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ParaChoice Model

Project ID#: VAN019

Rebecca Levinson (Presenter) & Todd West (PI)

Sandia National Laboratories

DOE Annual Merit Review, June 8, 2016

Overview

Timeline and Budget

- Start date: FY14
- End date: Project continuation determined annually
- FY14 VTO Budget: $80k
- FY15 VTO Budget: $150k
- FY16 VTO Budget: $350k

Total VTO funds spent*: $217k

*as of 3/25/2016,

*$150k of $350k FY16 budget approved mid year, received March 2016

Barriers

A. Availability of alternative fuels and electric charging station infrastructure
  - Lack of fueling infrastructure to compete with the fully mature conventional petroleum-based fuels
  - Few electric charging stations needed for the coming plug-in hybrid electric vehicles (PHEVs) and fully electric vehicles (EVs).

B. Availability of AFVs and electric drive vehicles
  - OEM supply limitations for technologies such as CNG
  - Cost limitations for technologies such as PHEVs

Partners: Interactions / Collaborations:

- Ford: Real World Driving Cycles
- Toyota
- American Gas Association
- DOT
- ANL, ORNL, NREL, LBNL, Energetics

Relevance & Objective: Parametric analysis to understand factors that influence vehicle, fuel, & infrastructure mix

- *Lifetime project goals*: Understand changes to the Light Duty Vehicle (LDV) stock, fuel use, & emissions
  - System level analysis of dynamic between vehicles, fuels, & infrastructure
  - Use parametric analysis to
    - Identify trade spaces, tipping points & sensitivities
    - Understand & mitigate uncertainty brought in by data sources and assumptions
- *April 2015-April 2016 goal*: Understand uncertainty in vehicle choice model & projections
  - Conducted model validation study comparing simulation to historical sales data, resulting in journal article "History v. Simulation: An analysis of the drivers of alternative energy vehicle sales", submitted to *SAE*, Sept 2015
  - Compared model projections to other DOE models through participation in multi-lab BaSce analysis led by Tom Stephens (ANL)
  - Presented at UC Davis STEPS Lookback Modeling Workshop, December 9, 2015 "Lookback: Sandia ParaChoice Model"
  - Gave invited talk at Stanford Sustainable Mobility Seminar Series, February 5, 2016 "Vehicle choice modeling with ParaChoice: parameterization and validation"

Results of study had significant implications for barrier B

- *April 2015-April 2016 goal*: Determine the impact of additional EV infrastructure on EV adoption and use
  - Added model capability to handle level 1, level 2, and DC fast EV charging infrastructure
  - Added model capability to handle optional 'convenient' daytime charging of EVs
    - Parameterized, reflecting workplace charging or equivalent
  - Conducted preliminary analysis demonstrating that a small number of convenient daytime electric miles made available to EVs can greatly reduce fleet wide gasohol and petrol use

Addresses barrier A

ParaChoice Approach: systems level economic analysis to model dynamic feedback between fuels, vehicles, & infrastructure

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Marches forward from present, when energy, fuel, and vehicle stock states known, to 2050. At each time step, vehicles compete for share in the stock based on value to consumers.

Energy demand

Fuel demand

Vehicle costs & efficiencies, infrastructure, stock, and stock emissions vary in time

ENERGY
Oil
Coal
Natural Gas
Bio Mass
Nuclear/wind/solar

FUEL
Gasohol
Diesel
CNG
Electricity (grid)
E85
B20
H_2
(seven fuel pathways)

VEHICLE STOCK

Red values are endogenously simulated

Commodity prices evolve

Energy prices

Fuel prices

RFS, carbon taxes, H_2 production pathways, electric grid composition, all vary in time

Baseline policies are taken to be current status quo

- No federal renewable H_2 mandate
- No CO_2 tax
- Federal EV, but no FCEV incentive
- State incentives included

Baseline data values & projections taken from trusted sources

- Energy prices: AEO 2015
- H_2 prices and pathways: MSM
- Emissions: GREET
- Fleet segmentation: NHTS
- Vehicle price projections: Autonomie
- 2010-2015 fueling stations: AFDC

Approach: At every time step, simulation assesses generalized vehicle costs for each vehicle. Choice function assigns sales based on these costs and updates stock.

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VEHICLE STOCK

Vehicle		Generalized Vehicle Cost				Percent of Sales
Conv. SI	→	$X /year				A %
FCEV	→	$Y /year	→	Nested Multinomial Logit Function	→	B %
PHEV40	→	$Z /year				C %

… And 17 more

Given:
- Input attribute(s)
- Fixed set of 2+ output choices

Nested Multinomial Logit Function

Outputs:
- Probability distribution

Generalized Vehicle Cost

Upfront Costs Amortized Over "Required Payback Period"

- Purchase price
- One time incentives
- One time penalties *(Infrastructure penalty)*

Recurring Costs

- Fuel cost
- Annual incentives
- Annualized penalties *(Range penalty)*

Approach: segment vehicles, fuels, & population to understand competition between powertrains & market niches

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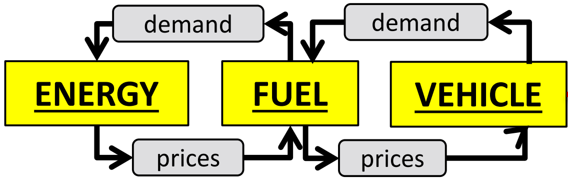


EV charging station densities will vary significantly by state and by population density.

