Electrification of Roadways for Wireless Power Transfer: Techno-Economic Assessment and Environmental Impact

Jason C. Quinn[1],
Zeljko Pantic[2], Paul Barr[3], Regan Zane[2]

[1]Mechanical and Aerospace Engineering
[2]Electrical & Computer Engineering
[3]Civil & Environmental Engineering

Utah State University

Acknowledgments

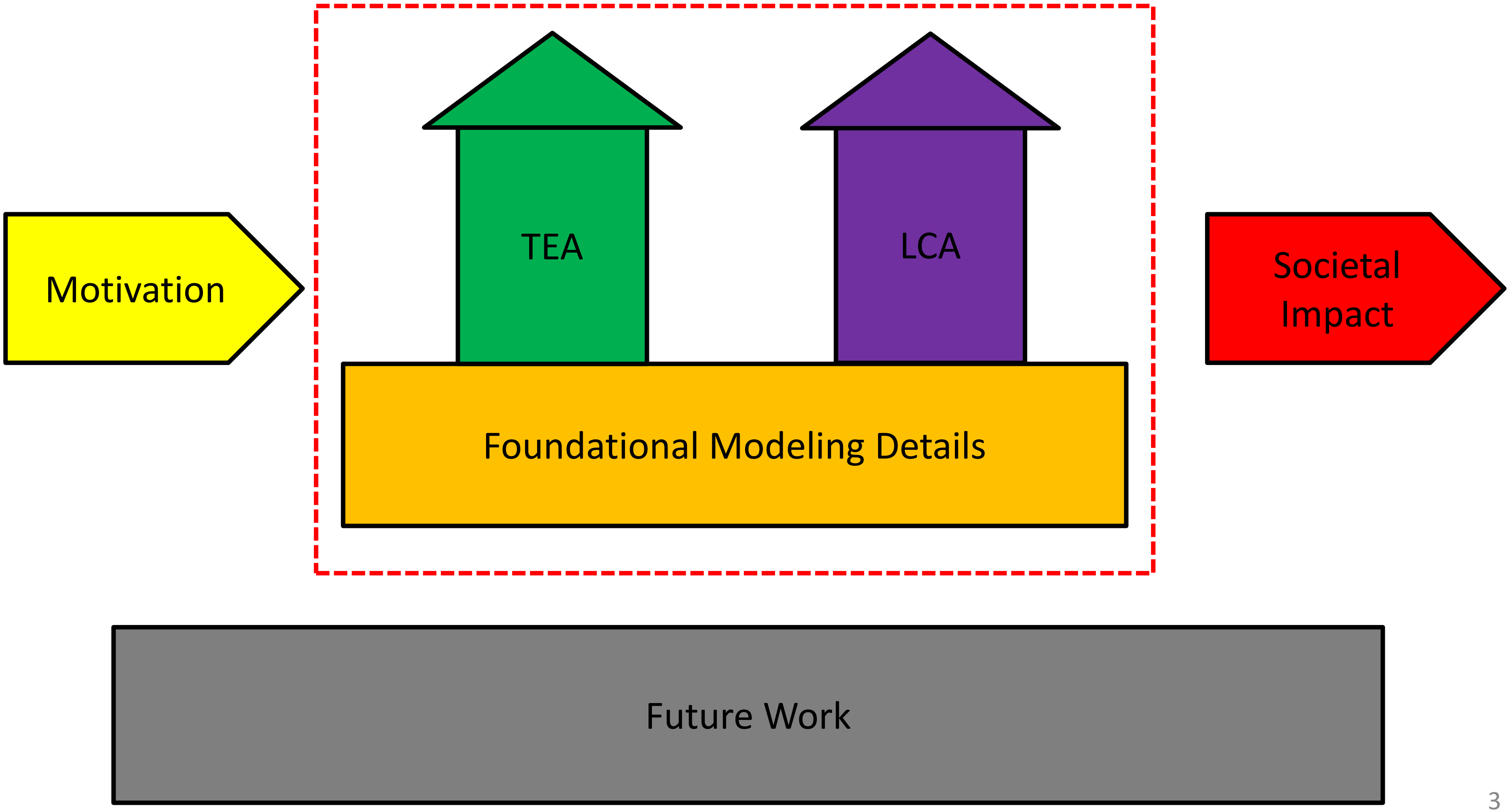
- Electric Vehicle & Roadway Research Group
- CERV conference organizers
- Ben B. Quinn, Braden Limb

USTAR
Turning innovation into industry.

