Environmental Life-cycle Assessment of Passenger Transportation

MIKHAIL CHESTER, ASSISTANT PROFESSOR
CIVIL, ENVIRONMENTAL, AND SUSTAINABILITY ENGINEERING
ARIZONA STATE UNIVERSITY

MCHESTER@ASU.EDU
WWW.TRANSPORTATIONLCA.ORG

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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
The Transportation “System”

Vehicle

Infrastructure

Energy Production

Extraction of Raw Materials

Manufacturing

Operation / Maintenance

End-of-life

Extraction of Raw Materials

Construction

Decommissioning

Operation / Maintenance

Raw Fuel Extraction

Transport

Processing / Refining

Electricity Generation

Distribution

Storage

Construction

Maintenance / Repair

Demolition

Landfill debris
<table>
<thead>
<tr>
<th>Life Cycle Grouping</th>
<th>Automobiles/Buses</th>
<th>Air</th>
<th>Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle</strong></td>
<td></td>
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</tr>
<tr>
<td>Manufacturing</td>
<td>Sedan</td>
<td>Aircraft Manufacturing</td>
<td>Train</td>
</tr>
<tr>
<td></td>
<td>Transport to Point of Sale</td>
<td>Engine Manufacturing</td>
<td>Transport to Point of Sale</td>
</tr>
<tr>
<td>Operation</td>
<td>Propulsion</td>
<td>APU / Startup / Taxi Out / Takeoff / Climb Out / Cruise / Approach / Landing / Taxi In</td>
<td>Propulsion</td>
</tr>
<tr>
<td></td>
<td>Idling</td>
<td>Idling</td>
<td>Idling</td>
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<tr>
<td>Maintenance</td>
<td>Typical Sedan Maintenance</td>
<td>Aircraft Maintenance</td>
<td>Typical Train Maintenance</td>
</tr>
<tr>
<td></td>
<td>Tire Replacement</td>
<td>Engine Maintenance</td>
<td>Train Cleaning</td>
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<tr>
<td></td>
<td>Battery Replacement</td>
<td></td>
<td>Flooring Replacement</td>
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<tr>
<td>Insurance</td>
<td>Sedan Liability</td>
<td>Crew Health &amp; Benefits</td>
<td>Train Liability</td>
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<td></td>
<td>Liability</td>
<td>Liability</td>
<td>Operator Fringe Benefits</td>
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<tr>
<td><strong>Infrastructure</strong></td>
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<tr>
<td>Construction</td>
<td>Roadway</td>
<td>Airport</td>
<td>Track</td>
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<td></td>
<td></td>
<td>Runway/Taxiway/Tarmac</td>
<td>Station</td>
</tr>
<tr>
<td>Operation</td>
<td>Roadway Lighting</td>
<td>Airport Energy</td>
<td>Track, Station, and Parking Lighting</td>
</tr>
<tr>
<td></td>
<td>Herbicide Use</td>
<td>Runway Lighting</td>
<td>Herbicide Use</td>
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<td></td>
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<td>Deicing Fluids</td>
<td>Train Control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground Support Equipment</td>
<td>Miscellaneous (Escalators, Equipment)</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Roadway maintenance is the result of heavy duty vehicles and thus not charged to the sedan.</td>
<td>Airport</td>
<td>Track and Station Maintenance</td>
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<td></td>
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<td>Runway/Taxiway/Tarmac</td>
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<tr>
<td>Parking</td>
<td>Curbside Parking</td>
<td>Airport Parking</td>
<td>Dedicated Parking</td>
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<tr>
<td>Insurance</td>
<td>Road Workers Fringe Benefits</td>
<td>Non-crew Health and Benefits</td>
<td>Non-vehicle Workers Fringe Benefits</td>
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<td>Infrastructure Liability</td>
<td>Infrastructure Liability</td>
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<tr>
<td><strong>Energy Production</strong></td>
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<tr>
<td>Extraction, Processing, &amp; Distribution</td>
<td>Gasoline/Diesel/Natural Gas Extraction, Processing, &amp; Distribution</td>
<td>Jet Fuel Extraction, Processing, &amp; Distribution</td>
<td>Raw Fuel Extraction and Processing, Electricity Generation, Transmission &amp; Distribution</td>
</tr>
</tbody>
</table>
Environmental Indicators