Geography

Vehicle

Demographics

Purchasing incentives for EVs and discounts for home chargers will also vary by state.

Driver intensity will dictate how often recharging is required.

Those without access to home recharging must be modeled differently than those with at home charging access.

Vehicle Stock Segmentation

Powertrain

SI
SI Hybrid
SI PHEV10
SI PHEV40
CI
CI Hybrid
CI PHEV10
CI PHEV40
FCEV
E85 FFV
E85 FFV Hybrid
E85 FFV PHEV10
E85 FFV PHEV40
BEV75
BEV100
BEV150
BEV225
CNG
CNG Hybrid
CNG Bi-fuel

Housing type

- Single family home without NG
- Single family home with NG
- No access to home charging/fueling

VMT Segmentation

Energy/Fuel Seg.

State

48 CONUS +
Washington, DC

Density

Urban
Suburban
Rural

Size

Compact
Midsize
Small SUV
Large SUV
Pickup

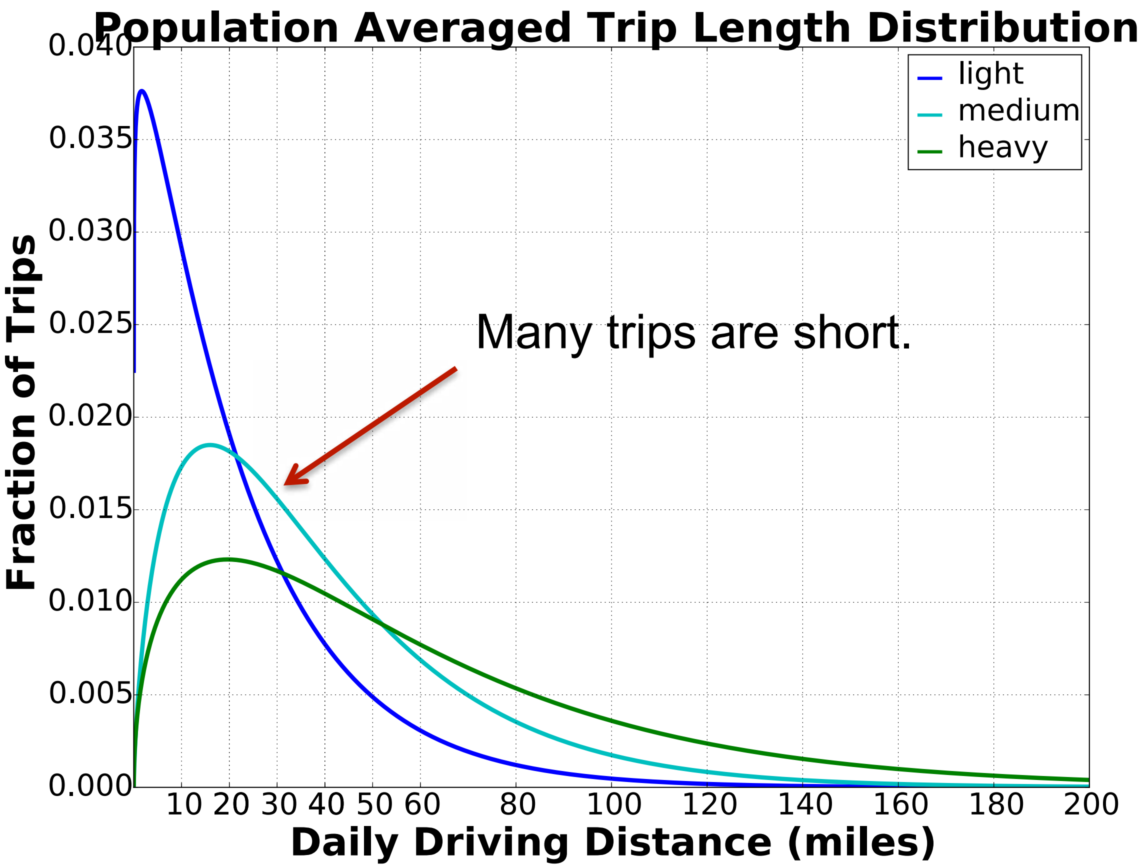
Age

0-46 years

Driver Intensity

High
Medium
Low

Approach: ParaChoice considers real world driving cycles when examining electrified mileage



Within each segment of low, medium, and high mileage drivers, daily driving trip distributions approximately follow a gamma function.

(Individual trip distributions may vary, but more generally follow a gamma function plus a normal distribution. The latter distribution washes out upon population averaging.)