Mechanical & Aerospace ENGINEERING

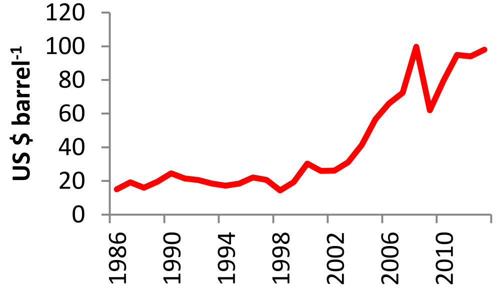
Electrical & Computer ENGINEERING

Talk outline

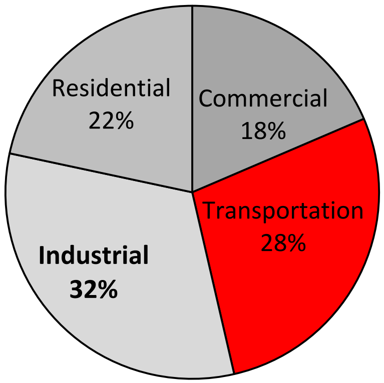


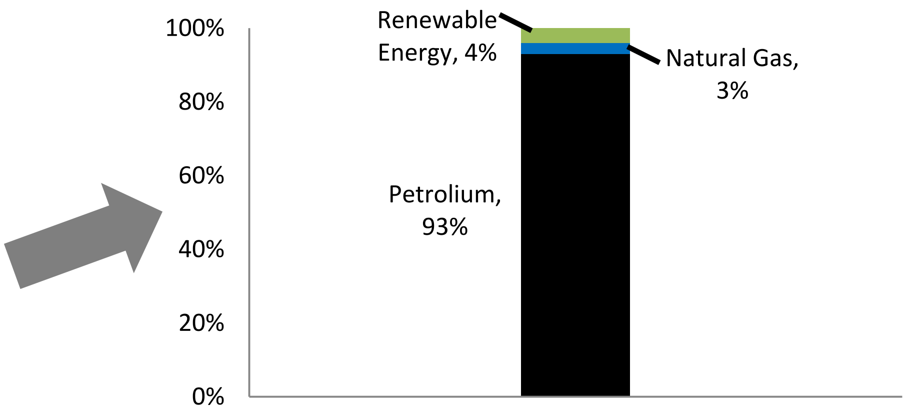
Motivation

- Transportation represents a significant portion of US energy
- Dominant consumer of petroleum
  - Large uncertainty in petroleum costs



US Energy consumption



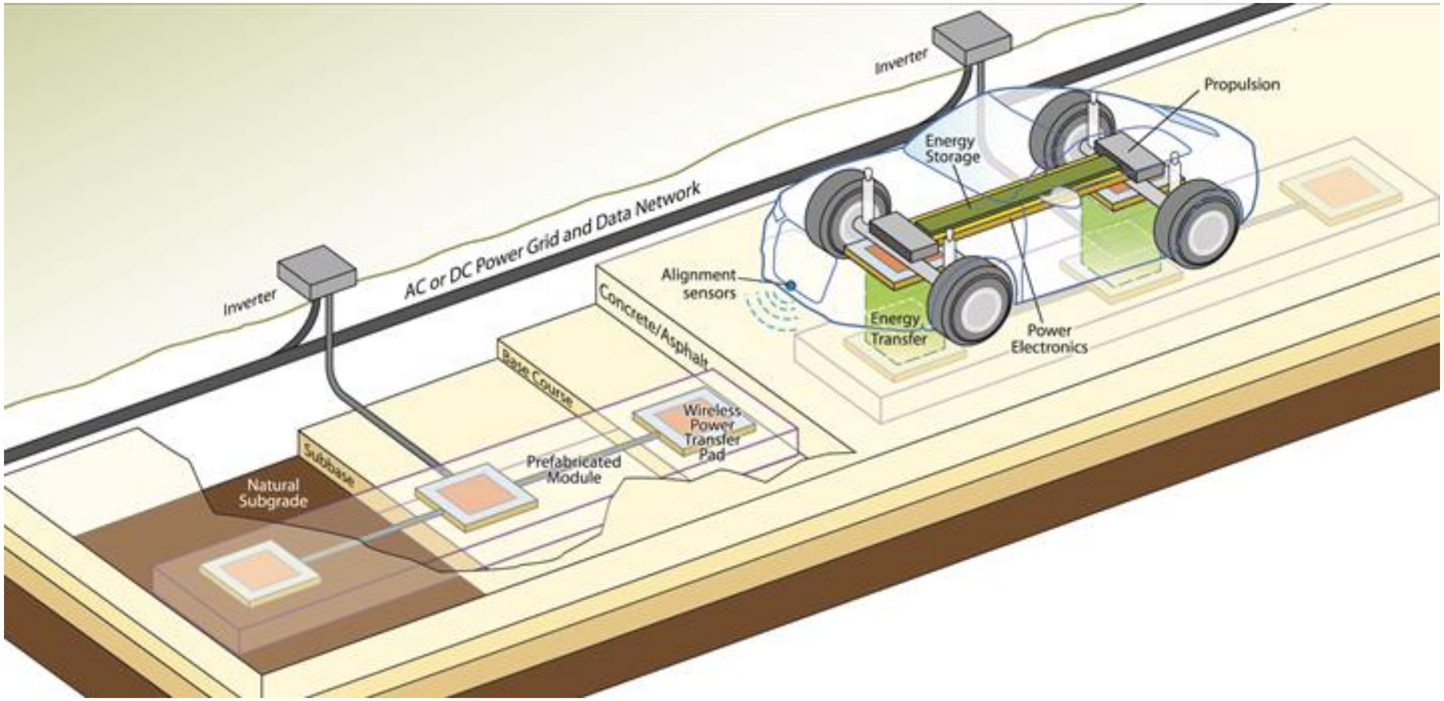


Utah State University

Feasibility of WPT

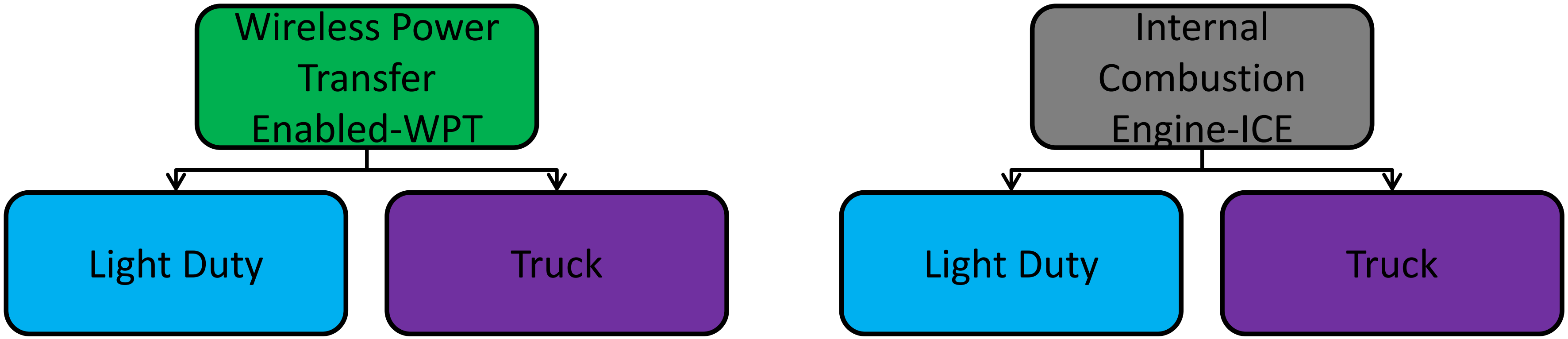
- Dynamic wireless charging
  – In motion charging
- Coil alignment and interaction time
  – Requires high power devices
- High efficiency power transfer
- Safety
- Implementation

