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ParaChoice

Parametric Vehicle Choice Modeling

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Sandia National Laboratories

Project ID#: **VAN014**

2015 DOE Vehicle Technologies Office

Annual Merit Review and Peer Evaluation Meeting

June 11, 2015

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Overview

Timeline

- Start date: FY14
- End date: FY15

Budget

- FY14 funding: $100K
  - Additional support from US-China Clean Energy Research Center – Clean Vehicle Consortium
  - Workshop support from FCTO, Toyota, and AGA
- FY15 funding: $150K

Barriers

- Availability of alternative fuel and charging infrastructure
- Availability of AFVs and electric drive vehicles
- Uncertainty in vehicle choice models and projections
- Identification of largest leverage points for reducing petroleum consumption and GHG emissions

Partners

- Interactions / Collaborations:
  - Ford: Real World Driving Cycles
  - Toyota and American Gas Association: Workshop
  - DOT
  - ANL, ORNL, NREL, Energetics

Project was not reviewed in previous Merit Reviews

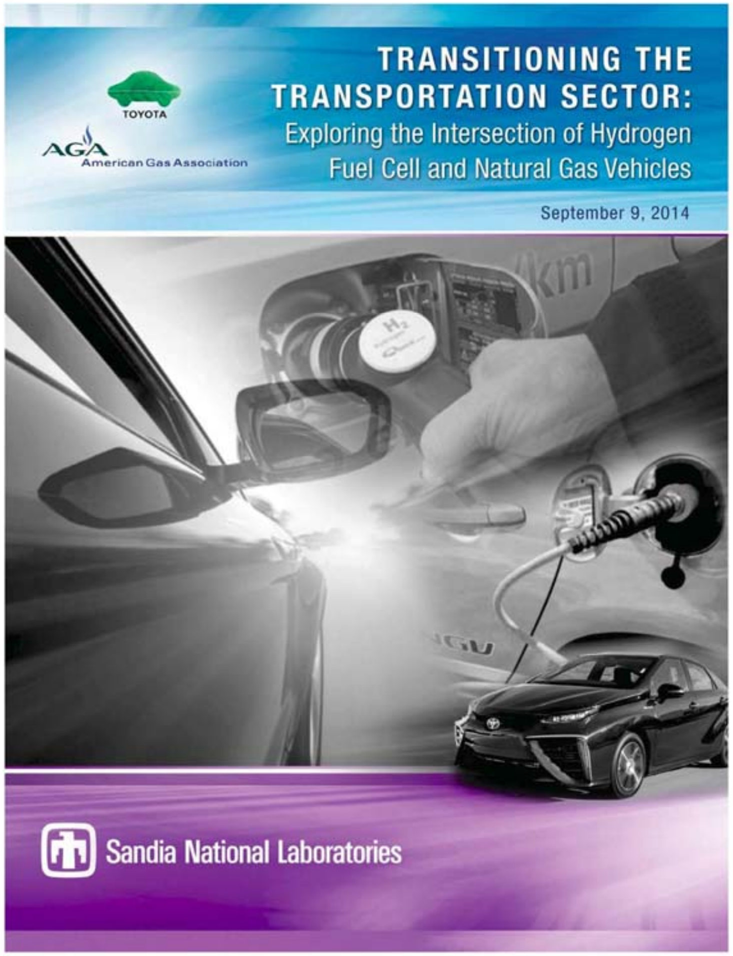
Relevance: We focus on identifying opportunities, challenges, and tradeoffs at the intersection of multiple alternative fuels and technologies

- **Approach**: We convened a workshop entitled, "Transitioning the Transportation Sector: Exploring the Intersection of Hydrogen Fuel Cell and Natural Gas Vehicles," September 9, 2014
  - For what **markets** are natural gas and hydrogen in direct competition, and how might they be better suited for different transportation applications?
  - How do we get fueling **stations** built? Are there business models that can simultaneously support hydrogen and natural gas?
  - What can we learn from programs and policies that have been implemented at the **state** level?
- **Collaboration**: Understanding context from diverse stakeholders informs our analyses

