Presentation to the California Air Resources Board on May 9, 2013

Environmental Life-cycle Assessment of Passenger Transportation

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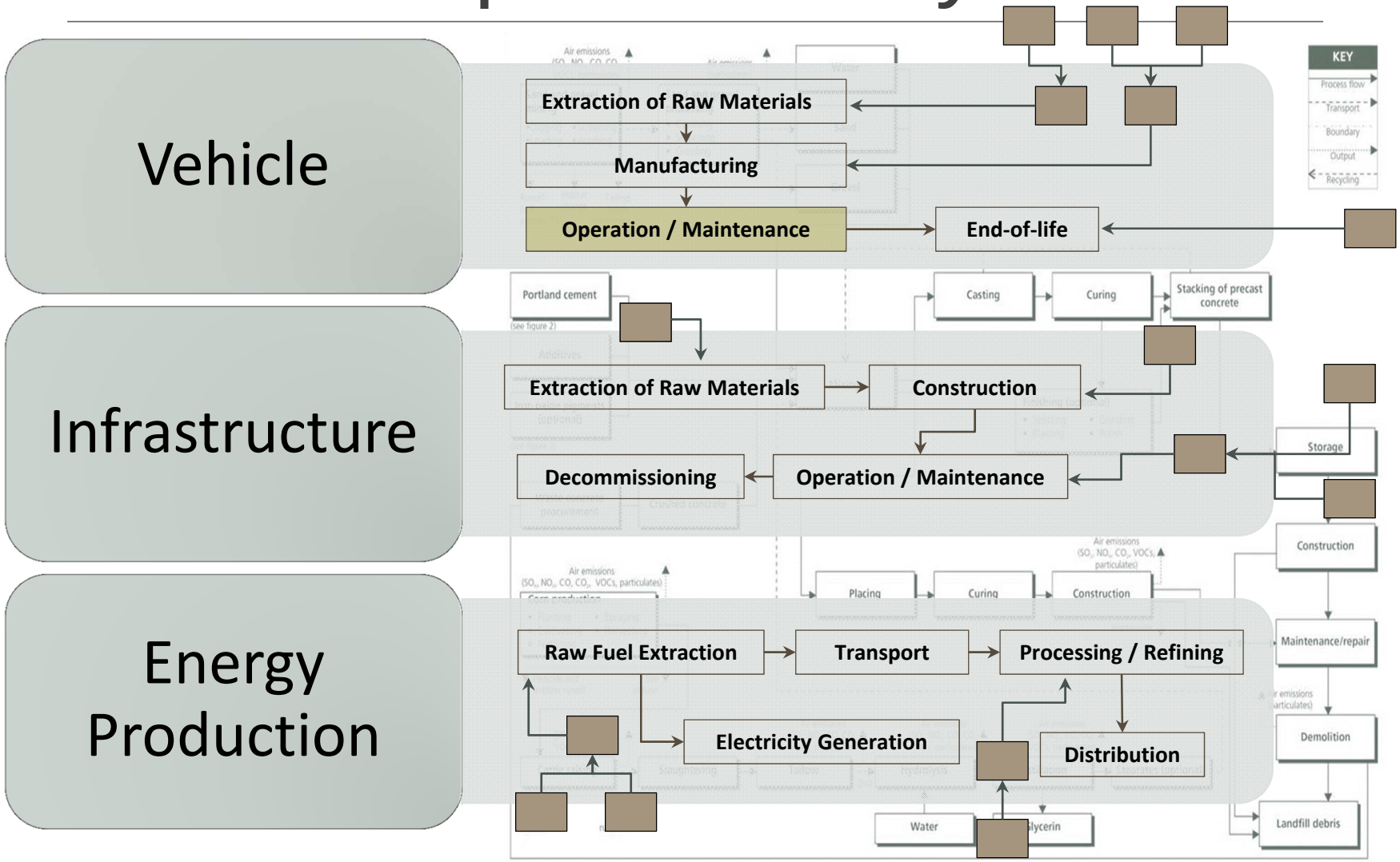
Presentation Overview

- Transportation Life Cycle Assessment Overview
  - Significance of infrastructure and supply chains
  - Forecasting future behavior and technologies
- Los Angeles Light Rail and Bus Rapid Transit
- California High-speed Rail
- Integrated Transportation and Land Use

Transportation LCA

The Transportation "System"



System Boundary

Life Cycle Grouping	Automobiles/Buses	Air	Rail
Vehicle			
Manufacturing	▪ Sedan ▪ Transport to Point of Sale	▪ Aircraft Manufacturing ▪ Engine Manufacturing	▪ Train ▪ Transport to Point of Sale
Operation	▪ Propulsion ▪ Idling	▪ APU / Startup / Taxi Out / Takeoff / Climb Out / Cruise / Approach / Landing / Taxi In	▪ Propulsion ▪ Idling
Maintenance	▪ Typical Sedan Maintenance ▪ Tire Replacement ▪ Battery Replacement	▪ Aircraft Maintenance ▪ Engine Maintenance	▪ Typical Train Maintenance ▪ Train Cleaning ▪ Flooring Replacement
Insurance	▪ Sedan Liability	▪ Crew Health & Benefits ▪ Liability	▪ Train Liability ▪ Operator Fringe Benefits
Infrastructure			
Construction	▪ Roadway	▪ Airport ▪ Runway/Taxiway/Tarmac	▪ Track ▪ Station
Operation	▪ Roadway Lighting ▪ Herbicide Use	▪ Airport Energy ▪ Runway Lighting ▪ Deicing Fluids ▪ Ground Support Equipment	▪ 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.	▪ Airport ▪ Runway/Taxiway/Tarmac	▪ Track and Station Maintenance
Parking	▪ Curbside Parking	▪ Airport Parking	▪ Dedicated Parking
Insurance	▪ Road Workers Fringe Benefits	▪ Non-crew Health and Benefits ▪ Infrastructure Liability	▪ Non-vehicle Workers Fringe Benefits ▪ Infrastructure Liability
Energy Production			
Extraction, Processing, & Distribution	▪ Gasoline/Diesel/Natural Gas Extraction, Processing, & Distribution	▪ Jet Fuel Extraction, Processing, & Distribution	▪ Raw Fuel Extraction and Processing, Electricity Generation, Transmission & Distribution

Environmental Indicators

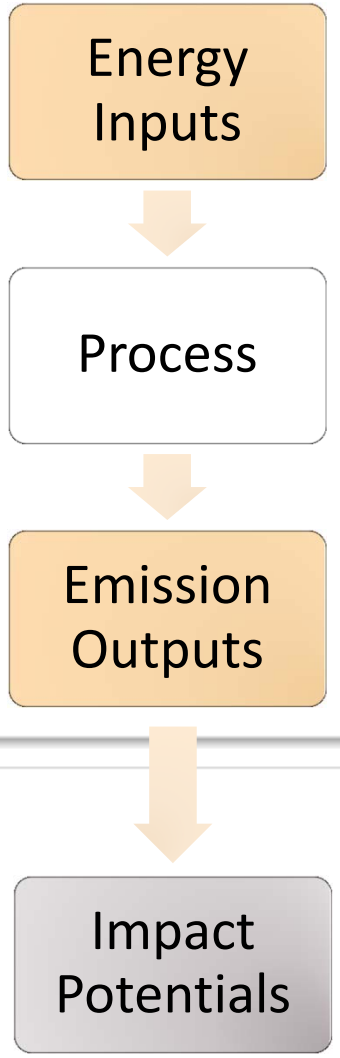
Energy

Air Emissions
- SO_X Respiratory irritant, acid deposition
- CO Asphyxiant
- NO_X Respiratory irritant, smog
- VOC Photochemical smog, cancerous
- PM Respiratory and cardiovascular damage

Greenhouse Gases
- CO_2, CH_4, N_2O

Others
- Water, labor, costs, toxics, hazardous, etc.

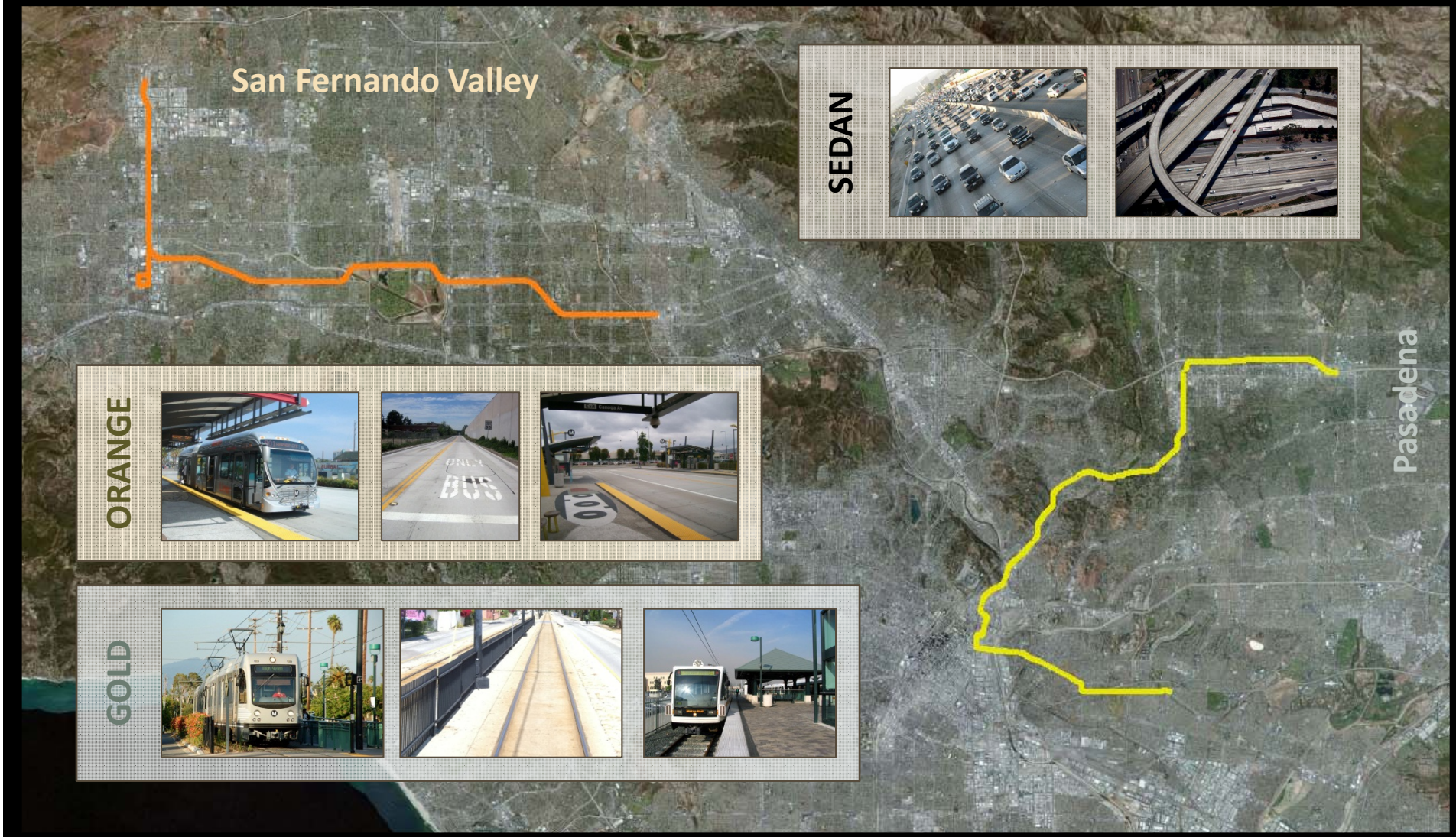
Human Health and Environmental Impact Potentials
- Respiratory: SOx, NOx and $PM_{2.5}$
- Acidification: SOx and NOx
- Photochemical Smog Formation: CH_4, CO, VOC, and NOx
- Eutrophication Potential



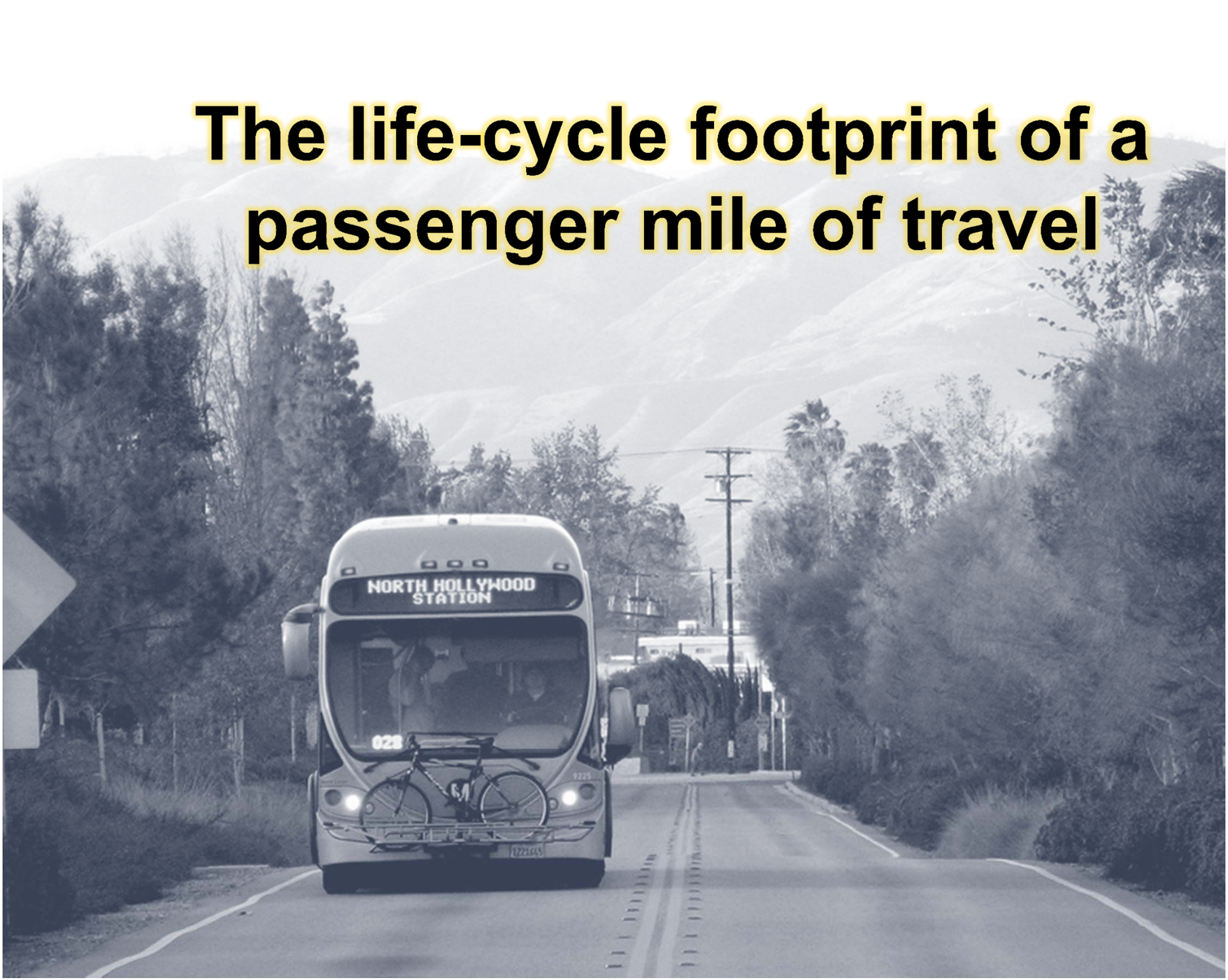
Los Angeles Metro

Infrastructure and automobile shifts: positioning transit to reduce life-cycle environmental impacts for urban sustainability goals