Conceptual Schematic



- Integrated WPT roadway and vehicle
- Range extending concept

Vehicle Modeling



Energy requirements based on vehicle velocity, weight, 0% grade, frontal area

	ICE		WPT	
	Light Duty	Truck	Light Duty	Truck
Weight (kg)	2000	20000	1400	20000
Frontal Area (m^2)	1.35	11.5	1.35	11.5
Energy Delivery η	28%	28%	84%	84%
Mech Energy (Whr km^{-1})	264	870	238	870

UtahState University

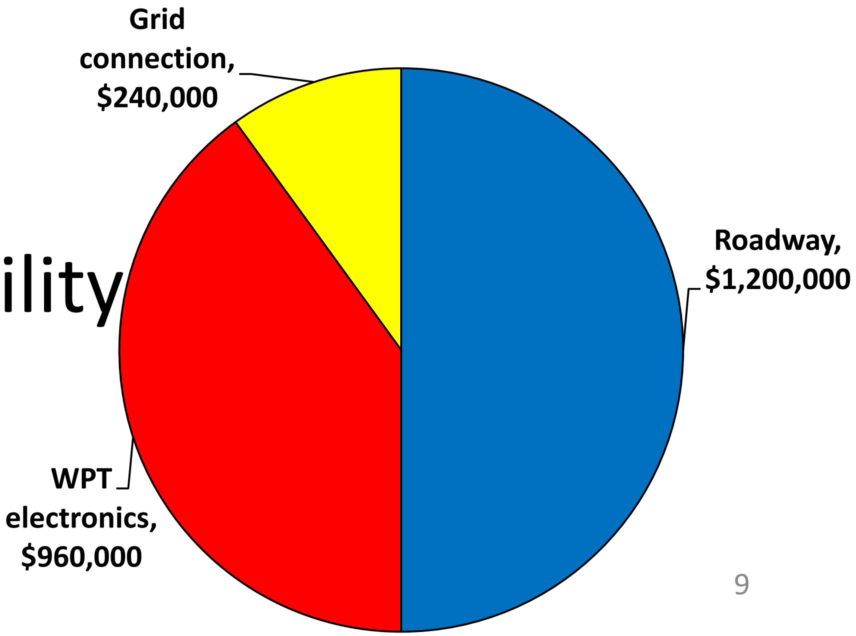
Vehicle Costs

- Cost savings for the WPT vehicle are assumed
  - Decreased battery size
  - Decrease in vehicle complexity

	ICE	WPT	WPT/ICE
	Light Duty	Light Duty	Truck
Purchase price (\$ vehicle^{-1})	34,410	24,807	250,000
Maintenance (% purchase price)	8	4	8
Vehicle life (yrs)	15	15	15

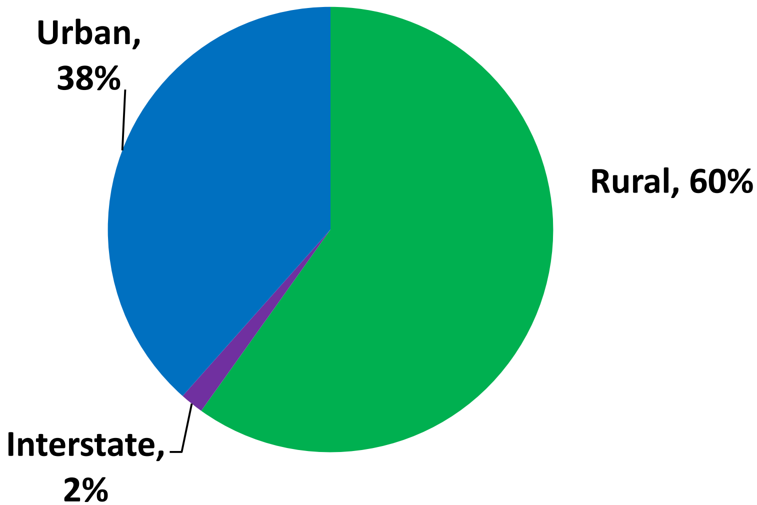
Roadway Modeling

- Roadway costs is $2.4 million per mile
- Roadway coverage
  - 25 kW power pads
  - 33% of the interstate (2 lanes, 1 per direction)
  - 6% of urban roadways
  - 50 yr life
- Large Roadway Cost Variability

