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SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

An Institute of Transportation Studies Program

Session 4:
Transition Scenarios and Related Modeling



STEPS Transportation Transition Scenarios for California:

Update on Fuels and Infrastructure Module

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STEPS Symposium

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www.steps.ucdavis.edu

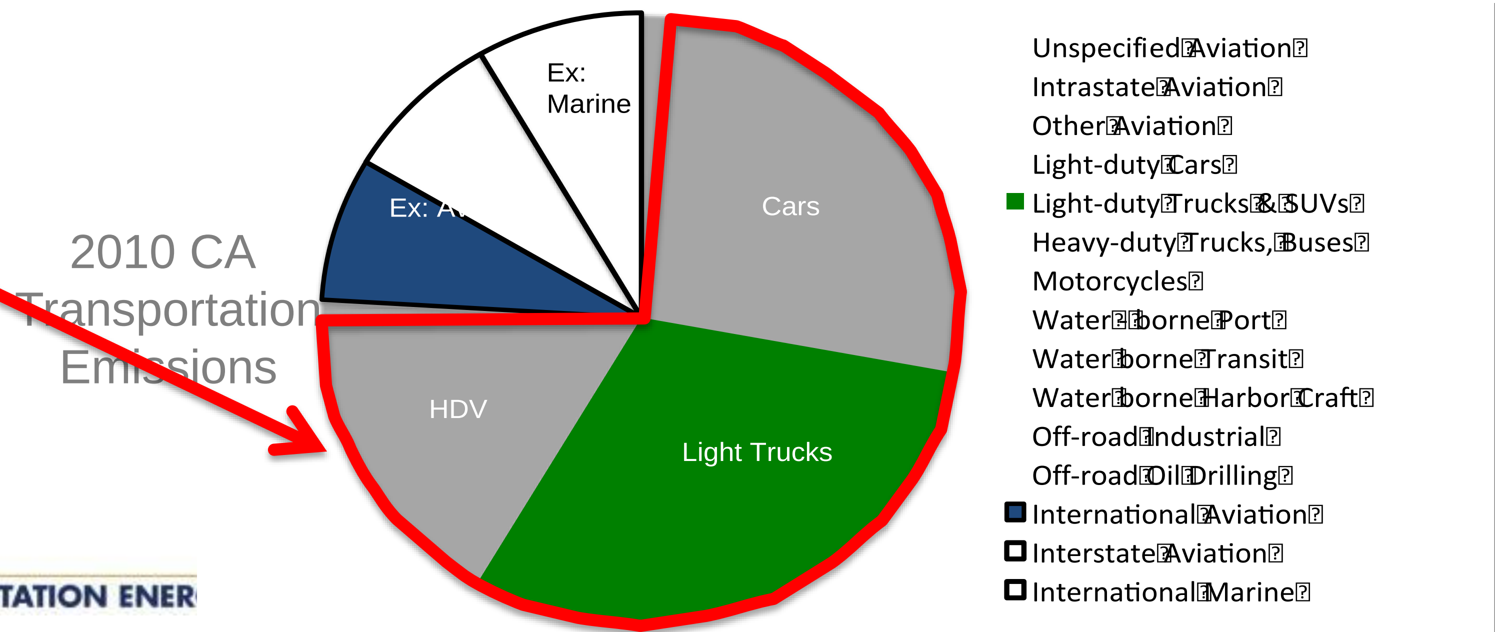
STEPS Decarbonization Scenarios for Transportation

- *Critical Transition Dynamics 2015-2030*
- Develop scenarios for transportation to analyze future vehicle mixes, fuel usage, emissions and costs
  - Integrate ongoing STEPS research on vehicles and fuels
  - Focus on the cost and emissions impacts of a transition to decarbonized transportation system (advanced vehicles and alternative fuels)
  - Analyze 2010-2050 with particular focus on **2015-2030**
  - Explore detailed vehicle/fuel scenarios across many transport sectors
- Project goals
  - Develop scenario modeling framework
  - Produce realistic scenarios estimating the contribution of transportation to emissions reductions and meeting climate change goals
  - Exploring technology/fuel/resource mix and emissions
  - Assess investments required (and potential subsidies required)
  - Scenarios enable "what-if" analyses and improve understanding of sensitivities of the system to inputs

Decarbonization Scenarios for Transportation

- Analyze **reference (BAU)** and **decarbonization (GHG)** scenarios
- Look across transportation sectors
  - **Light-duty, medium and heavy-duty/medium-duty trucks**
  - Additional sectors (rail, aviation, marine) will be included *next year*
- Started with focus on **California** to build up modeling capabilities but plan to develop US scenarios *next year*
  - Similar approach (technology specifications, modeling framework)
  - Differences (additional data collection, infrastructure and resource availability and cost)

LDV, MDV, HDVs account for ~75% of CA transportation emissions



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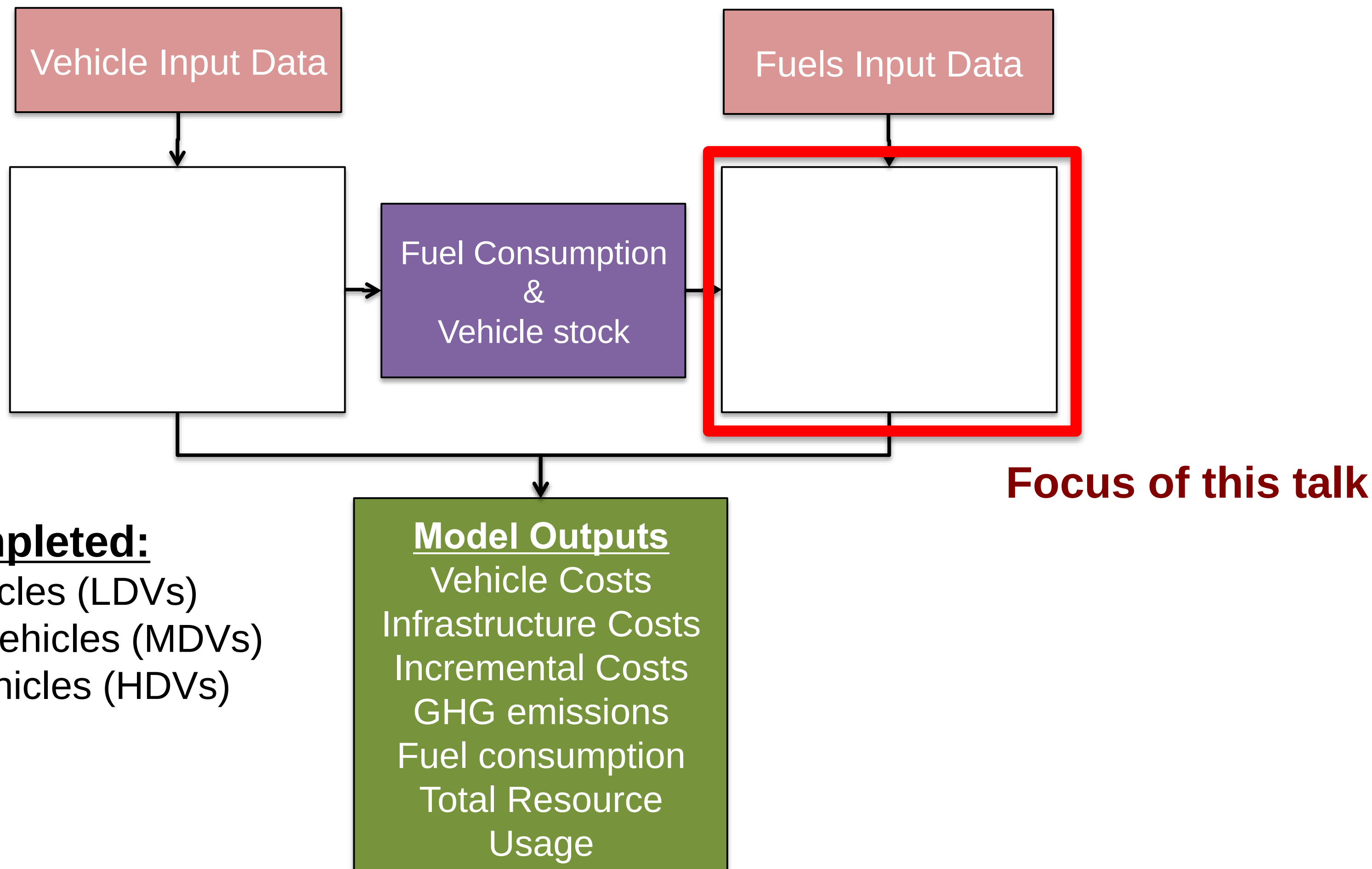
Transition Scenario Modeling Framework

- Spreadsheet-based model
  - Specify vehicle technologies (sales mix, fuel economy, cost)
  - Specify fuel supply (mix of production/delivery pathways, carbon intensity, infrastructure capital cost)



Sectors completed:
Light-duty vehicles (LDVs)
Medium-duty vehicles (MDVs)
Heavy-duty vehicles (HDVs)

Fuel Module

- Fuel are modeled from “bottom-up”
  - Number of vehicles of specified technology →
  - Number and size of stations supplying a given fuel →
  - Number and size of production plants producing fuel
- **Inputs:**
  - Plant and station cost as a function of scale and time
  - Process efficiencies and energy inputs
- **Stock turnover**
  - Key element of model
  - Infrastructure has lifetime so you can’t change to new fuels too quickly or you incur higher costs
  - Current assumptions: 25 years for production, 15 years for stations

Fuel Modeling System Boundaries

Resource Supply → Production/ conversion facility → Fuel transport → Station

- Hydrogen

Resource Supply → Production/ conversion facility → Fuel transport → Station

- Biofuels

Resource Supply → Production/ conversion facility → Fuel transport → Station

- Electricity

Finished Fuel → Station

- Natural gas

RNG: Resource Supply → Production/ conversion facility → Finished Fuel → Station

New fuel types require (H2 and Biofuels) require modeling of resources, production facilities for multiple pathways, transport and new stations

Existing fuels/energy carriers only require modeling of fueling infrastructure and the cost of supplying finished fuels

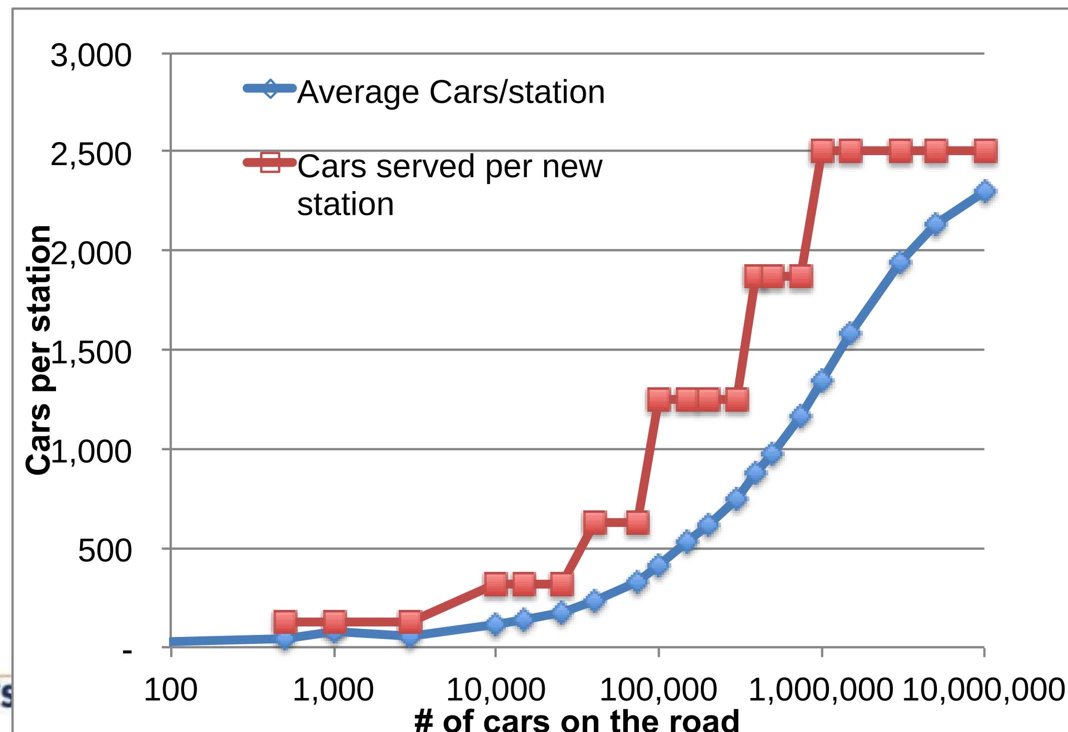
Refueling Stations

- Different types of stations for different vehicles
  - **LDV stations:** LDVs and heavy-duty pickups use network of "gas station" analogues (except for EVs)
  - **Heavy-duty truck stops:** Class 8, long and short-haul trucks are assumed to use larger "truck stop" refueling stations
  - **Central fleet refueling:** buses, vocational and delivery trucks are assumed to use central fleet refueling
- These categories affect the number of stations required to serve a given number of vehicles
  - Smaller, more dispersed stations for LDVs and larger, fewer "stations" for HDVs and fleets.

Modeling Refueling Stations

- Key Assumptions:
  - Convenience is important in early market, so early stations are small and underutilized
  - As # of cars grow, the size of new stations also increases
- Create lookup table for number of cars vs. station capacity

# of LDVs (output of vehicle model) → **Lookup table** → **# and size of Stations**



Fuels and Pathways Modeled

	Fuels	Processes	Resources
Natural Gas	CNG LNG		Fossil Natural Gas[1] Renewable Natural Gas[2]
Electricity	Electricity		Grid mix Renewables only
Biofuels	Ethanol Biodiesel	Corn Ethanol Cellulosic Ethanol FAME Biodiesel Fischer-Tropsch Hydrotreatment	Corn Cellulosic biomass[2] Waste oil[2] Oil crops
Hydrogen	Liquid Gaseous	Onsite Steam Reforming Onsite Electrolysis Central Steam Reforming Biomass gasification Central electrolysis Gas truck delivery Liquid truck delivery Pipeline delivery	Fossil Natural Gas[1] Renewable electricity Cellulosic biomass[2]