We assume that availability of charging has no impact on VMT or driving distributions

G. E. Barter, M. A. Tamor, D. K. Manley, and T. H. West. The implications of modeling range and infrastructure barriers to battery electric vehicle adoption. Transportation Research Record Journal of the Transportation Research Board, (2502):80–88, Sept. 2015. doi: 10.3141/2502-10.

Approach: Penalties for EVs
(applied to all miles that are not charged at home overnight, or otherwise specified)

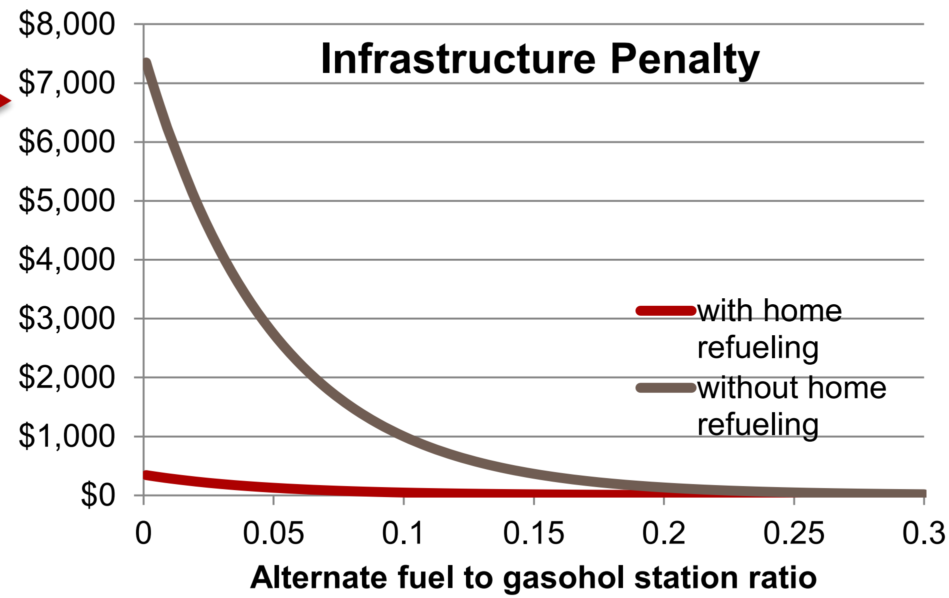
These may be applied separately or in combination depending on the technology

- Station scarcity/ infrastructure penalty
  - straight from Greene (2001)
  - Applied once at purchase and amortized over vehicle payback period
- Refuel time penalty- also from Greene (2001)

  25.93(2012$/hr) x *time spent refueling* (hr)
- Range/ rental penalty

  n days vehicle is driven outside of its range

  x *cost of rental vehicle* ($/day)
  - Uses daily trip driving distributions from previous slide



- For PHEVs- only refuel time penalty is used, using gasohol refueling times.
  - Assumption- PHEV owners will only recharge the battery if it doesn't inconvenience them
- For BEVs
  - A net infrastructure & refuel time penalty is computed considering all available level 1, level 2, & DC fast chargers in the region
  - If that infrastructure/refuel time penalty is less than the range/rental penalty, the infrastructure/refuel penalty is used
  - Else the net penalty is a weighted average of the two, based on a parameterized infrastructure willingness s-curve

Approach/ Accomplishments & Progress: Integrating penalties for level 1, 2, and DC fast charging infrastructure

- Assuming vehicle is charged outside of the home using only level X chargers, penalty is sum of amortized infrastructure and refuel time penalties
  - $P_X = I_X + R_X$
- Every charger helps relieve total the penalty, if only a little…
  - If multiple charger types are available, they each alleviate the resistance to charging
  - Use parallel resistor model to capture benefit of infrastructure for different charger levels given their relative refueling times.
  - $P_{total} = (P_1^{-1} + P_2^{-1} + P_{DC}^{-1})^{-1}$

Example 1: CA

Level 1 charging at 5 mi/hr, ~75 stations *

Level 2 charging at 20 mi/hr, ~2410 stations*

DC Fast charging at 210 mi/hr, ~290 stations*

~10,100 gasohol stations

* station numbers increase throughout the simulation with new EV sales

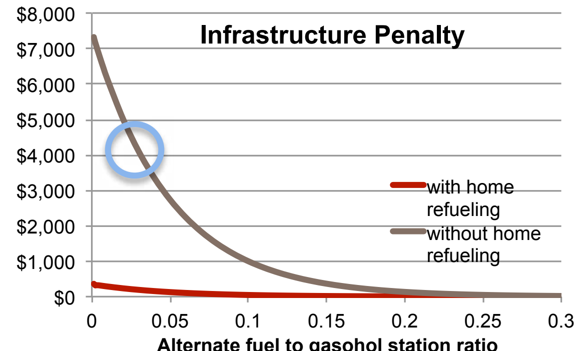
Mid mileage driver in a SF home owning a BEV100, needs to charge ~4,900 miles in addition to nightly charging per year

DC fast refuel time penalty:

4,900 mi charged out of home / (210 mi/hr) * ($25.93/hr) = $610

DC fast infrastructure penalty:

Station ratio = 290 DC fast stations/ 10,100 gas stations = 0.029



*Only have level 1 & 2 at home, not DC fast

DC fast infrastructure penalty: $4,210

Cost spread over 3 years: $1,400

DC fast total penalty = P_{DC} = $1,400 + $610

Integrating penalties for level 1, 2, and DC fast charging infrastructure, continued...