AGA Toyota Sandia DOE National Conference of State Legislatures SRNL UPS Plug Power Mercedes-Benz National Governors Association CARB Chrysler GM American Council for an Energy-Efficient Economy Honda Air Products and Chemicals Aaqius Pioneer Natural Resources Hyundai Fuel Cell and Hydrogen Energy Association Linde NREL Council on Competitiveness UC Davis Nuvera Southern California Gas Ford GE Fuel Cell Energy

Relevance and Collaboration: Understanding context from diverse stakeholders informs our analyses

- First workshop to actively probe synergies, competition, and new ways of developing H2 and natural gas in tandem
- Supported by:
  - DOE Vehicle Technologies Office
  - DOE Fuel Cell Technologies Office
  - Toyota
  - American Gas Association
- Report published in February 2015 & available on EERE websites
  - VTO: http://energy.gov/eere/vehicles/articles/new-report-describes-joint-opportunities-natural-gas-and-hydrogen-fuel-cell
  - FCTO: http://energy.gov/eere/fuelcells/downloads/transitioning-transportation-sector-exploring-intersection-hydrogen-fuel



Accomplishments: Key findings

- Market and manufacturer signals indicate hydrogen and natural gas will naturally segment
- Starting from common standards and equipment may enable synergistic development of both fuels
- Co-location of fueling stations would create new business opportunities
- Roles of fuel providers and utilities will shift
- Thorough system requirements and cost assessments are needed to quantify the benefit of co-development
- The near term may not grow up to look like the long term
- Sometimes you know that the chicken came first – states have identified different mechanisms to incentivize transitions

ParaChoice Relevance/Objective: parametric analysis across factors that influence the vehicle, fuel, & infrastructure mix

- *Objective*: ParaChoice captures the **changes to the Light Duty Vehicle (LDV) stock through 2050** and its dynamic, economic relationship to fuels and energy sources

- *Uniqueness*: The model occupies an **system-level analysis layer with input from other VTO models** to explore the uncertainty and trade space (with 10,000s of model runs) that is not accessible in individual scenario-focused studies

- *Approach*: Model **dynamics and competition** among LDV powertrains and fuels using **regional-level** feedback loops from vehicle use to energy source
  - Technologies are allowed to flourish or fail in the marketplace

