

# Life-cycle Assessment of High-speed Rail

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Image source: Wired Magazine, February 2010, Superfast Bullet Trains Are Finally Coming to the U.S.

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# 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

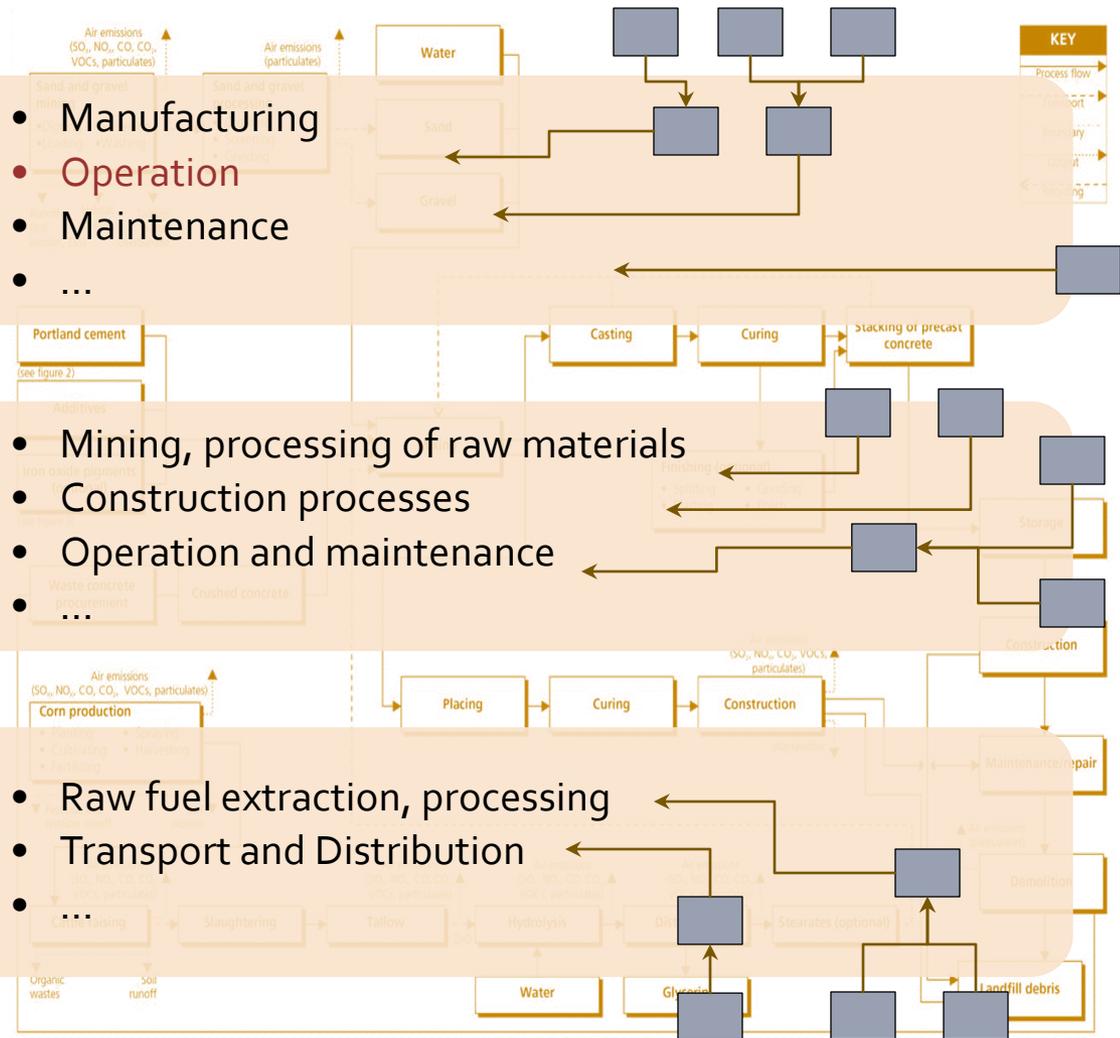
- Manufacturing
- Operation
- Maintenance
- ...