- Assuming vehicle is charged outside of the home using only level X chargers, penalty is sum of amortized infrastructure and refuel time penalties
  - $P_X = I_X + R_X$
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Example 1: CA

Level 1 charging at 5 mi/hr, ~75 stations

Level 2 charging at 20 mi/hr, ~2410 stations

DC Fast charging at 210 mi/hr, ~290 stations

~10,100 gasohol stations

- $P_X = I_X + R_X$
- P_{DC} = \$1,400 + \$610 P_1 = \$100 + \$25,410, P_2 = \$0 + \$6,350
- $P_{total} = (P_1^{-1} + P_2^{-1} + P_{DC}^{-1})^{-1}$
- P_{total} = \$1,440

Example 2: NJ

Level 1 charging at 5 mi/hr, ~2 stations

Level 2 charging at 20 mi/hr, ~150 stations

DC Fast charging at 210 mi/hr, ~20 stations

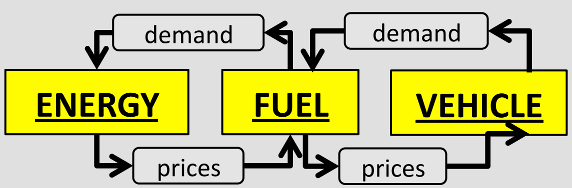
~3,220 gasohol stations

- $P_X = I_X + R_X$
- P_{DC} = \$2,230 + \$610 P_1 = \$120 + \$25,410, P_2 = \$50 + \$6,350
- $P_{total} = (P_1^{-1} + P_2^{-1} + P_{DC}^{-1})^{-1}$
- P_{total} = \$1,830

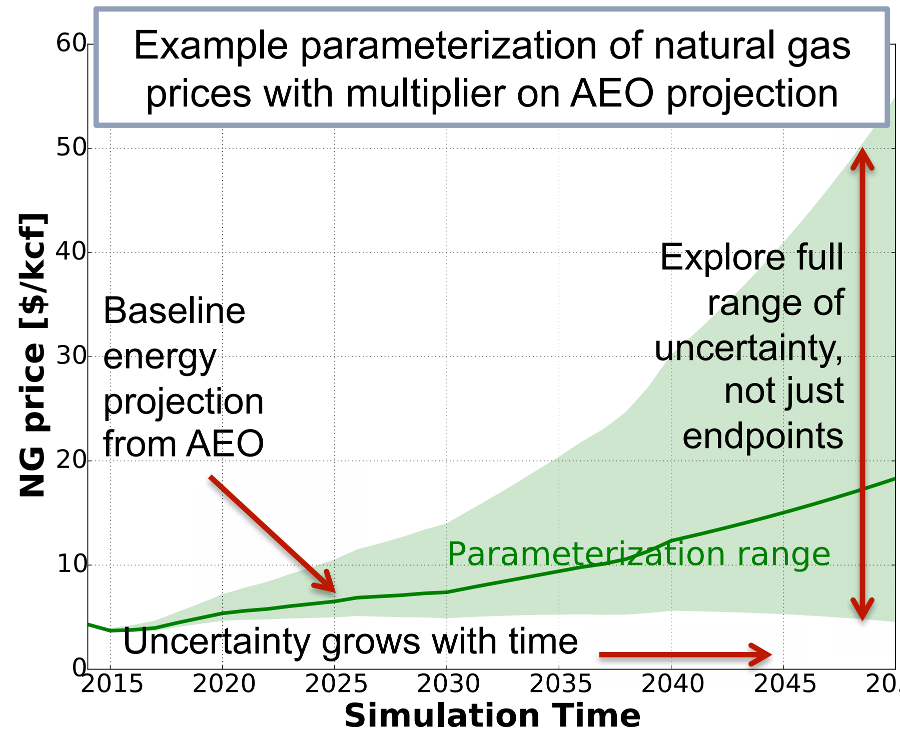
Approach: Use parameterization to understand and mitigate uncertainty brought in by data sources and assumptions

***Uniqueness from other DOE models*:**
ParaChoice is <u>designed to explore uncertainty & trade spaces</u>, easily allowing identification of tipping points & sensitivities

- Core simulation is a system-level analysis of dynamic, economic relationship between energy, fuels, & vehicles with baseline values from trusted DOE sources. Technologies compete in the simulation, are allowed to flourish or fail in the marketplace.