Los Angeles Metro Orange & Gold Lines



The life-cycle footprint of a passenger mile of travel



Parameterizing LCA

Vehicle
- Manufacturing
- Maintenance

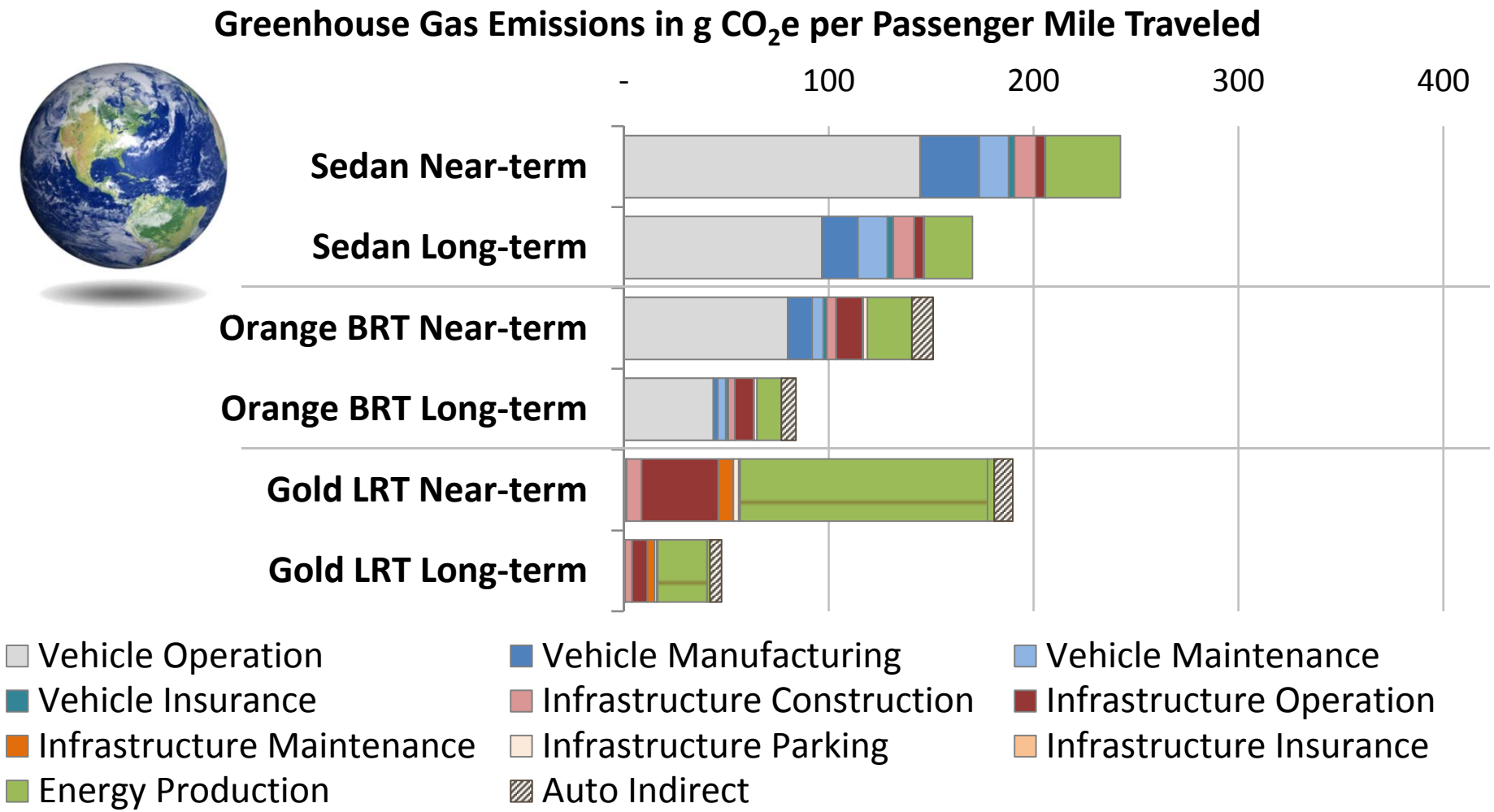
Vehicle Operation

Infrastructure
- Construction
- Maintenance
- Operation

Energy Production
- Sources
- Processing

Today

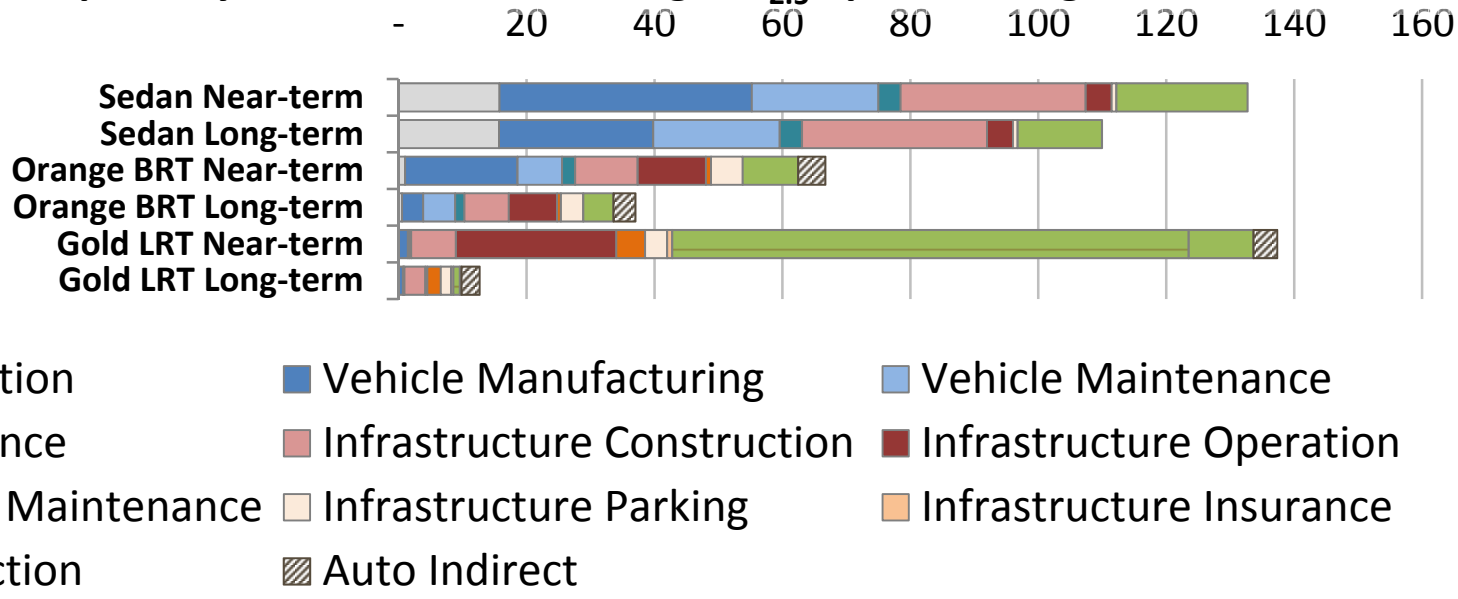
Greenhouse Gas Emissions



M Chester, S Pincetl, Z Elizabeth, W Eisenstein, & J Matute, Infrastructure and Automobile Shifts: Positioning Transit to Reduce Life-cycle Environmental Impacts for Urban Sustainability Goals, *Environmental Research Letters* 8(1), 015041, doi:10.1088/1748-9326/8/1/015041.

Preliminary Results: Respiratory Stressors

Human Health Respiratory Effects Potential in mg $PM_{2.5}e$ per Passenger Mile Traveled



Life-cycle Respiratory Effects Hotspots

$PM_{2.5}$: Steel and alum. production furnace emissions for vehicle manuf.

$PM_{2.5}$: Supply chain diesel truck use.

NOx: Supply chain diesel truck emissions.

SOx: Direct and supply chain electricity consumption.

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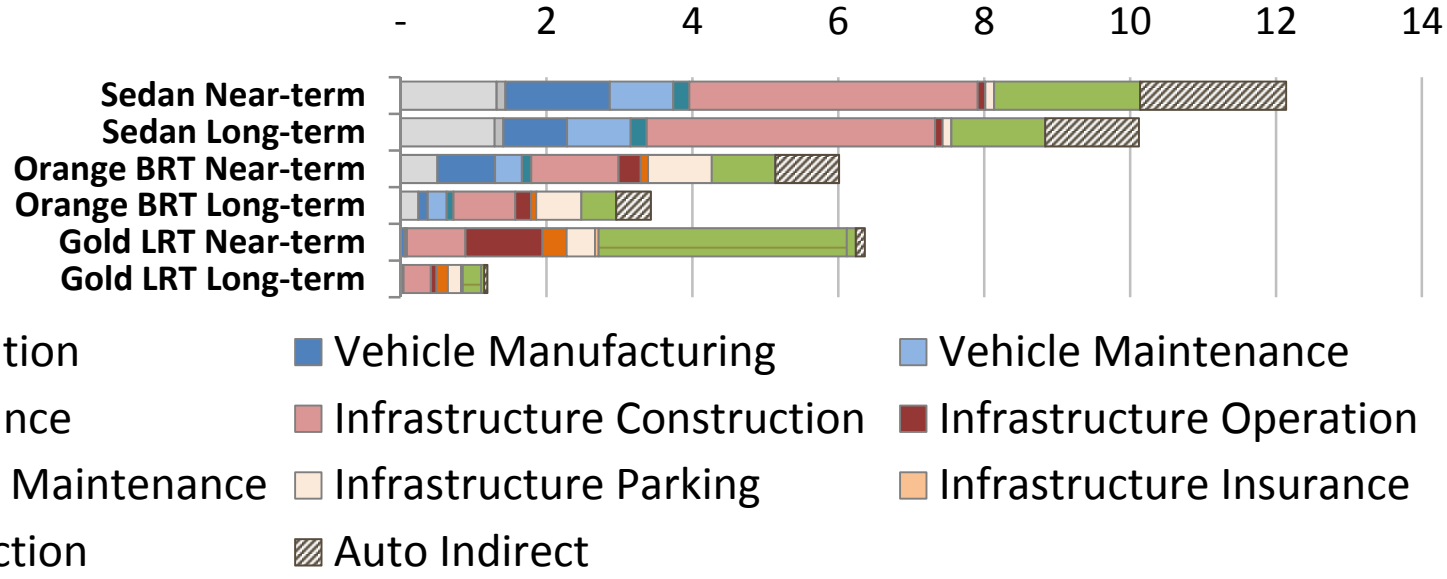
Preliminary Results
Photochemical Smog Stressors

Photochemical Smog Formation Potential in Mg O_3e per Passenger Mile Traveled



Life-cycle Smog Hotspots

NOx: Orange line tailpipe.
NOx: Supply chain diesel truck emissions.
VOC: Vehicle fluids (steering, brake, transmission, coolants, etc.).
VOC: Vehicle manufacturing and truck transport.
VOC: Volatile organic diluents in asphalt.

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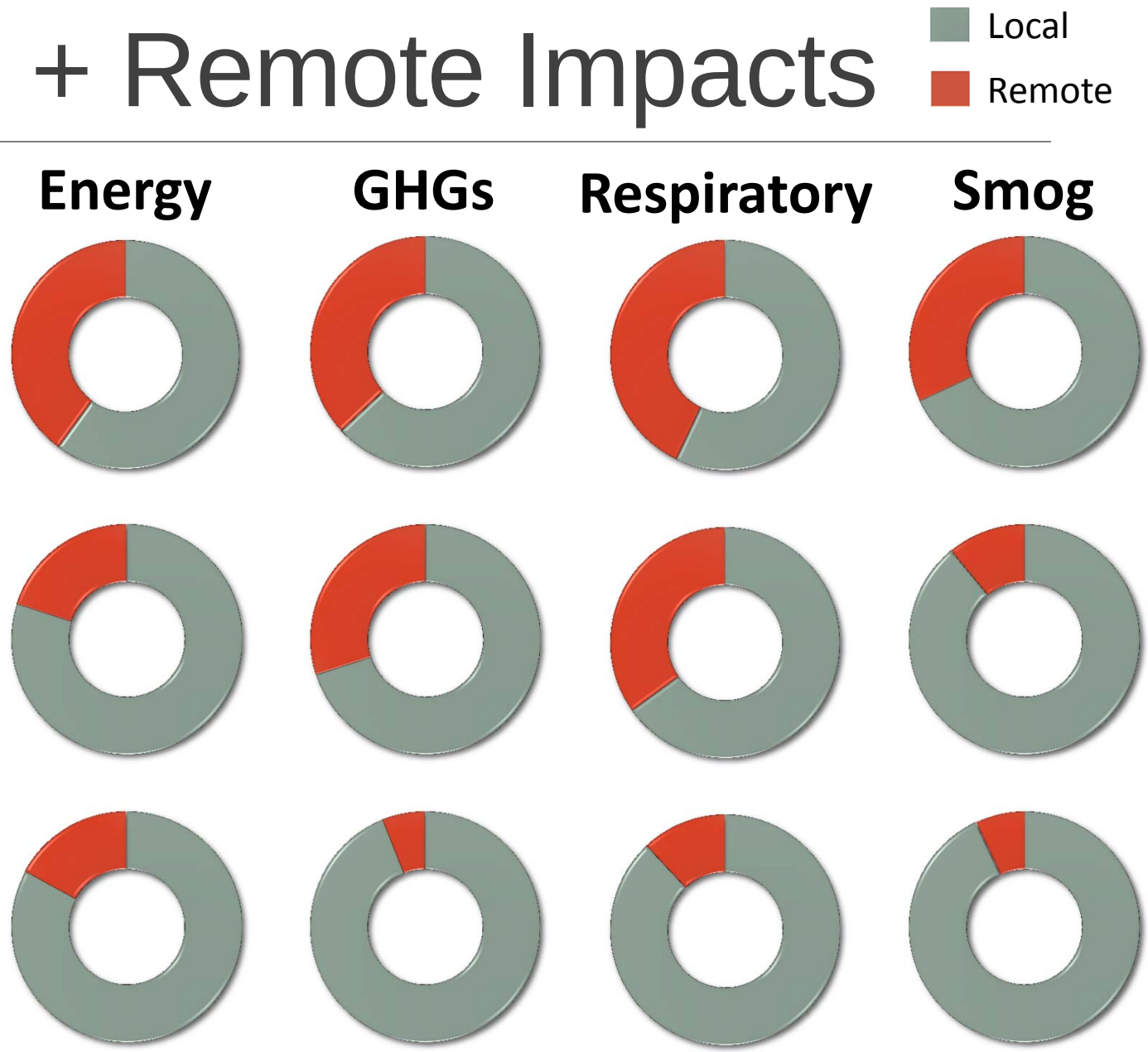
Los Angeles