Infrastructure

- Mining, processing of raw materials
- Construction processes
- Operation and maintenance
- ...

Energy Production

- Raw fuel extraction, processing
- Transport and Distribution
- ...

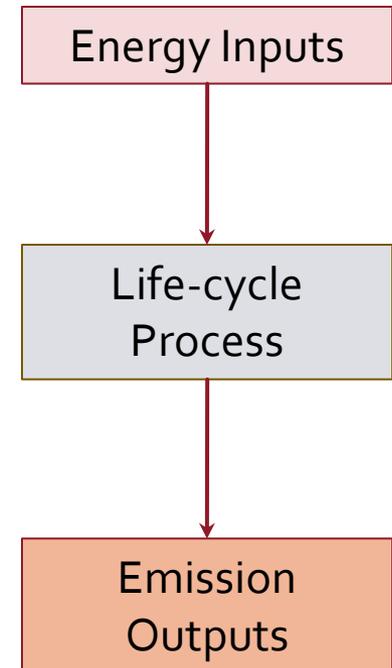


# Components Included

	ONROAD	RAIL	AIR
<b>Vehicle</b>			
<b>Manufacturing</b>	<ul style="list-style-type: none"> <li>• Vehicle manufacturing</li> </ul>	<ul style="list-style-type: none"> <li>• Train manufacturing</li> </ul>	<ul style="list-style-type: none"> <li>• Aircraft manufacturing</li> <li>• Engine manufacturing</li> </ul>
<b>Active Operation</b>	<ul style="list-style-type: none"> <li>• Running</li> <li>• Cold Start</li> <li>• Brake Wear</li> <li>• Tire Wear</li> <li>• Idling</li> </ul>	<ul style="list-style-type: none"> <li>• Propulsion</li> </ul>	<ul style="list-style-type: none"> <li>• Take off</li> <li>• Climb out</li> <li>• Cruise</li> <li>• Approach &amp; Landing</li> </ul>
<b>Inactive Operation</b>	<ul style="list-style-type: none"> <li>• Evaporative Losses</li> </ul>	<ul style="list-style-type: none"> <li>• Idling</li> <li>• Auxiliaries</li> </ul>	<ul style="list-style-type: none"> <li>• Auxiliary Power Unit operation</li> <li>• Startup</li> <li>• Taxi out</li> <li>• Taxi in</li> </ul>
<b>Maintenance</b>	<ul style="list-style-type: none"> <li>• Vehicle maintenance</li> <li>• Tire replacement</li> </ul>	<ul style="list-style-type: none"> <li>• Train maintenance</li> <li>• Train cleaning</li> <li>• Flooring replacement</li> </ul>	<ul style="list-style-type: none"> <li>• Aircraft maintenance</li> <li>• Engine maintenance</li> </ul>
<b>Insurance</b>	<ul style="list-style-type: none"> <li>• Vehicle liability</li> </ul>	<ul style="list-style-type: none"> <li>• Crew health and benefits</li> <li>• Train liability</li> </ul>	<ul style="list-style-type: none"> <li>• Crew health and benefits</li> <li>• Aircraft liability</li> </ul>
<b>Infrastructure</b>			
<b>Construction</b>	<ul style="list-style-type: none"> <li>• Roadway construction</li> </ul>	<ul style="list-style-type: none"> <li>• Station construction</li> <li>• Track construction</li> </ul>	<ul style="list-style-type: none"> <li>• Airport construction</li> <li>• Runway/Taxiway/Tarmac construction</li> </ul>