- Simulation is run 1000s of times with varying inputs. This parametric analysis provides:
  - Perspectives in uncertain energy & technology futures
  - Sensitivities and tradeoffs between technology investments, market incentives, and modeling uncertainty
  - The set of conditions that must be true to reach performance goals



- Vary two parameters at once- trade space analysis (~400 scenarios)
- Vary many parameters- sensitivity analysis (~3000 scenarios)
- Parameterization ranges designed to explore plausible AND 'what if' regimes, covering all bases

Accomplishments & Progress: Determine the impact of additional EV infrastructure on EV adoption & use

Examining effects of convenient charging in addition to at home nightly charging on

- Total fleet wide electrified mileage
- Petroleum use reduction
- PHEV and BEV adoption

Part 1: Parametric study of impact of added e-miles ← Analysis presented this AMR

- 'Added e-miles' are convenient electric miles that EV adopters can access each day in addition to at home nightly charging
  - From workplace charging
  - From midday at-home charging
  - From public chargers placed in locations where time spent charging isn't an inconvenience (e.g. grocery stores and restaurants)
- These miles are exempt from recharge time, infrastructure, and range/rental penalties
- For PHEVs, added e-miles are capped at two non-at-home battery charges per day in order to reflect real word driving and charging behavior
- Added e-miles are a rough representation of
  - Build out of convenient available public infrastructure
  - Awareness of, or encouragement to use, existing infrastructure

  That avoids the behavioral uncertainty of how the existence of infrastructure maps to usage

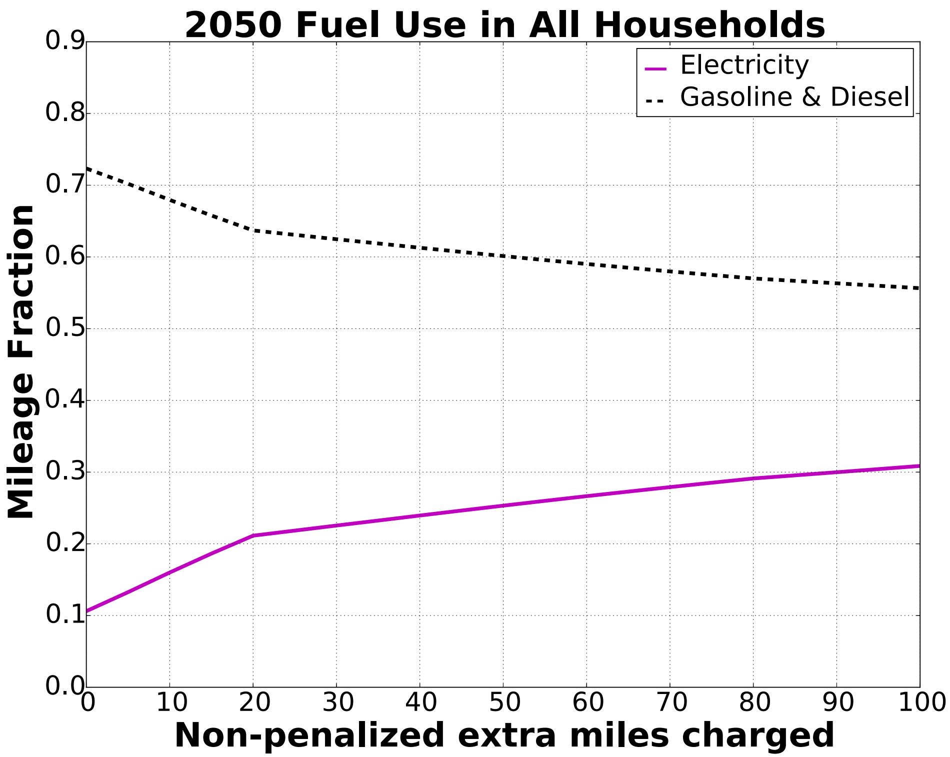
Part 2: Impact of charging time and charging infrastructure levels

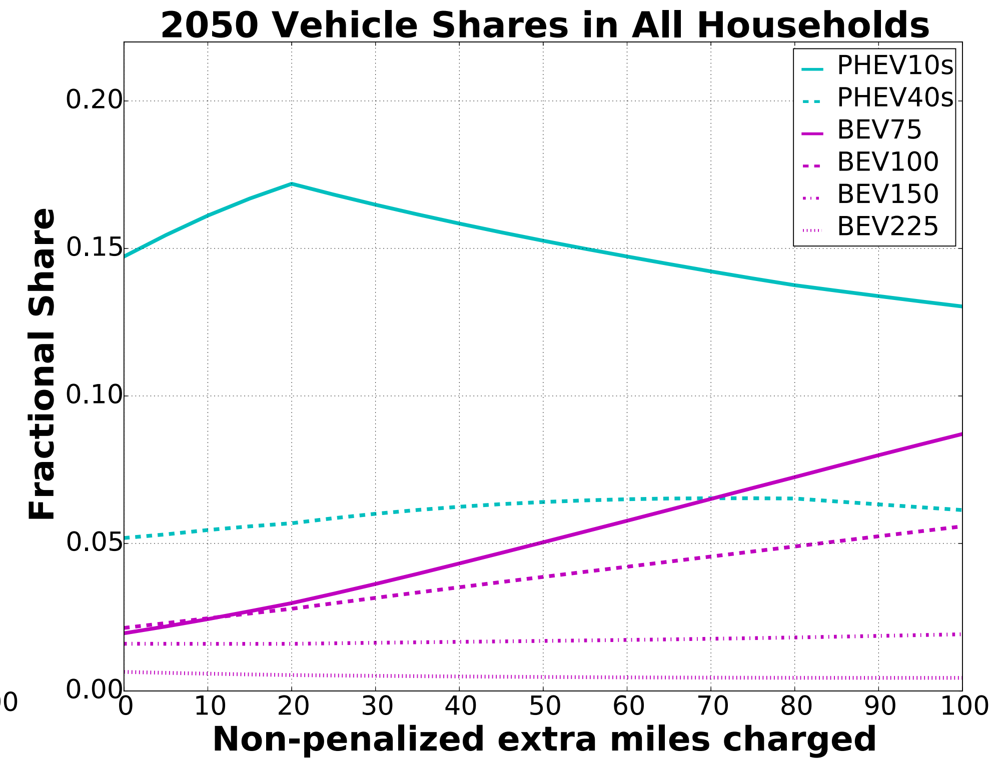
Part 3: Impact of added charging infrastructure ← Q3 & Q4 analyses, begin to rely on more tenuous behavioral infrastructure usage assumptions