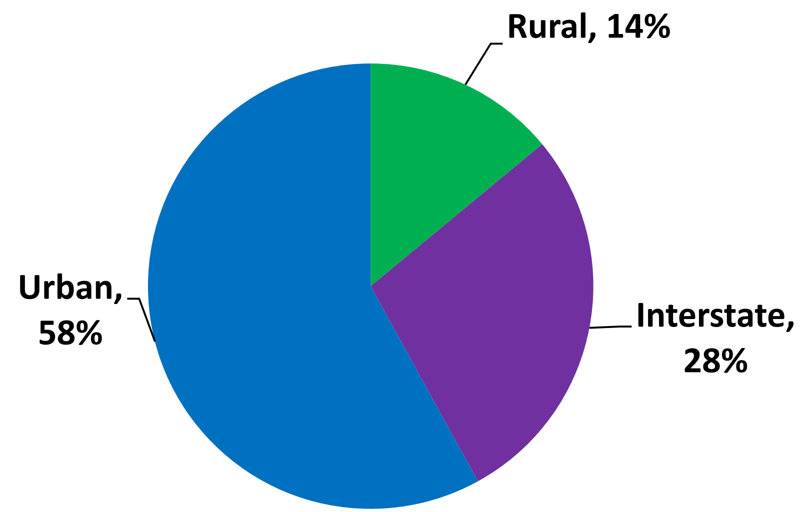


Modeled Scenarios

Paved Roads in the US-2.6 million miles



Miles Driven in the US-2.58 trillion miles



- Scenarios:
  - Interstate Systems
  - Interstate and Rural Systems
- Integration of WPT for Rural represents an economic challenge

Techno-Economics

- Societal level assessment
  - Return on investment (ROI)

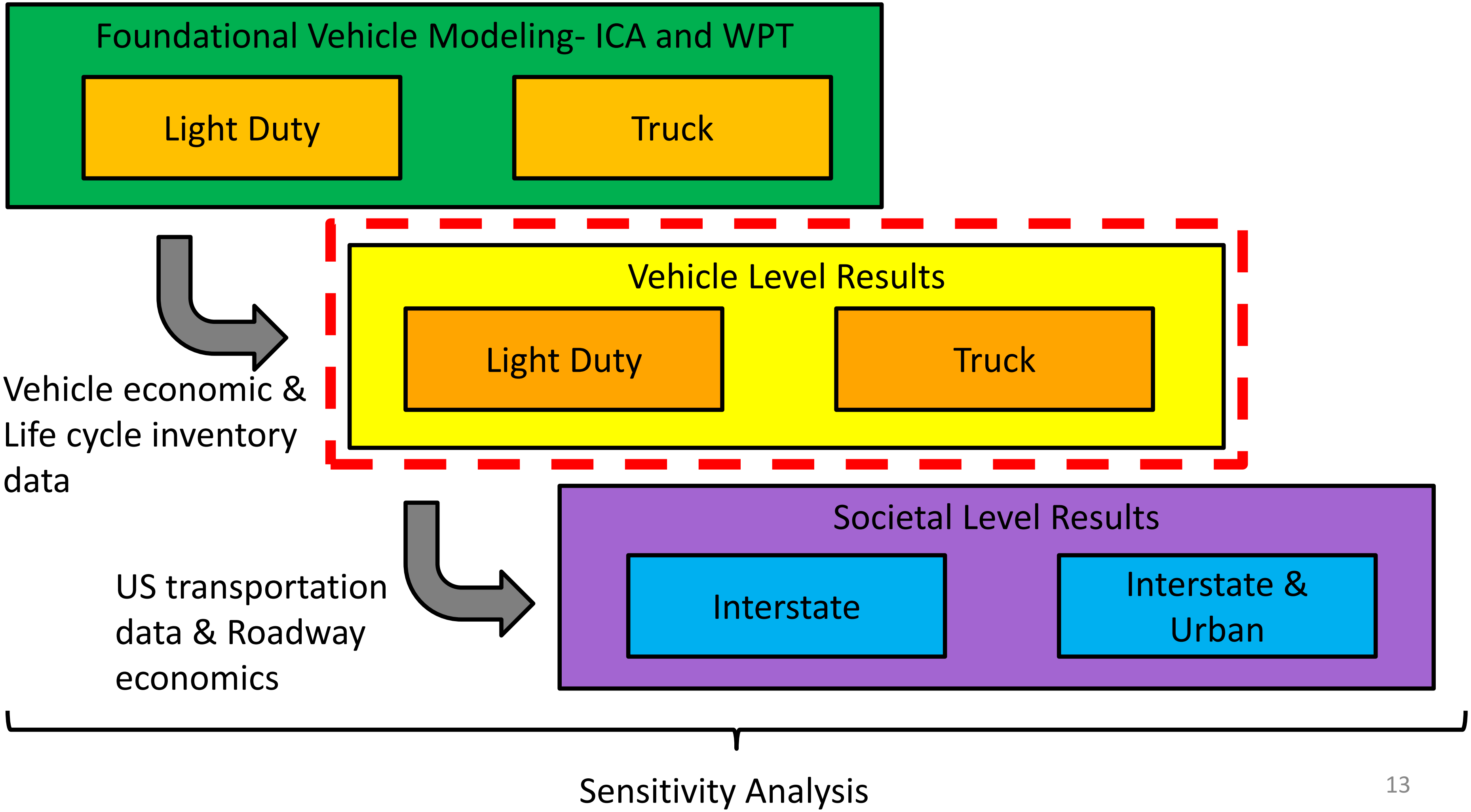
$$Total\ roadyway\ cost = (Cost\ of\ ownership\ ICE - Cost\ of\ ownership\ WPT)$$

- Assumes:
  - instant technology deployment
  - Energy costs
    - Electricity \$0.107 $kWhr^{-1}$ (minimal change expected)
    - Fuel \$4.07 gal^{-1} (Low-\$2.30, High-\$5.89

