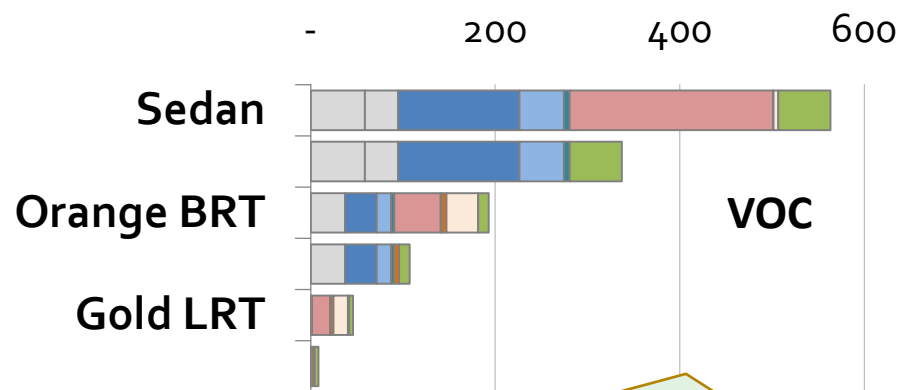
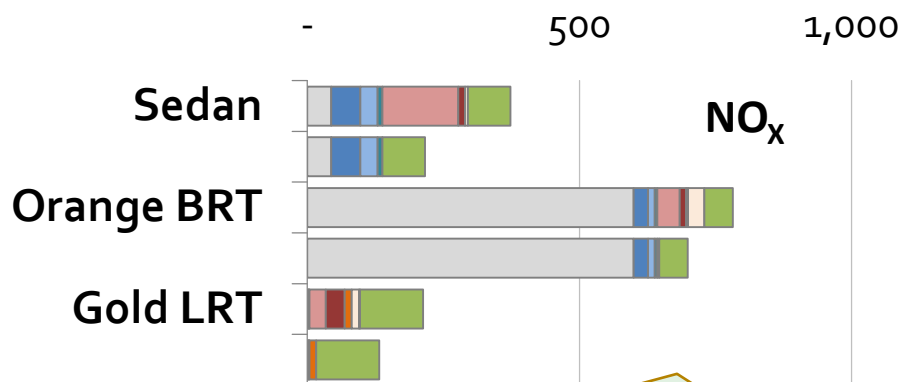
- 1) Steel and aluminum production furnace emissions for vehicle manufacturing.
- 2) Supply chain diesel truck use.



Preliminary Results

Ozone Precursor Inventories

Emissions in mg per Passenger Mile Traveled



Life cycle **NO_x** emissions are dominated by:
 1) Orange line tailpipe @ 19 grams/VMT
 Range: 8.2 to 73 grams/VMT.
 2) Supply chain diesel truck use.

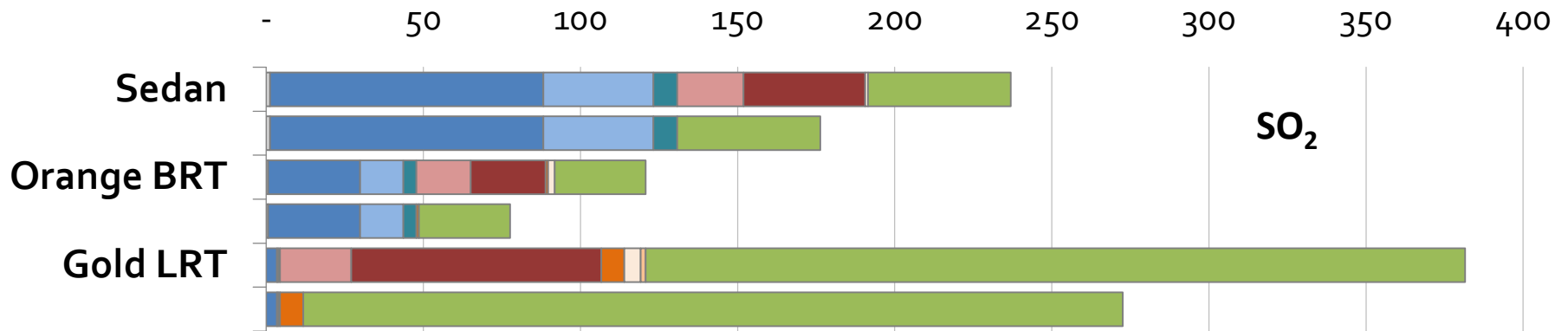
Life cycle **VOC** emissions are dominated by:
 1) Vehicle fluids (steering, brake, transmission, coolants, etc.).
 2) Vehicle manufacturing and truck transport.
 3) Volatile organic diluents in asphalt.