Energy

Air Emissions
- $\text{SO}_x$ Respiratory irritant, acid deposition
- CO Asphyxiant
- $\text{NO}_x$ Respiratory irritant, smog
- VOC Photochemical smog, cancerous
- PM Respiratory and cardiovascular damage

Greenhouse Gases
- $\text{CO}_2$, $\text{CH}_4$, $\text{N}_2\text{O}$

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
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

Future
Greenhouse Gas Emissions in g CO₂e per Passenger Mile Traveled

- Sedan Near-term
- Sedan Long-term
- Orange BRT Near-term
- Orange BRT Long-term
- Gold LRT Near-term
- Gold LRT Long-term

Vehicle Operation,
Vehicle Insurance,
Infrastructure Maintenance,
Energy Production

Vehicle Manufacturing,
Infrastructure Construction,
Infrastructure Parking,
Auto Indirect

Vehicle Maintenance,
Infrastructure Operation,
Infrastructure Insurance

Preliminary Results: Respiratory Stressors

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

<table>
<thead>
<tr>
<th>Vehicle Operation</th>
<th>Vehicle Manufacturing</th>
<th>Vehicle Maintenance</th>
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</thead>
<tbody>
<tr>
<td>Vehicle Insurance</td>
<td>Infrastructure Construction</td>
<td>Infrastructure Operation</td>
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<tr>
<td>Infrastructure Maintenance</td>
<td>Infrastructure Parking</td>
<td>Infrastructure Insurance</td>
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<tr>
<td>Energy Production</td>
<td>Auto Indirect</td>
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</tr>
</tbody>
</table>

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.

Preliminary Results
Photochemical Smog Stressors

Photochemical Smog Formation Potential in Mg O$_3$e per Passenger Mile Traveled

- 2 4 6 8 10 12 14

Sedan Near-term
Sedan Long-term
Orange BRT Near-term
Orange BRT Long-term
Gold LRT Near-term
Gold LRT Long-term

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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.

Local + Remote Impacts

<table>
<thead>
<tr>
<th></th>
<th>Energy</th>
<th>GHGs</th>
<th>Respiratory</th>
<th>Smog</th>
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</thead>
<tbody>
<tr>
<td>Auto</td>
<td><img src="auto.png" alt="Chart" /></td>
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<tr>
<td>(most remote)</td>
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<tr>
<td>Orange BRT</td>
<td><img src="orange.png" alt="Chart" /></td>
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<td><img src="orange.png" alt="Chart" /></td>
<td><img src="orange.png" alt="Chart" /></td>
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<td>(second most remote)</td>
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<tr>
<td>Gold LRT</td>
<td><img src="gold.png" alt="Chart" /></td>
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<td><img src="gold.png" alt="Chart" /></td>
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<tr>
<td>(least remote)</td>
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LCA of the decision to deploy the Orange and Gold lines
Footprinting (per PMT)

Consequential (Corridor Effects)

PMT

- Auto Travel

+ Transit Travel
Orange Line Mode Shifts

Payback Speed

(1-10 yrs) **FAST**

(100+ yrs) **SLOW**

NEVER

Percentage of Orange Line Trip Takers Shifted from Automobiles

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

Environmental Assessment

Mode Shifting

Emerging Technologies

Emerging Fuel Mixes

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

Life Cycle Assessment

Environmental Assessment

Mode Shifting

Emerging Technologies

Emerging Fuel Mixes

Infrastructure Tradeoffs
Broad Suites of Environmental Indicators
Human Health, Ecosystem Services, Resource Depletion Impacts
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$_2$e per PKT

- 100 200 300

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

Human Health and Environmental Impact Potentials per PKT

**Greenhouse Gases (grams CO₂eq)**
- 35mpg Sedan
- Future WECC-RPS, 670 Seats
- Boeing 737-800

**Respiratory Effects (mg PM₂.₅eq)**
- 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 O₃eq)**
- 35mpg Sedan
- Future WECC-RPS, 670 Seats
- Boeing 737-800