Life Cycle Modeling

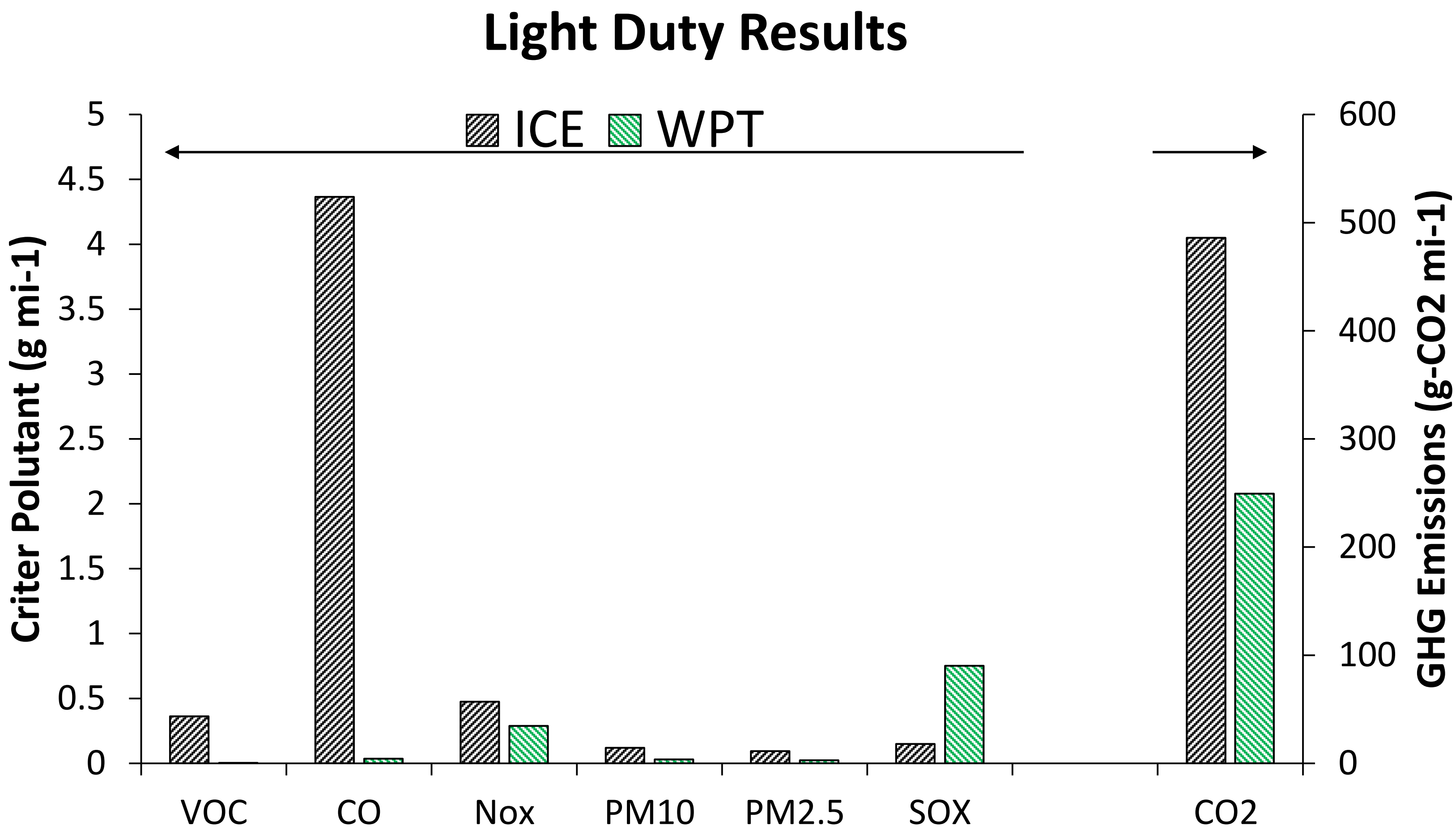
- Limited to emissions associated with use
  - Excluded manufacturing of vehicles and roadway system
- Life cycle inventory data from ANL GREET model
  - Standard for life cycle modeling of transportation
- Emissions for electricity are based on std. US mix
  - (Natural gas-27%, Coal-29%, Nuclear-18%, others-18%)

Results



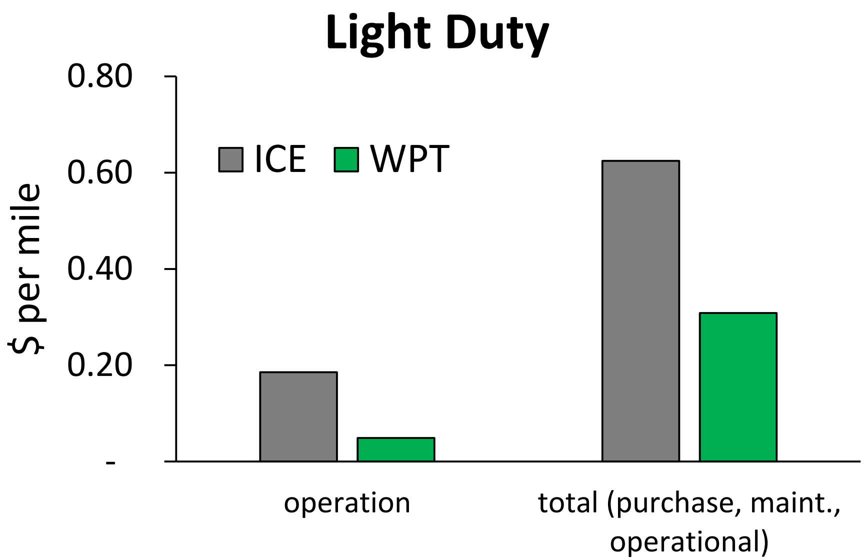
Foundational Vehicle Modeling- ICA and WPT
Light Duty
Truck
Vehicle economic & Life cycle inventory data
Vehicle Level Results
Light Duty
Truck
US transportation data & Roadway economics
Societal Level Results
Interstate
Interstate & Urban
Sensitivity Analysis