Preliminary Results

SO₂ Inventory

Emissions in mg per Passenger Mile Traveled



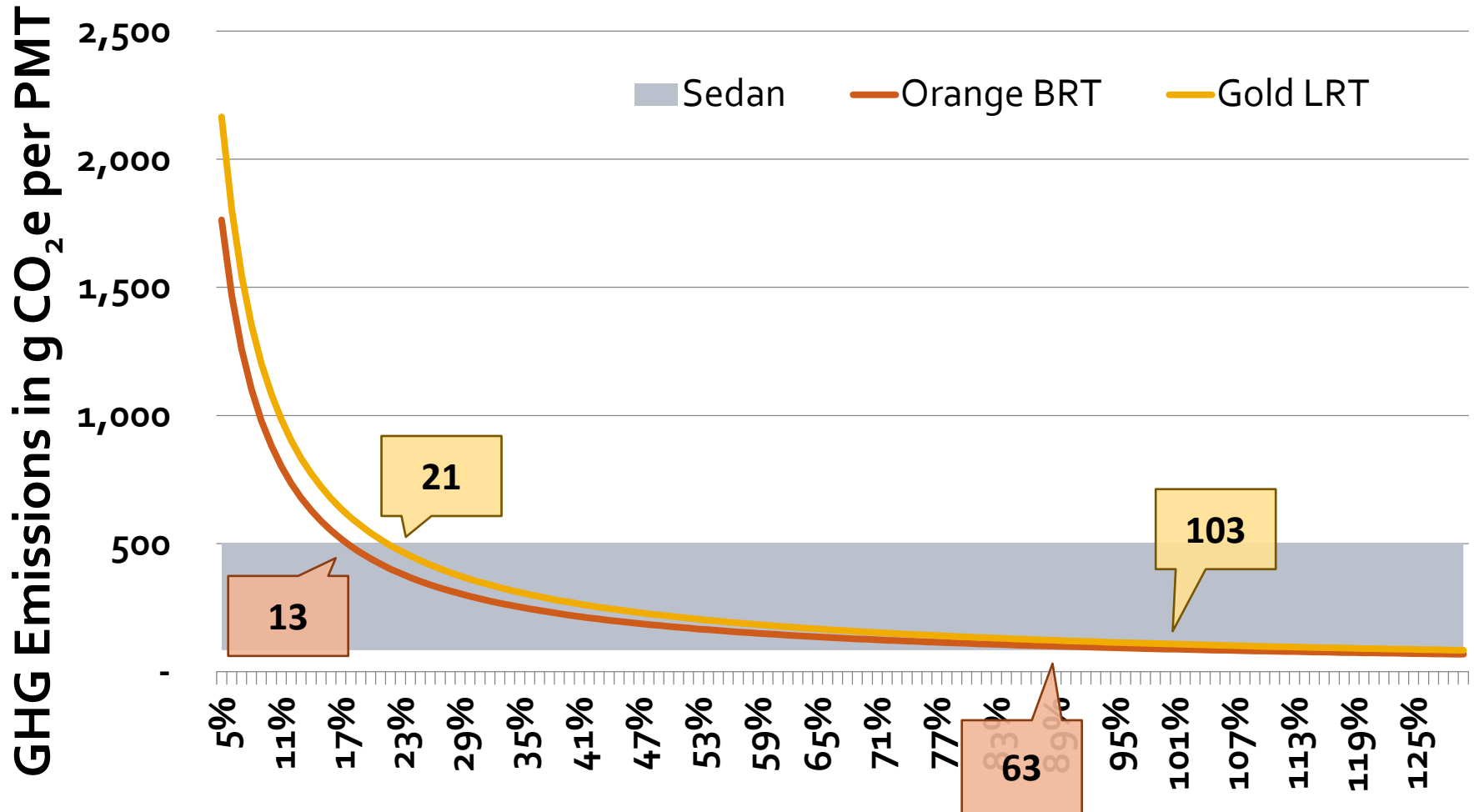
Life cycle SO₂ emissions are dominated by:
 Direct and supply chain electricity use
 Gold line uses LADWP (39% coal).