1. AEO 2016
2. Resource supply defined by supply curve (UCD)

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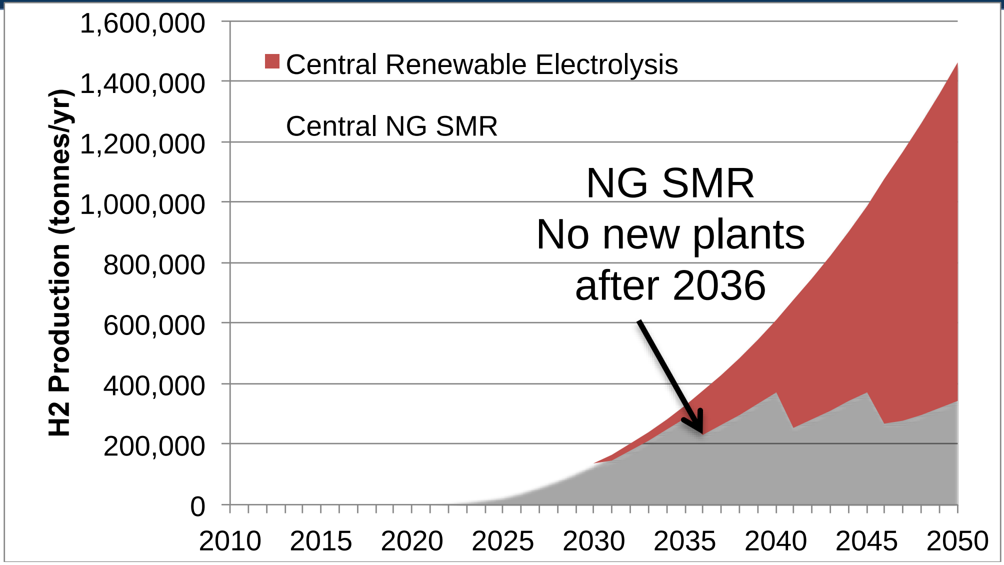
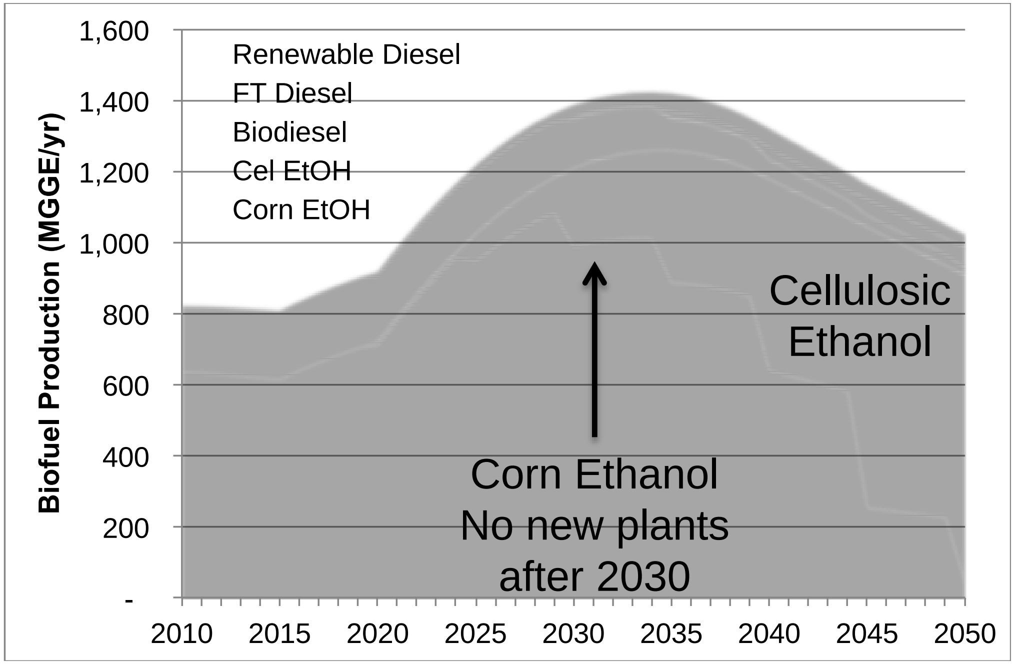
Stock turnover of infrastructure

- Slow turnover of fueling infrastructure is an important factor affecting the rate of decarbonization
- Cannot make transitions too quickly





Cost Methodology

- **Production plants**
  - Production facility costs are a function of capacity scale
    - Scaling factors derived from literature values or bottom up assessments
  - Many assessments have “current” and “future” cost estimates so assumptions are made about when these costs might be valid
  - Plant sizes are chosen looking at 5 year periods

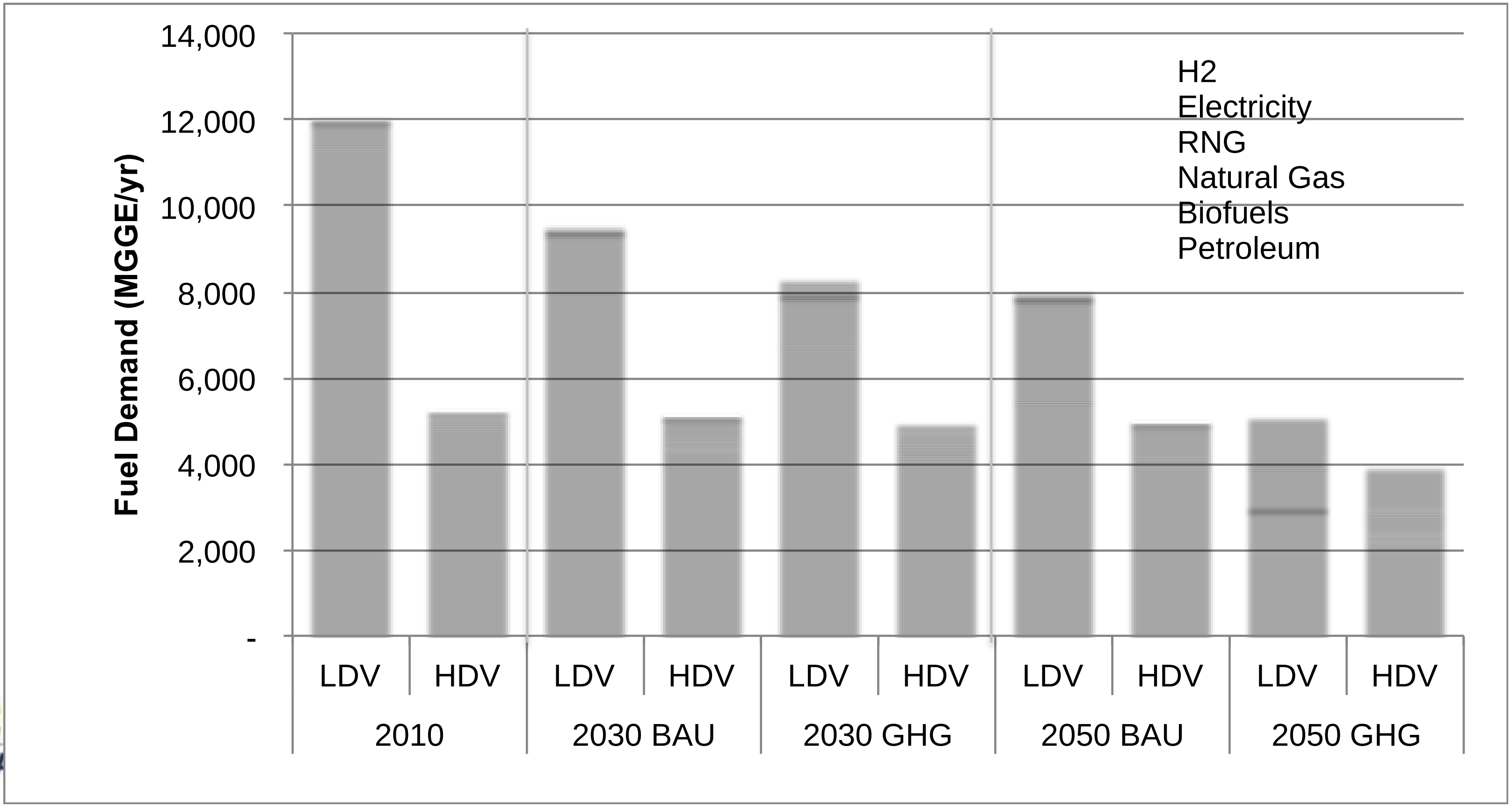
- **Simplified levelized cost calculation**

$$\text{Levelized Fuel Cost (\$/GGE)} = \frac{\sum \left(\text{CapitalCost} \times \text{CRF} + \text{Fix.O\&M} + \text{Var.O\&M} + \text{AnnualEnergyInputs} \times \text{EnergyCost}\right)}{\text{Total Fuel Production}}$$

- Currently no representation of subsidies/incentives, fuel taxes or trading credits (LCFS)

Two Scenarios (BAU vs GHG)

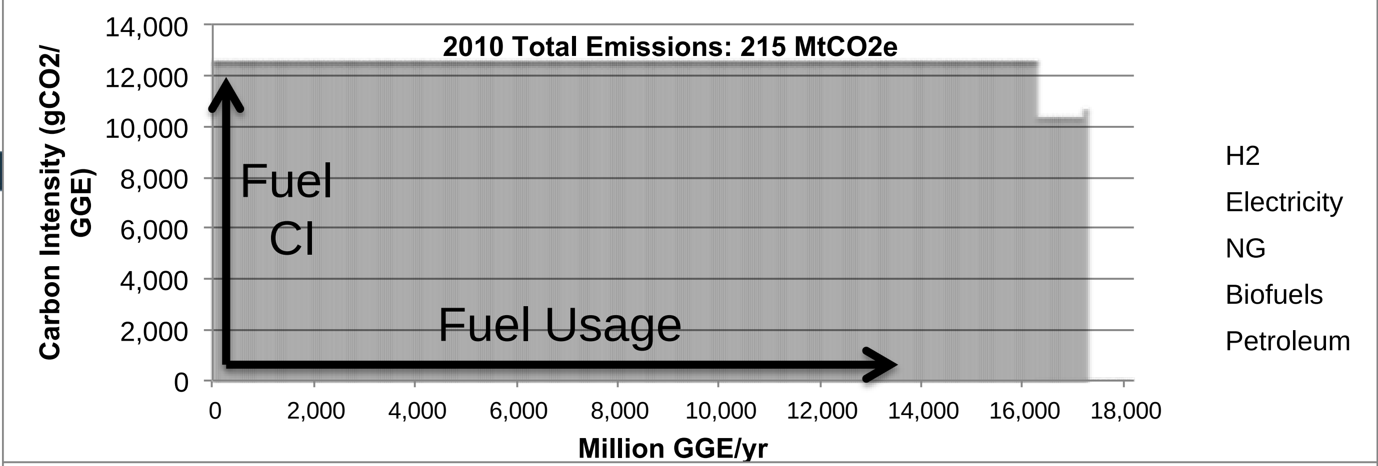
	Vehicles	Fuels
Business-As-Usual (BAU)	Low penetration of alternative fueled vehicles	Relatively high CI values
GHG (ZEV) Scenario	High penetration of alternative fueled vehicles	Relatively low CI values