Local + Remote Impacts



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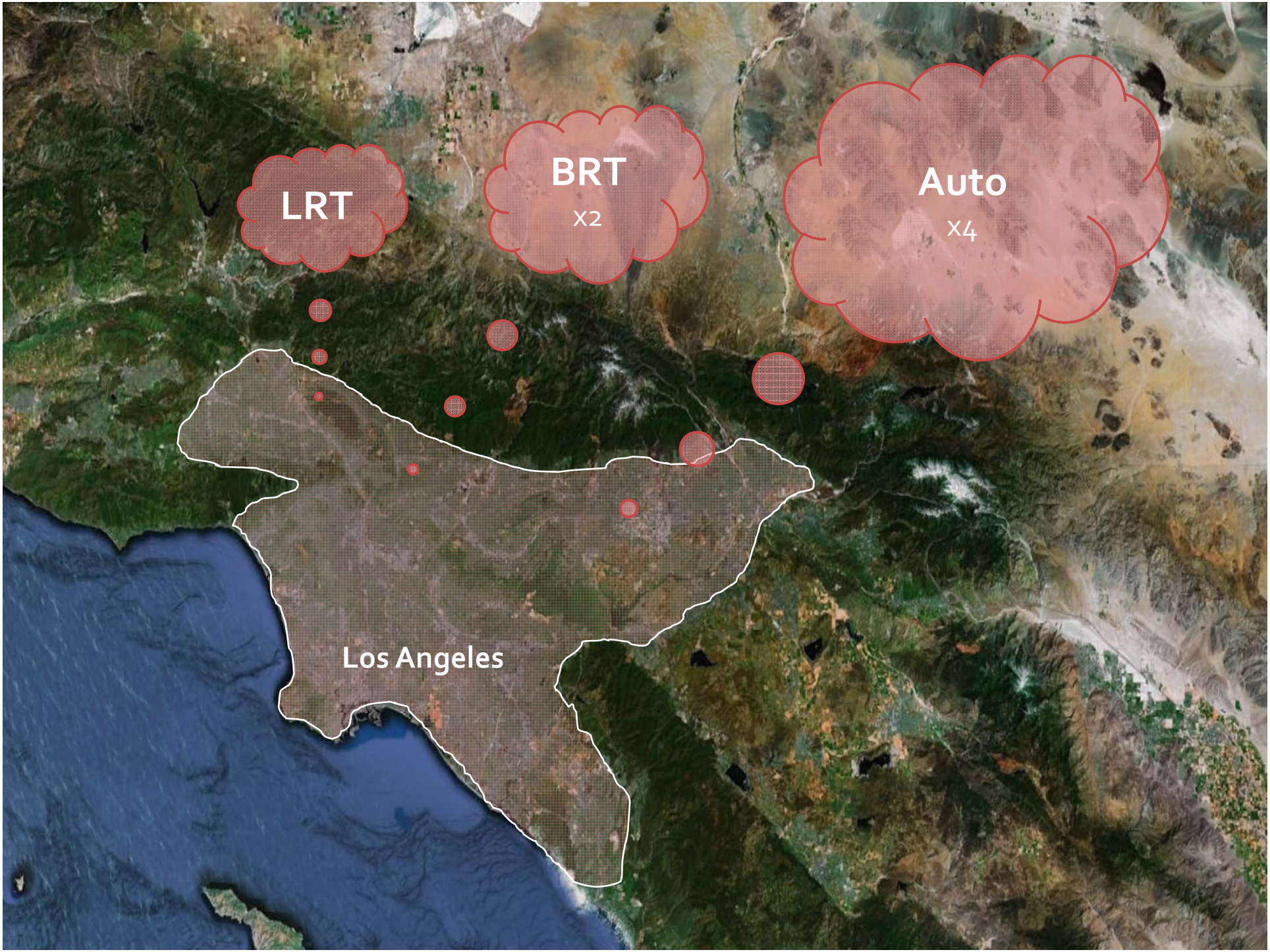
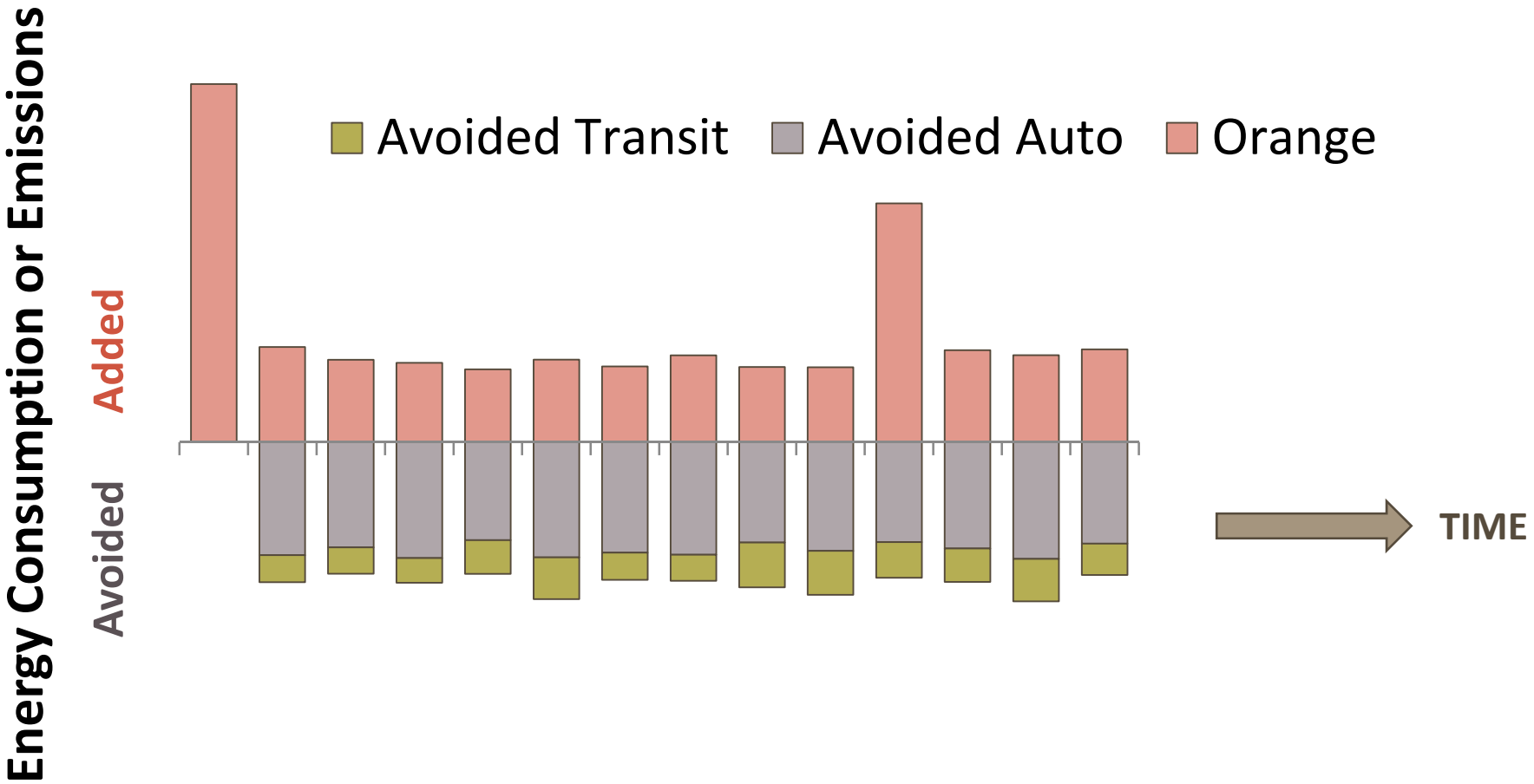

LRT
BRT
x2
Auto
x4
Los Angeles

LCA of the decision to deploy the Orange and Gold lines

Footprinting
(per PMT)

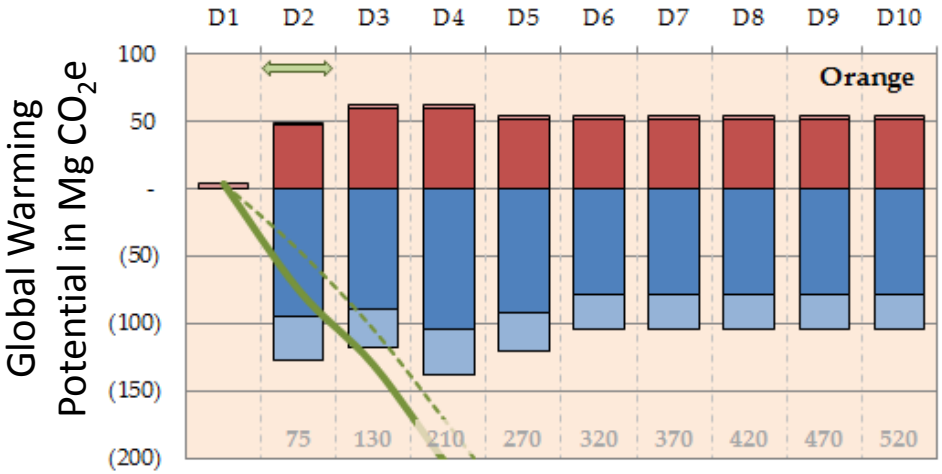
Consequential
(Corridor Effects)

Consequential Effects



Orange BRT Impacts by Decade (D)

Gold LRT Impacts by Decade (D)



Respiratory Impact Potential in kg $PM_{2.5}$e

Transit Operation/Propulsion | Transit Life-cycle | Automobile Operation | Automobile Life-cycle | Cumulative | Cumulative (Local)

Payback occurs in decade. Gray text (e.g., 470) are the impact savings in decade.

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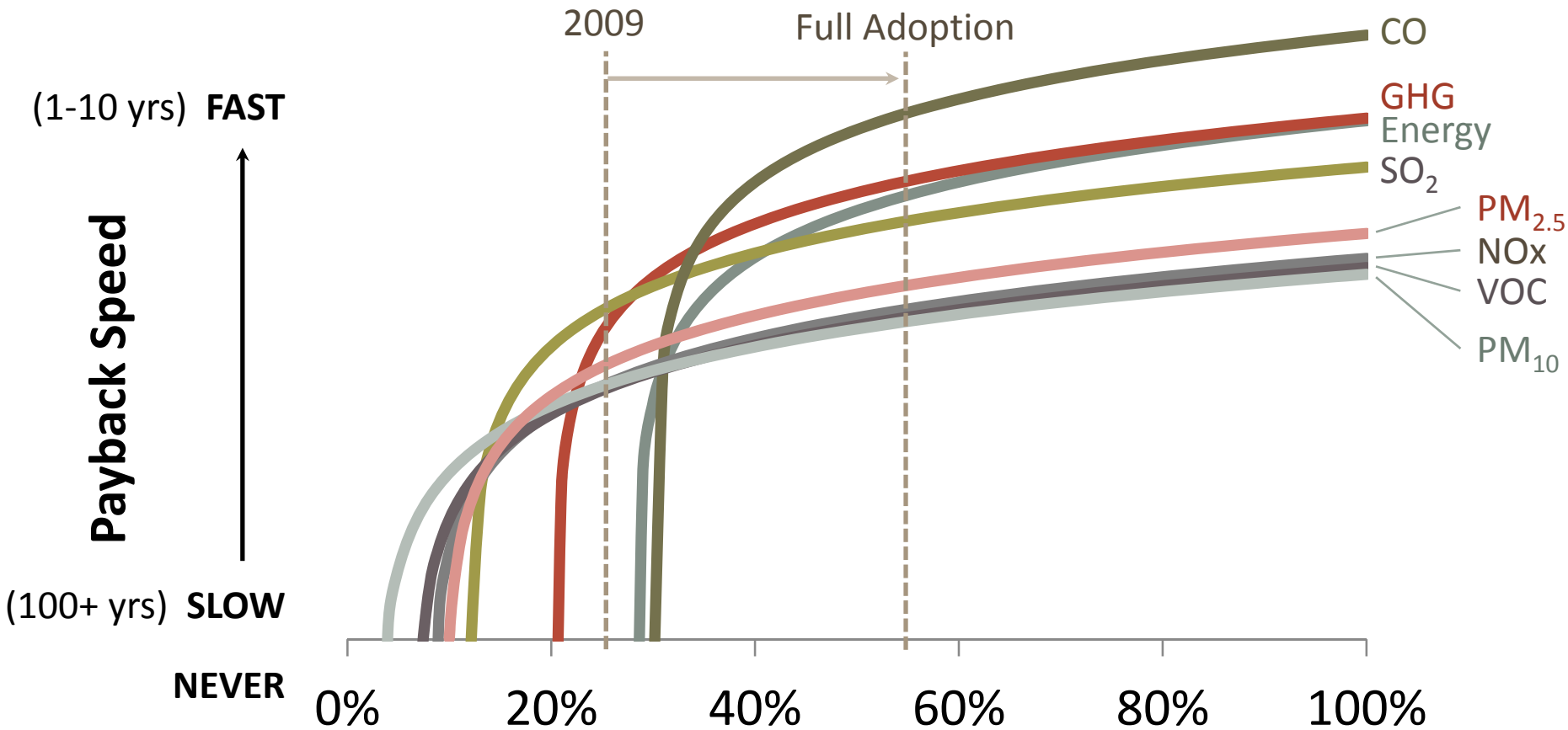
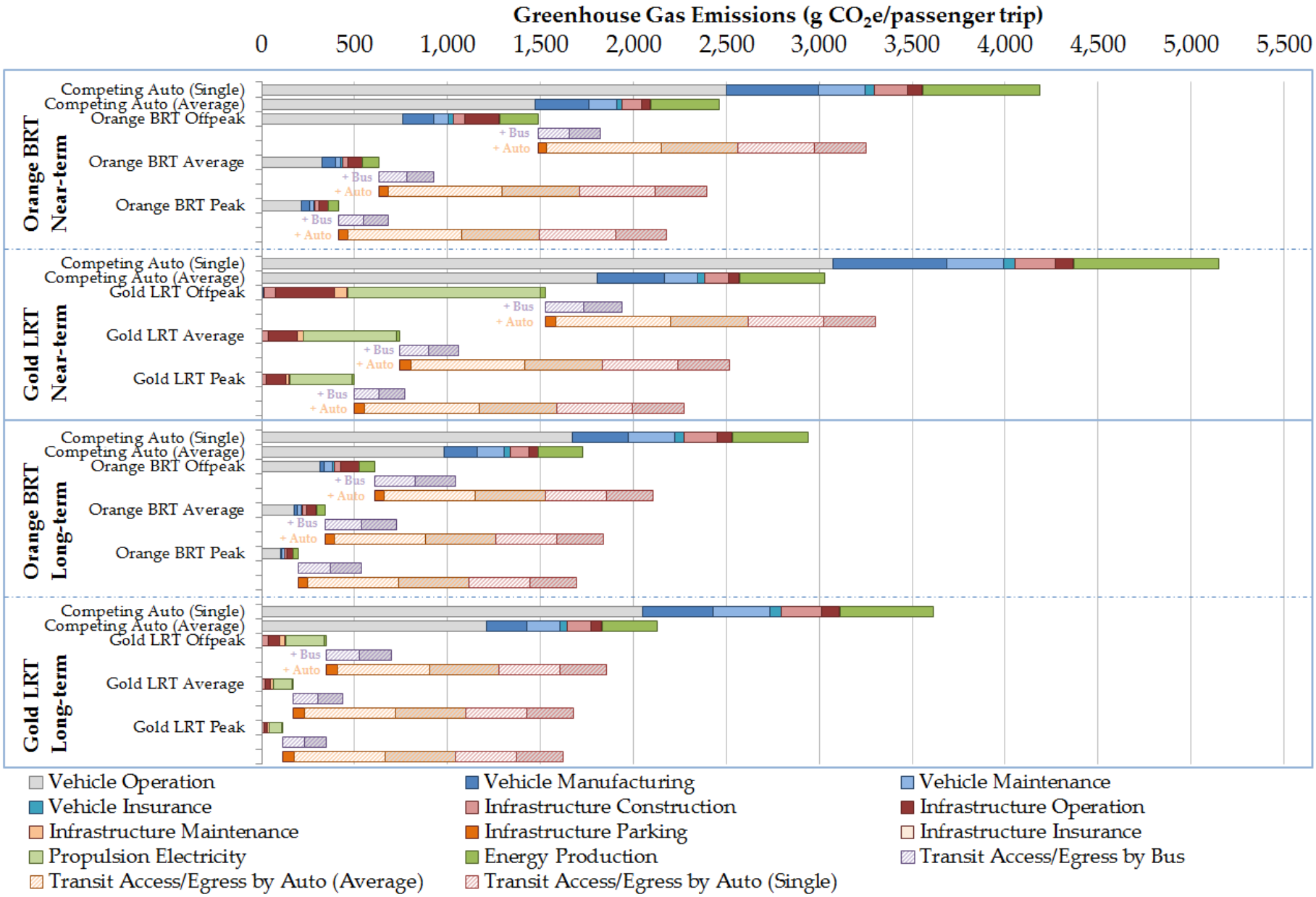
Orange Line Mode Shifts



Percentage of Orange Line Trip Takers Shifted from Automobiles

M Chester, S Pincetl, Z Elizabeth, W Eisenstein, & J Matute, Infrastructure and Automobile Shifts: Positioning Transit to Reduce Life-cycle Environmental Impacts for Urban Sustainability Goals, *Environmental Research Letters* 8(1), 015041, doi:10.1088/1748-9326/8/1/015041.