<b>Operation</b>	<ul style="list-style-type: none"> <li>• Roadway lighting</li> <li>• Herbicide spraying</li> <li>• Roadway salting</li> </ul>	<ul style="list-style-type: none"> <li>• Station lighting</li> <li>• Escalators</li> <li>• Train control</li> <li>• Station parking lighting</li> <li>• Station miscellaneous (e.g., other electrical equipment)</li> </ul>	<ul style="list-style-type: none"> <li>• Runway lighting</li> <li>• Deicing fluid production</li> <li>• GSE operation</li> </ul>
<b>Maintenance</b>	<ul style="list-style-type: none"> <li>• Roadway maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Station maintenance</li> <li>• Station cleaning</li> </ul>	<ul style="list-style-type: none"> <li>• Airport maintenance</li> <li>• Runway/Taxiway/Tarmac maintenance</li> </ul>
<b>Parking</b>	<ul style="list-style-type: none"> <li>• Roadside, surface lot, and parking garage parking</li> </ul>	<ul style="list-style-type: none"> <li>• Station parking</li> </ul>	<ul style="list-style-type: none"> <li>• Airport parking</li> </ul>
<b>Insurance</b>	<ul style="list-style-type: none"> <li>• Road workers health insurance and benefits</li> </ul>	<ul style="list-style-type: none"> <li>• Non-crew health insurance and benefits</li> <li>• Infrastructure liability insurance</li> </ul>	<ul style="list-style-type: none"> <li>• Non-crew health and benefits</li> <li>• Infrastructure liability</li> </ul>
<b>Fuels</b>			
<b>Extraction, Processing, and Distribution</b>	<ul style="list-style-type: none"> <li>• Gasoline and diesel fuel refining and distribution</li> </ul>	<ul style="list-style-type: none"> <li>• Train electricity generation</li> <li>• Train diesel fuel refining and distribution</li> <li>• Train electricity T&amp;D losses</li> <li>• Infrastructure electricity production</li> <li>• Infrastructure electricity T&amp;D losses</li> </ul>	<ul style="list-style-type: none"> <li>• Jet fuel refining and distribution</li> </ul>