- Vehicle Operation
- Vehicle Manufacturing
- Vehicle Maintenance
- Vehicle Insurance
- Infrastructure Construction
- Infrastructure Operation
- Infrastructure Maintenance
- Infrastructure Parking
- Infrastructure Insurance
- Fuel Cycle

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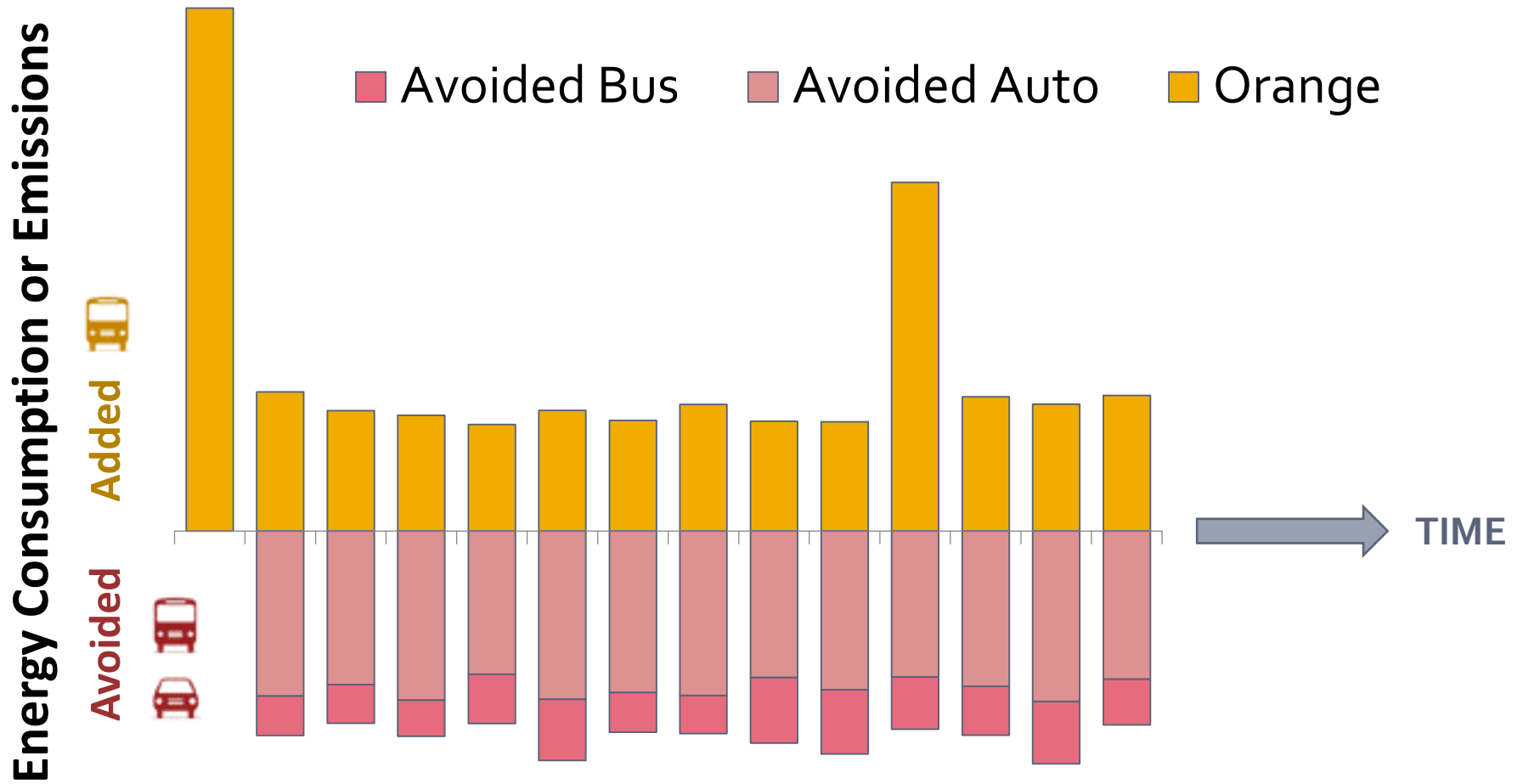
Preliminary Results