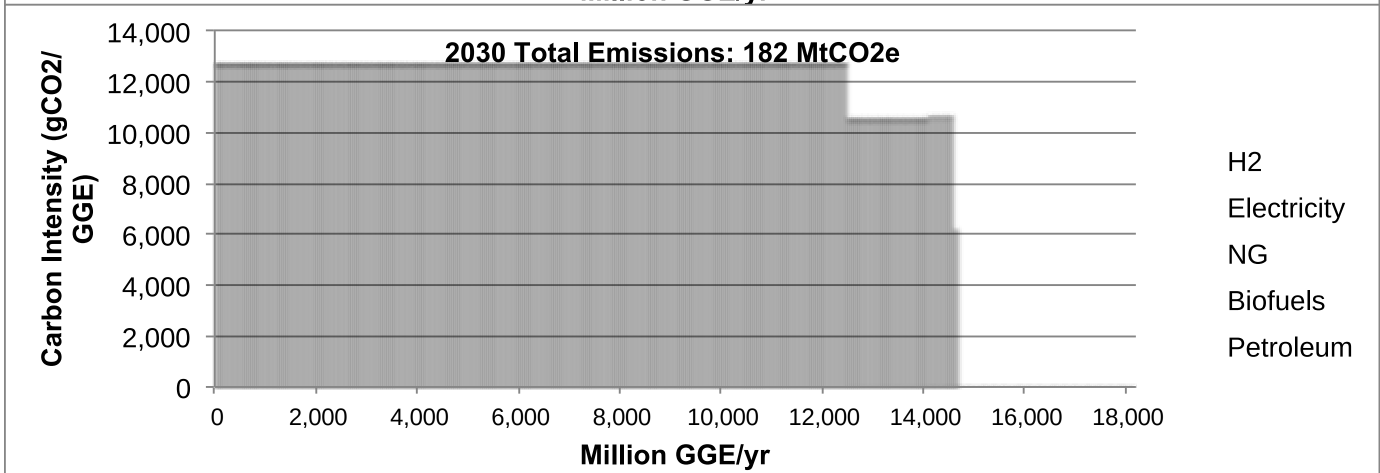


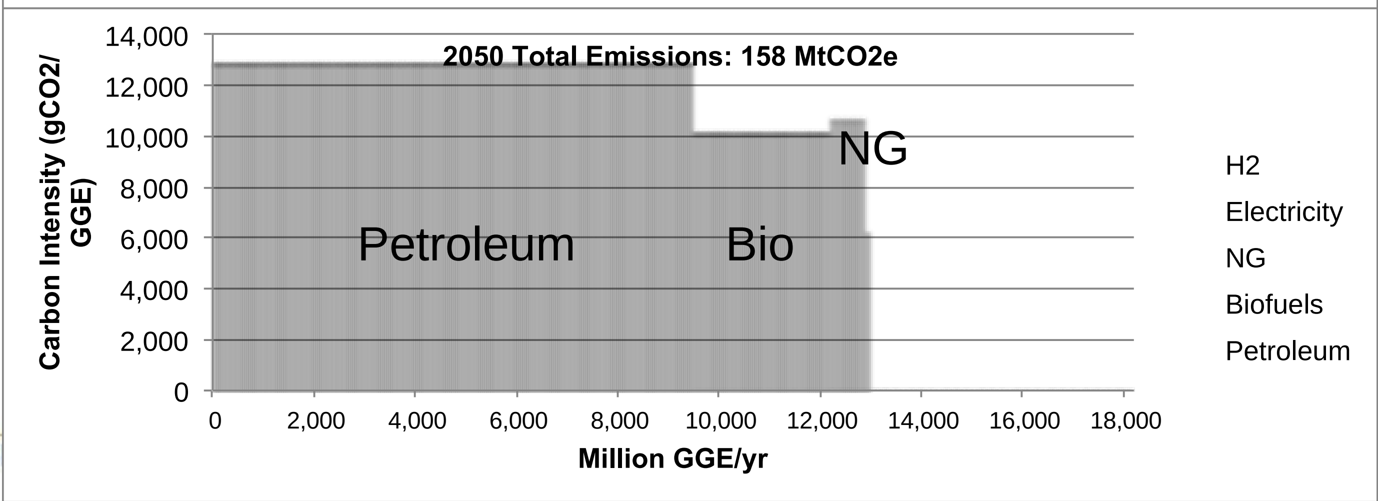
BAU Scenario

Total emissions =
Fuel Usage x
Fuel CI

BAU average CI doesn’t change much, but overall fuel usage declines







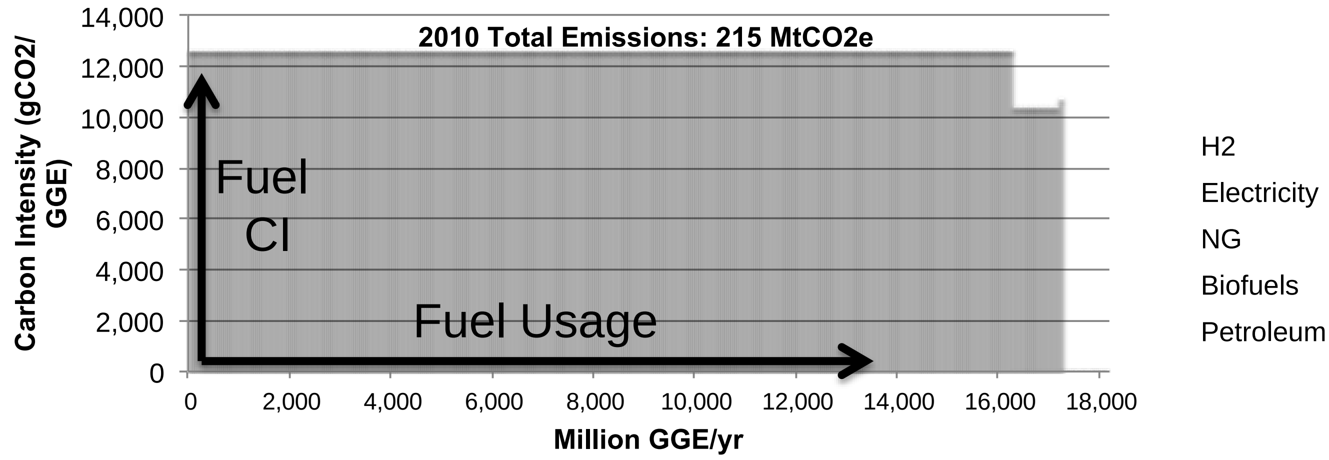
GHG Scenario

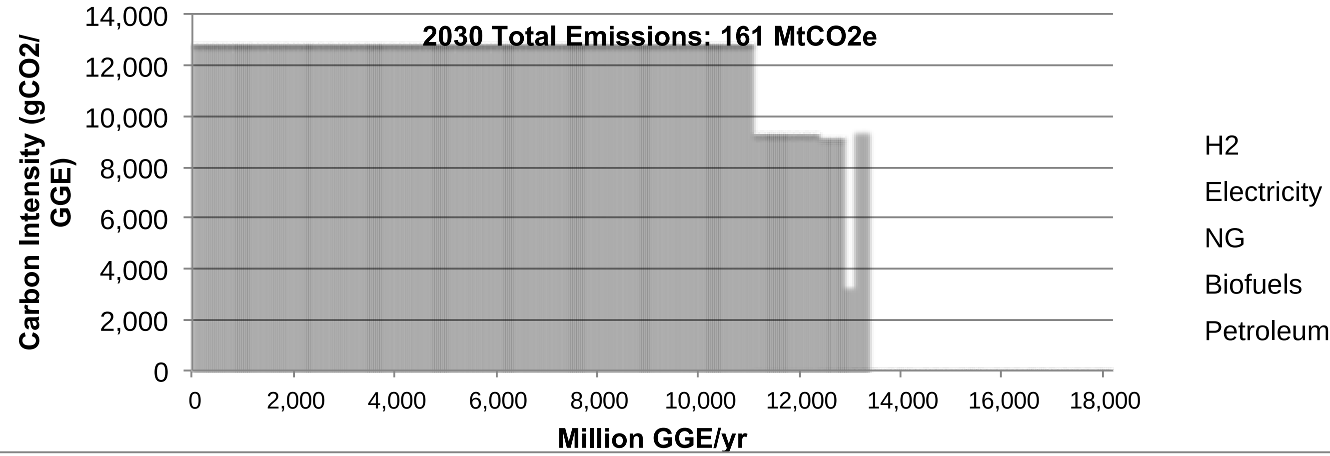
Total emissions =
Fuel Usage x
Fuel CI

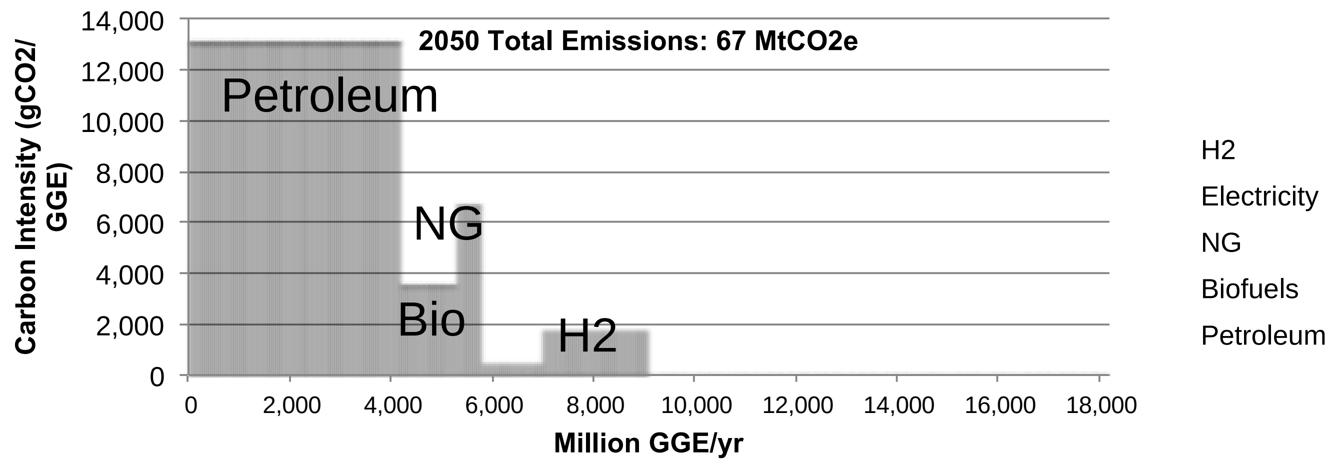
GHG: average CI declines by 40% in 2050,

Overall fuel usage declines by 48%

GHG emissions decline by ~68%







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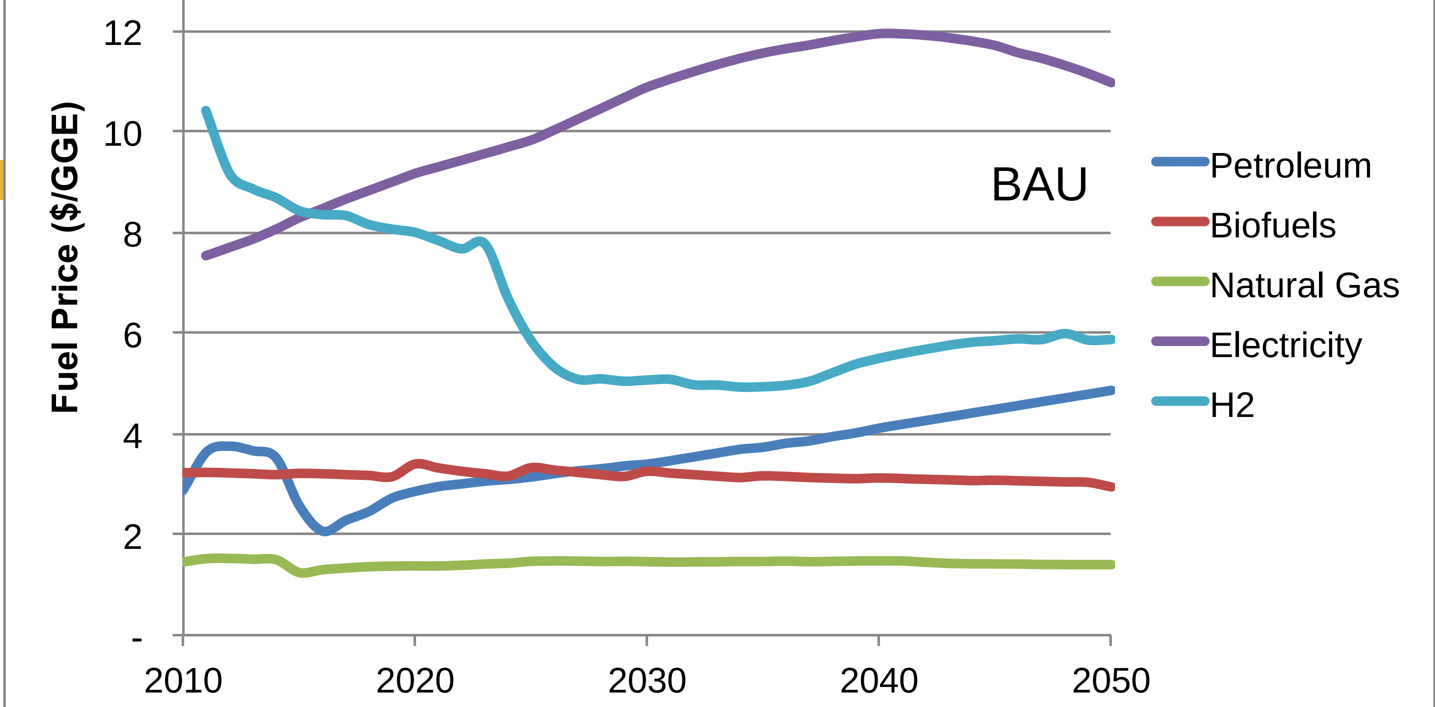
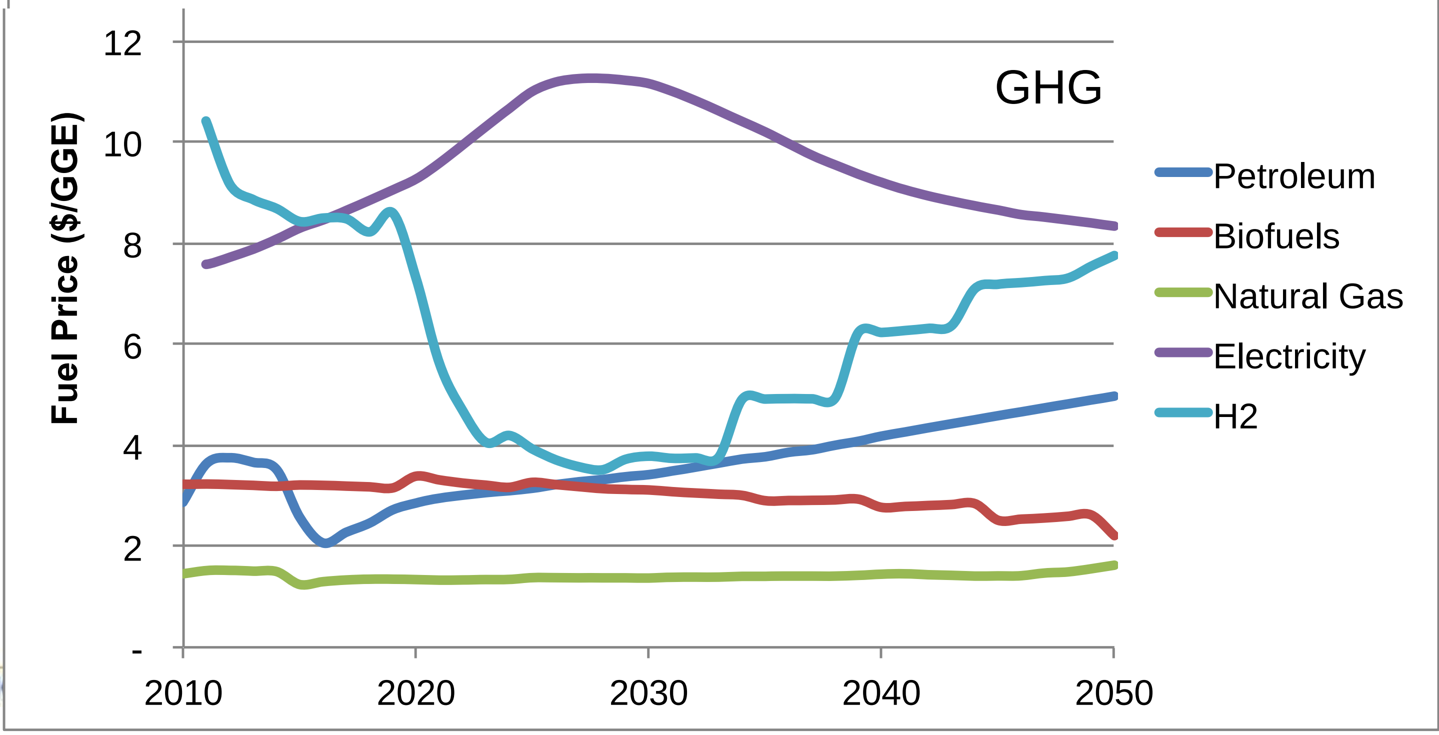
Fuel Costs

Averaged across LDV, and HDV and fleet stations





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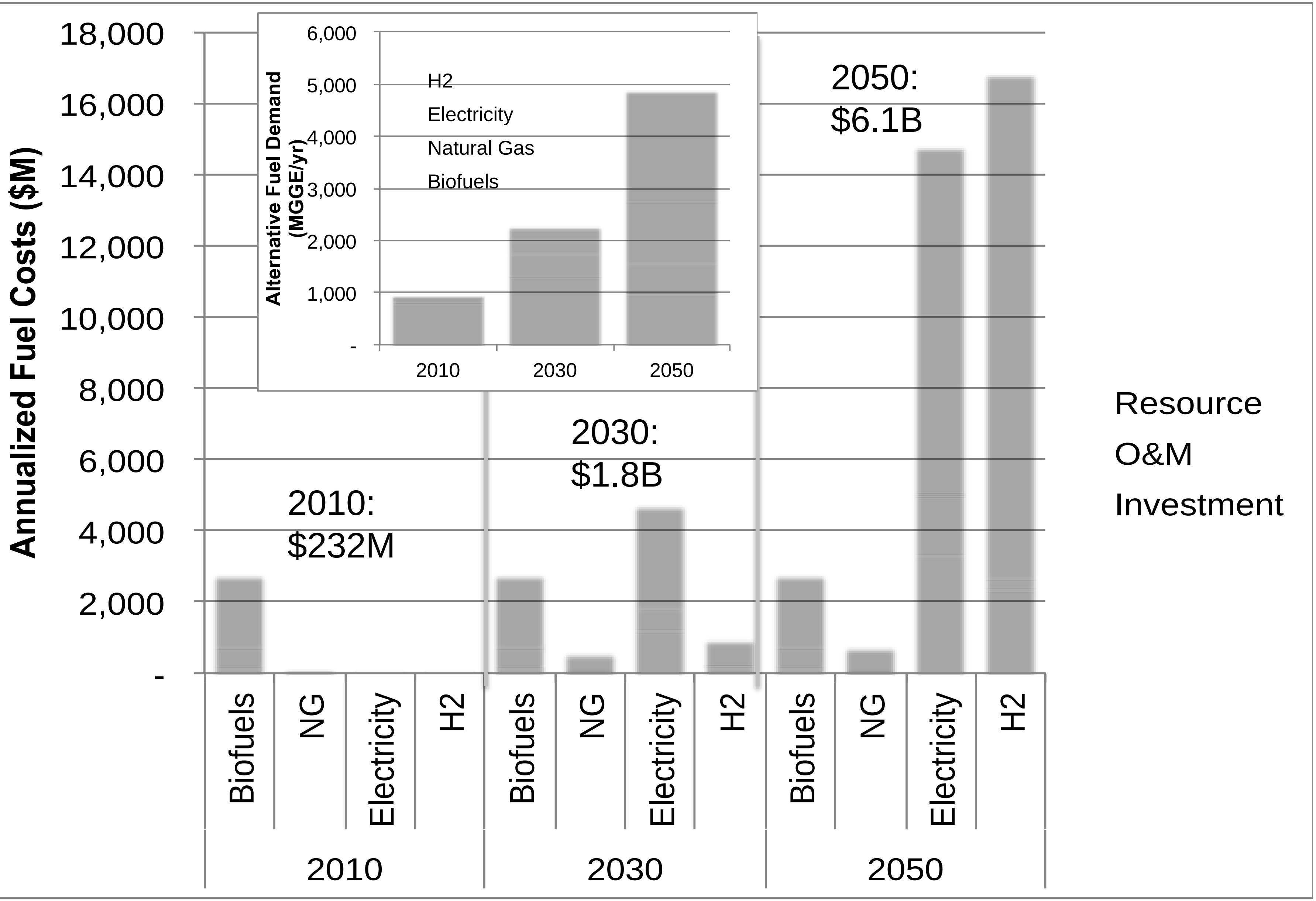
Alternative Fuel Infrastructure and Resource Costs



Summary and Conclusions

- Completed a preliminary version of the fuel infrastructure module
  - Separate representation of multiple pathways of alternative fuels (biofuels, natural gas, electricity and hydrogen)
  - Modeled fuel production and fueling infrastructure (resource supply, production, transport, refueling)
  - Demand for fuels affects size and number of plants and stations which affects fuel costs
  - Detailed models but still lots of assumptions (need to specify mix of resources, pathways, CI values and infrastructure and resource costs)
- Next steps
  - Continue to review literature and speak to experts/sponsors to update assumptions on fuel infrastructure
  - Explore other scenarios and uncertainty in cost assumptions

Thanks!

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Infrastructure Costs and Parameters Sources

	Resources	Production
Natural Gas	Fossil NG: AEO 2016 RNG: UC Davis study	--
Electricity	--	Grid mix
Biofuels	Biomass: Parker (UCD)	Antares (2009)
Hydrogen	Fossil NG: AEO 2016 Biomass: Parker (UCD)	Stations: H2A Central Production: H2A

Modeling and analyzing near term transitions to alternative fueled vehicles using a spatial regional consumer choice and fueling infrastructure model

Kalai Ramea, Christopher Yang, Michael Nicholas, Joan Ogden

November 30, 2016

STEPS Symposium, Davis, CA

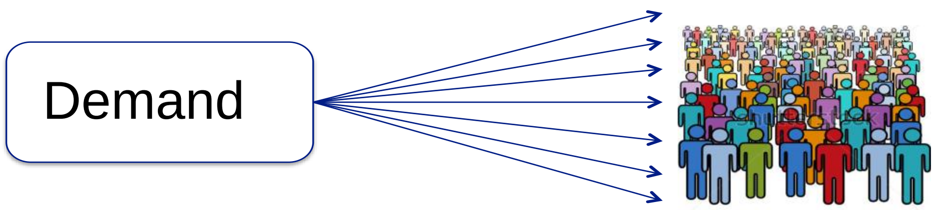
Project Background and Motivation

- Consumer preferences, especially in the transportation sector are captured through discrete choice models
  - Has heterogeneous consumer segments
  - Captures consumer perception towards various technologies based on consumer characteristics and vehicle attributes
  - But, they typically operate on a spatially aggregated level
  - Spatial details are especially important while considering the effect of infrastructure availability in the neighborhood
- Implements consumer vehicle purchase behavior into a detailed spatial model with geographic specification of charging and refueling stations
- This research project illustrates the vehicle purchase behavior of consumers in California at zip code level

Consumer Choice Representation

MA^{3}T model developed by Oak Ridge National Laboratory (Lin & Greene, 2010) is used to represent vehicle consumer choice (typically the choice representation is done in two stages):

First, demand is disaggregated into different consumer segments based on their characteristics (driving behavior, risk attitude, etc.).