# Environmental Indicators

- Energy
- Criteria Air Pollutants & VOCs
  - SO<sub>2</sub> – Respiratory irritant, acid deposition
  - CO – Asphyxiant
  - NO<sub>x</sub> – Respiratory irritant, smog
  - VOC – Photochemical smog, cancerous
  - PM – Respiratory and cardiovascular damage
- Greenhouse Gases
  - CO<sub>2</sub>, CH<sub>4</sub> (~24×), N<sub>2</sub>O (~290×)



# Uncertainty in Train Size & Ridership

- The train model and size is a critical factor
  - Train specified in planning literature is likely an overestimate (1200 seats)
  - More likely around 400-600 passengers and  $\frac{1}{4}$  electricity consumption
- 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

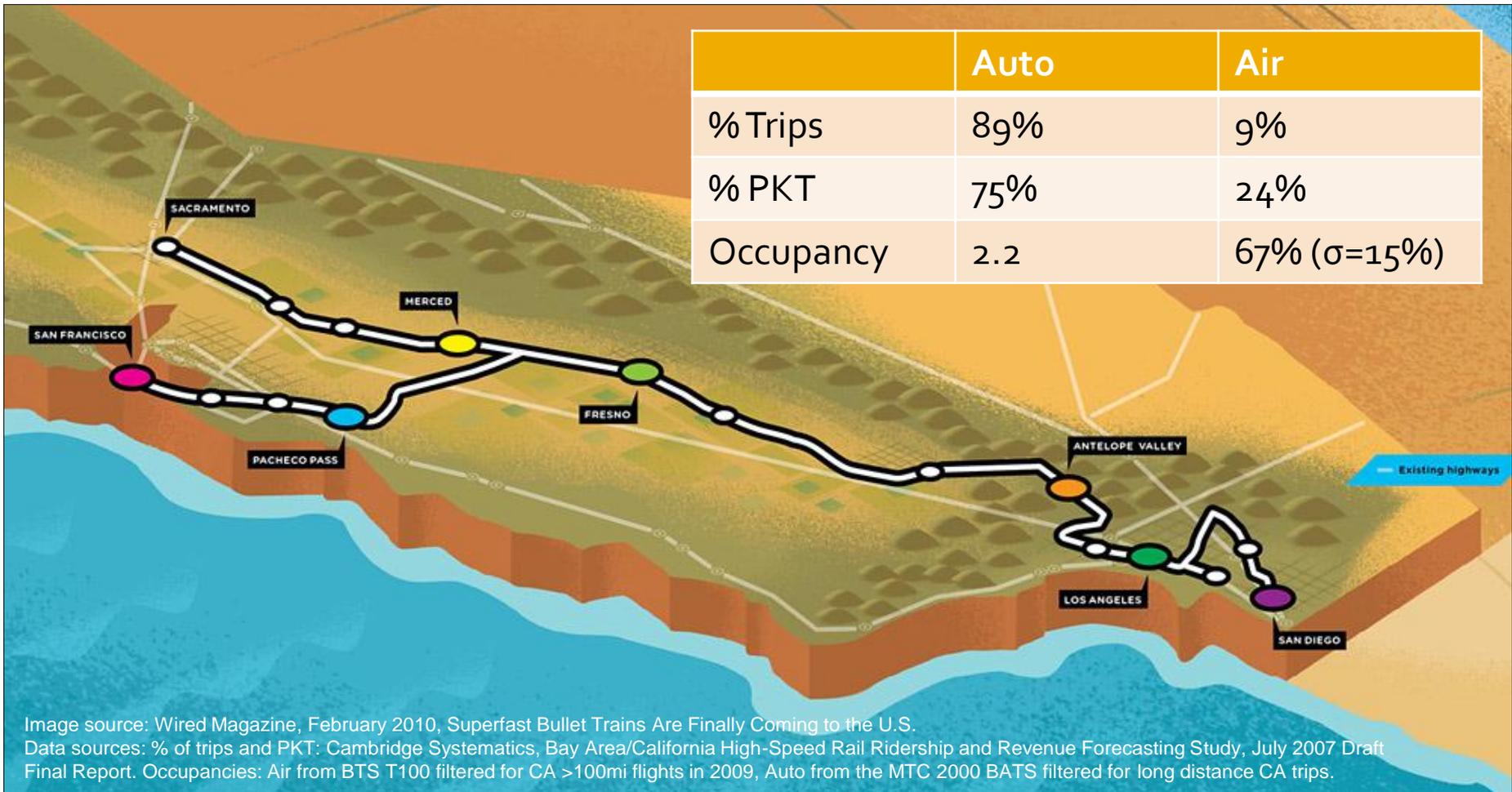


# A 2030 Comparison for the CA Corridor

- New vehicle technologies
  - Cars: 35 miles/gallon, hybrids, PHEV20s
  - Aircraft: older models phased out, new models enter market
- CAHSR with shorter trains, clean ⚡
  - 400-600 seats
  - 80/20 wind/solar, 100% wind, 100% solar