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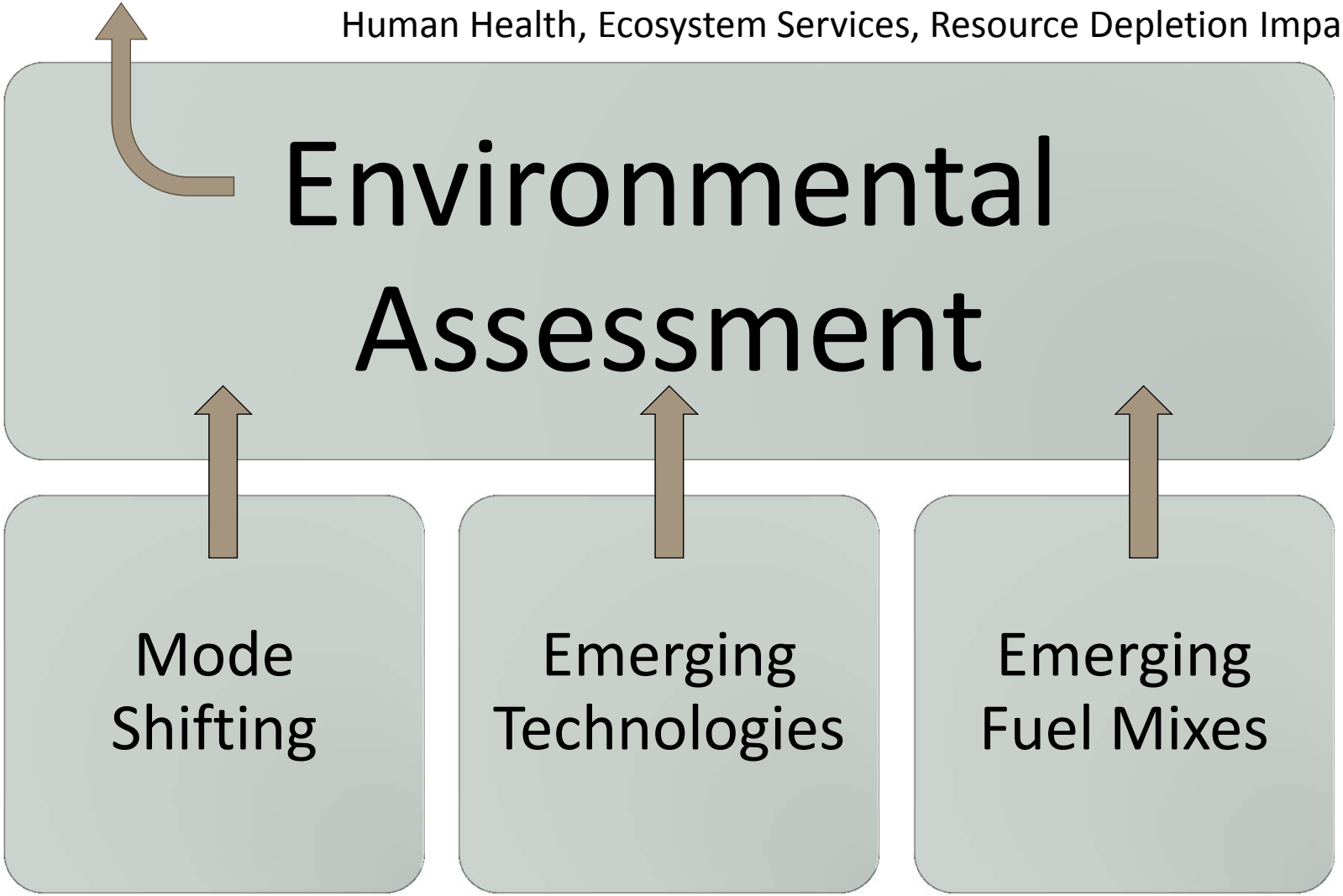
High-speed Rail with Emerging Automobiles and Aircraft Can Reduce Environmental Impacts in Future Long-distance Transportation

Life Cycle Assessment

Infrastructure Tradeoffs
Broad Suites of Environmental Indicators
Human Health, Ecosystem Services, Resource Depletion Impacts



Today
2030-2050
② Sacramento
HERCED
FRESNO
PACHECO PASS
ANTELOPE VALLEY
① San Francisco
① Los Angeles
② San Diego
Phase 1: San Francisco to Los Angeles
Phase 2: Sacramento to San Diego

Uncertainty

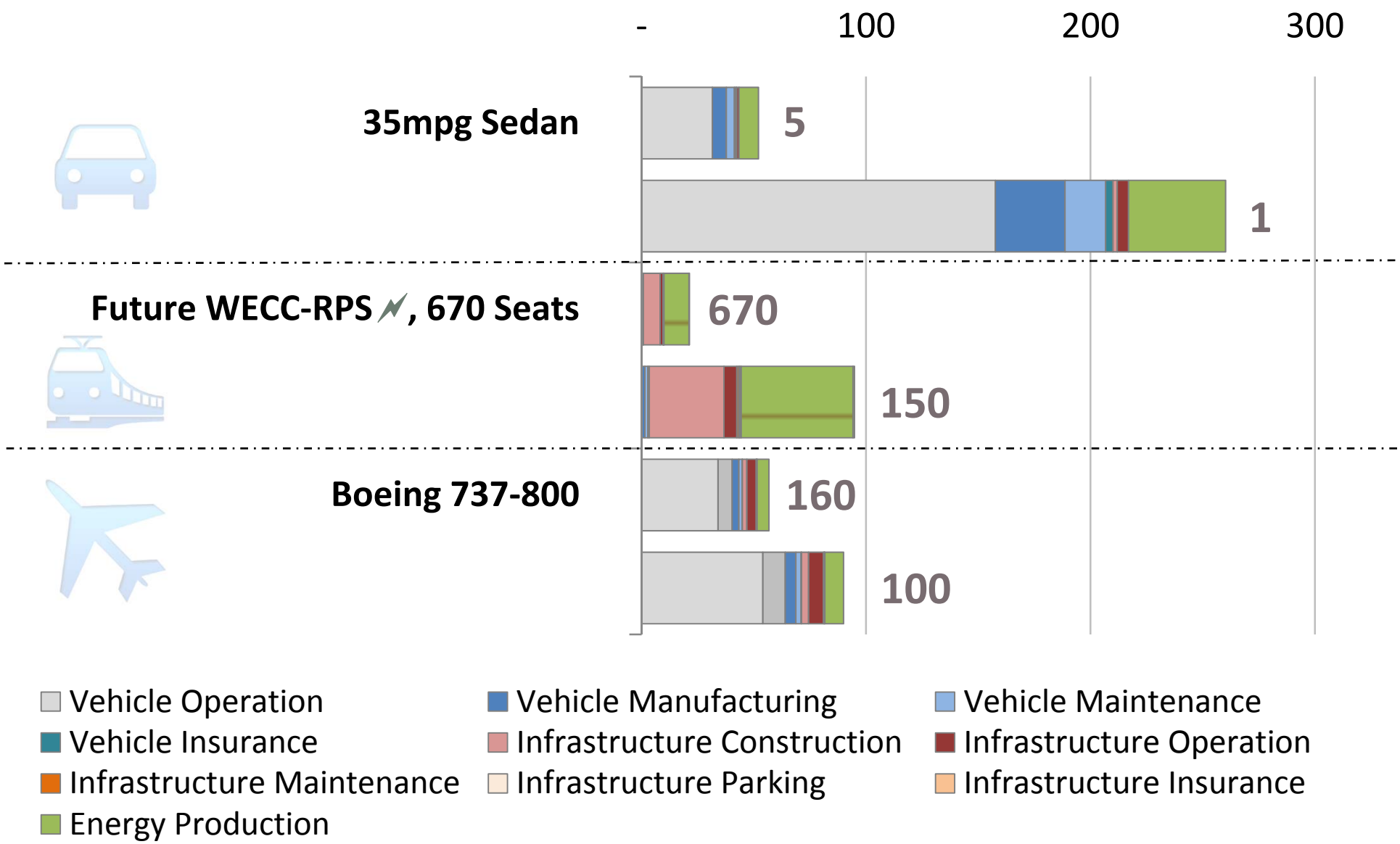
Future vehicle technologies

Future energy mixes

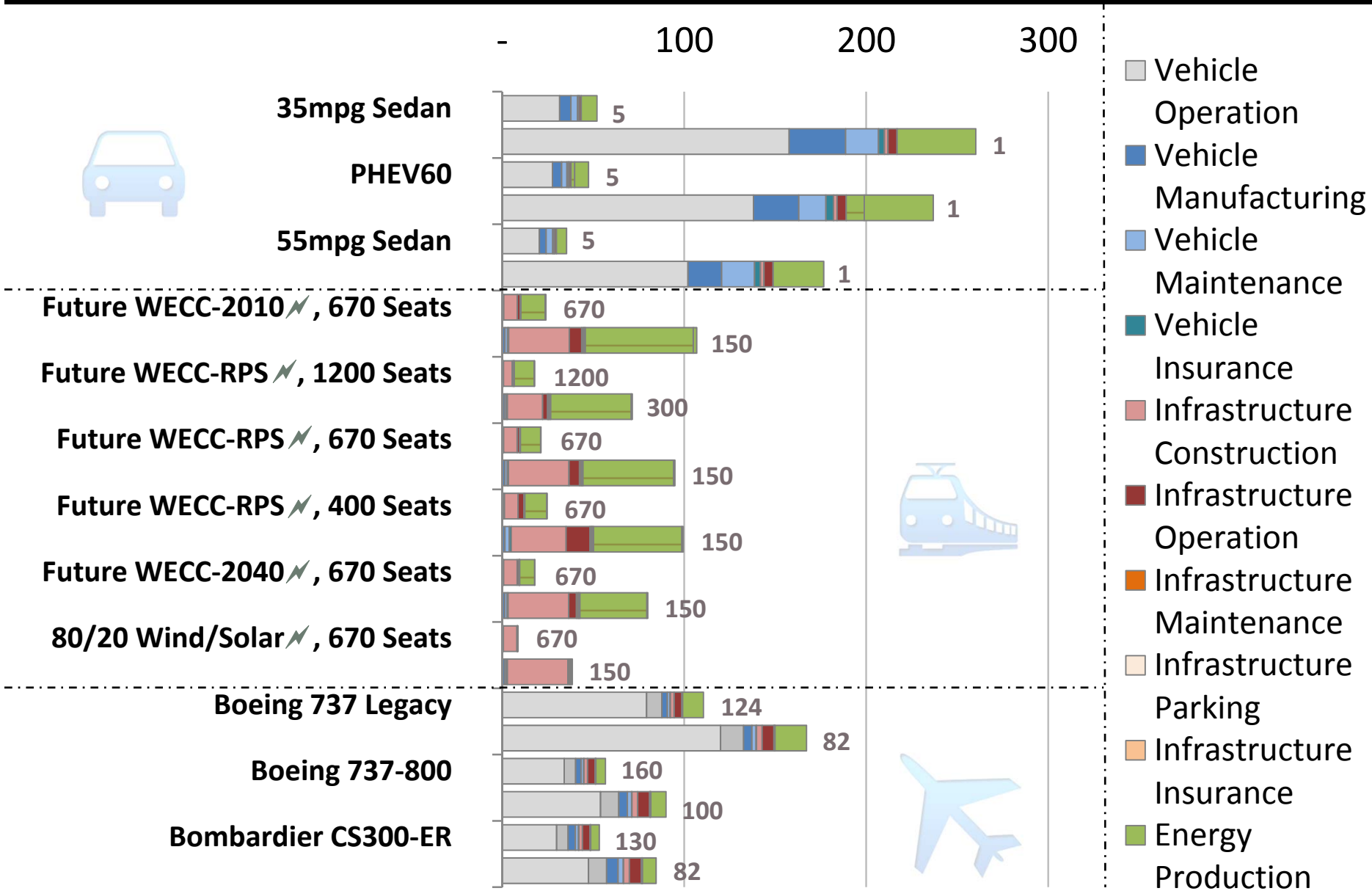
Ridership uncertainty produces a range in per-PKT performance

- Challenges: Adoption period, full adoption (typical peak and off-peak)
- Without a strong understanding of ridership, breakeven points can be more illustrative of environmental tradeoffs

Greenhouse Gas Emissions in Grams CO_2e per PKT



Greenhouse Gas Emissions in Grams CO_2e per PKT

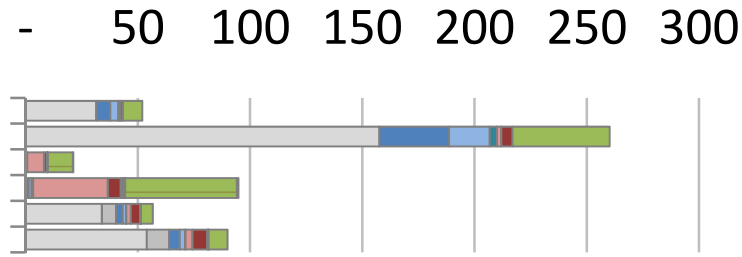


Chester M and Horvath A, 2012, High-speed Rail with Emerging Automobiles and Aircraft Can Reduce Environmental Impacts in California's Future, Environmental Research Letters 7(3), doi:10.1088/1748-9326/7/3/034012.

Human Health and Environmental Impact Potentials per PKT

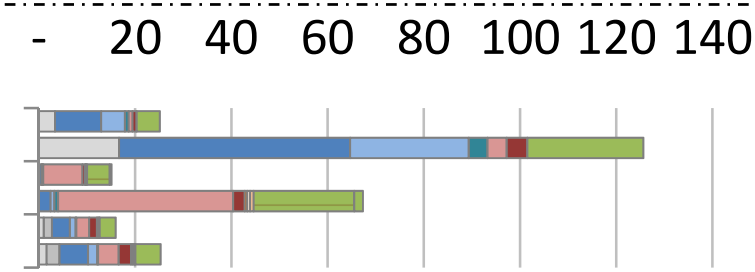
Greenhouse Gases (grams CO_2eq)

35mpg Sedan
Future WECC-RPS , 670 Seats
Boeing 737-800



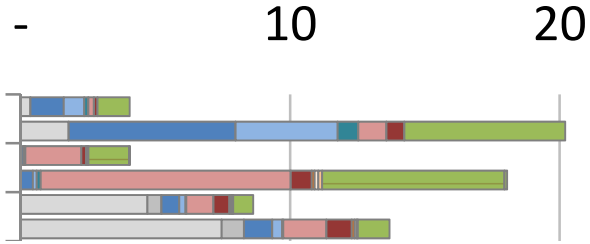
Respiratory Effects (mg $PM_{2.5}$eq)

35mpg Sedan
Future WECC-RPS , 670 Seats
Boeing 737-800



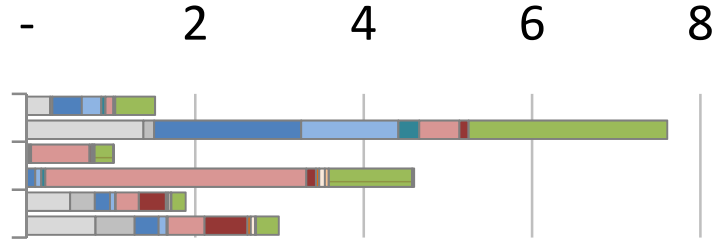
Acidification (grams H+ moles eq)

35mpg Sedan
Future WECC-RPS , 670 Seats
Boeing 737-800



Smog Formation (tonnes O_3eq)

35mpg Sedan
Future WECC-RPS , 670 Seats
Boeing 737-800



- Vehicle Operation
- Vehicle Manufacturing
- Vehicle Maintenance
- Vehicle Insurance
- Infrastructure Construction
- Infrastructure Operation
- Infrastructure Maintenance
- Infrastructure Parking
- Infrastructure Insurance
- Energy Production

Chester M and Horvath A, 2012, High-speed Rail with Emerging Automobiles and Aircraft Can Reduce Environmental Impacts in CA's Future, *Environmental Research Letters* 7(3), 034012, doi:10.1088/1748-9326/7/3/034012.