Secondly, non-monetary costs ("disutility costs") that capture consumer perception of different vehicle technologies are added to the model

These costs go through a nested multinomial-logit module to determine purchase probability of each vehicle technology for each consumer group

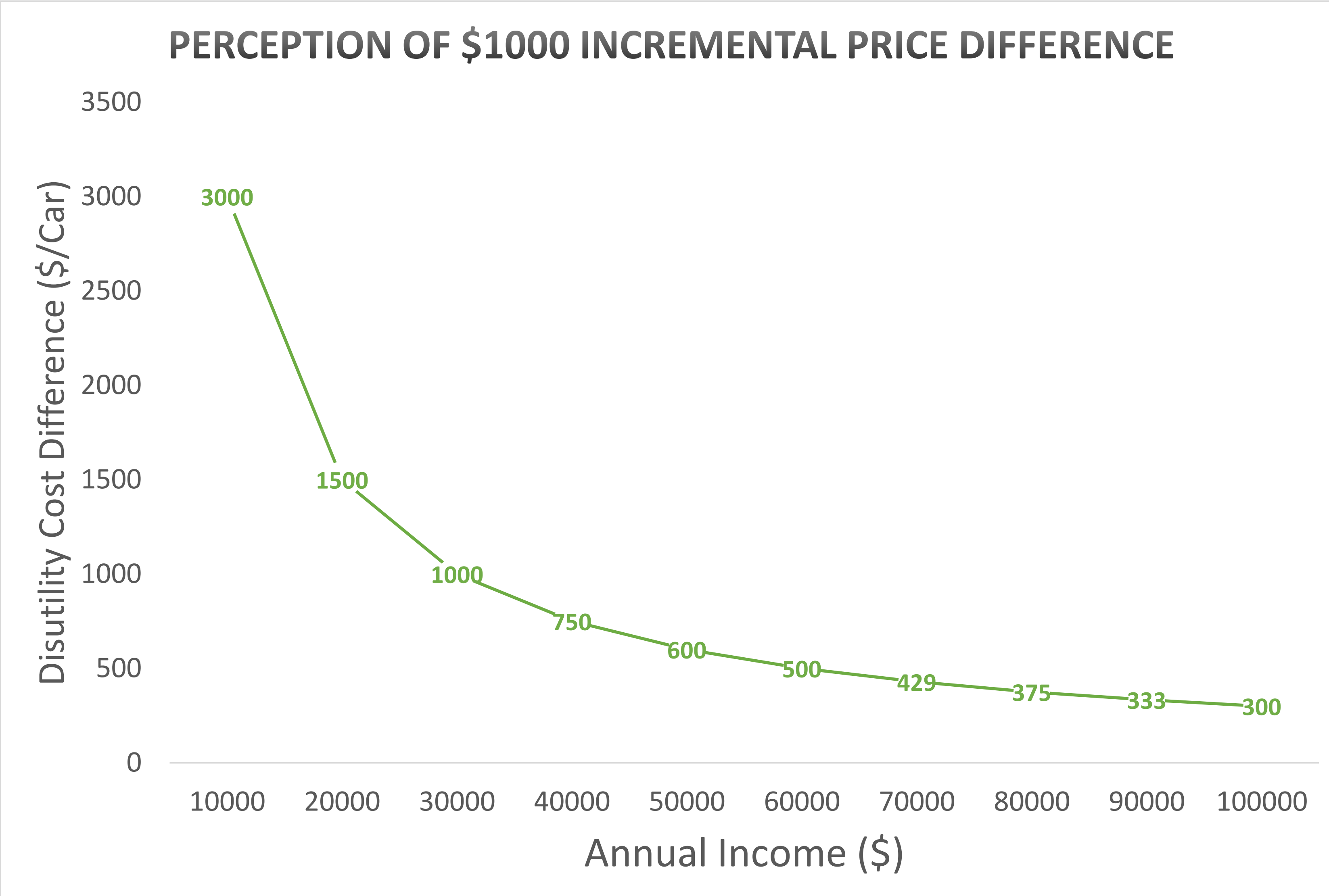
Lin, Z., & Greene, D. (2010). The MA^{3}T Model: Projecting PHEV Demands with Detailed Market Segmentation. 2010 TRB Annual Meeting CD-Room.

Major Disutility Cost Components in the MA^{3}T Model

	Disutility Cost Component	Description	Dependent Characteristics
Spatially sensitive	Refueling inconvenience cost (for non-electric vehicles—eg. FCVs)	The combined time and inconvenience cost to refuel a vehicle	Annual miles driven, fuel economy, vehicle storage, station availability, value of time
	Range Limitation Cost (BEVs)	The estimated generalized cost incurred by a BEV owner due to limited range of battery electric vehicles in conjunction with the owners VMT pattern	Daily VMT, annual miles driven, infrastructure availability, anxiety cost (consumer-specific, based on their risk attitude)
Nationwide	Model availability cost	Estimated cost of consumer perception based on make and model diversity available in the market	Cumulative vehicle sales
	Risk Premium	The risk premium perceived by the consumer based on their ability to take risk	Cumulative vehicle sales

Effect of Household Income on Vehicle Price

- Perception of incremental vehicle price (difference from gasoline vehicles) significantly depends on the household income
- The income related disutility cost is estimated from the (incremental vehicle price / income) ratio
- For lower income households, the ratio (incremental vehicle price/income) is higher than higher income households, indicating, as household income increases, the “disutility” associated with larger incremental vehicle prices decreases.
- Current work focuses on calibrating this method based on historic vehicle sales data for different income groups.



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Purchase Probability Estimation

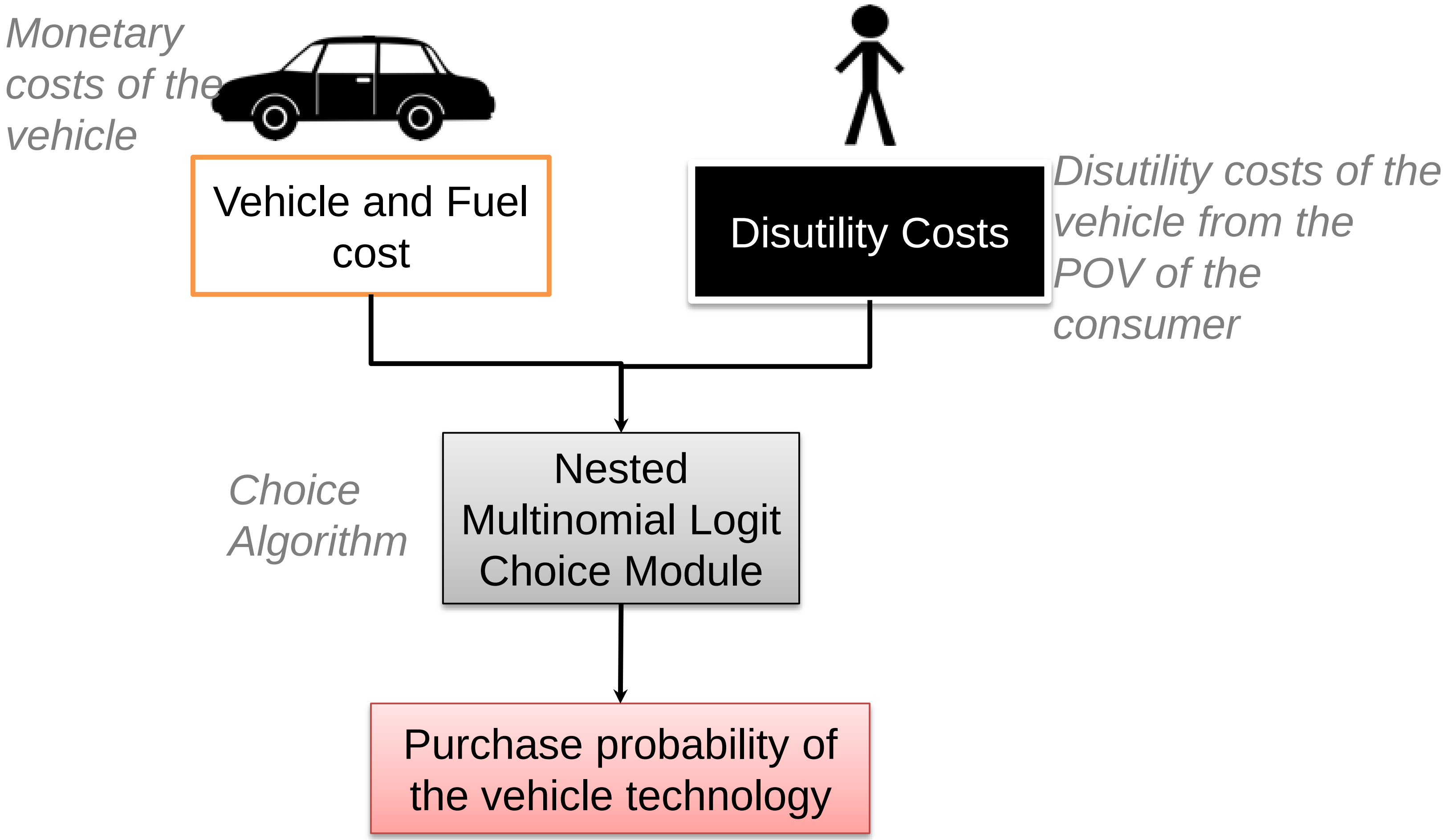
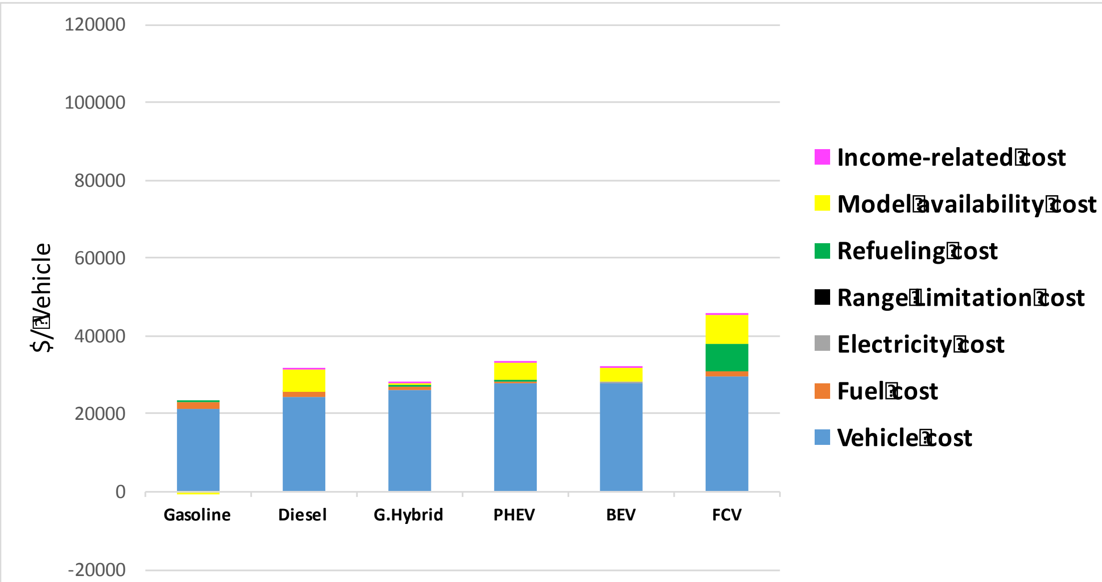


