Session 4:
Transition Scenarios
and Related Modeling
STEPS Transportation Transition Scenarios for California: 
*Update on Fuels and Infrastructure Module*

Christopher Yang

Joan Ogden, Marshall Miller, Guozhen Li, Lew Fulton, Dan Scheitrum, Julie Witcover, Nathan Parker, Rosa Dominguez-Faus

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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

![Diagram](image.png)
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)

Focus of this talk

Model Outputs
Vehicle Costs
Infrastructure Costs
Incremental Costs
GHG emissions
Fuel consumption
Total Resource Usage
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

- Hydrogen
- Biofuels
- Electricity
- Natural gas

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

<table>
<thead>
<tr>
<th># of LDVs (output of vehicle model)</th>
<th># and size of Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
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<td>1,000</td>
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<td>10,000</td>
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<td>1,000,000</td>
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<tr>
<td>10,000,000</td>
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</tbody>
</table>

- **Diagram:**
  - Average Cars/station
  - Cars served per new station

- **Graph:**
  - X-axis: # of cars on the road
  - Y-axis: Cars per station
  - Blue line: Average Cars/station
  - Red line: Cars served per new station
# Fuels and Pathways Modeled

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Processes</th>
<th>Resources</th>
</tr>
</thead>
</table>
| **Natural Gas** | CNG  
LNG                                                                   | Fossil Natural Gas\(^1\)  
Renewable Natural Gas\(^2\)                    |
| **Electricity**  | Electricity                                                               | Grid mix  
Renewables only                                 |
| **Biofuels**    | Ethanol  
Biodiesel                                                            | Corn  
Cellulosic biomass\(^2\)  
Waste oil\(^2\)  
Oil crops                                      |
| **Hydrogen**    | Liquid  
Gaseous                                                               | Fossil Natural Gas\(^1\)  
Renewable electricity  
Cellulosic biomass\(^2\)                    |

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

  \[
  \text{Levelized Fuel Cost ($/GGE)} = \frac{(\text{Capital Cost} \cdot CRF + \text{Fix. O&M} + \text{Var. O&M} + \text{Annual Energy Inputs} \cdot \text{Energy Cost})}{\text{Total Fuel Production}}
  \]

- Currently no representation of subsidies/incentives, fuel taxes or trading credits (LCFS)
## Two Scenarios (BAU vs GHG)

<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business-As-Usual (BAU)</td>
<td>Low penetration of alternative fueled vehicles</td>
</tr>
<tr>
<td>GHG (ZEV) Scenario</td>
<td>High penetration of alternative fueled vehicles</td>
</tr>
</tbody>
</table>

### Fuel Demand (MGGE/yr)

- **H2**
- **Electricity**
- **RNG**
- **Natural Gas**
- **Biofuels**
- **Petroleum**

<table>
<thead>
<tr>
<th>Year</th>
<th>LDV</th>
<th>HDV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030 BAU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030 GHG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050 BAU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050 GHG</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **LDV**: Light Duty Vehicles
- **HDV**: Heavy Duty Vehicles
Total emissions = Fuel Usage x Fuel CI

**BAU** average CI doesn’t change much, but overall fuel usage declines.
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%
Fuel Costs
Averaged across LDV, and HDV and fleet stations

[Graph showing fuel price trends from 2010 to 2050, with lines for Petroleum, Biofuels, Natural Gas, Electricity, and H2. The graph is divided into two sections: BAU and GHG.]
Alternative Fuel Infrastructure and Resource Costs

Annualized Fuel Costs ($M)

<table>
<thead>
<tr>
<th>Alternative Fuel Demand (MGGE/yr)</th>
<th>2010</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>1,000</td>
<td>3,000</td>
<td>6,000</td>
</tr>
<tr>
<td>Electricity</td>
<td>2,000</td>
<td>4,000</td>
<td>5,000</td>
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<tr>
<td>Natural Gas</td>
<td>3,000</td>
<td>2,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Biofuels</td>
<td>4,000</td>
<td>5,000</td>
<td>6,000</td>
</tr>
</tbody>
</table>

Resource O&M Investment

2010: $232M
2030: $1.8B
2050: $6.1B
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!

ccyang@ucdavis.edu
## Infrastructure Costs and Parameters Sources

<table>
<thead>
<tr>
<th>Resources</th>
<th>Production</th>
</tr>
</thead>
</table>
| **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

MA³T 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.