Conclusions

- A relatively small number of added e-miles, 20 miles, can increase the fleet wide electrified mileage fraction by approximately 10%
- Many of these miles come from the increased utilization of the battery in existing low range PHEVs, not necessarily new EV sales, though EV sales do increase
- Added e-miles have a clear positive effect on the adoption of short range BEVs in homes with dedicated recharging capacity and on PHEV40 sales in homes without

20 added e-miles can increase the fleet wide electrified mileage fraction by approximately 10%



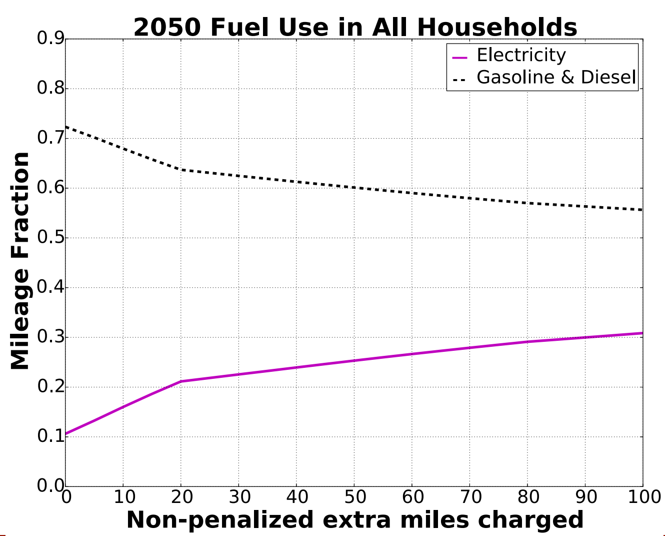


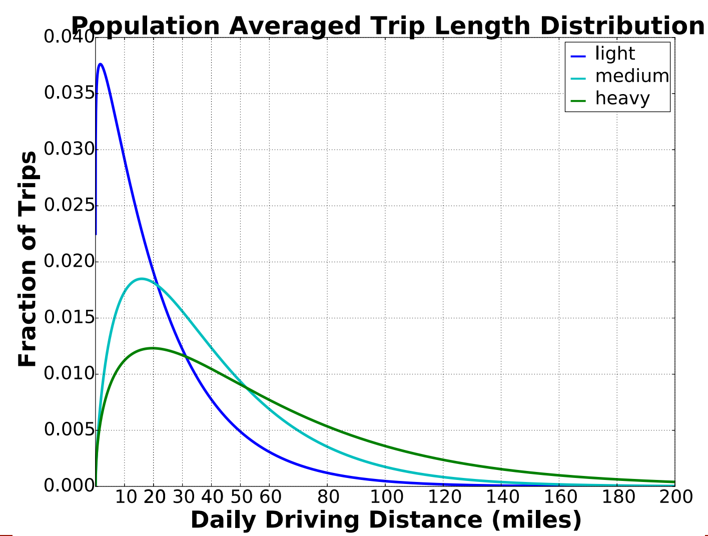
- 10% gain in fleet wide electrified miles for the first 20 added e-miles.
- Clear tipping point at 20 added e-miles, where diminishing returns seen.
- EV ownership only increases ~4% for these first 20 e-miles. Mostly in PHEV10s.
- Increase in fleet wide electrified miles is largely due to increased use of the battery in PHEVs, not new sales.
- This is consistent with daily driving distributions. Many days < 30 miles driven by any one vehicle.