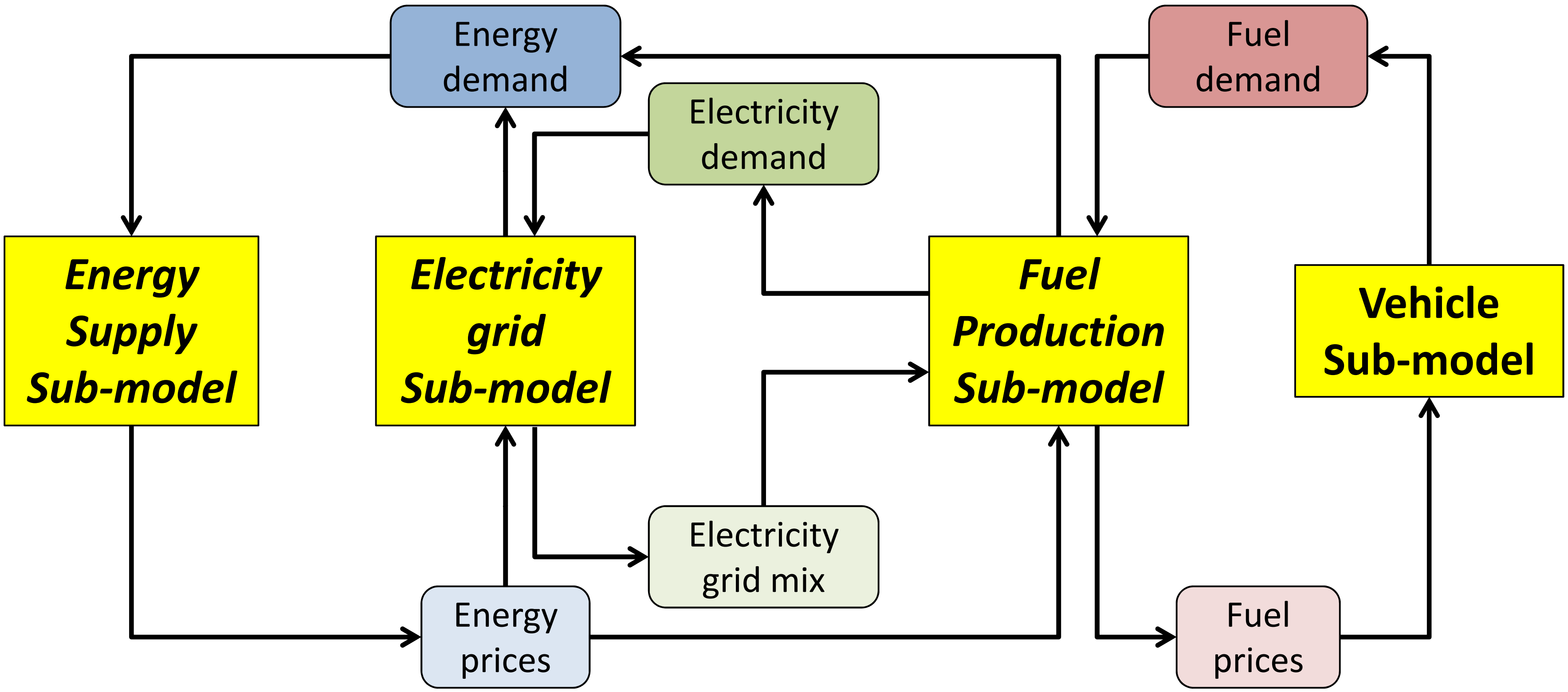
- *Targets*: By conducting parametric analyses, we can identify:
  - The set of conditions that must be true to reach performance goals
  - Sensitivities and tradeoffs between technology investments, market incentives, and modeling uncertainty

- *Focus for FY15*: Understanding the factors that affect adoption and electrified miles driven by battery electric and plug-in hybrid vehicles
  - Impact of access to home charging
  - Impact of widespread public charging infrastructure availability

Milestones and status

- Q1 – Incorporate data sets and model edits
  - Updated model baseline datasets & capability to analyze data by region and demographics
  - Presented/reviewed modeling approach, assumptions, results at U.S. Department of Energy Vehicle Choice Modeling Workshop, Davis, CA
  - Held Transitioning the Transportation Sector Workshop and presented initial findings at AIChE Alternative Natural Gas Applications Workshop, Alexandria, VA
- Q2 – Complete model testing and initial scenario analysis
  - Conducted assessment of factors that affect adoption and electrified miles driven by BEVs and PHEVs
  - Completed workshop report
  - Presented/reviewed analysis and workshop results at U.S. Department of Transportation Climate Adaptation and Mitigation Workshop, Washington DC
- Q3 – Compete analysis – on track
- Q4 – Draft and submit publication – on track

Modeling Approach: The high-level model diagram depicts the feedback loop of energy supply<-->energy carrier<-->vehicle



- Model background presented in AMR **Project SA055 – Hydrogen Analysis with ParaChoice Model**, 6/9/15, 3:15pm, Crystal City, Room/Salon F

Modeling Approach: The model has many segments to capture the different niches of LDV consumers

Vehicle Stock Segmentation

Powertrain
SI
SI Hybrid
SI PHEV10
SI PHEV40
CI
CI Hybrid
CI PHEV10
CI PHEV40
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

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

Geography
Vehicle
Demographics

Fuels
Gasoline
Diesel
Biodiesel
Ethanol
Electricity
CNG

Energy Sources
Petroleum
Natural Gas
Coal
Biomass
Solar/Wind

Modeling Approach: Model baseline inputs are taken from published sources when possible, and many are parameterized

Energy sources

- Oil, coal, NG: EIA Annual Energy Outlook 2014 price
- Biomass: State supply curves *Billion Ton Study*