<table>
<thead>
<tr>
<th>Disutility Cost Component</th>
<th>Description</th>
<th>Dependent Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refueling inconvenience cost (for non-electric</td>
<td>The combined time and inconvenience cost to refuel a vehicle</td>
<td>Annual miles driven, fuel economy, vehicle storage, station availability, value of time</td>
</tr>
<tr>
<td>vehicles—eg. FCVs)</td>
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<tr>
<td>Range Limitation Cost (BEVs)</td>
<td>The estimated generalized cost incurred by a BEV owner due to limited range of battery electric vehicles in conjunction with the owners VMT pattern</td>
<td>Daily VMT, annual miles driven, infrastructure availability, anxiety cost (consumer-specific, based on their risk attitude)</td>
</tr>
<tr>
<td>Model availability cost</td>
<td>Estimated cost of consumer perception based on make and model diversity available in the market</td>
<td>Cumulative vehicle sales</td>
</tr>
<tr>
<td>Risk Premium</td>
<td>The risk premium perceived by the consumer based on their ability to take risk</td>
<td>Cumulative vehicle sales</td>
</tr>
</tbody>
</table>
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.
PERCEPTION OF $1000 INCREMENTAL PRICE DIFFERENCE

Disutility Cost Difference ($/Car)

Annual Income ($)

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Purchase Probability Estimation

- **Monetary costs of the vehicle**
- **Vehicle and Fuel cost**
- **Disutility Costs**
  - Disutility costs of the vehicle from the POV of the consumer
- **Nested Multinomial Logit Choice Module**
  - Purchase probability of the vehicle technology
Illustration of Cost Components

- Income-related cost
- Model availability cost
- Refueling cost
- Range Limitation cost
- Electricity cost
- Fuel cost
- Vehicle cost

High-income household: Good Infrastructure availability, Early Adopter, Low VMT

Low-income household: Poor infrastructure availability, Late Majority, Frequent driver

<table>
<thead>
<tr>
<th>Income-related cost</th>
<th>Model availability cost</th>
<th>Refueling cost</th>
<th>Range Limitation cost</th>
<th>Electricity cost</th>
<th>Fuel cost</th>
<th>Vehicle cost</th>
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<tbody>
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<td>$/Vehicle</td>
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<td>Gasoline</td>
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<td>Diesel</td>
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<td>G.Hybrid</td>
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<td>PHEV</td>
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<td>BEV</td>
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<tr>
<td>FCV</td>
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</table>
Early adopter, low VMT, high income, good infrastructure availability

Late majority, high VMT, low income, poor infrastructure availability
1565 zip code regions * 5 income groups * 7 VMT categories * 3 Risk categories * Home charger Population share * Workplace charger population share = 657,300 consumer groups

Source
- MA³T
- DOE¹
- CHTS²
- ACS³

Input Data
- Fueling data
  - Fuel prices
- Vehicle attributes
  - Cost, efficiency, range, storage
- Infrastructure data
  - Infrastructure locations
- Spatial Consumer data
  - Income, driving profile, housing type
  - Risk tolerance of consumers
- US Sales
  - National vehicle sales

Sensitivity and scenario analysis
- Nested Multinomial-logit module
- Vehicle Technology Market shares

Estimated at neighborhood level

US Sales Link statewide sales with national sales

Vehicle and fuel costs

Disutility costs*

Vehicle and fuel costs

*Refueling inconvenience cost, range limitation cost, risk premium, model availability cost, and income related utility

¹Department of Energy, ²California Household Travel Survey; ³American Community Survey
Income Distribution in CA regions

**San Francisco Bay Area**

- <$20K
- $20K-$50K
- $50K-$75K
- $75K-$125K
- $125K+

**Southern California**

- <$20K
- $20K-$50K
- $50K-$75K
- $75K-$125K
- $125K+

**Central California**

- <$20K
- $20K-$50K
- $50K-$75K
- $75K-$125K
- $125K+

**State Income Distribution**

- <$20K
- $20K-$50K
- $50K-$75K
- $75K-$125K
- $125K+

*SF Bay area has greater high income population share than the state average*
Assumption:
People working in tech sector tend to be more interested in new technologies.

Place of employment from ACS micro census data is used to obtain early adopter population (e.g., People employed in technology, scientific professions).

These are 51 zip code regions (SF bay area & some parts of Southern California), constituting almost 60% of the early adopter population.
• 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 is a function of public charger availability
- Refueling cost is a function of hydrogen station availability

57 zip code regions, 3% of population

27 zip code regions, 2.5% of population
• This cost trajectory reflects the consumers who have no access to home or work chargers, and rely only on public chargers.

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

Source: MA³T Model (Lin & Greene, 2010)
PRELIMINARY RESULTS
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

12 out of 20 cities belong to SF Bay Area
11 out of 20 cities are located in Southern California.
• BEV adoption is more prevalent compared to FCV.
• SF Bay area leads in BEV adoption, Southern California leads in FCV adoption
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
Vehicle Prices

Vehicle Prices in the year 2020

Vehicle prices are from the MA3T model (based on DOE's Autonomie model). This does not include subsidies or tax credits.
## Input Module—Consumer Characteristics (data)

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

VMT Distribution for each annual mile category

Probability Density

Daily eVMT availability (mile)

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Map of Existing Hydrogen Station Locations

Source: California Fuel Cell Partnership
Map of Planned Hydrogen Station Locations in 2016

Source: California Fuel Cell Partnership
National Level—Hydrogen Stations (Existing)
Discussion