Long-run per PMT Rankings

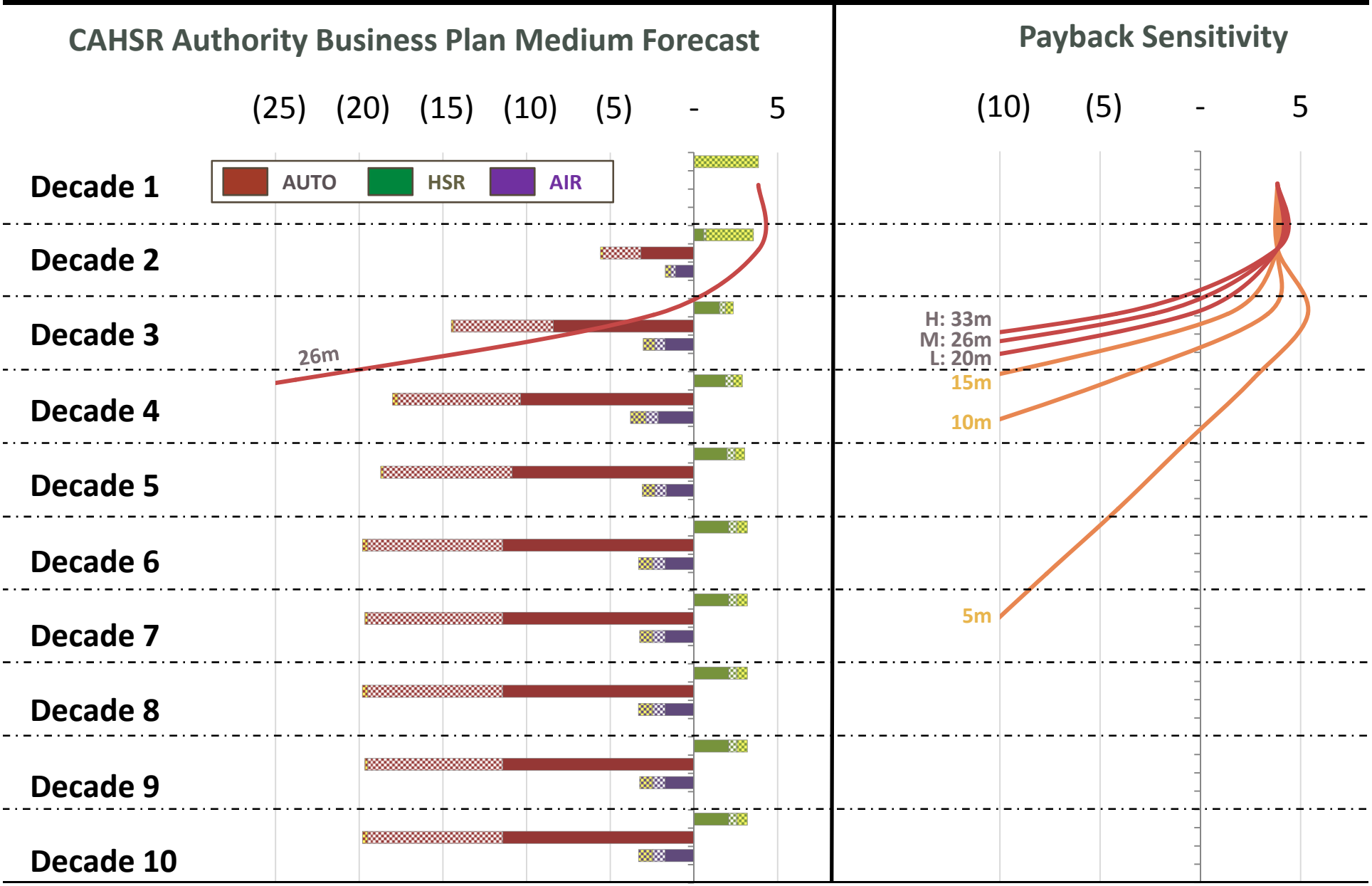
Impact Potential	Ranking		
	Auto	HSR	Air
End-use Energy	Highest	Lowest	Middle
Greenhouse Gases	Highest	Lowest	Middle
Respiratory Effects	Middle	Highest	Lowest
Acidification	Middle	Lowest	Highest
Smog Formation	Middle	Highest	Lowest
Eutrophication	Middle	Highest	Lowest

Lowest Middle Highest

Footprinting
(per PMT)

Consequential
(Corridor Effects)

Greenhouse Gas Payback in Million Tonnes



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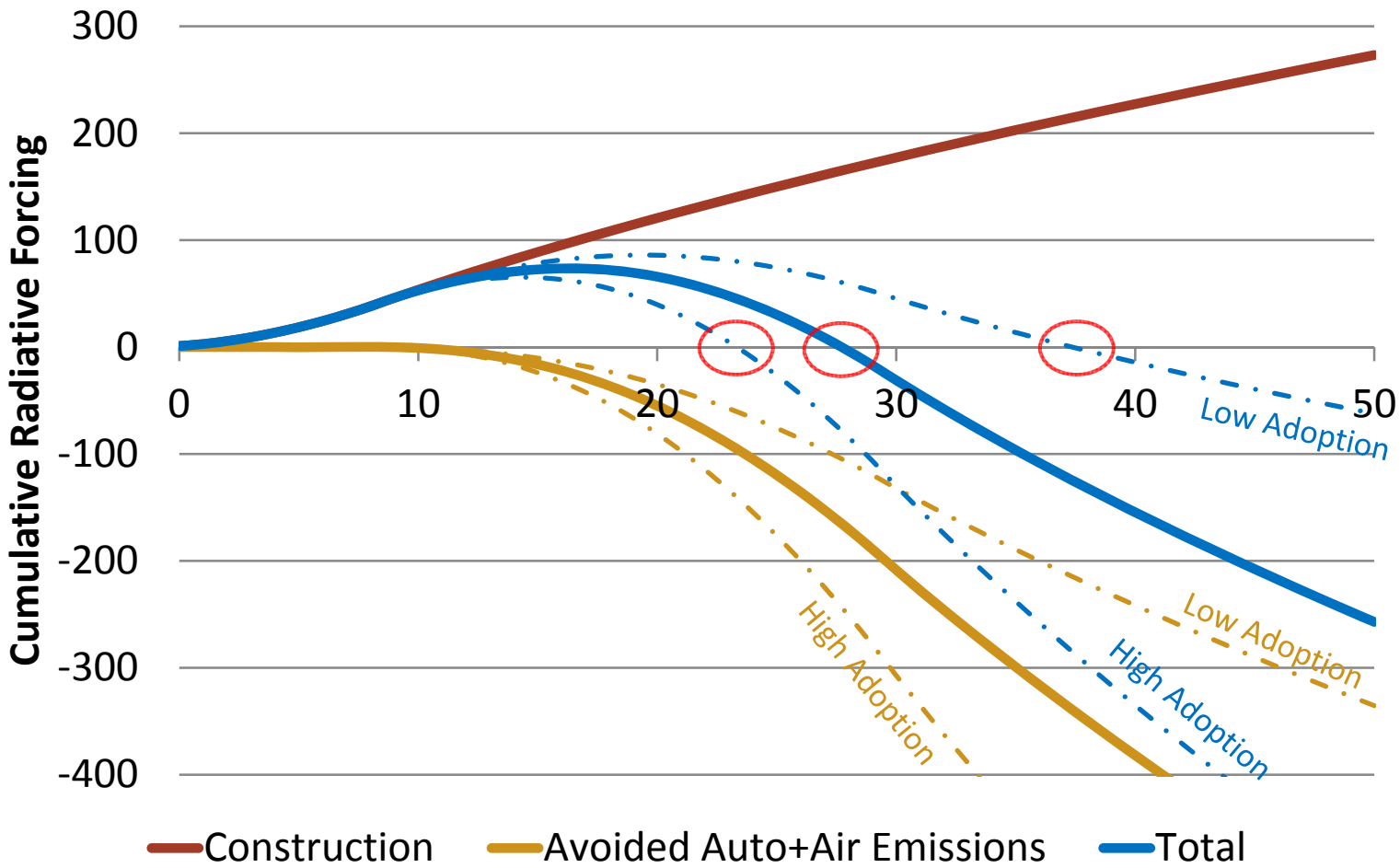
Payback with Cumulative Radiative Forcing



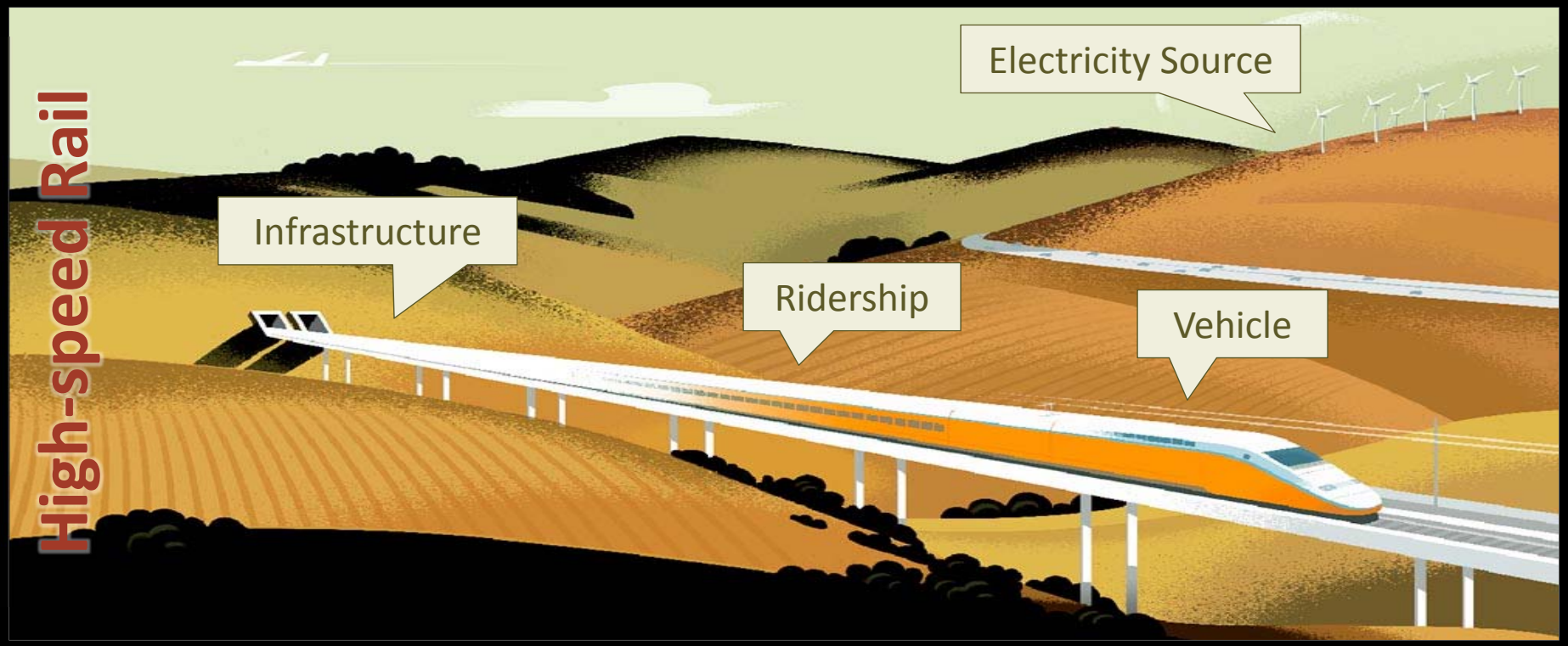
CO_2 Decay Function:

$$C_i(t) = 0.217 + 0.259e^{-t/172.9} + 0.388e^{-t/18.51} + 0.186e^{-t/1.186}$$

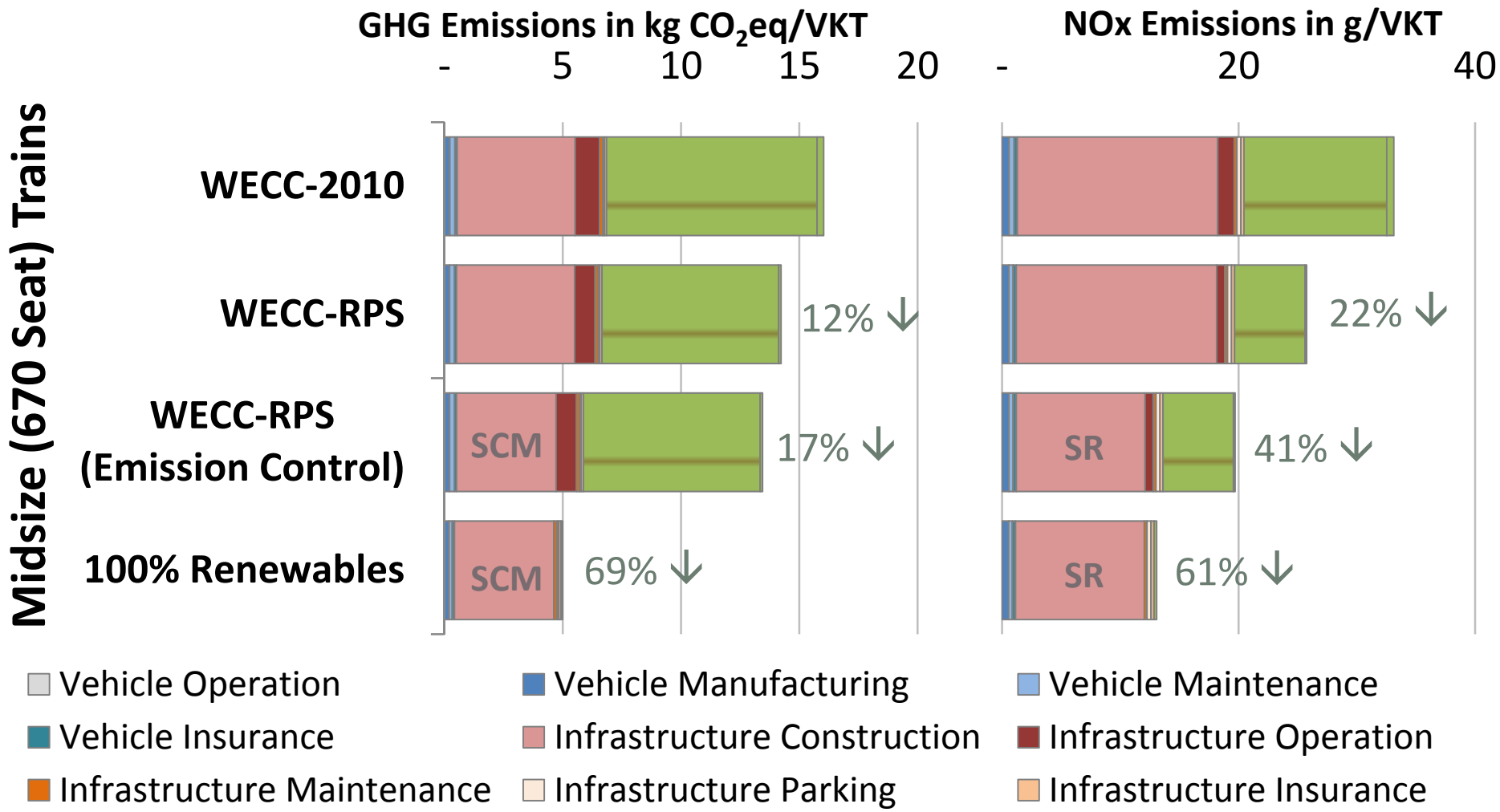
$$CRF = \int_0^{TH} \alpha_i C_i(t)dt$$

Methodology: IPCC 4th Assessment Report, 2007, citing the Bern carbon cycle model.