If all PHEV10s can electrify an extra 20 miles per day, fleet wide average electrified mileage increases 4.5%

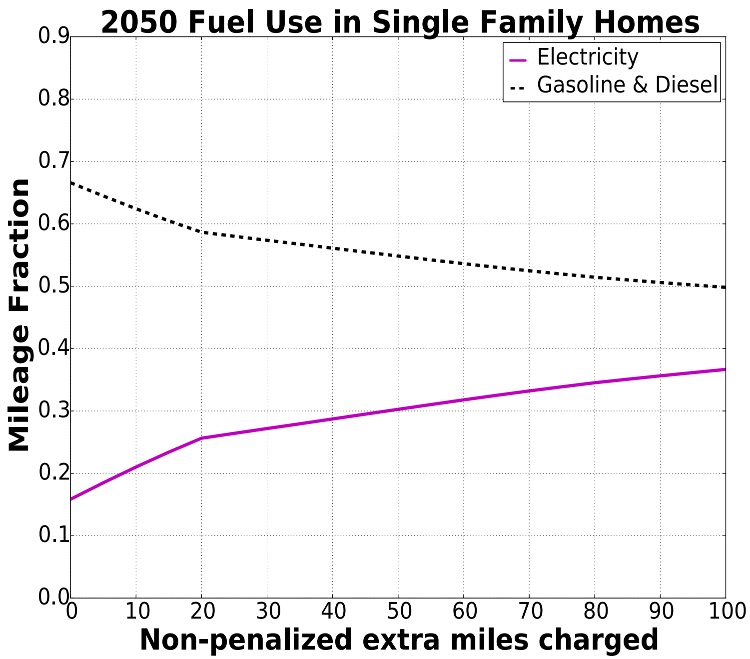
For the average new vehicle:

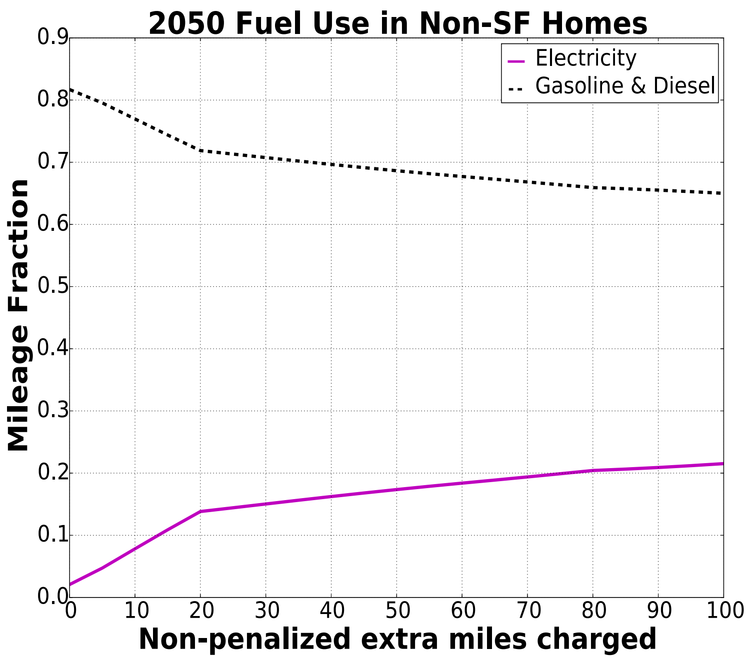
- In a single family home
  - any days where less than 30 miles are driven are fully electrified
  - that's 90 of 261 total driving days (compared to 21 without the added miles)
  - 47% of total driving is electrified (compared to 18% without the added miles)
- In a non-single family home
  - any days where less than 20 miles are driven are fully electrified
  - that's 55 of 261 total driving days
  - 34% of total driving is electrified (compared to none without the added miles)
- If 15% of vehicles have 30% gain in electrification, that's a 4.5% gain for the fleet