Fuel conversion and distribution

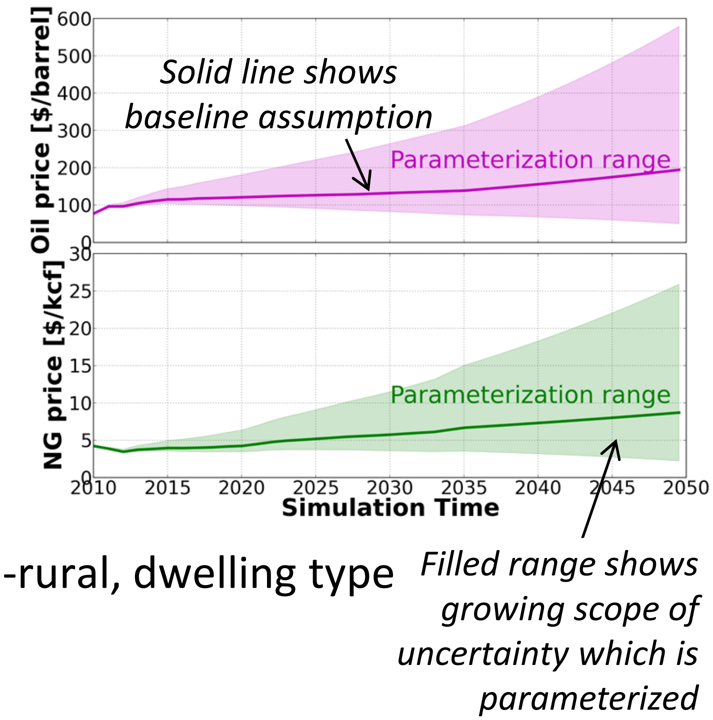
- Conversion costs, GHG emissions derived from *GREET*
- RFS grain mandate is satisfied first, then cellulosic
- Ethanol can be transported between regions

State variations

- Driver demographics – VMT intensity, urban-suburban-rural, dwelling type
- Electricity provided by marginal mix
- Subsidies & incentives