Aviation
Aircraft Manufacturing
Aircraft Operation
Infrastructure Construction
GSE
AIR CANADA
Sky Chefs


High-speed Rail
Electricity Source
Infrastructure
Ridership
Vehicle

CAHSR Impact Reduction Strategies



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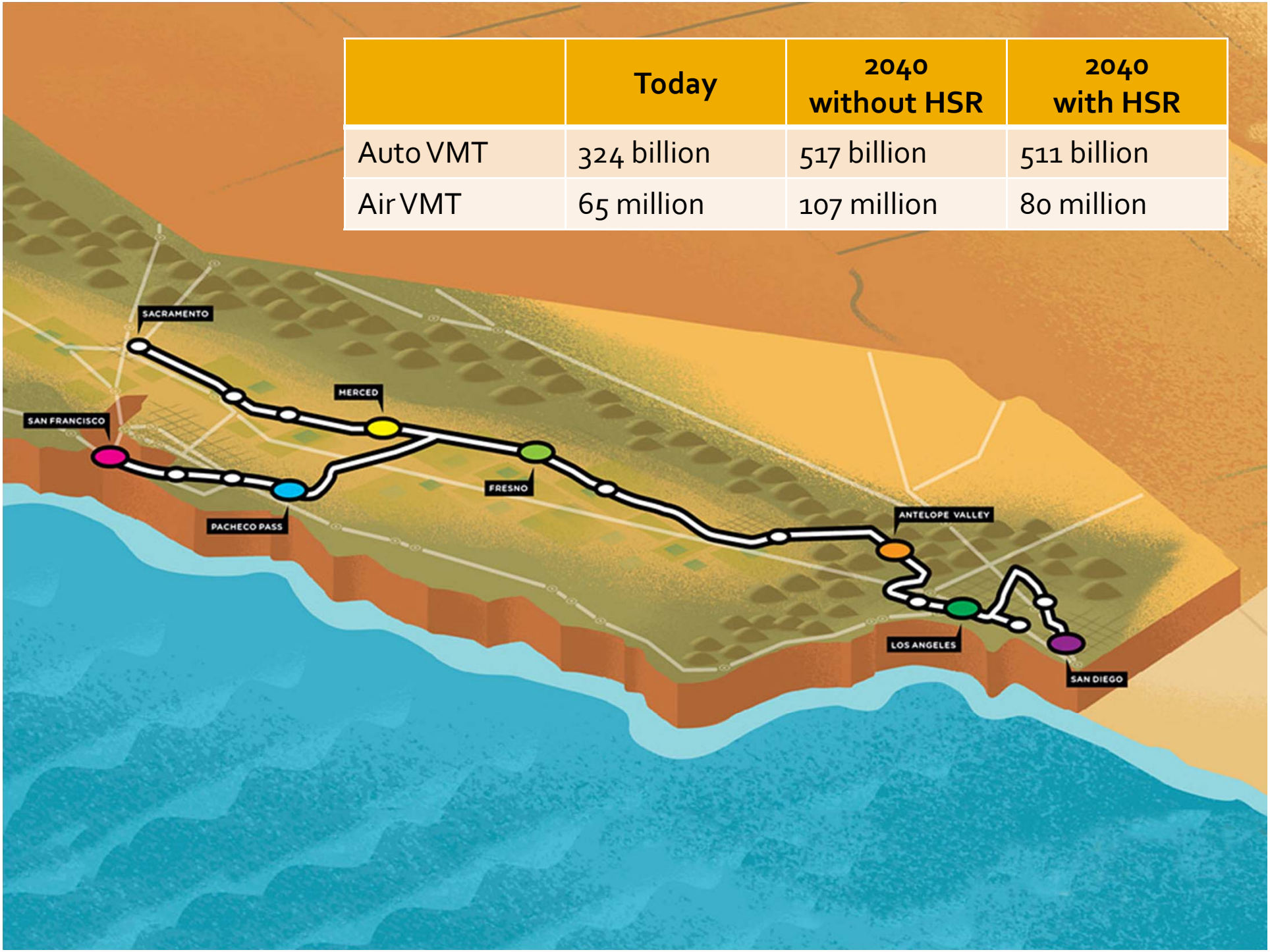
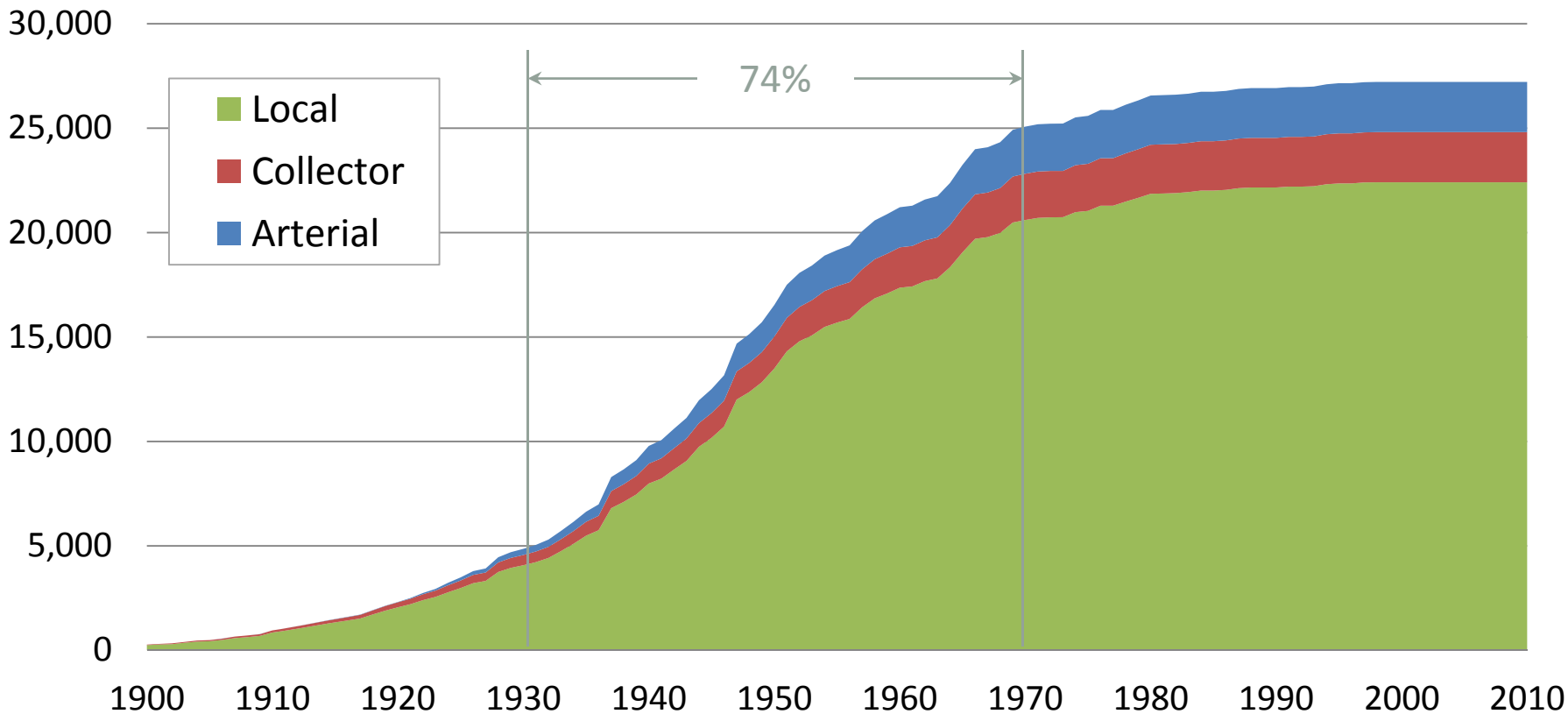
	Today	2040 without HSR	2040 with HSR
Auto VMT	324 billion	517 billion	511 billion
Air VMT	65 million	107 million	80 million



LA's roadway network has enabled automobile use but the infrastructure may be saturated.

Cumulative Roadway Miles



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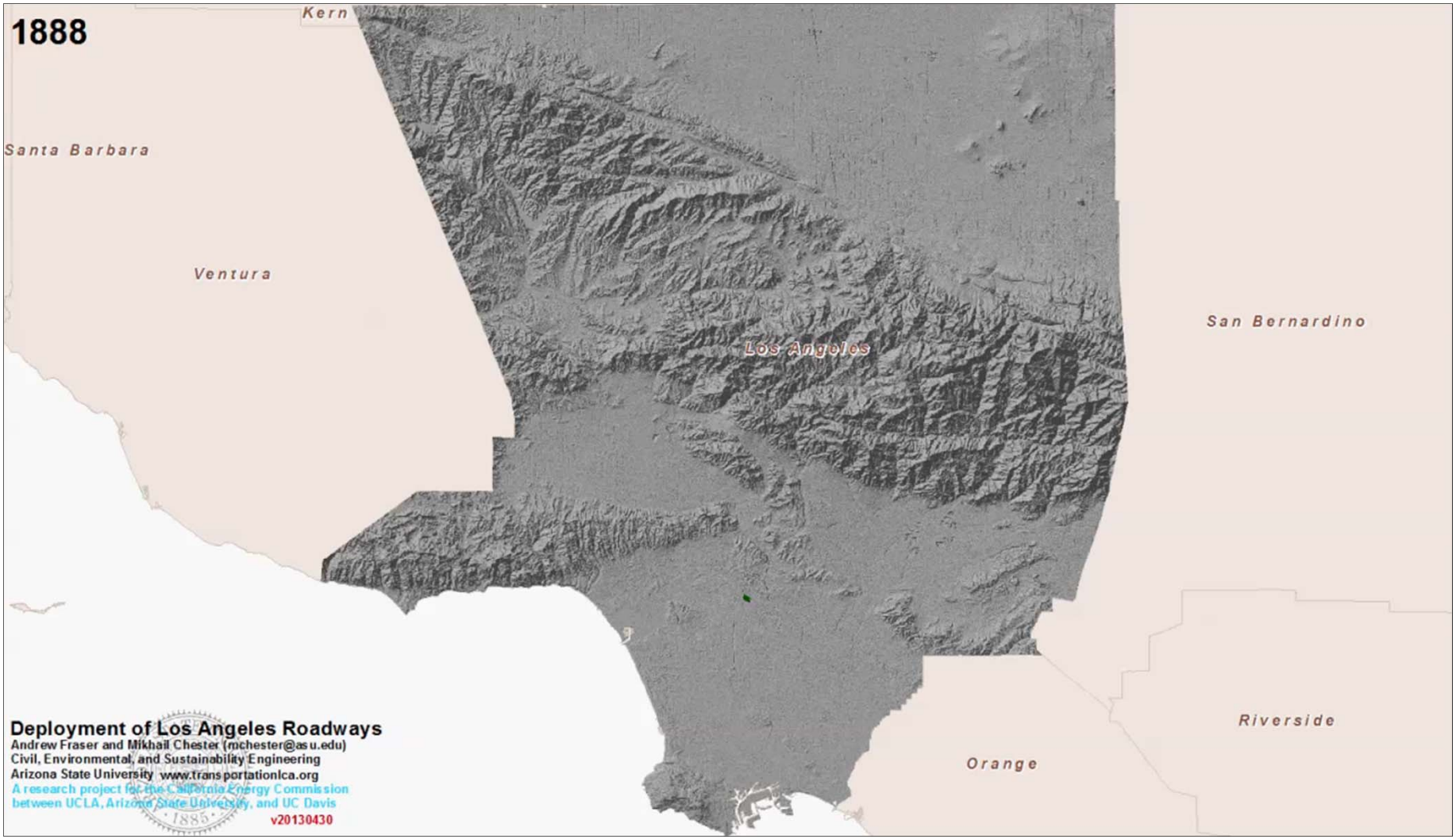
Los Angeles Network Growth



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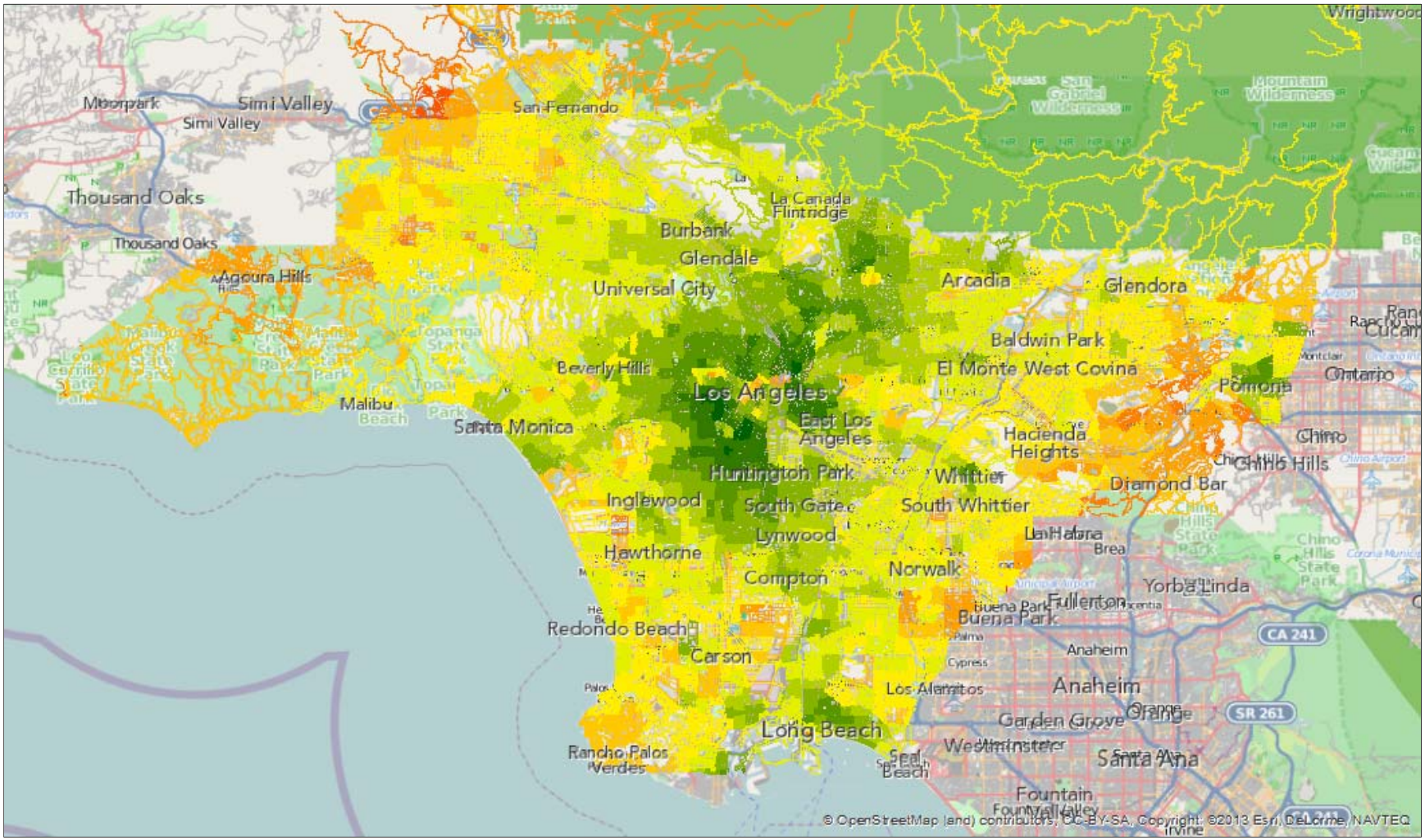
Los Angeles Network Growth



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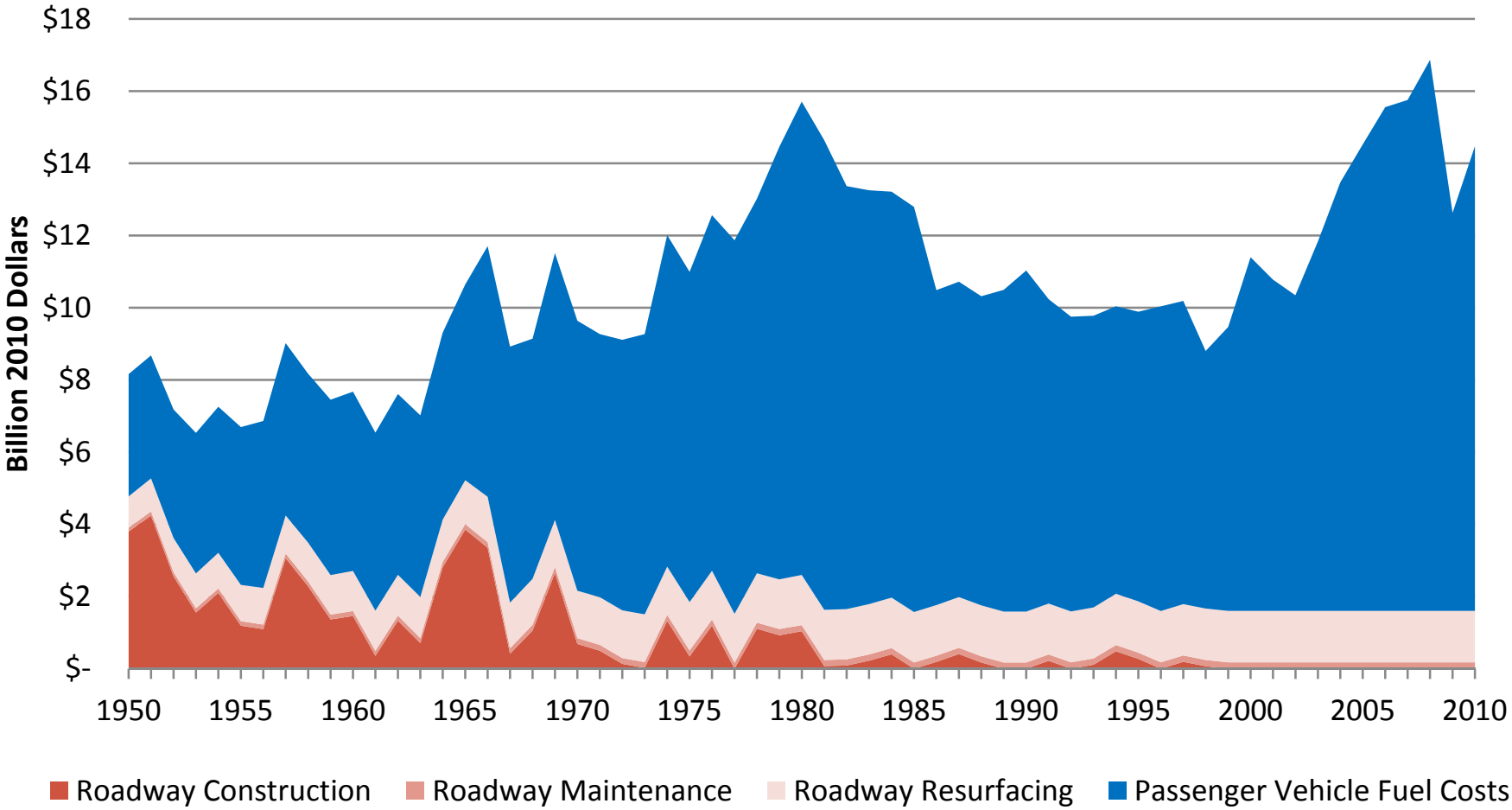
Unsustainable Long-term Financing?