Illustration of Cost Components

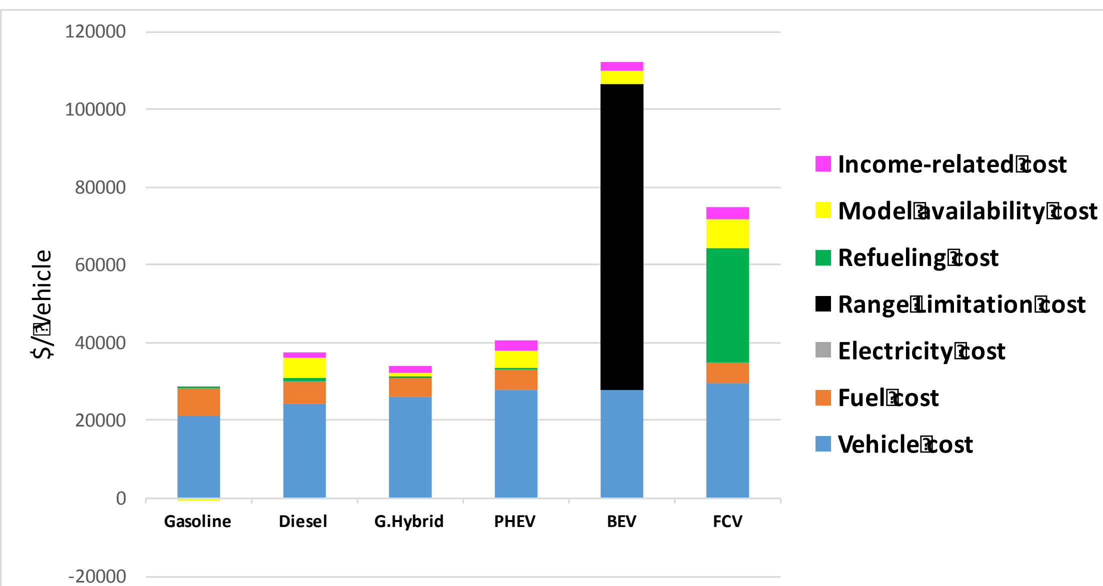


Good Infrastructure availability

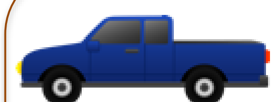
Early Adopter

Low VMT

High-income household



Poor infrastructure availability

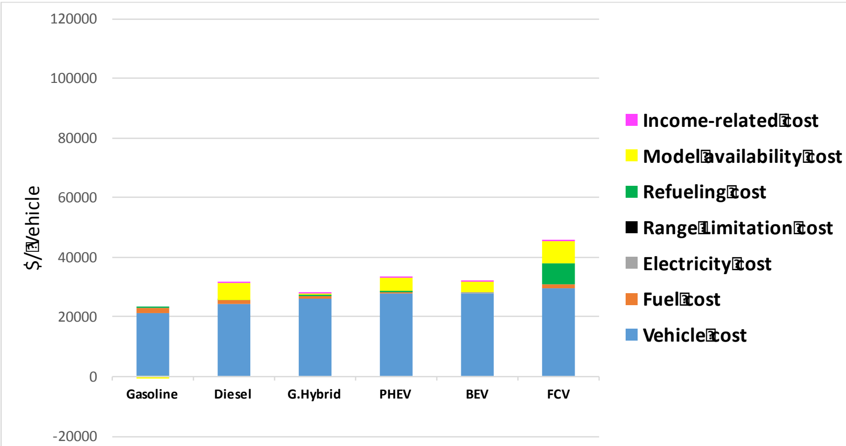


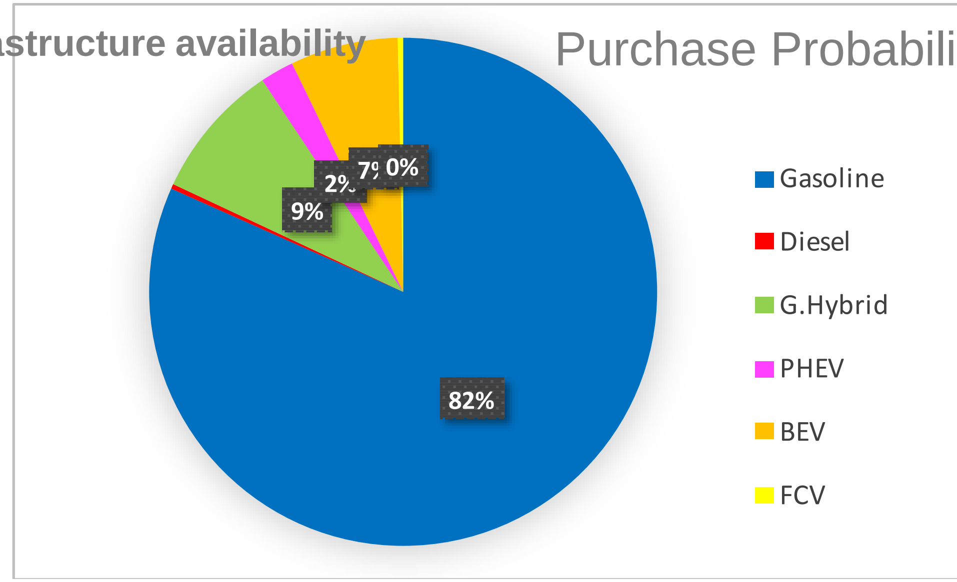
Late Majority

Frequent driver

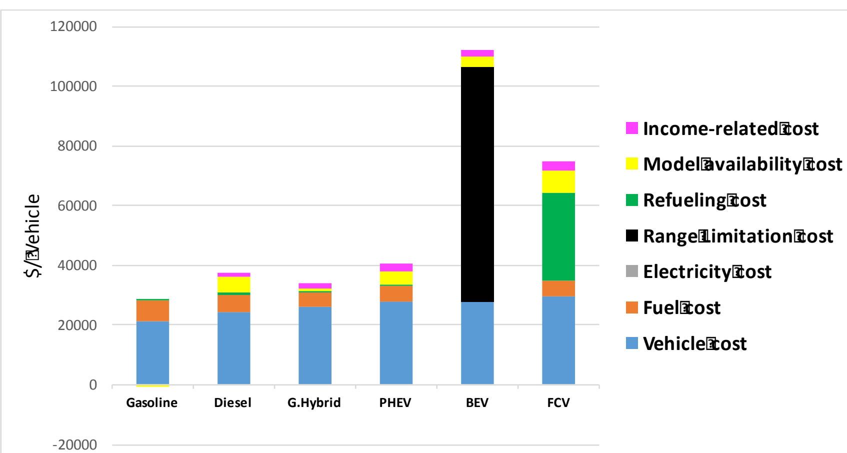
Low-income household

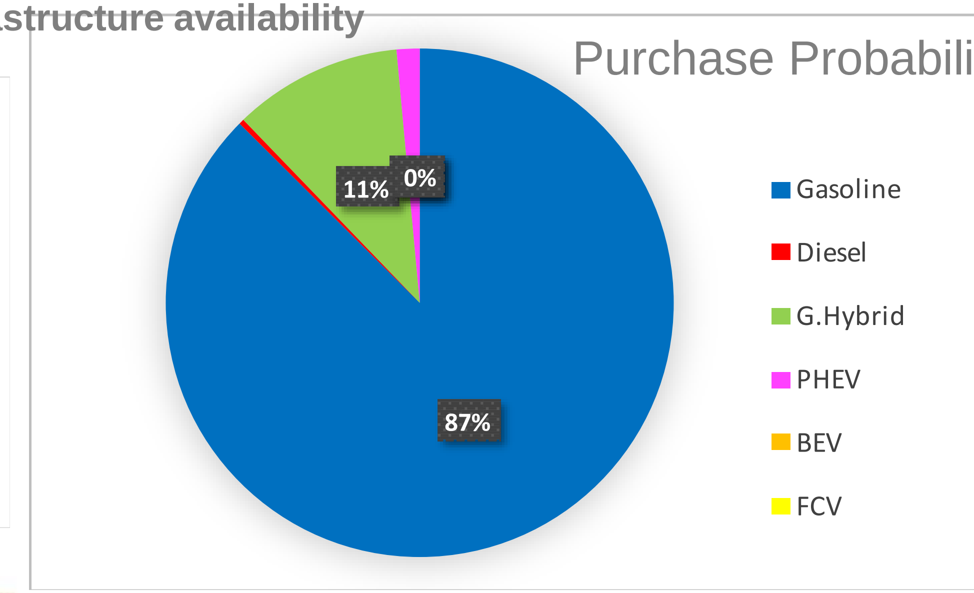
Early adopter, low VMT, high income, good infrastructure availability





Late majority, high VMT, low income, poor infrastructure availability





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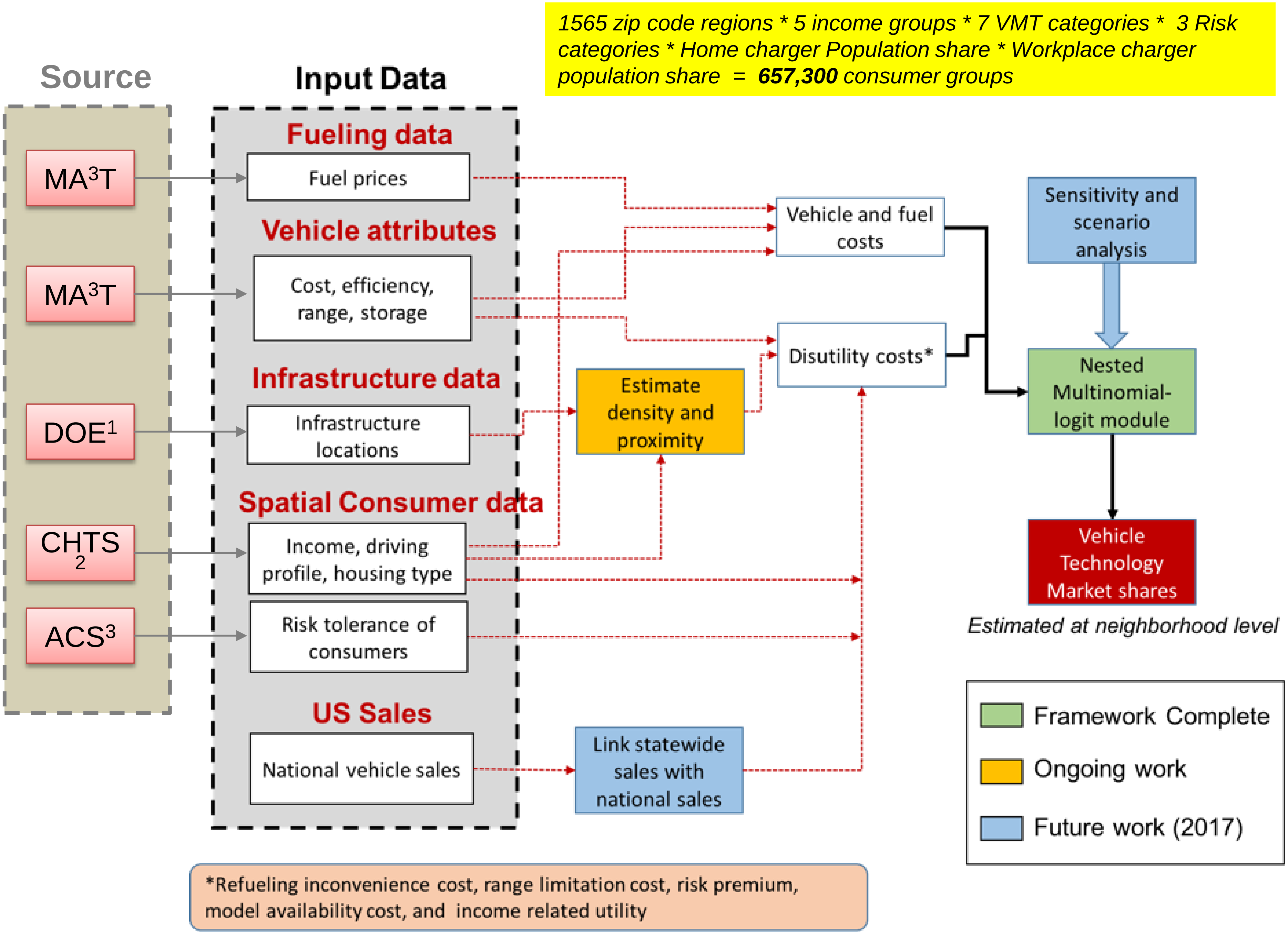
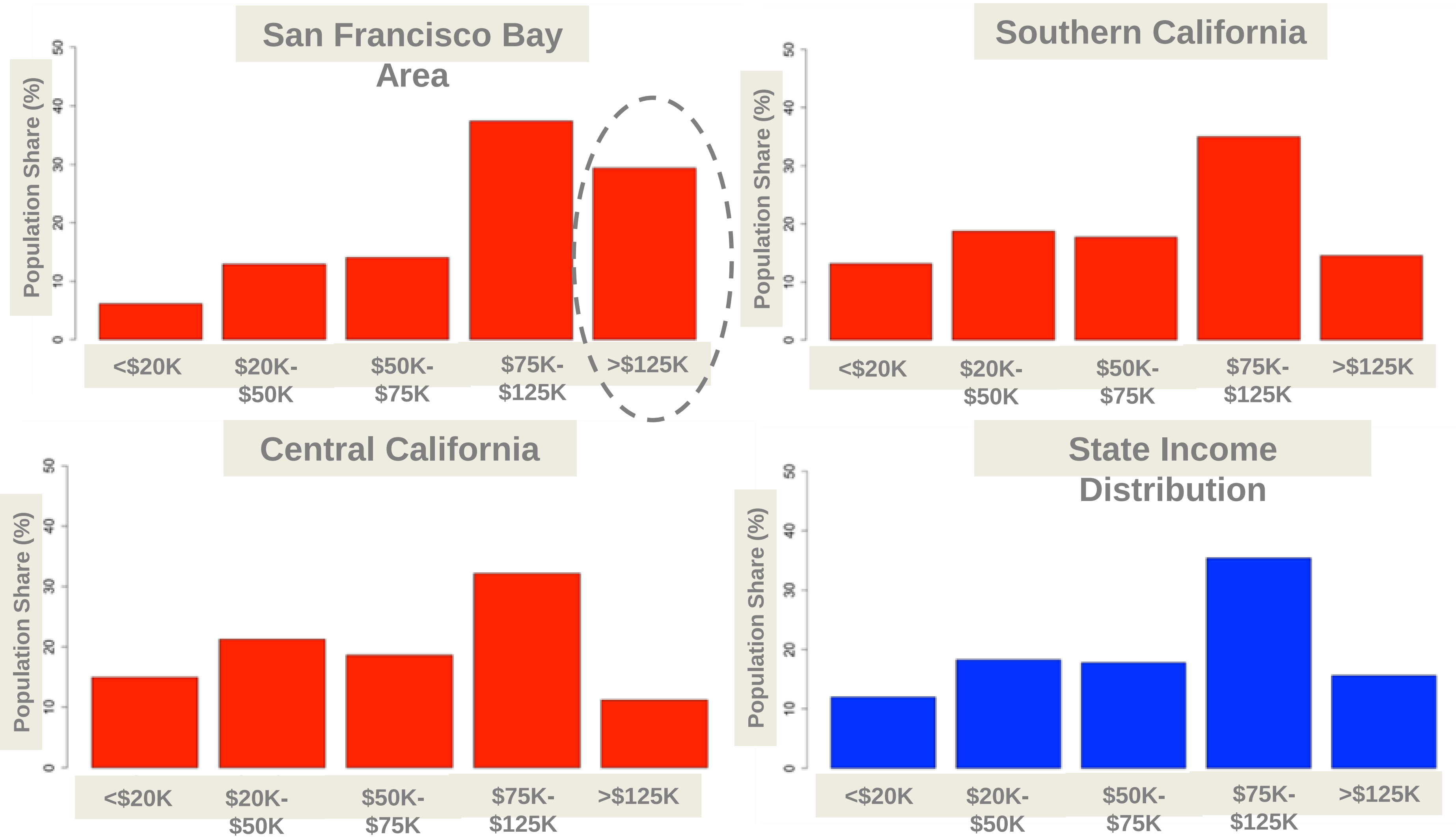


[1]Department of Energy, [2] California Household Travel Survey; [3]American Community Survey

Income Distribution in CA regions

SF Bay area has greater high income population share than the state average



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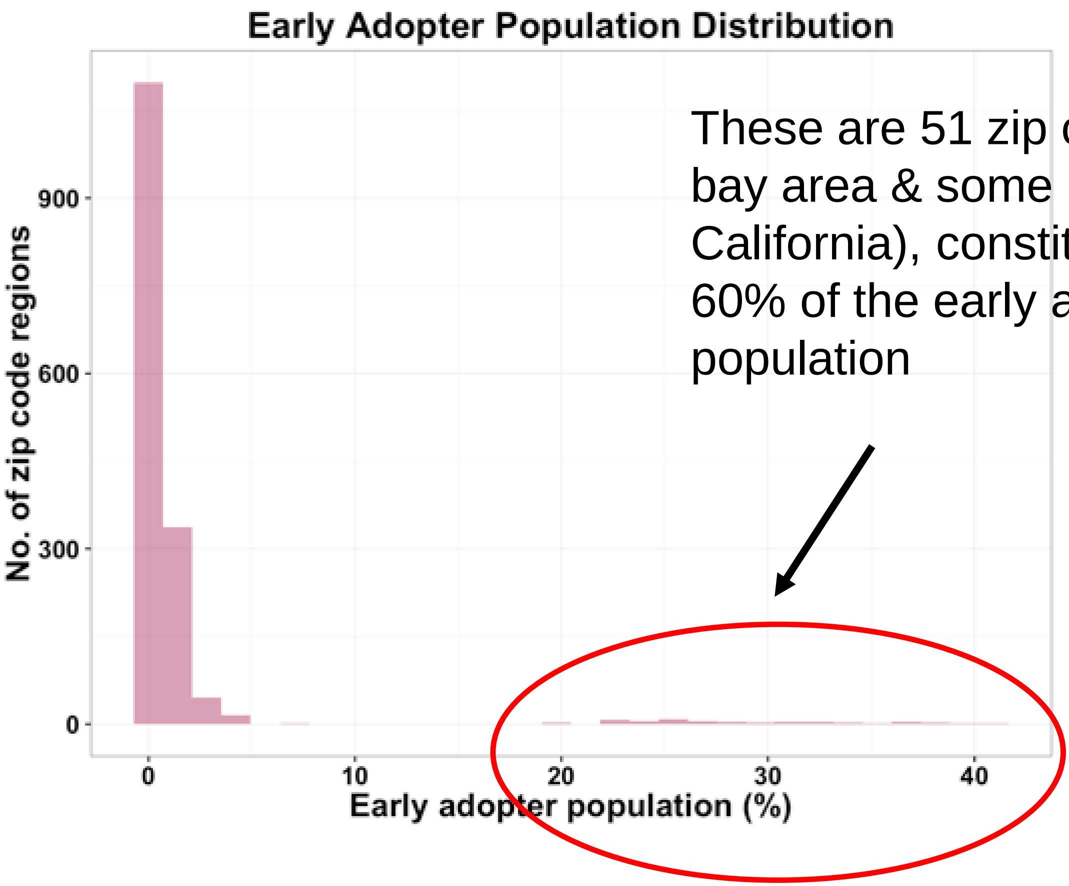
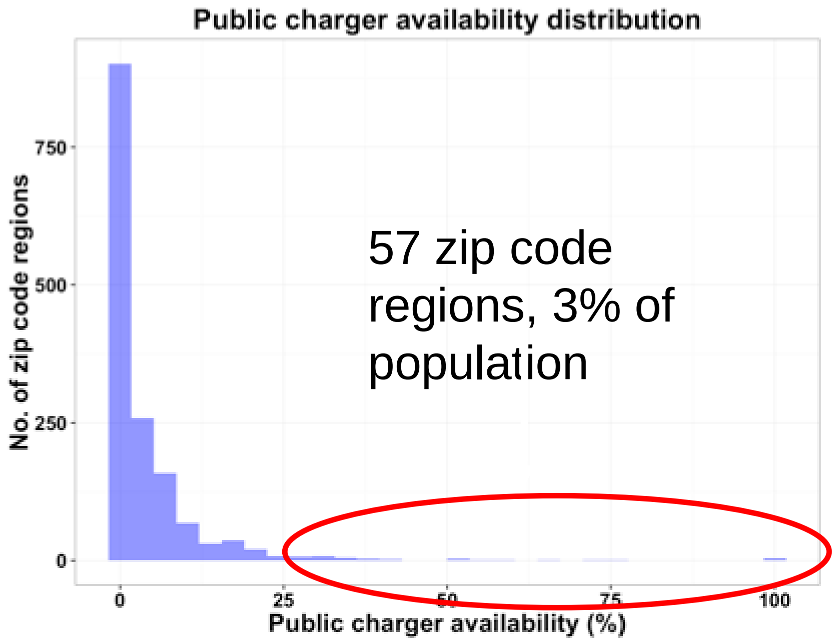