Occupancy Sensitivity

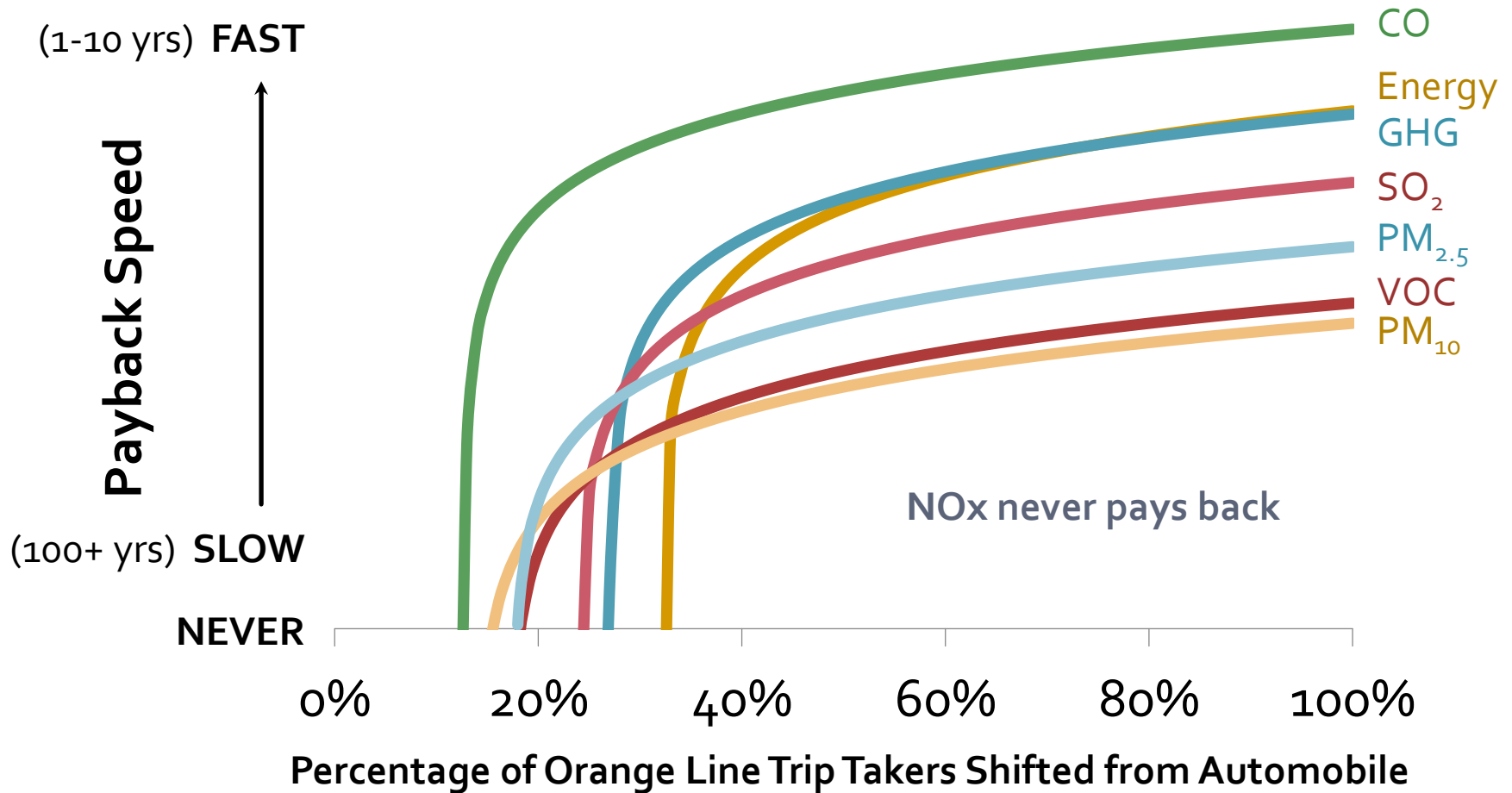


Phase ②: Work in Progress

Consequential Effects



Orange Line Mode Shifts



www.sustainable-transportation.com