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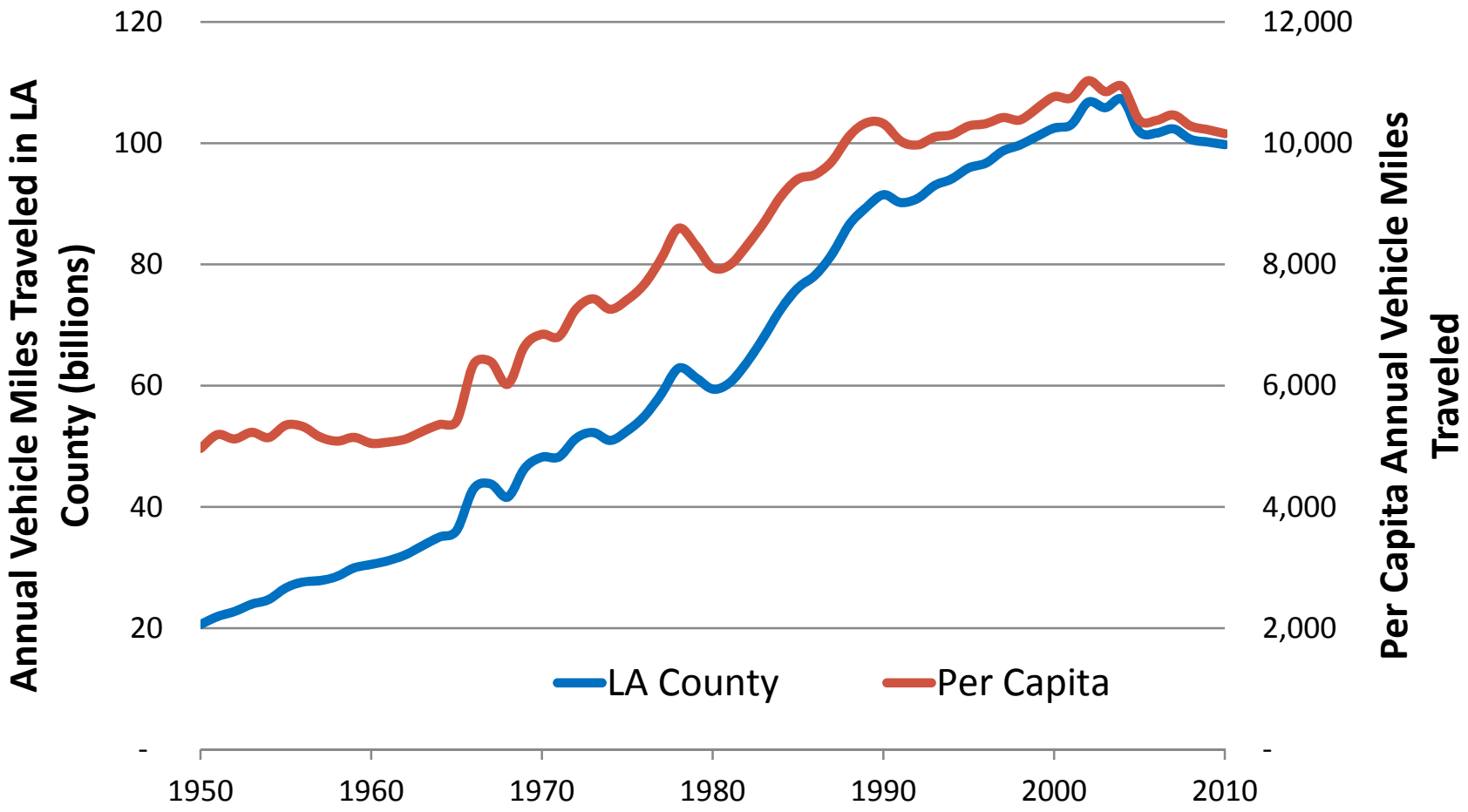
Natural Limits to Infrastructure Services?



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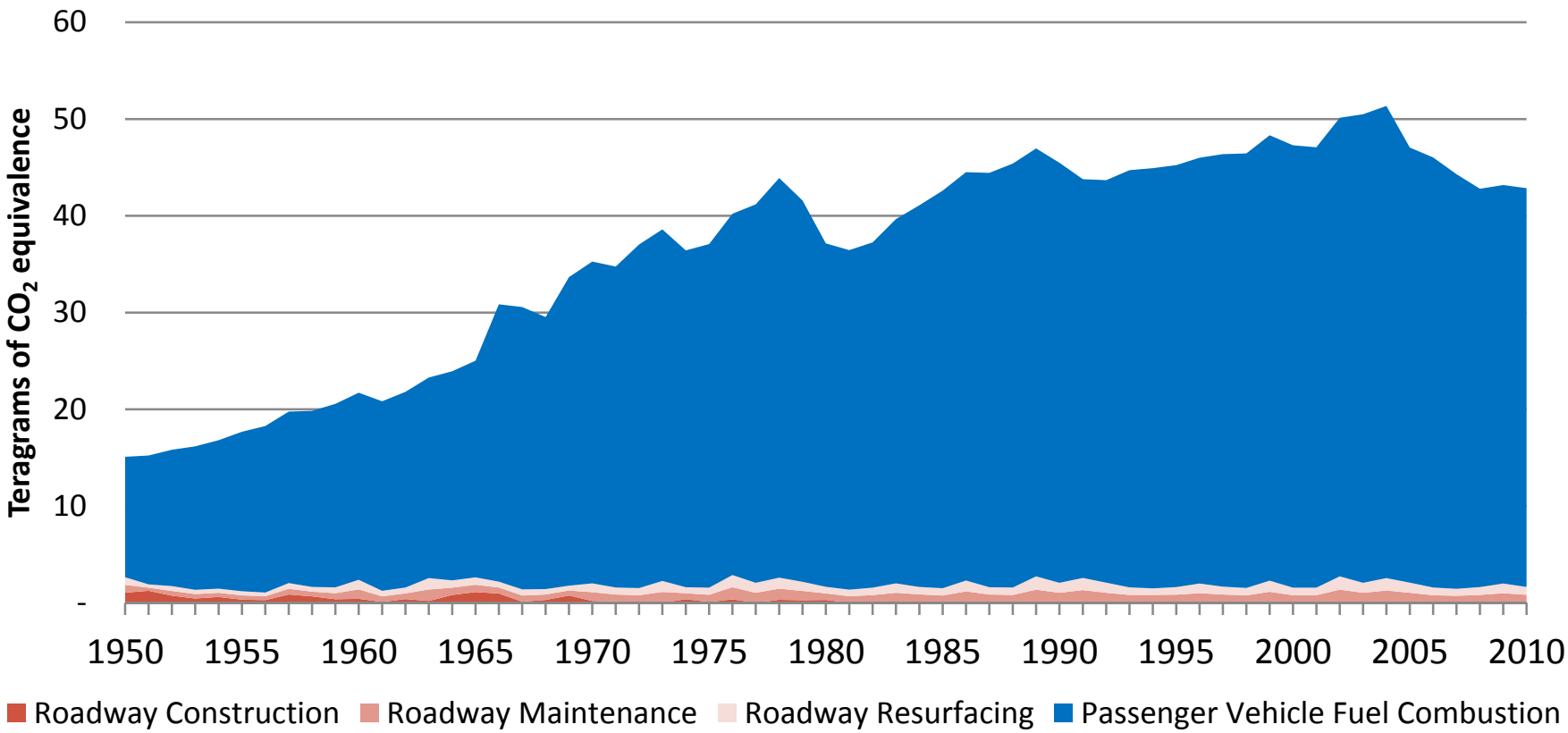
Emergent Greenhouse Gas Emissions from Vehicle Travel



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Integrated Transportation + Land Use Life Cycle Assessment

Energy Consumption

Greenhouse Gases

Respiratory Impacts

Smog Formation

Kimball M, Chester M, Gino C, and Reyna J, TOD Infill in Phoenix Can Reduce Future Transportation and Land Use Life-cycle Environmental Impacts, *In Review at the Journal of Planning, Education, and Research*.

Potential Development around Stations

Kimball M, Chester M, Gino C, and Reyna J, TOD Infill in Phoenix Can Reduce Future Transportation and Land Use Life-cycle Environmental Impacts, *In Review at the Journal of Planning, Education, and Research*.

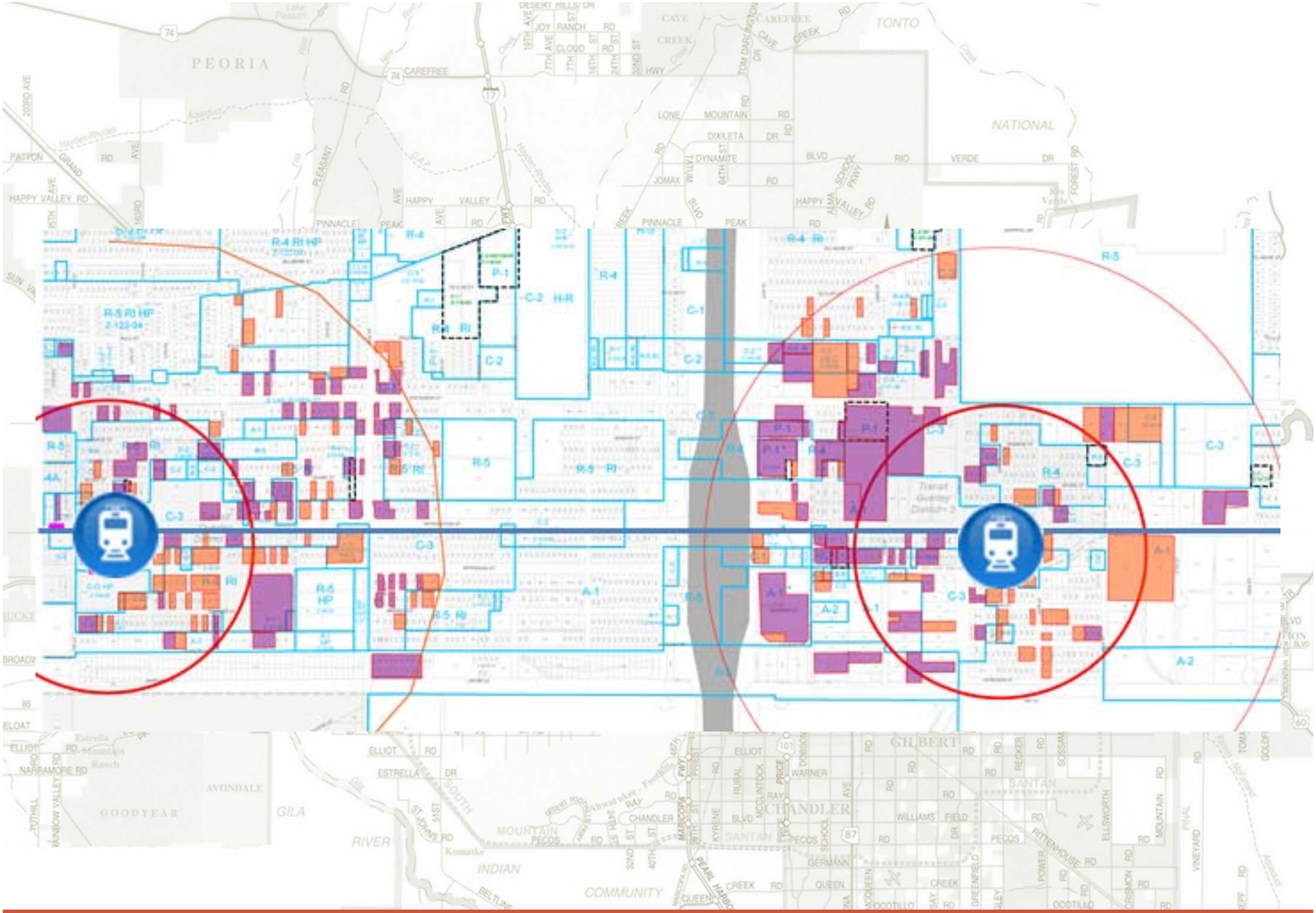

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Photo courtesy of Arnim Wiek & Aaron Golub. Reinvent Phoenix project.