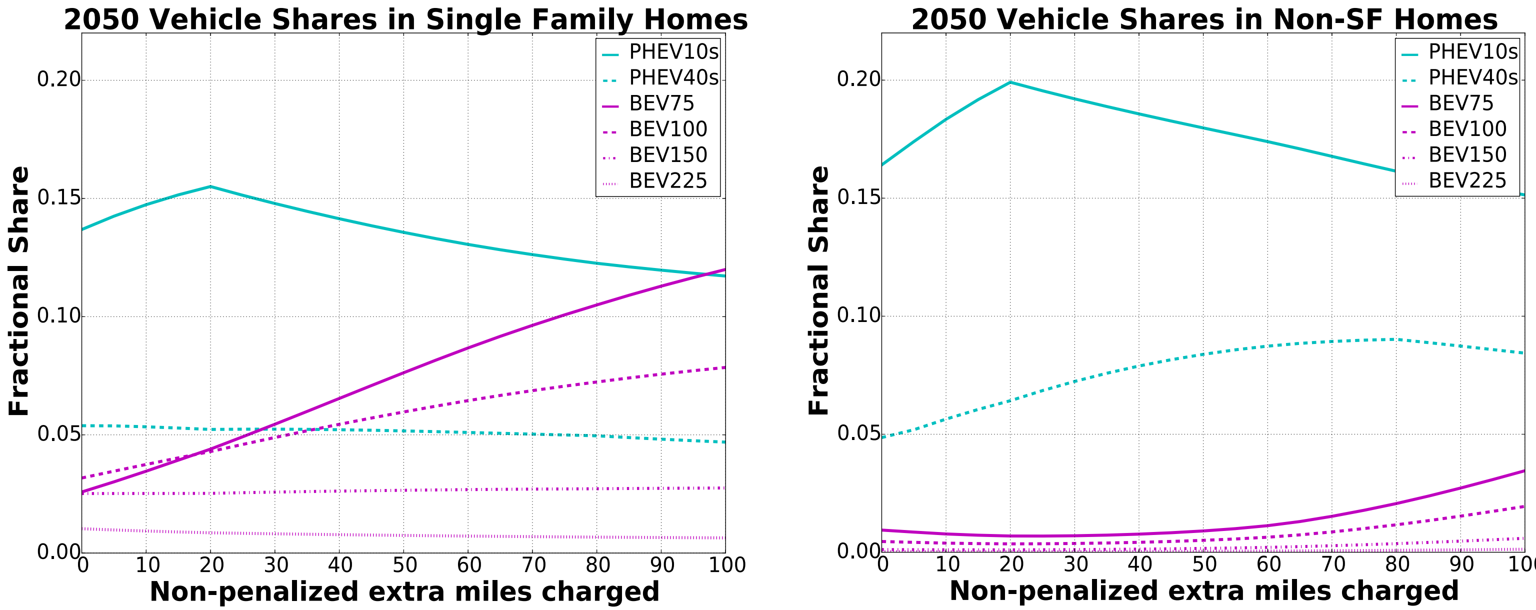
Electrified mileage is greater in single family homes, but increased infrastructure reduces petrol use in all dwelling types





- As expected, electricity consumption is greater for single family homes and lesser in homes without the option of at home vehicle charging
- The tipping point on return for fleet wide electrified mileage fraction for added e-miles is 20 for both household types. Trends in fuel consumption with added e-miles are also very similar.

Added e-miles have a clear positive effect on the adoption of short range BEVs in homes with dedicated recharging capacity and on PHEV40 sales in homes without



- BEV market share is consistently low in non-SF homes.
- BEV150 and 225 adoption is relatively unaffected by additional e-miles, as one would expect for vehicles that are largely price limited, not range limited.
- In SF homes, BEV75 and 150 adoption is strongly influenced by added e-miles. In non-SF homes, PHEV40s largely take the place of these low range BEVs until the number of added e-miles begins to meet the range of the BEVs and exceed twice the electric range of the PHEV.
- PHEV10s are more popular in non-SF homes than SF homes, even if there are no or very few added e-miles. This is likely due to the PHEV10s capturing some of the market that would have otherwise fallen to BEVs.

Collaborations

- No funding given to other institutions on behalf of this work
- Technical critiques received from Ford Motor Company, General Electric, American Gas Association, and other conference engagements
- The underlying ParaChoice model has been developed using funding from a variety of sources including
  - Sandia Laboratory Directed Research & Development Funds
  - Clean Energy Research Consortium
  - Fuel Cell Technologies Office
- This work is complemented by modeling and analysis for the FCTO. Rebecca Levinson presented on the FCTO-funded ParaChoice analysis (project ID SA055) Wednesday June 8 at 9:30AM

Proposed Future Work

- Part 2: Impact of charging time and charging infrastructure levels
  - Trade off between adding level 2 and DC Fast
  - Regional variations
- Part 3: Impact of added charging infrastructure
  - Include anticipated Station builds
    - Tesla/BMW/PG&E
    - Parameterized policy driven?
  - Create data driven, parameterized behavioral map between increased infrastructure and increased electrified mileage
    - Differentiate between penalty reduction with infrastructure and convenient charging (i.e. added e-miles) that infrastructure can create
- Journal article summarizing findings

Summary

- ParaChoice
  - Is a validated system level analysis model of dynamic between vehicles, fuels, & infrastructure
    - Leveraging other DOE models and inputs
  - Is designed for parametric analysis in order to
    - Understand & mitigate uncertainty brought in by data sources and assumptions
    - Identify trade spaces, tipping points & sensitivities
- We have added capabilities to the ParaChoice model
  - To handle multiple EV charging levels
  - To perform parametric assessments of non-penalized, convenient daytime vehicle charging
    - This charging simulates the build out of convenient charging infrastructure such as workplace charging or efforts to make consumers aware of and willing to use the same
- We have conducted an initial analysis to assess the effects of convenient charging through 'added e-miles' finding
  - A relatively small number of added e-miles, 20 miles, can increase the fleet wide electrified mileage fraction by approximately 10%
  - Many of these miles come from the increased utilization of the battery in existing low range PHEVs, not necessarily new EV sales, though new EV sales do increase
  - Added e-miles have a clear positive effect on the adoption of short range BEVs in homes with dedicated recharging capacity and on PHEV40 sales in homes
- Future work will continue to assess the effects of increased infrastructure and convenient charging