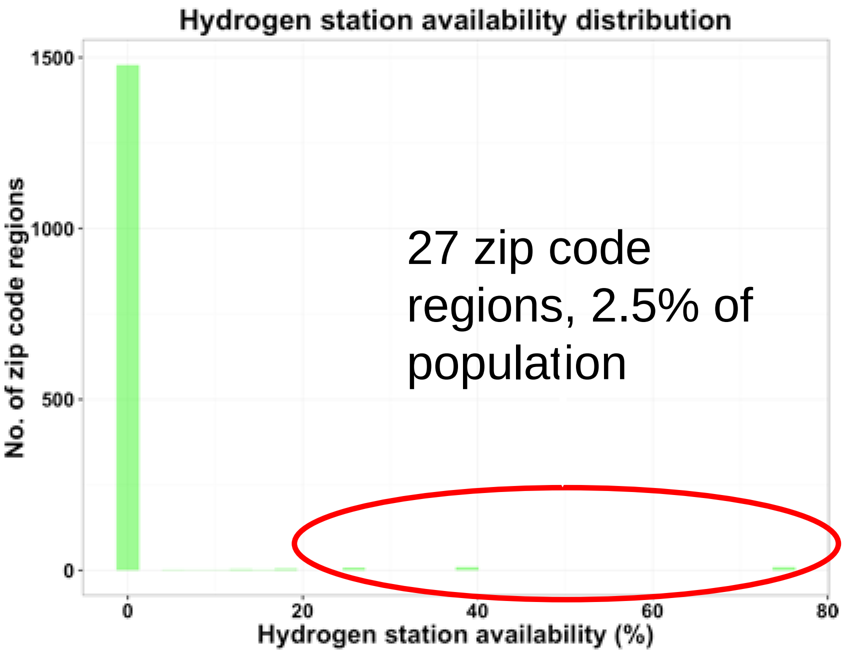
These are 51 zip code regions (SF bay area & some parts of Southern California), constituting almost 60% of the early adopter population

Infrastructure Availability Calculation for each Zip Code

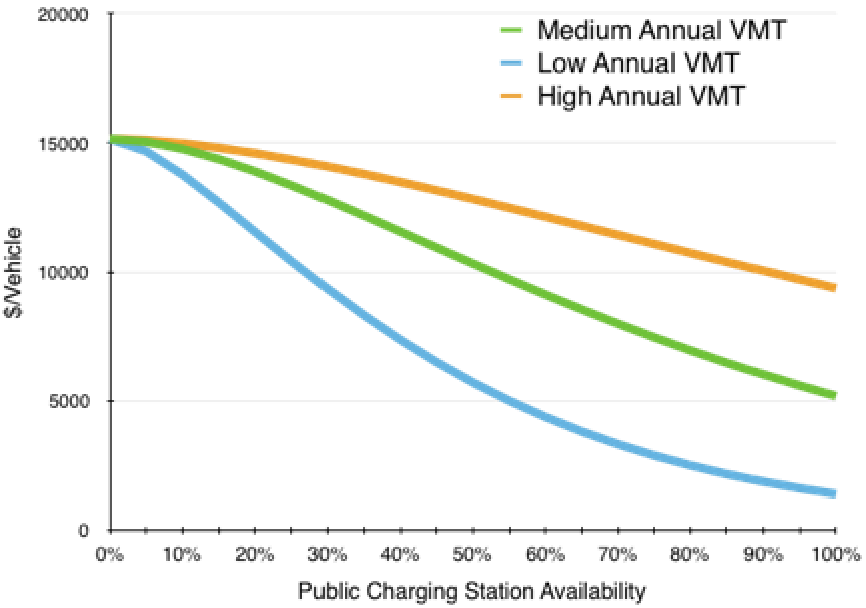
- We currently use a simplified approach for calculating refueling availability
  - For each zip code, a 5-mile buffer radius is constructed around the region
  - The number of hydrogen stations / public charging stations inside the region is calculated.
  - This is divided by the number of gasoline stations in the neighborhood for hydrogen stations or divided by the number of public attractor locations in the neighborhood for charging stations
  - The resulting percentage is the “station availability” value for that region.
- This parameter will be further refined to include all the stations in the nearby region, and the availability parameter will be estimated based on both proximity and density.

Infrastructure Availability Distribution

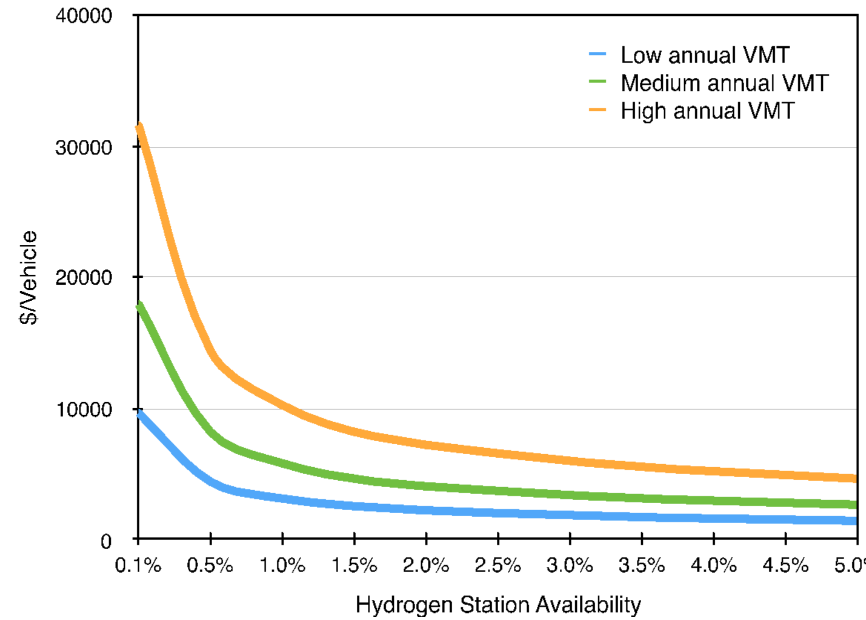




Range limitation cost of BEV 100-mile range: Late majority group



Refueling Inconvenience Cost for Fuel Cell Vehicles



- This cost trajectory reflects the consumers who have no access to home or work chargers, and rely only on public chargers.

- Station availability is typically the percentage of hydrogen stations to gasoline stations in the region.

- Low annual VMT: 8656 miles; Medium annual VMT: 16,068 miles, and high annual VMT: 28,288 miles

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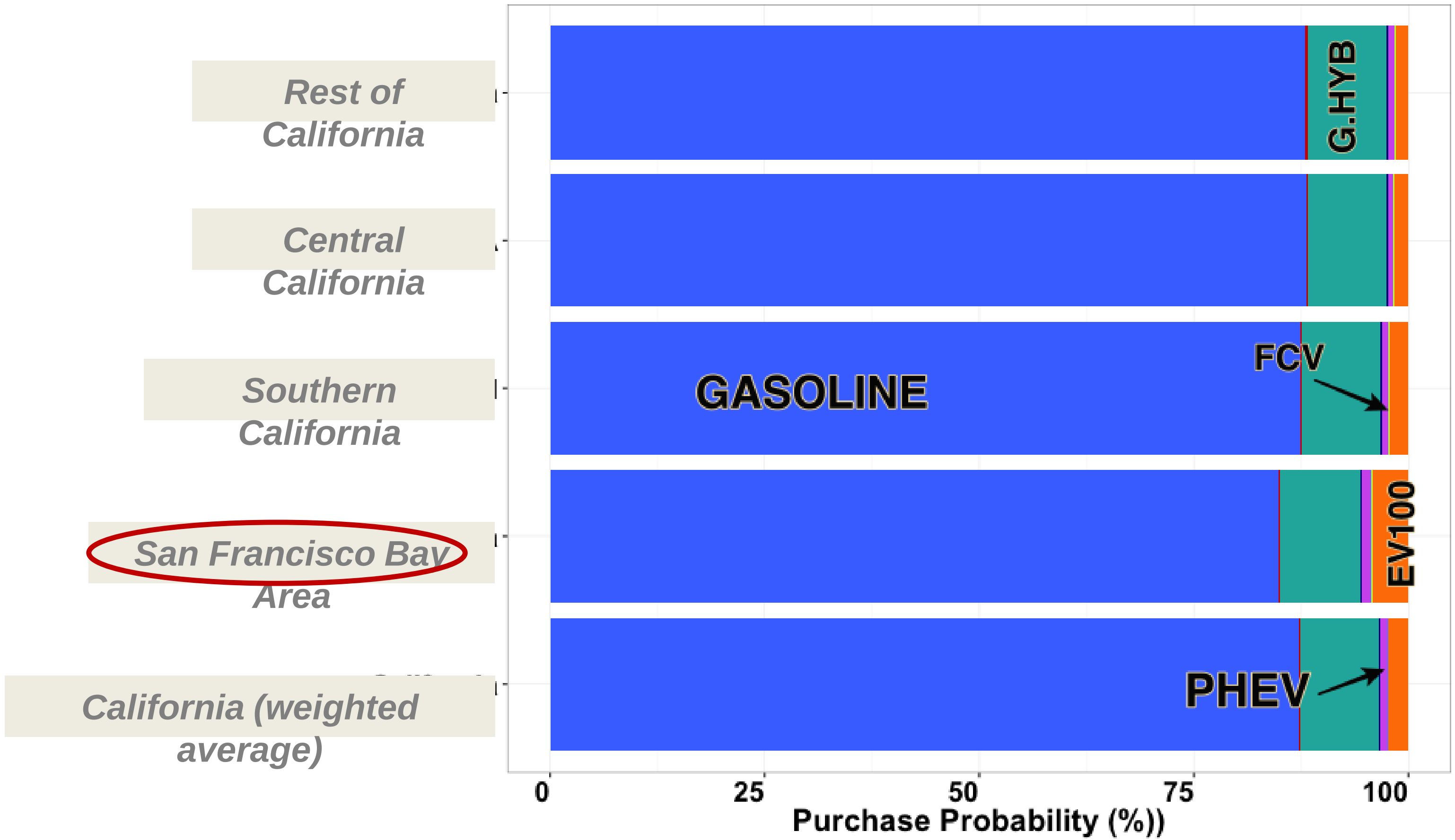
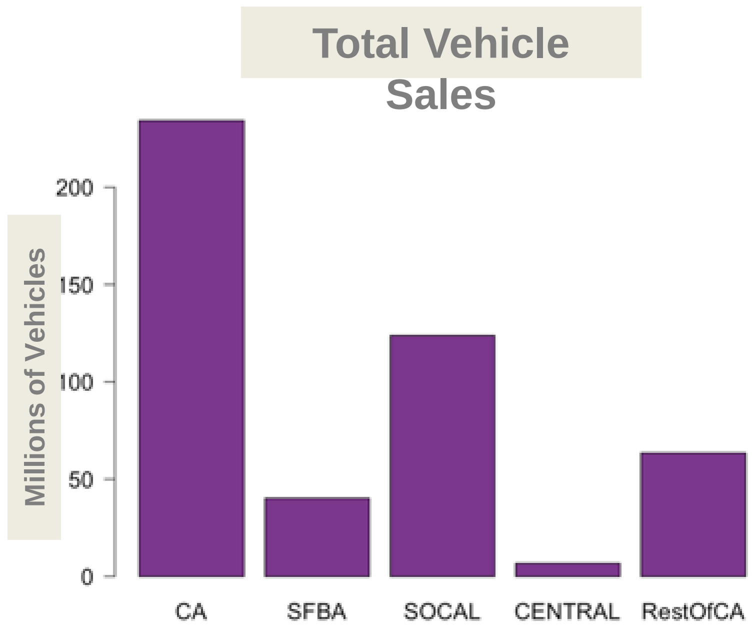
Source: MA³T Model (Lin & Greene, 2010)