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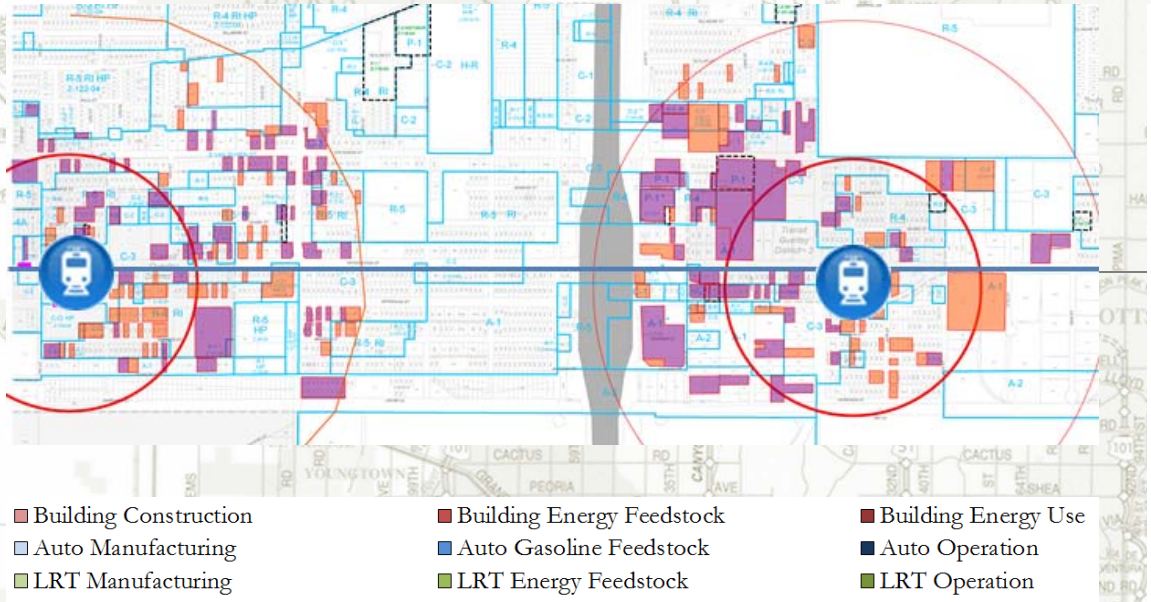
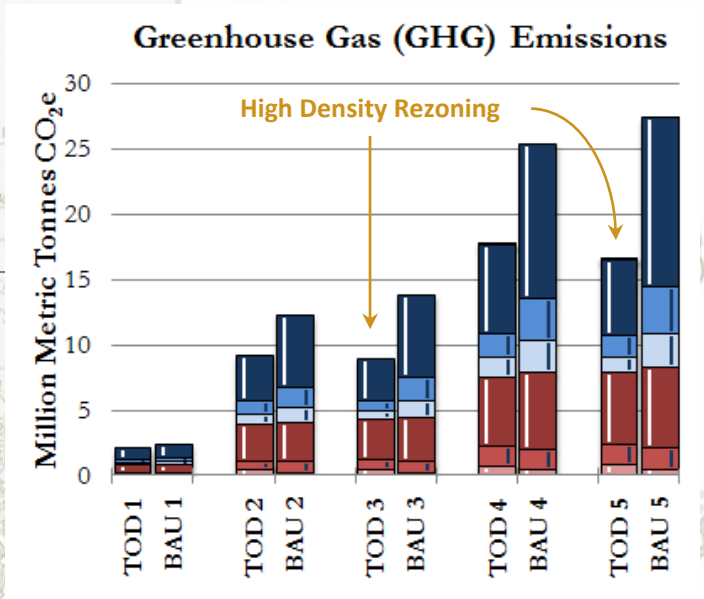
Las Manos
BAKERY

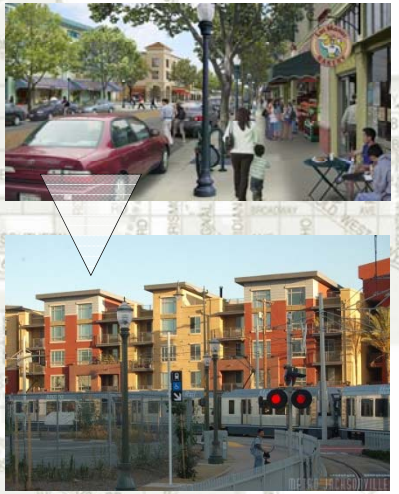




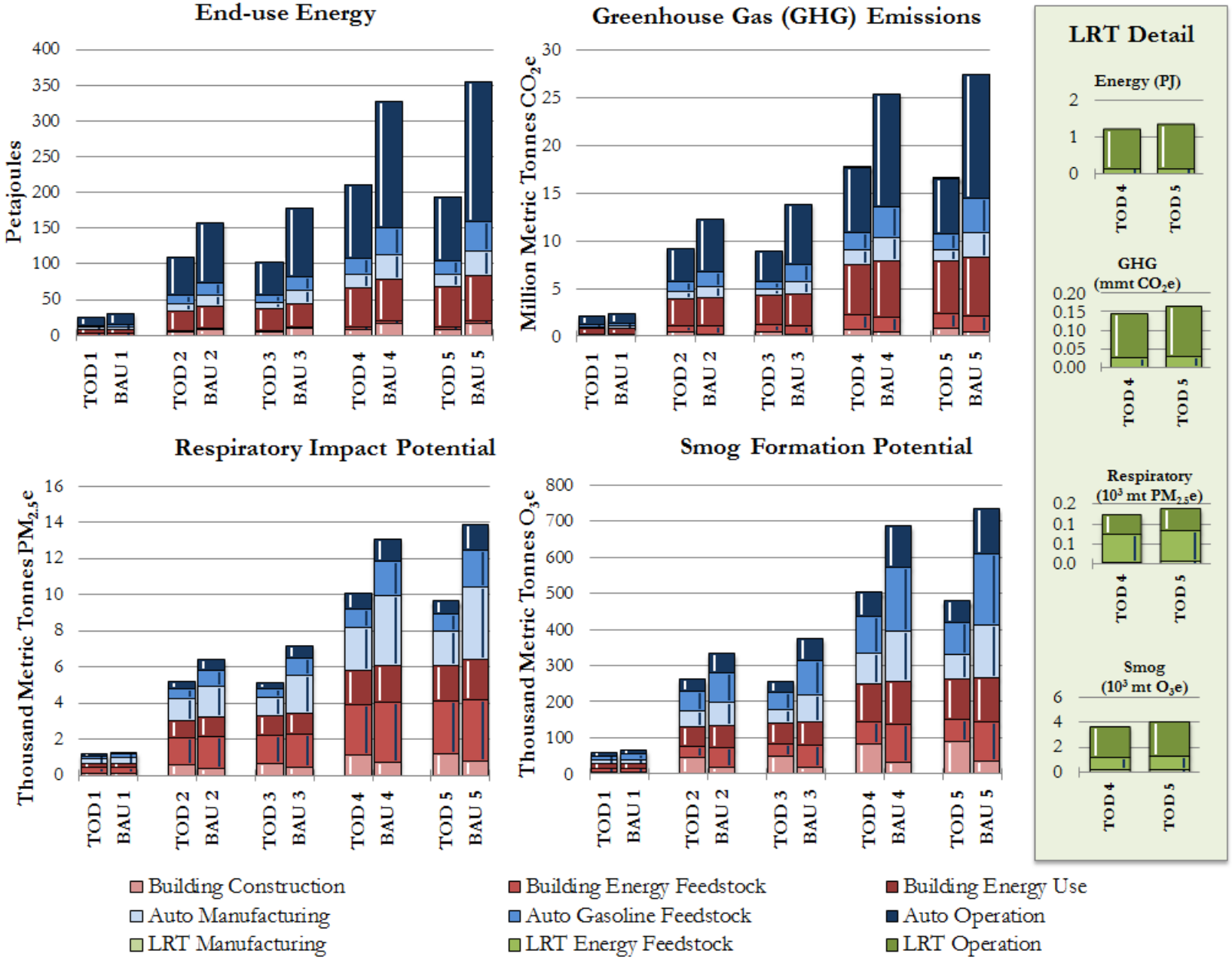
Option 1 ▽

Option 2 ▽

Option 3 ▷

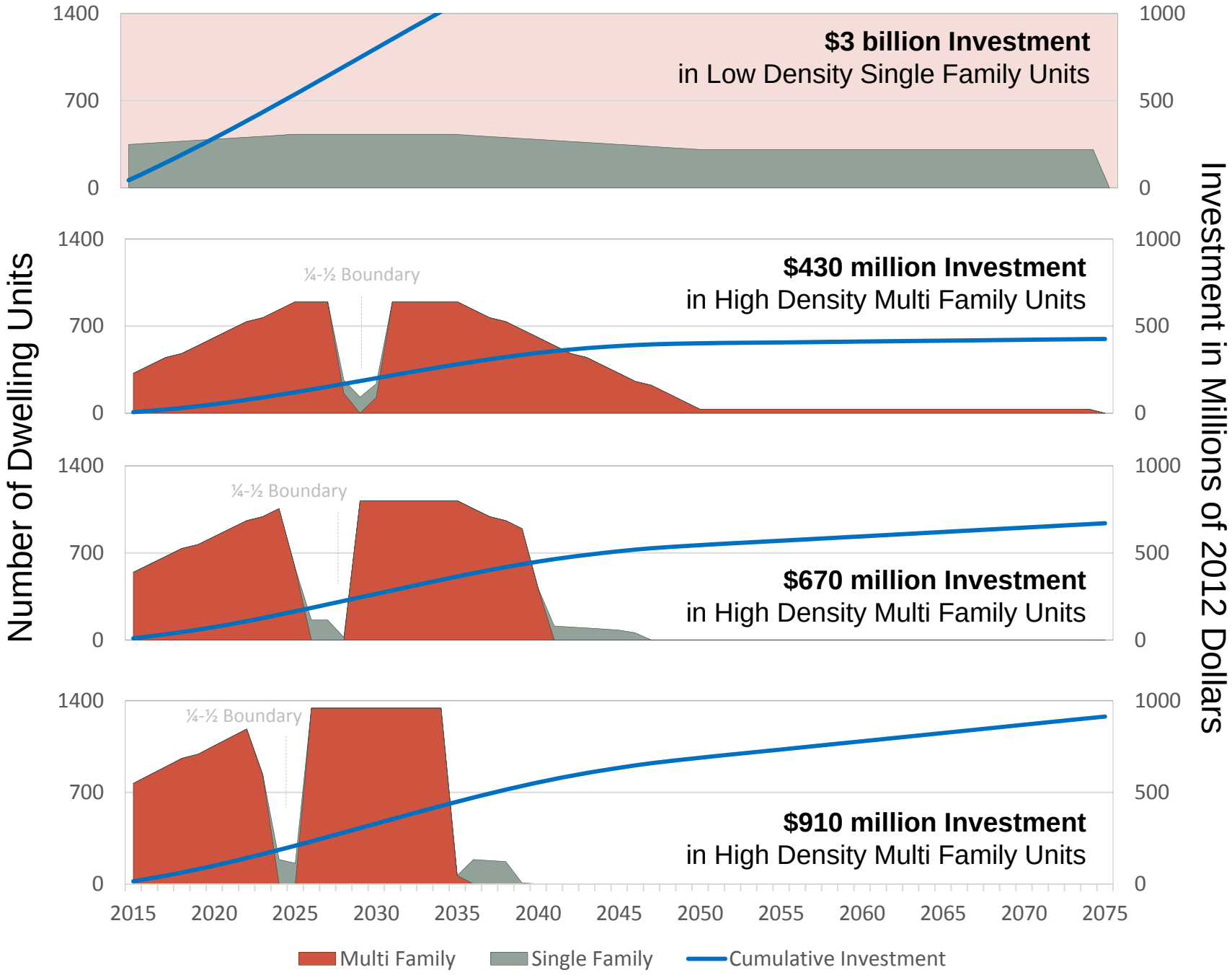


Kimball M, Chester M, Gino C, and Reyna J, TOD Infill in Phoenix Can Reduce Future Transportation and Land Use Life-cycle Environmental Impacts, *In Review at the Journal of Planning, Education, and Research*.



Kimball M, Chester M, Gino C, and Reyna J, TOD Infill in Phoenix Can Reduce Future Transportation and Land Use Life-cycle Environmental Impacts, *In Review at the Journal of Planning, Education, and Research*.

Cost Investments for 22,000 Homes



Maximizing the Investment[1/2]

- The transportation-land use interdependency can be used to the region's advantage:
  - Investments in light rail yield transportation <u>and</u> land use energy and environmental gains
- The marginal benefits received from land use strategies that utilize light rail are significantly larger than the marginal costs

Maximizing the Investment[2/2]

- Reduction potentials (over 60 yrs):
  - GHG emissions: 500 tonnes CO_2e/du
  - Energy consumption by 7.5 TJ/du

(the equivalent of 1.2 million households each driving 600 fewer annual miles, or turning off 22,000 households for 2.6 days of the year).

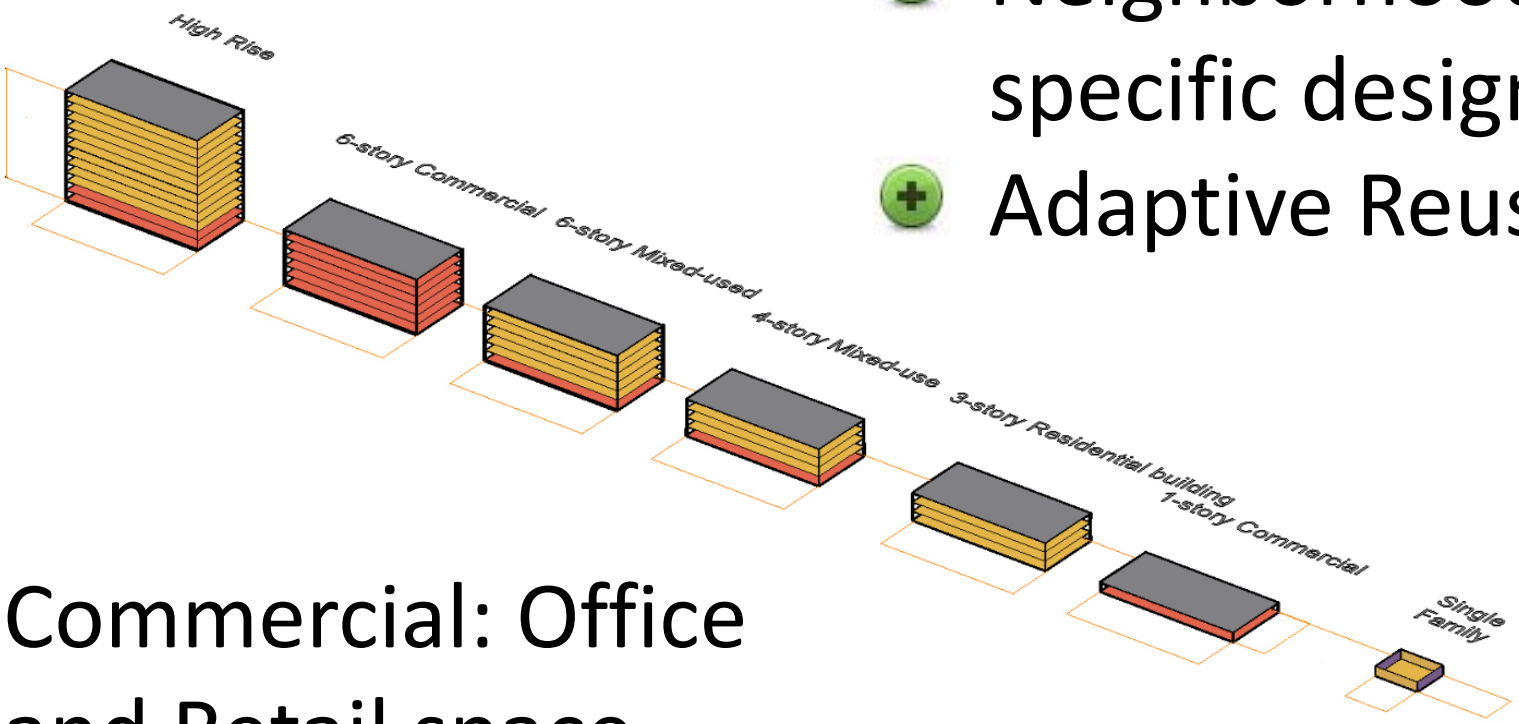
- The potential for human health respiratory effects will be reduced by 18% and smog formation by 21% for TOD households

- Phoenix could reduce their GHG emissions footprint to 1990 levels by targeting 120,000 dwelling units for TODs
  - We show how up to 22,000 dwelling units can be added.

Kimball M, Chester M, Gino C, and Reyna J, TOD Infill in Phoenix Can Reduce Future Transportation and Land Use Life-cycle Environmental Impacts, *In Review at the Journal of Planning, Education, and Research*.

Phase 2

- Neighborhood-specific designs
- Adaptive Reuse



- Commercial: Office and Retail space

Redevelopment

	Redevelopment Outcome	Development
1	Vacant + Surface (New Construction)	Single Family Residential
2	Vacant + Surface (New Construction)	Multi Family Residential + Commercial
3	Vacant + Surface (New Construction) + Low Value (Adaptive Reuse)	Multi Family Residential + Commercial
4	Vacant + Surface (New Construction) + Low Value (New Construction)	Multi Family Residential + Commercial

Opportunities for Future Research

- Economic activity changes
- Project Life Cycle Costing
- Cost optimization of energy and environmental investments
- Socio-demographic assessment to prioritize households that will produce the greatest benefits by moving to TODs
- Long-run infrastructure cost changes

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