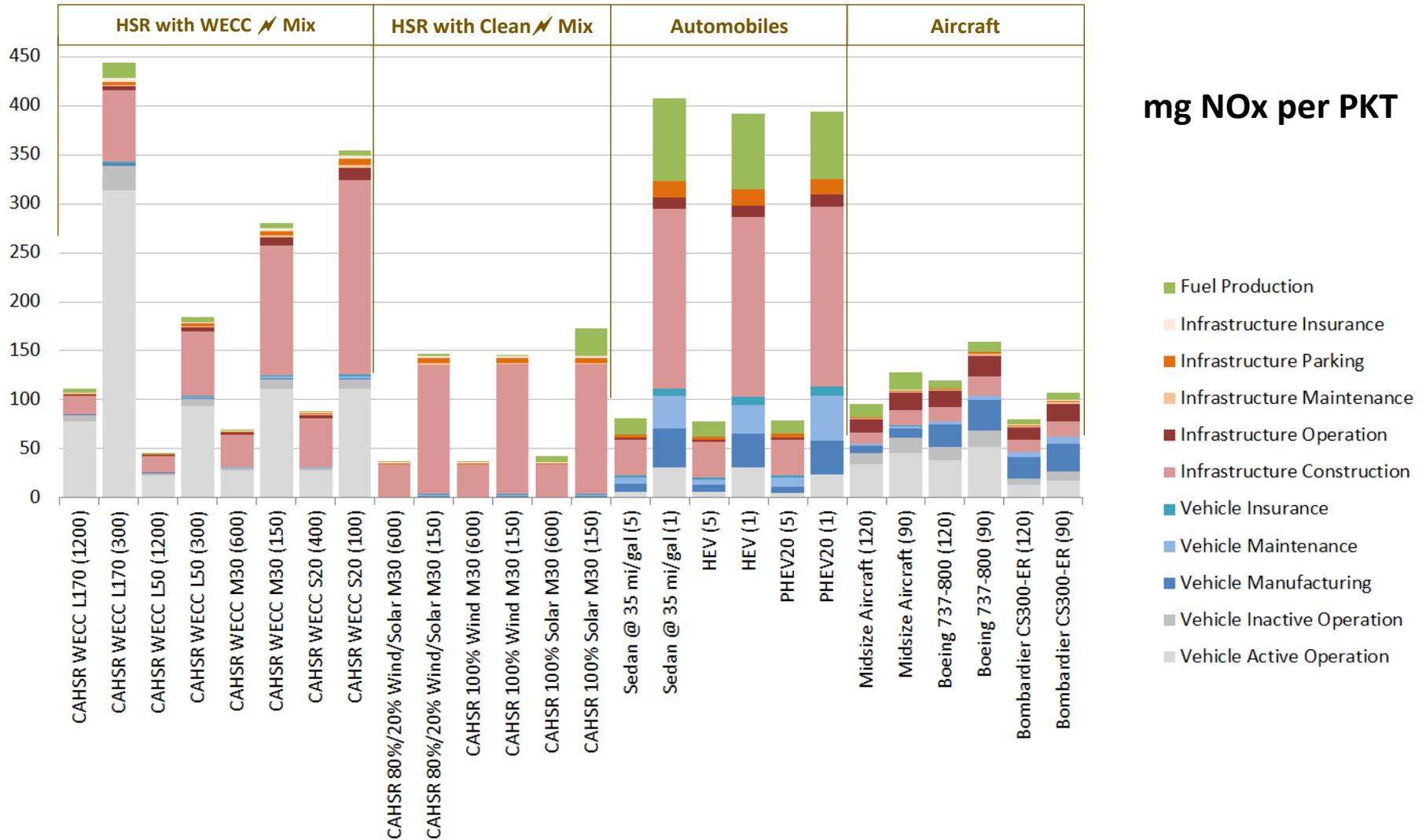


# California Corridor Travel

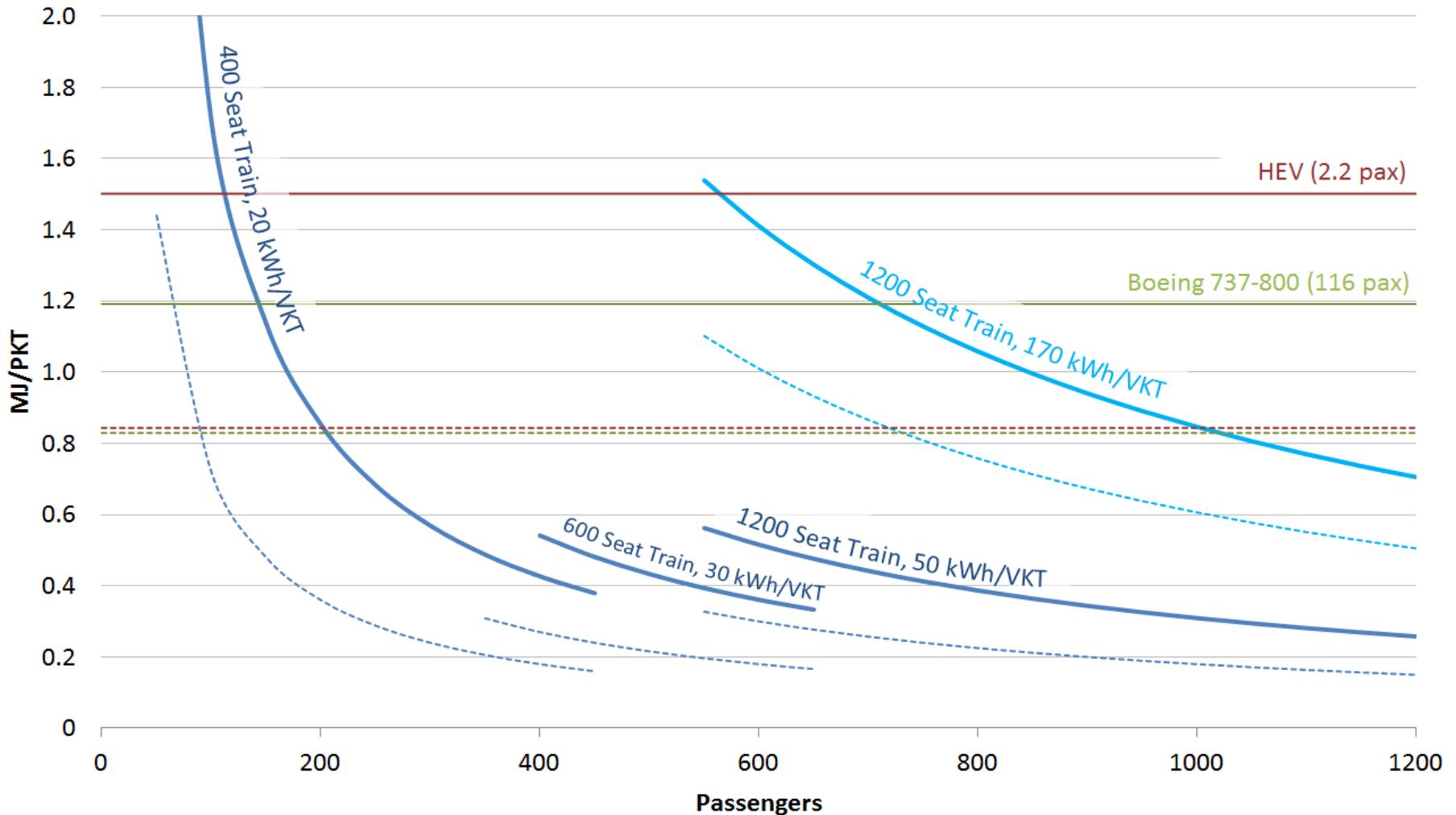




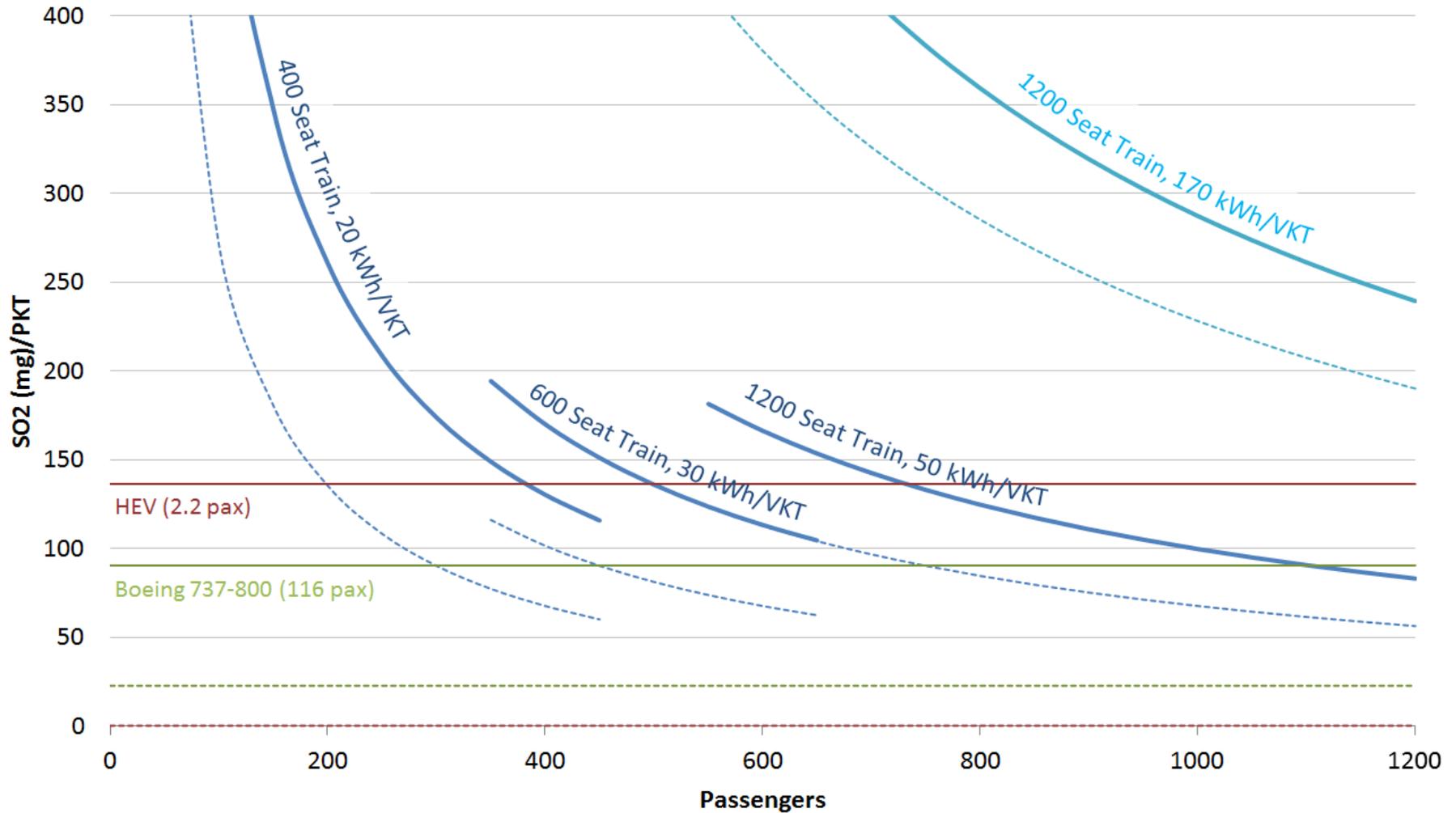
# Life-cycle NOx Emissions



# Breakeven Energy Consumption & Ridership



# Breakeven SO<sub>2</sub> Emissions & Ridership



# Payback

105 PJ of Energy, 10 Tg CO<sub>2</sub>e,  
29 Gg SO<sub>2</sub>, 83 Gg CO,  
36 Gg NO<sub>x</sub>, 25 Gg VOC,  
3 Gg PM<sub>2.5</sub>

- CAHSR construction will produce 10 Tg CO<sub>2</sub>e
  - 2% of California's GHG emissions in 2006



	Automobiles and air at low occupancy, CAHSR at high occupancy	Automobiles and air at mid-level occupancy, CAHSR at mid-level occupancy	Automobiles and air at high occupancy, CAHSR at low occupancy
CAHSR Loading	80%	60%	40%
Automobile Passengers	1.5	2	2.5
Air Loading	52% (μ-σ)	67% (μ)	82% (μ+σ)
CAHSR Energy ROI	4 years	7 years	14 years
CAHSR GHG ROI	6 years	11 years	41 years
CAHSR NO <sub>x</sub> ROI	27 years	65 years	never

# Takeaways

- Importance of including life-cycle emissions
  - Energy use & GHG emissions, increases of
    - 38% to 137% to CAHSR, 77% to 127% for cars, & 21%-66% for aircraft
  - SO<sub>2</sub>, NO<sub>x</sub>, VOC, PM<sub>2.5</sub> emissions can increase
    - 47% to 4200% for CAHSR, a minimum of 580% for cars, and a minimum of 110% for aircraft
  - Tradeoffs may exist (e.g., ↓ GHGs for ↑ SO<sub>2</sub>/NO<sub>x</sub>)
- Incentivizing high ridership is critical
- Co-deployment of renewable capacity