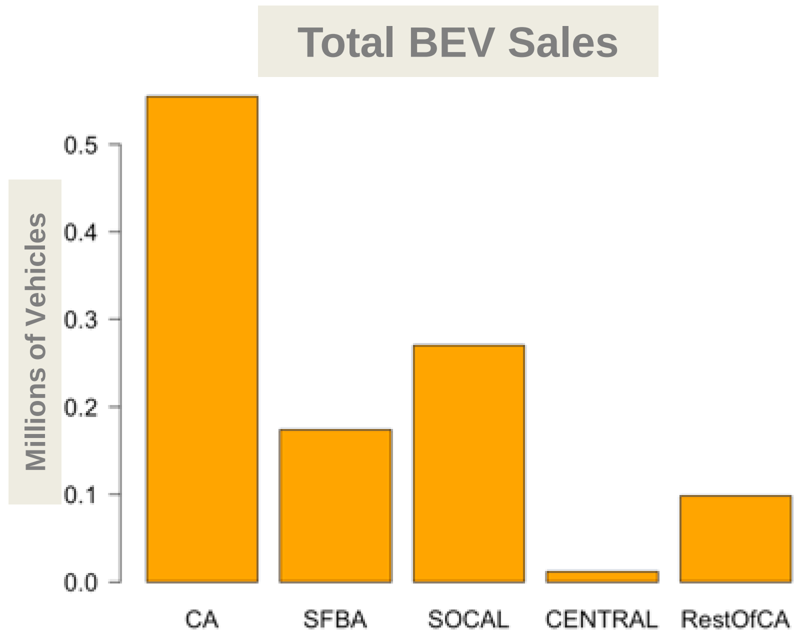
PRELIMINARY RESULTS

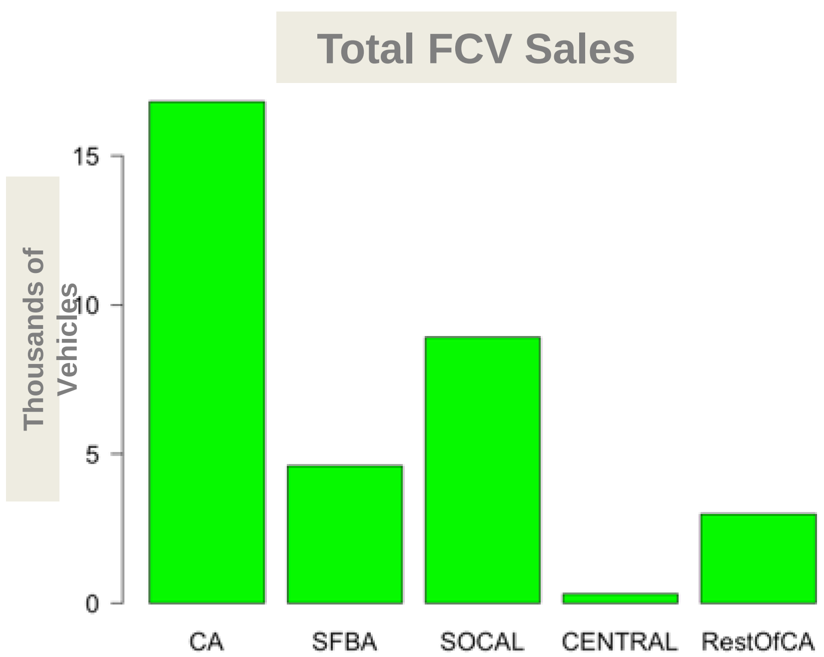
Aggregated Purchase Probability in 2020



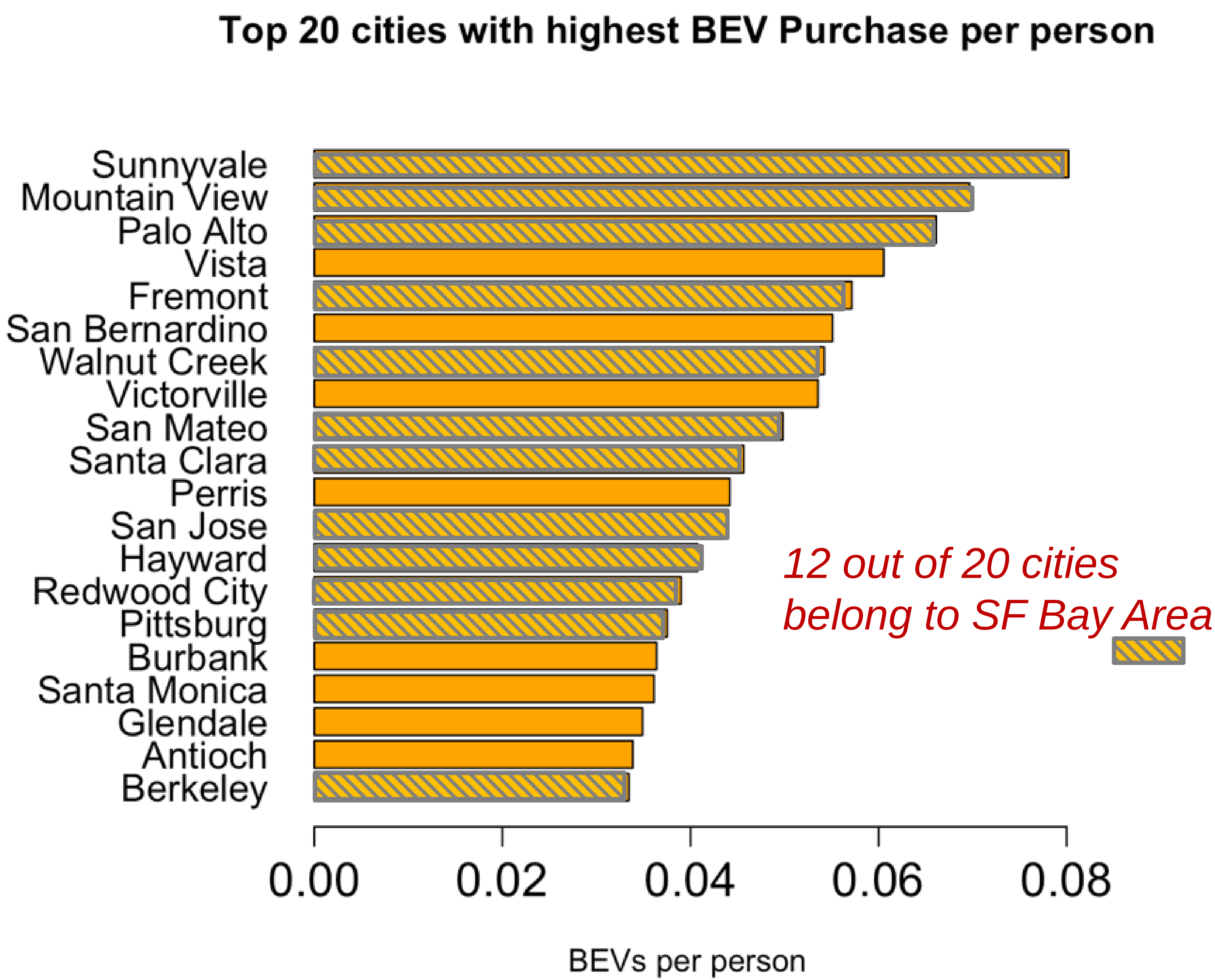
- Bay area has 78% higher BEV purchase probability than the state average due to presence of high income population and better access to workplace charging



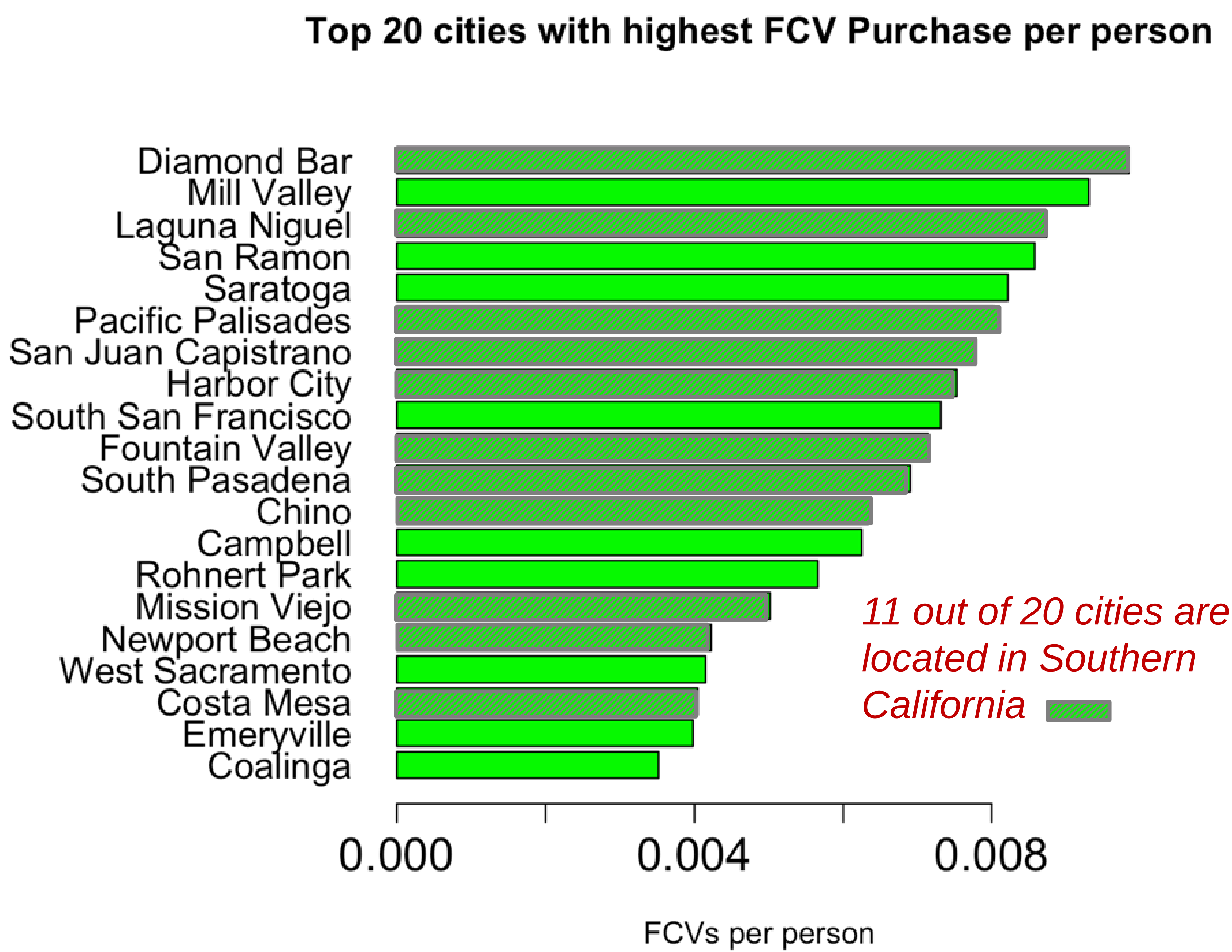




- The number of households with vehicles is higher in Southern California than other regions in CA.
- Therefore, SoCal leads in actual vehicle purchase numbers in all categories.
- Total vehicle sales in SF bay area is 17.6% of the total sales in CA, but their BEV sales is about 31% in the state, and FCV sales is 27% of total.

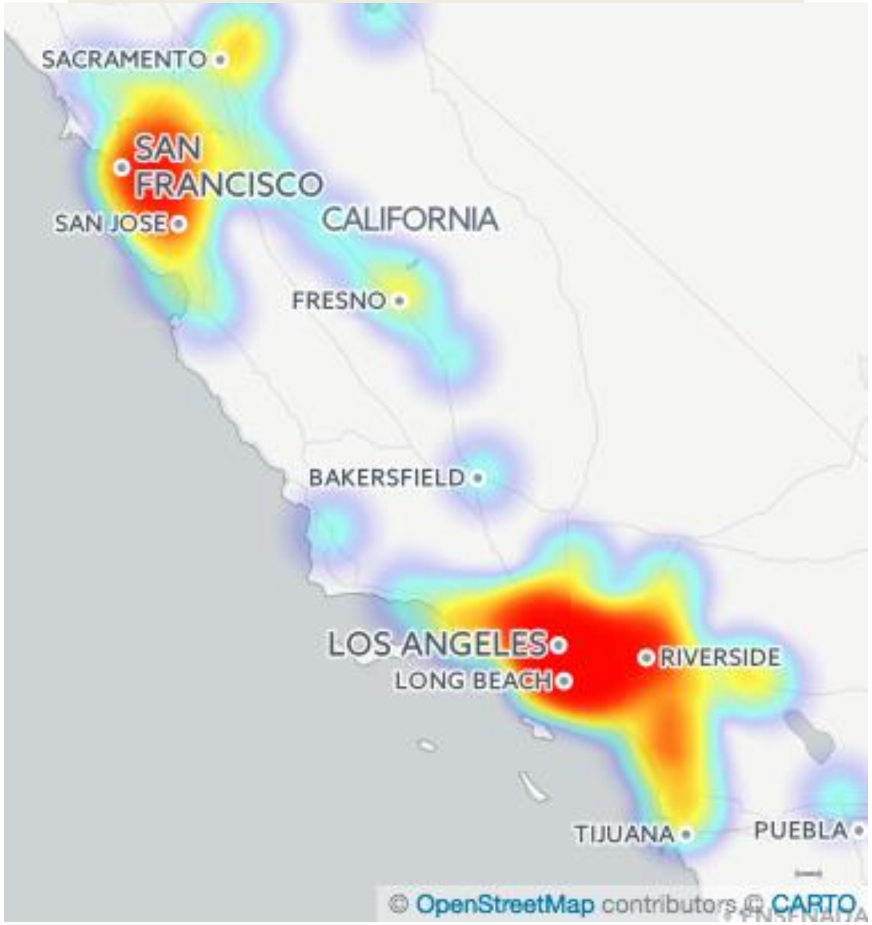


Top 20 cities with highest BEV Purchase per person
Sunnyvale
Mountain View
Palo Alto
Vista
Fremont
San Bernardino
Walnut Creek
Victorville
San Mateo
Santa Clara
Perris
San Jose
Hayward
Redwood City
Pittsburg
Burbank
Santa Monica
Glendale
Antioch
Berkeley
12 out of 20 cities belong to SF Bay Area
0.00
0.02
0.04
0.06
0.08
BEVs per person

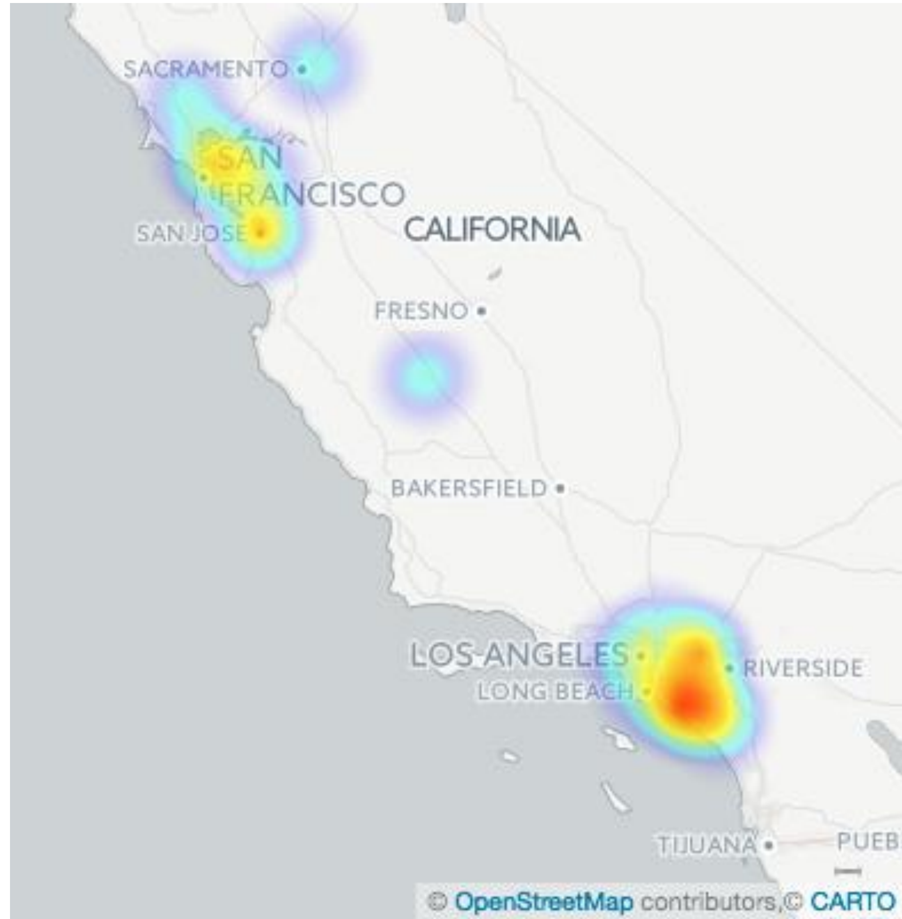

Top 20 cities with highest FCV Purchase per person
Diamond Bar
Mill Valley
Laguna Niguel
San Ramon
Saratoga
Pacific Palisades
San Juan Capistrano
Harbor City
South San Francisco
Fountain Valley
South Pasadena
Chino
Campbell
Rohnert Park
Mission Viejo
Newport Beach
West Sacramento
Costa Mesa
Emeryville
Coalinga
11 out of 20 cities are located in Southern California
0.000
0.004
0.008
FCVs per person

Heat Map of Adoption Patterns

BEVs per person



FCVs per person



- BEV adoption is more prevalent compared to FCV.
- SF Bay area leads in BEV adoption, Southern California leads in FCV adoption

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FCV Purchases per person

Presence of hydrogen station in the neighborhood is very important for FCV adoption.

On the other hand, workplace charging plays a significant role in BEV adoption compared to the presence of public chargers.