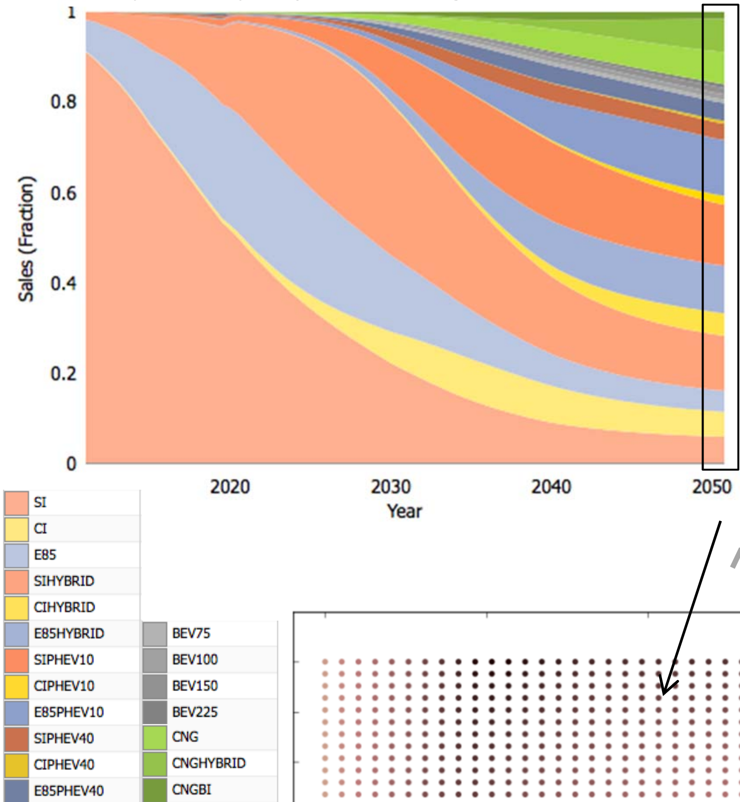
Vehicle model

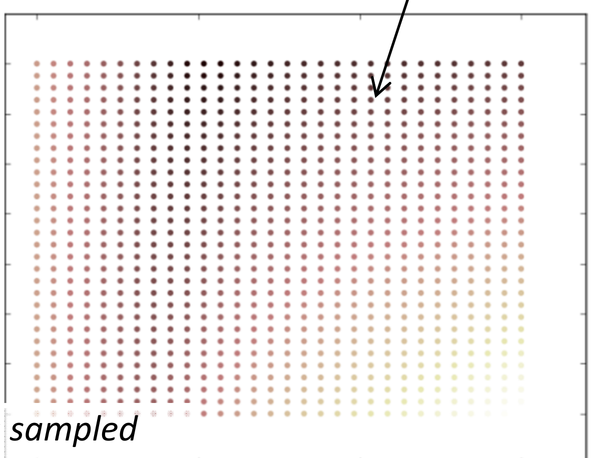
- Consumer choice is nested, multinomial logit type (like *MA3T*)
- Vehicle efficiency, cost, battery capacity from *Autonomie* 2011
- Three year consumer payback period
- CAFE satisfied
- Bifuel vehicles dynamically choose fuel



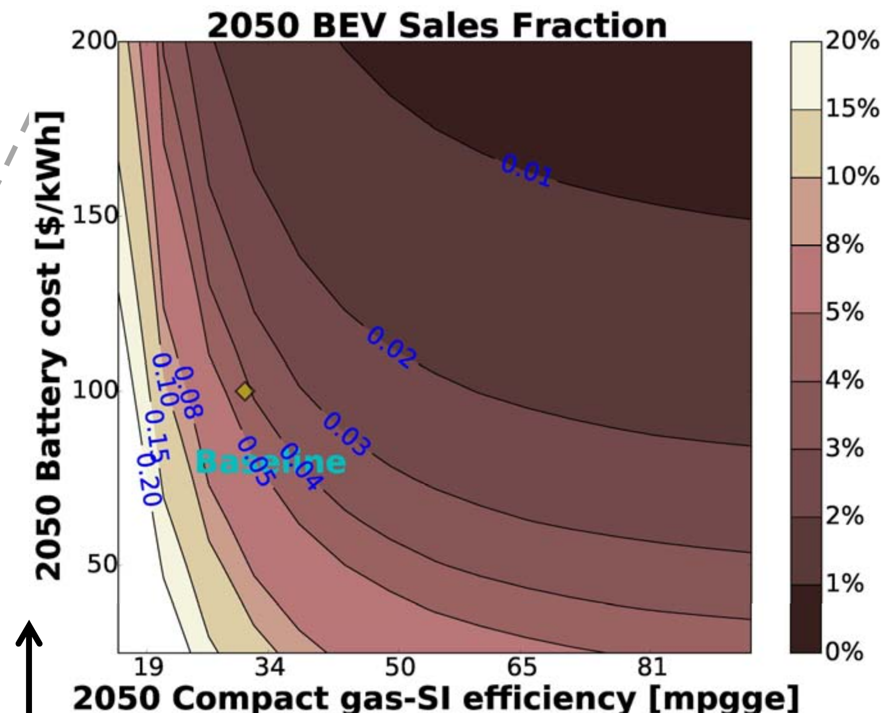
Modeling Approach: Parametric studies focus on one, two, and all parameter variations to explore the trade space