## Long-run per PMT Rankings

<table>
<thead>
<tr>
<th>Impact Potential</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Auto</td>
</tr>
<tr>
<td>End-use Energy</td>
<td>![Yellow]</td>
</tr>
<tr>
<td>Greenhouse Gases</td>
<td>![Yellow]</td>
</tr>
<tr>
<td>Respiratory Effects</td>
<td>![Red]</td>
</tr>
<tr>
<td>Acidification</td>
<td>![Red]</td>
</tr>
<tr>
<td>Smog Formation</td>
<td>![Red]</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>![Red]</td>
</tr>
</tbody>
</table>

Colors: Lowest = Green, Middle = Red, Highest = Yellow

Legend: 1 point = Low, 2 points = Middle, 3 points = High
Footprinting (per PMT)

Consequential (Corridor Effects)

- Auto Travel

+ Transit Travel
Greenhouse Gas Payback in Million Tonnes

CAHSR Authority Business Plan Medium Forecast

Payback Sensitivity

Payback with Cumulative Radiative Forcing

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

CO₂ Decay Function:

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

\[ CRF = \int_0^{TH} \alpha_i C_i(t) dt \]
CAHSR Impact Reduction Strategies

GHG Emissions in kg CO₂eq/VKT

- 5 10 15 20

WECC-2010

WECC-RPS

WECC-RPS (Emission Control)

100% Renewables

NOx Emissions in g/VKT

- 20 40

12% ↓

17% ↓

69% ↓

22% ↓

41% ↓

61% ↓

Vehicle Operation

Vehicle Manufacturing

Vehicle Insurance

Infrastructure Construction

Infrastructure Maintenance

Infrastructure Parking

Infrastructure Operation

Infrastructure Insurance

<table>
<thead>
<tr>
<th>Mode</th>
<th>Today</th>
<th>2040 without HSR</th>
<th>2040 with HSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto VMT</td>
<td>324 billion</td>
<td>517 billion</td>
<td>511 billion</td>
</tr>
<tr>
<td>Air VMT</td>
<td>65 million</td>
<td>107 million</td>
<td>80 million</td>
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</table>
LA’s roadway network has enabled automobile use but the infrastructure may be saturated.
Cumulative Roadway Miles

Los Angeles Network Growth

Los Angeles Network Growth

Unsustainable Long-term Financing?

Natural Limits to Infrastructure Services?

Emergent Greenhouse Gas Emissions from Vehicle Travel

Integrated Transportation + Land Use Life Cycle Assessment
Potential Development around Stations

Vacant Lots

Dedicated Parking Lots

Low Density

High Density

Photo courtesy of Arnim Wiek & Aaron Golub. Reinvent Phoenix project.
Photo courtesy of Arnim Wiek & Aaron Golub. Reinvent Phoenix project.
Photo courtesy of Arnim Wiek & Aaron Golub. Reinvent Phoenix project.
Photo courtesy of Arnim Wiek & Aaron Golub. Reinvent Phoenix project.
Photo courtesy of Arnim Wiek & Aaron Golub. Reinvent Phoenix project.
Option 1 ▼ Option 2 ▼ Option 3 ▶

Greenhouse Gas (GHG) Emissions

$3 billion Investment in Low Density Single Family Units

$430 million Investment in High Density Multi Family Units

$670 million Investment in High Density Multi Family Units

$910 million Investment in High Density Multi Family Units

Cost Investments for 22,000 Homes

Number of Dwelling Units

Investment in Millions of 2012 Dollars

Multi Family
Single Family
Cumulative Investment
Maximizing the Investment[1/2]

- The transportation-land use interdependency can be used to the region’s advantage:
  - Investments in light rail yield transportation and 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$_2$e/du
  - Energy consumption by 7.5 TJ/du

- 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.

(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).

Phase 2

- Neighborhood-specific designs
- Adaptive Reuse

Commercial: Office and Retail space
Phase 3:
Los Angeles Redevelopment

<table>
<thead>
<tr>
<th>Redevelopment Outcome</th>
<th>Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacant + Surface (New Construction)</td>
<td>Single Family Residential</td>
</tr>
<tr>
<td>Vacant + Surface (New Construction)</td>
<td>Multi Family Residential + Commercial</td>
</tr>
<tr>
<td>Vacant + Surface (New Construction) + Low Value (Adaptive Reuse)</td>
<td>Multi Family Residential + Commercial</td>
</tr>
<tr>
<td>Vacant + Surface (New Construction) + Low Value (New Construction)</td>
<td>Multi Family Residential + Commercial</td>
</tr>
</tbody>
</table>
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