Summary

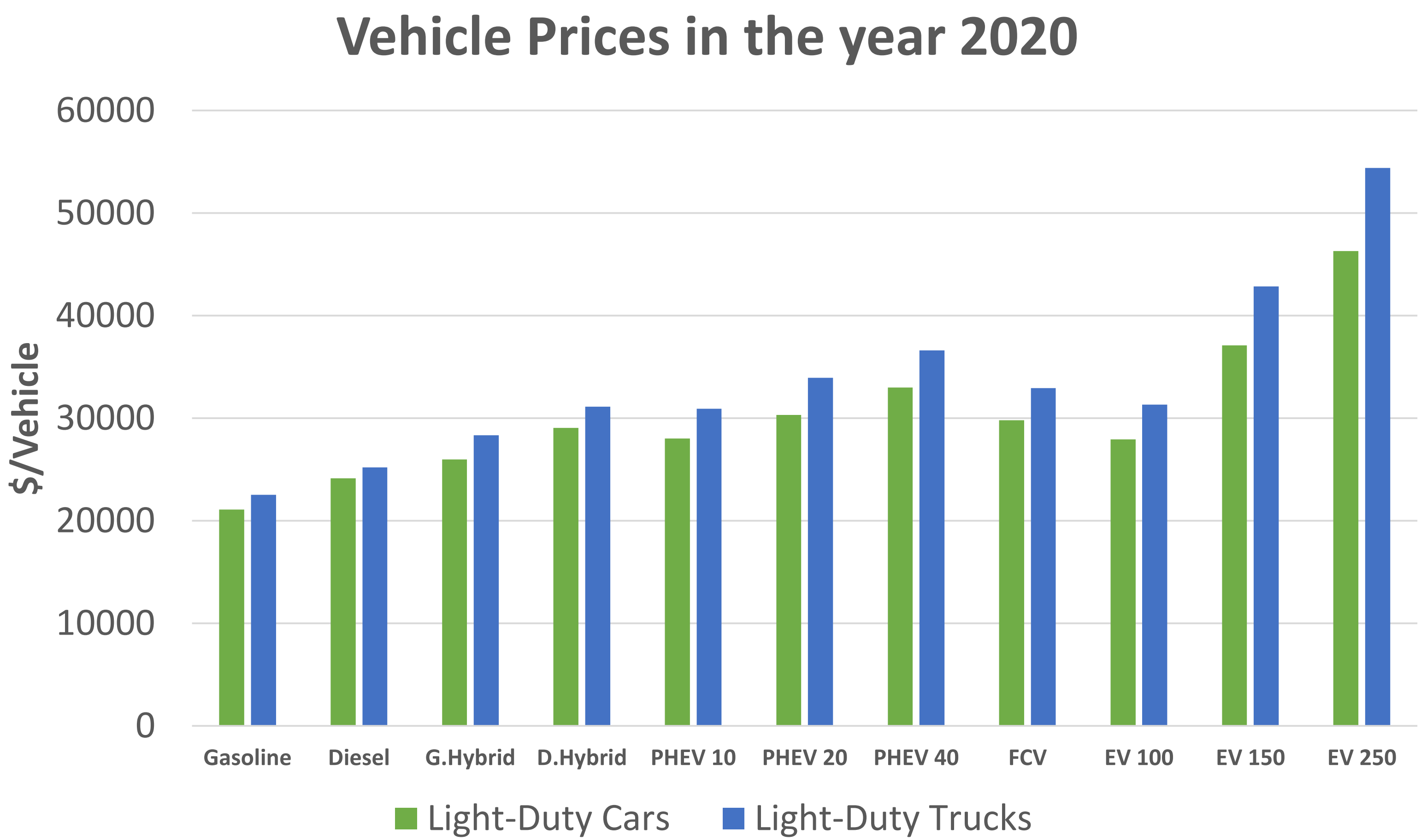
- This research estimates spatial distribution of alternative-fueled vehicle purchases with a consumer choice model
  - Segmenting consumers using spatially sensitive attributes such as income, driving behavior and utility factors related to infrastructure proximity.
- Initial results:
  - Can match patterns of adoption in higher income, early adopter areas such as SF Bay Area
  - The AFV adoption numbers are higher than expected—better calibration to data needed
- Main challenge: insufficient data at the detailed spatial level

Future Work

- Continue calibrating the model, collect more data
- Constructing a feedback loop between the years to analyze vehicle transitions for the next 5-10 years
- Split the spatial resolution into 1-sq.mile grids to refine infrastructure analysis
- Analyzing different infrastructure investment patterns (eg. What are the optimal locations for the next 100 hydrogen stations? Which pattern would lead to maximum adoption of FCVs?)
- Cost and emissions estimation of the model scenarios

ADDITIONAL SLIDES

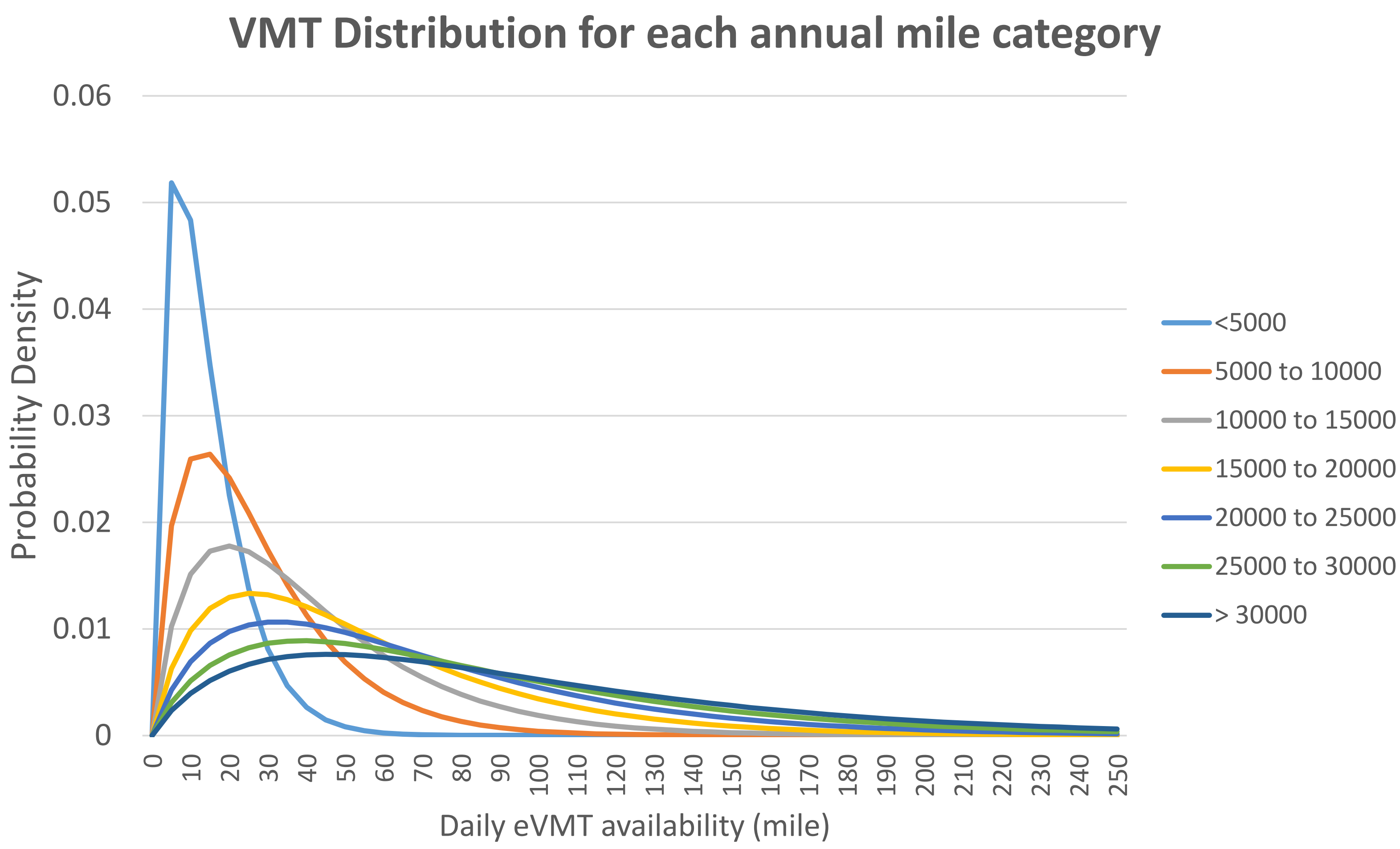
Vehicle Prices



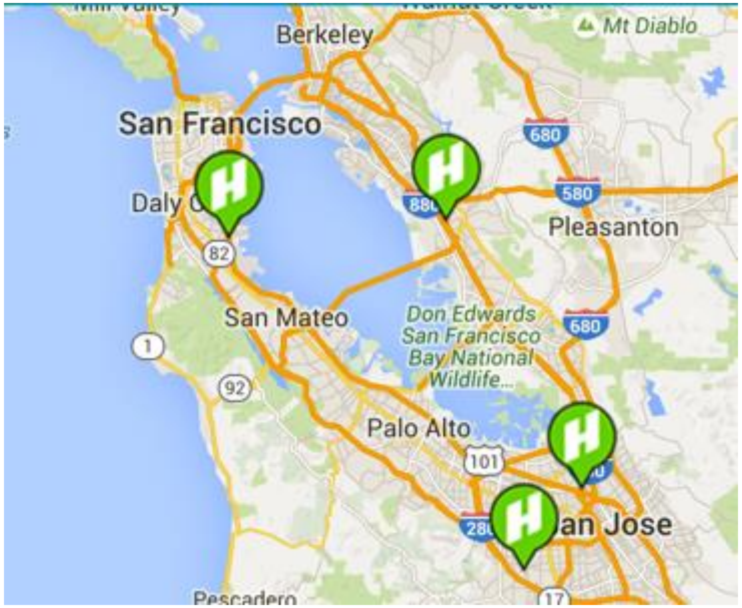
Input Module—Consumer Characteristics (data)

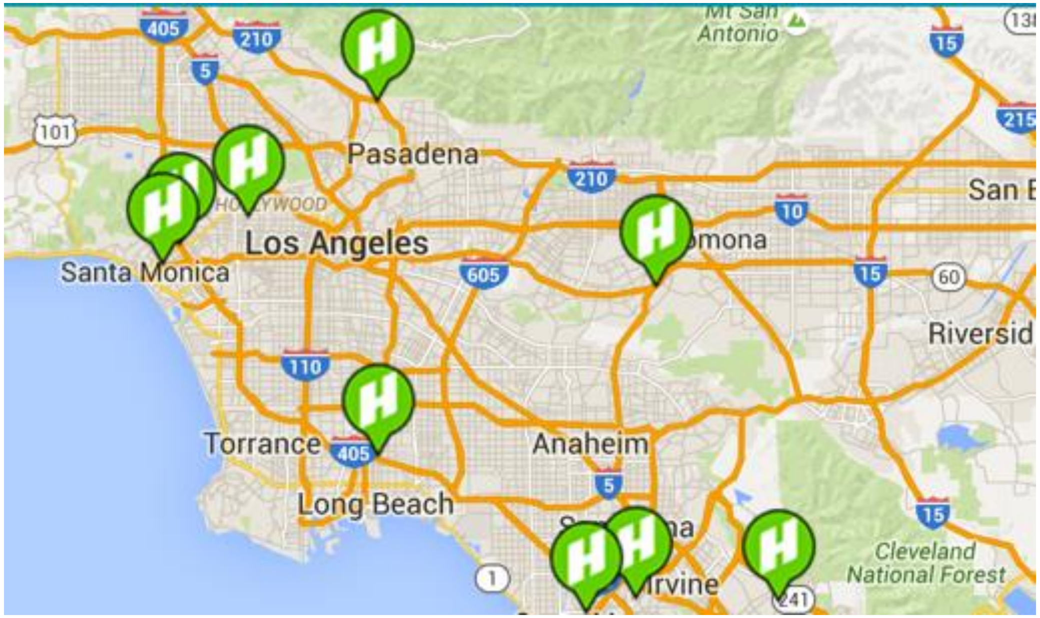
Attribute	Description	Source
Consumer driving profile	Expressed in annual miles traveled (divided into seven categories—5000 to 35,000 miles)	California Household Travel Survey (VMT profile at zip code level)
Risk Attitude	Division of consumers based on their perception of risk towards new technologies: Early adopters , Early Majority and late majority .	Early adopter population is determined from employment type (tech sector) from ACS data.
Income	Average household income. Willingness to pay for a vehicle technology increases with increase in income (divided into 5 categories)	California Household Travel Survey (Annual household income)
Home Charger Access	Estimates consumers with dedicated garage access. This determines how much they rely on public chargers	American Community Survey 2015 (single detached household percentage at zip code level)
Workplace charger access	Estimates consumers with access to workplace chargers	Assumptions are made for each region (20% for SF bay area, 5% for SoCal, and 0.1% for the rest of CA)

Daily VMT Distribution for each VMT Category

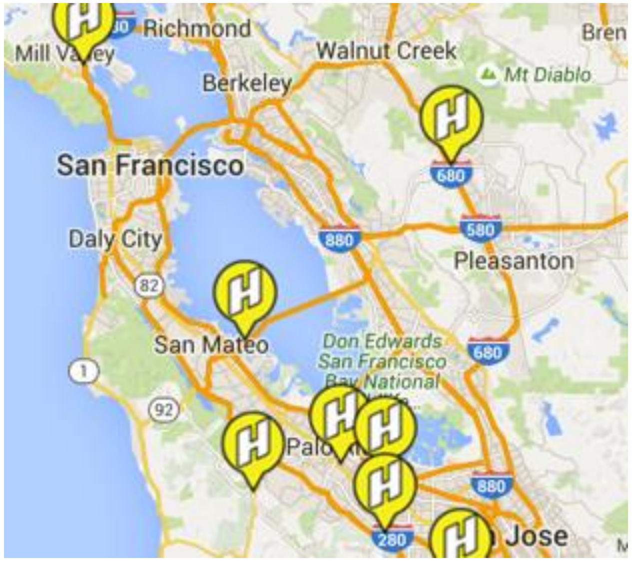


Map of Existing Hydrogen Station Locations

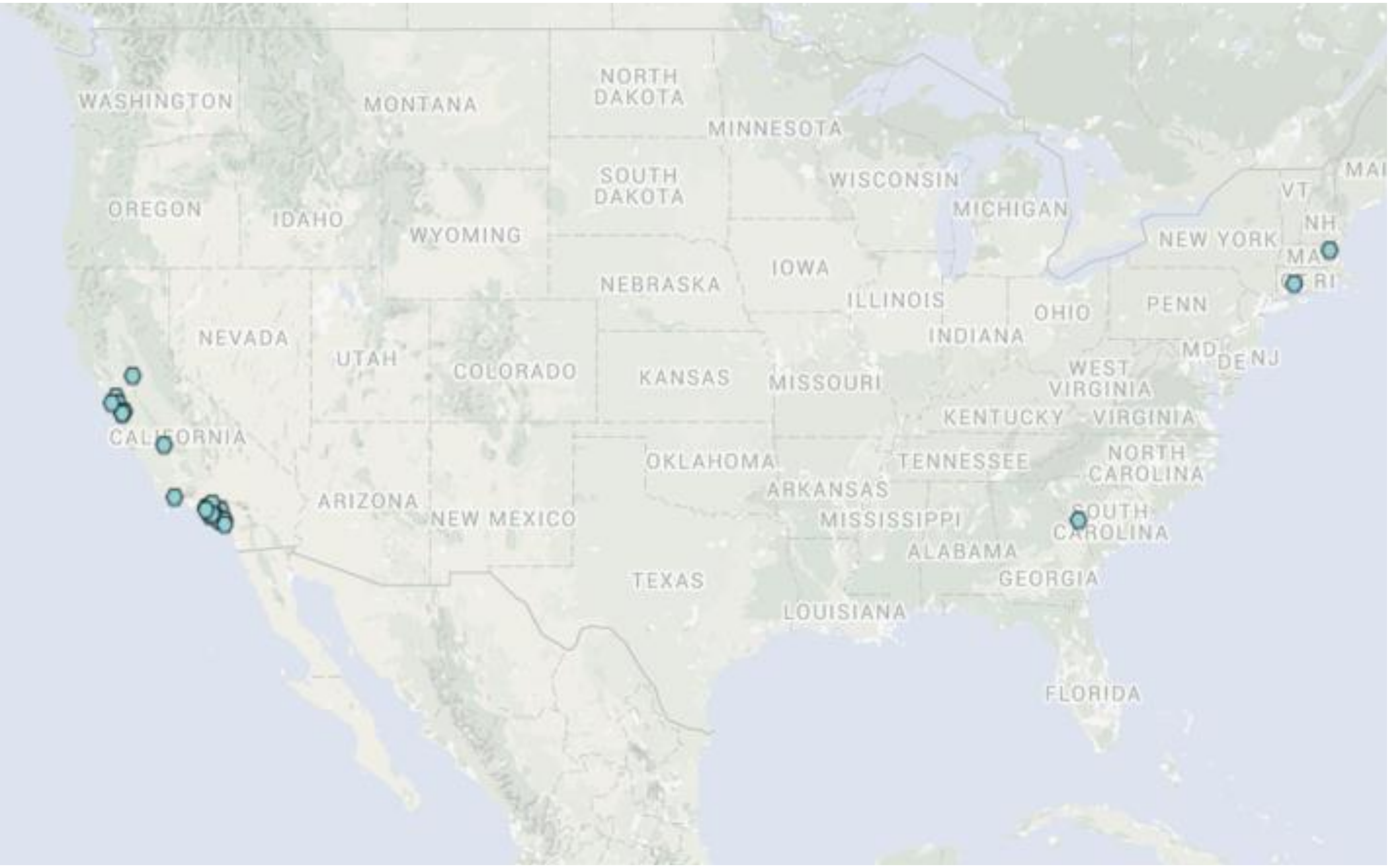




Map of Planned Hydrogen Station Locations in 2016



National Level—Hydrogen Stations (Existing)



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SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

Discussion