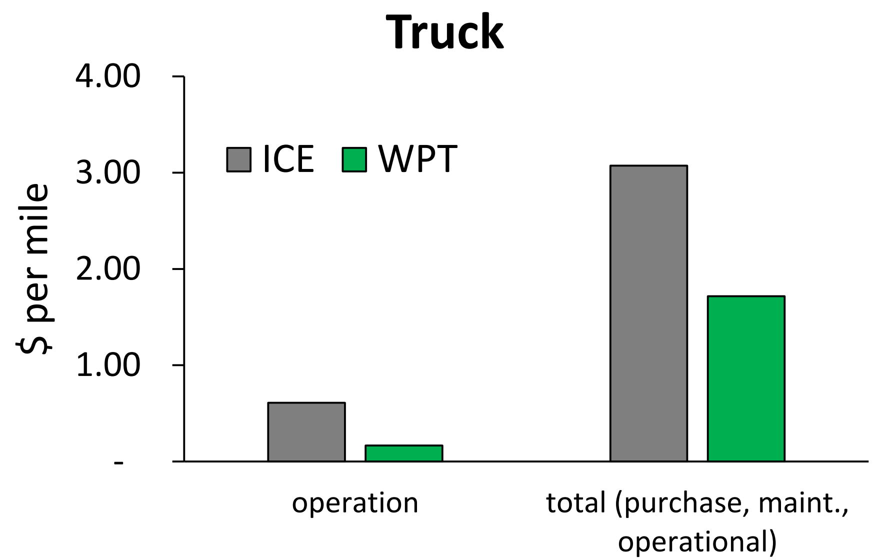
Vehicle Level Results-LCA



- 99% reduction in VOC and CO, 75% reduction in PM10 and PM2.5, and 40% reduction in NOx.