# Critical Factors

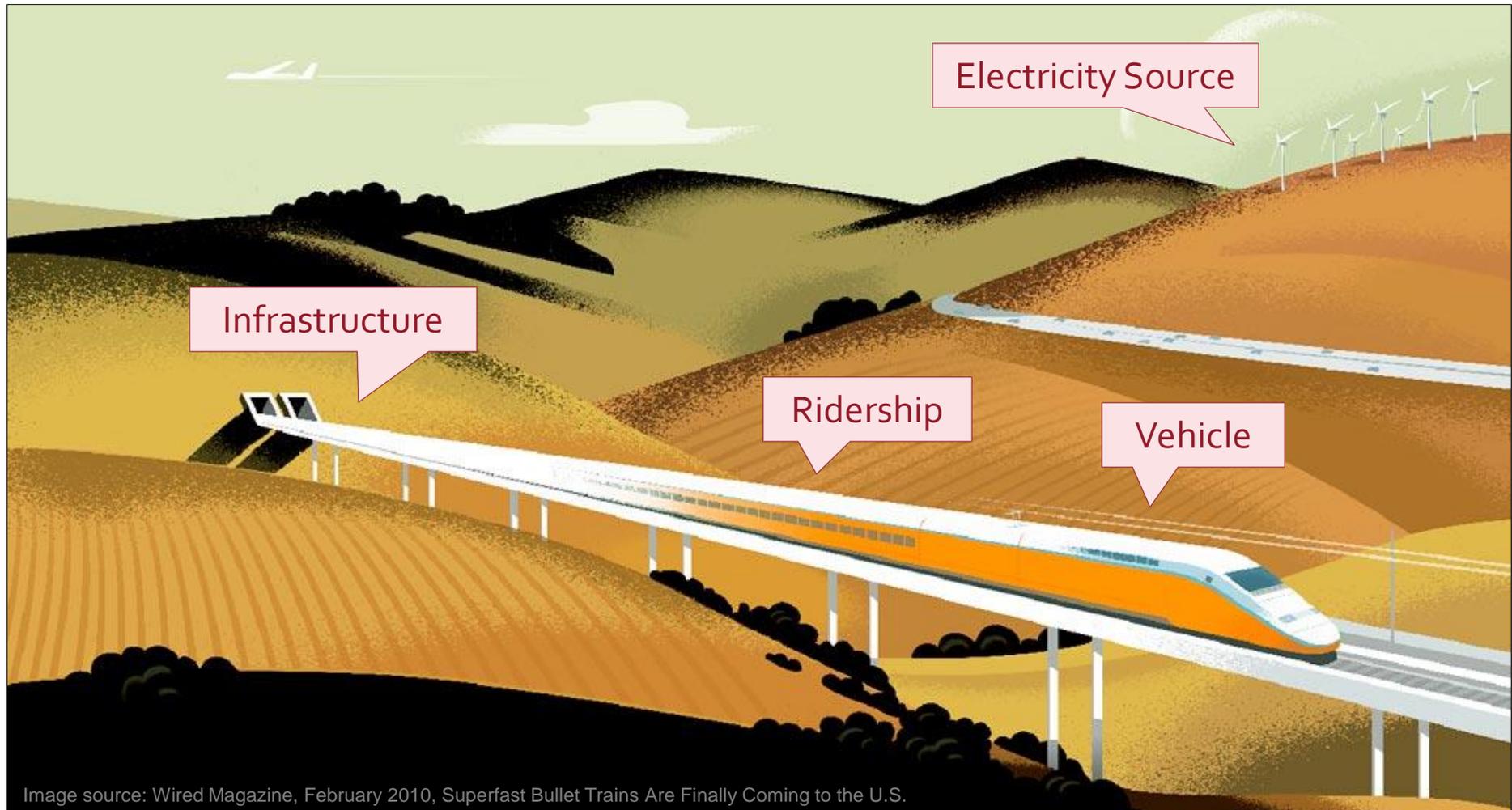


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# Questions / Comments



[www.sustainable-transportation.com](http://www.sustainable-transportation.com)