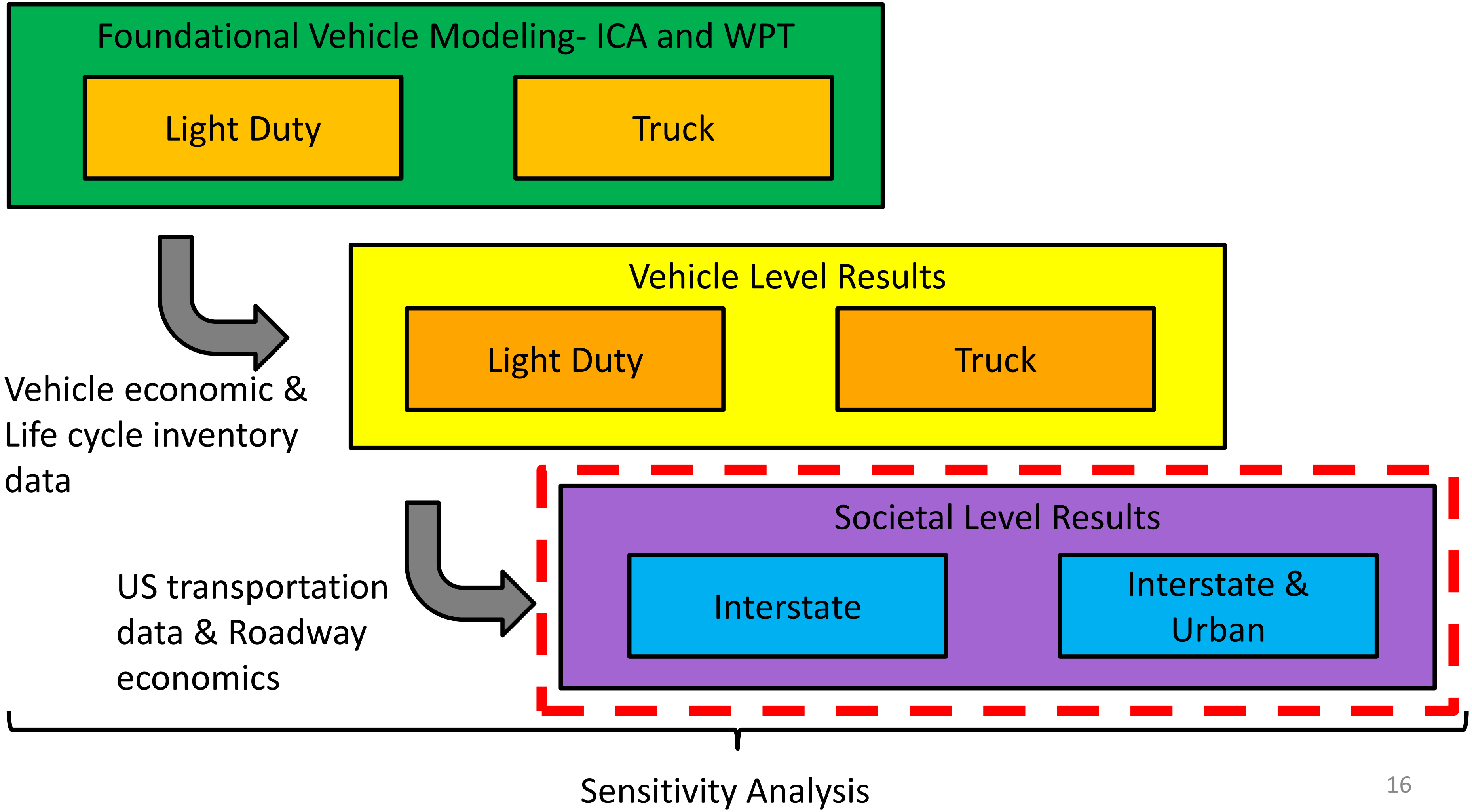
Vehicle Level Results-TEA





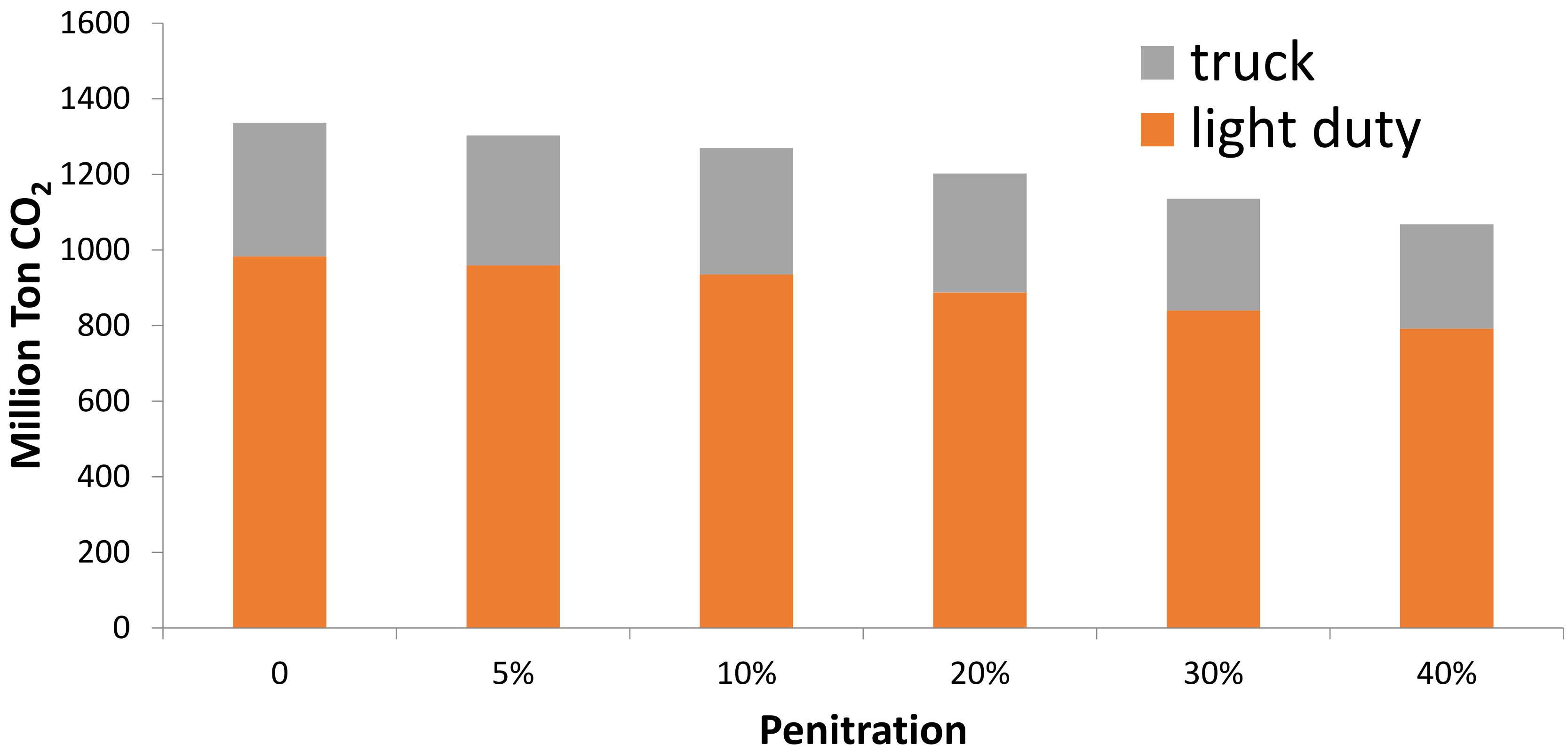
- WPT has significant cost savings compared to ICE
- 4 x difference in operation costs, light duty

Results



Foundational Vehicle Modeling- ICA and WPT
Light Duty
Truck
Vehicle economic & Life cycle inventory data
Vehicle Level Results
Light Duty
Truck
US transportation data & Roadway economics
Societal Level Results
Interstate
Interstate & Urban
Sensitivity Analysis

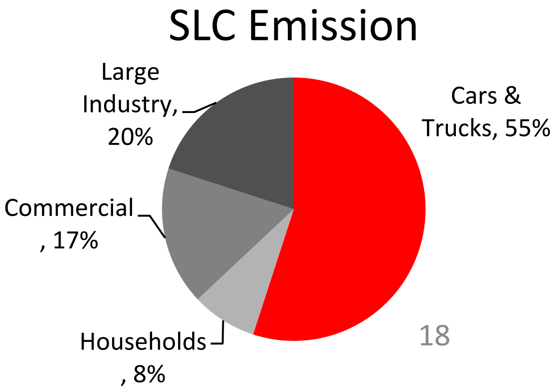
Environmental Impact



- 134 million tons of CO_2 saved at 20% penetration
  - 8% of the total CO_2 emissions from coal

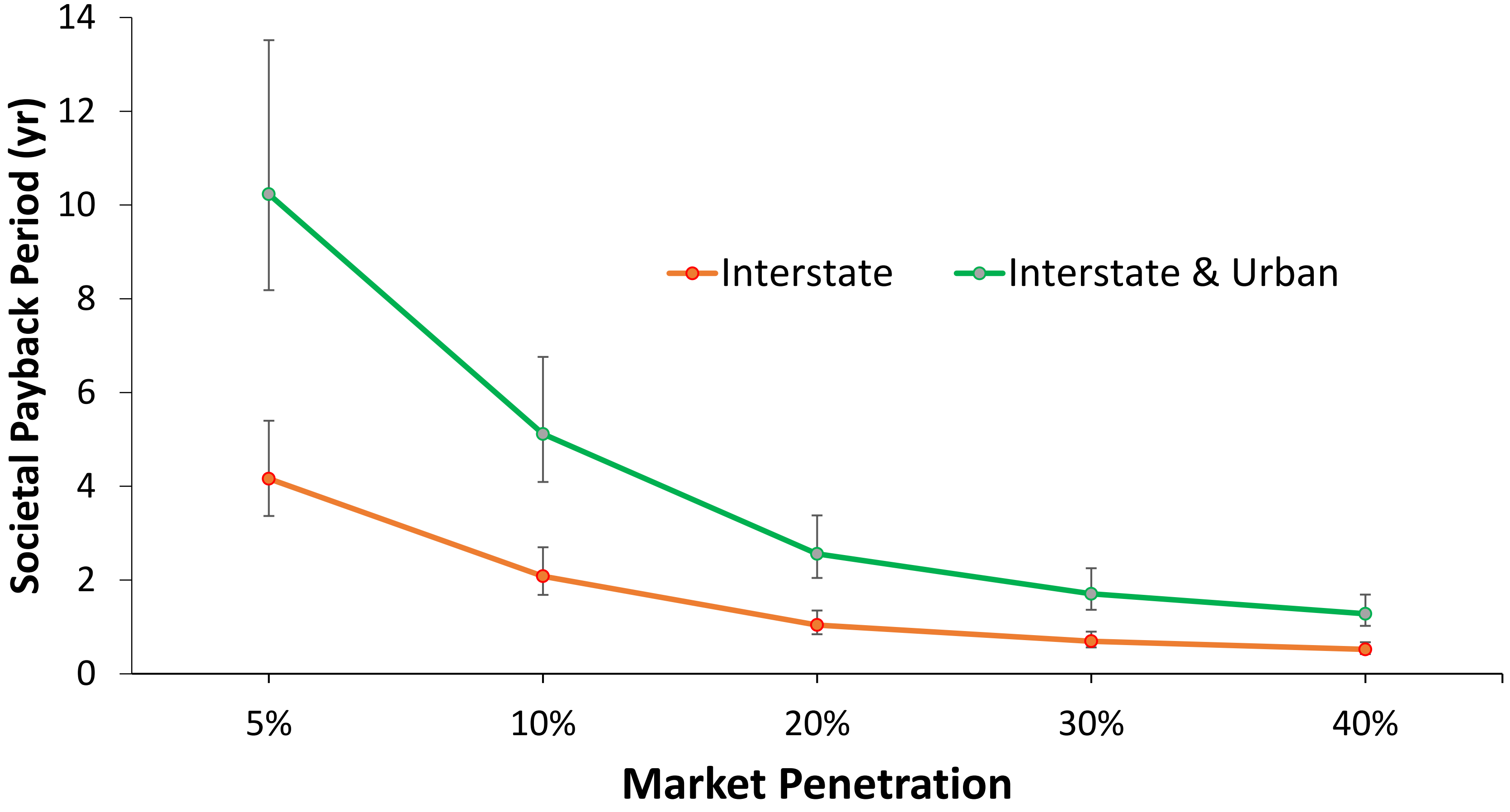
Criteria Pollutants

- Delta in the location of emissions
  - WPT shifts criteria emissions to electrical generation cites
  - PM2.5 and PM10 major contributors



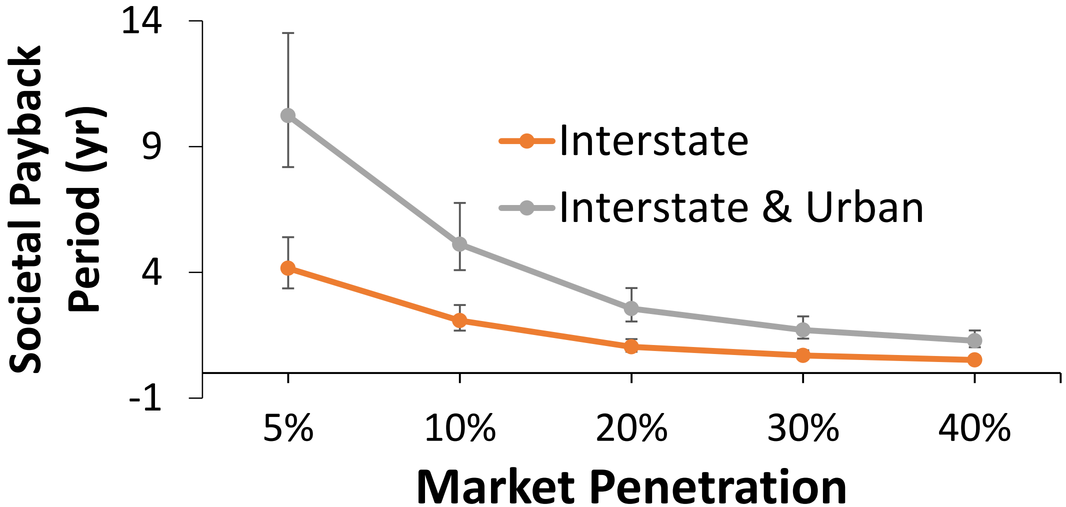
UtahState University

Societal ROI



Societal ROI

- Initial analysis shows promising economics
- Small improvements in operational costs are magnified by 2.6 trillion miles per year
- Need for more detailed analysis



Future Work

- Development of dynamic vehicle models
- Evaluation and optimization of vehicle architecture
- Investigation of performance requirements for commercial viability
- Roadway infrastructure optimization
- Case studies-city bus routes, airports, DOD facilities, industrial processing

UtahState University

Contact Information:
Jason.Quinn@usu.edu
435-797-0341