Sample output from a single-scenario case





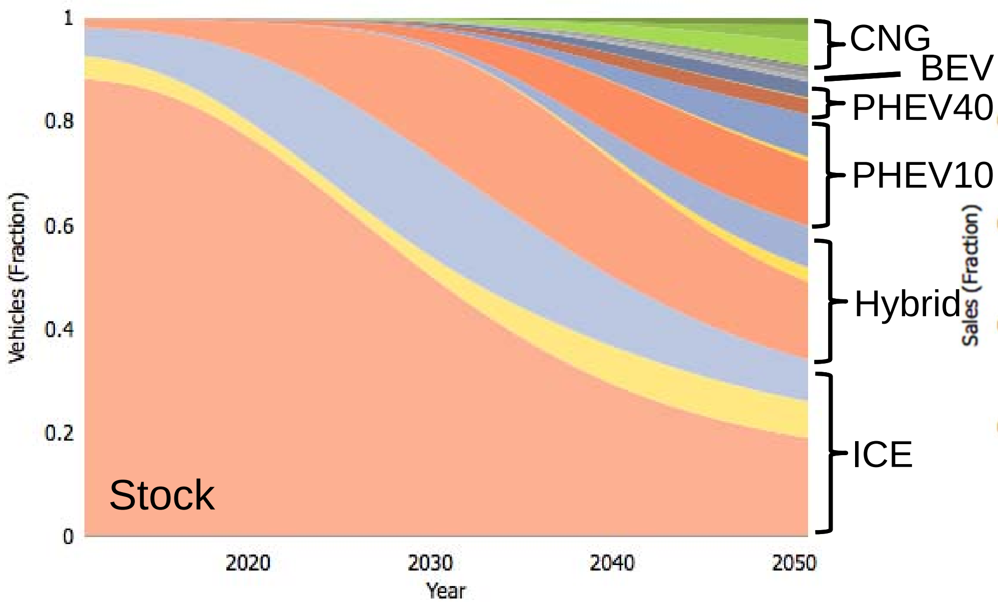
Parameter space is sampled 1000 times to explore tradeoffs

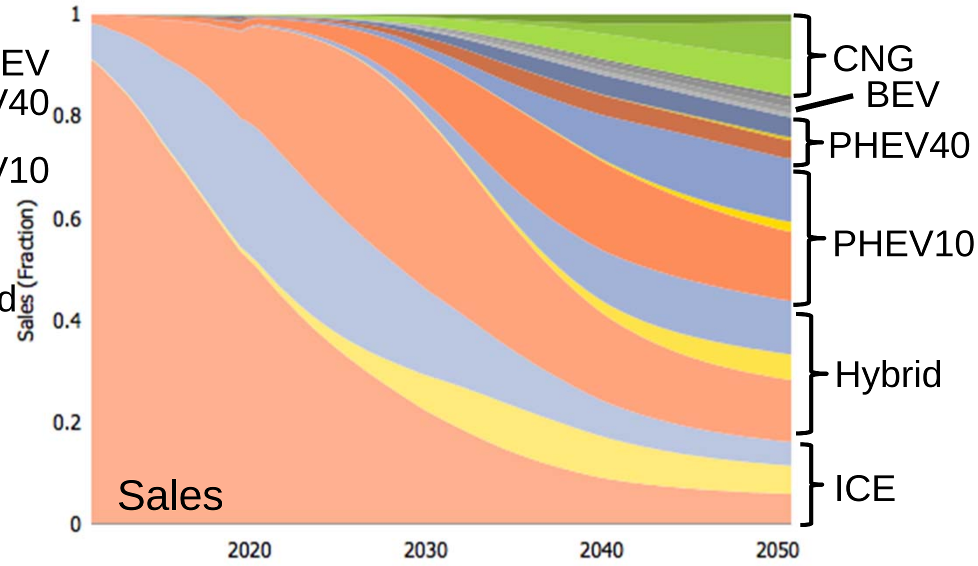


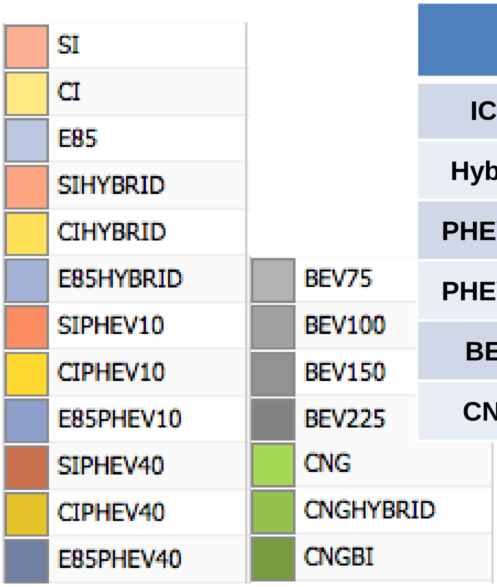
Tradeoff between battery cost uncertainty and engine efficiency

Contour features reveal trade-space insights

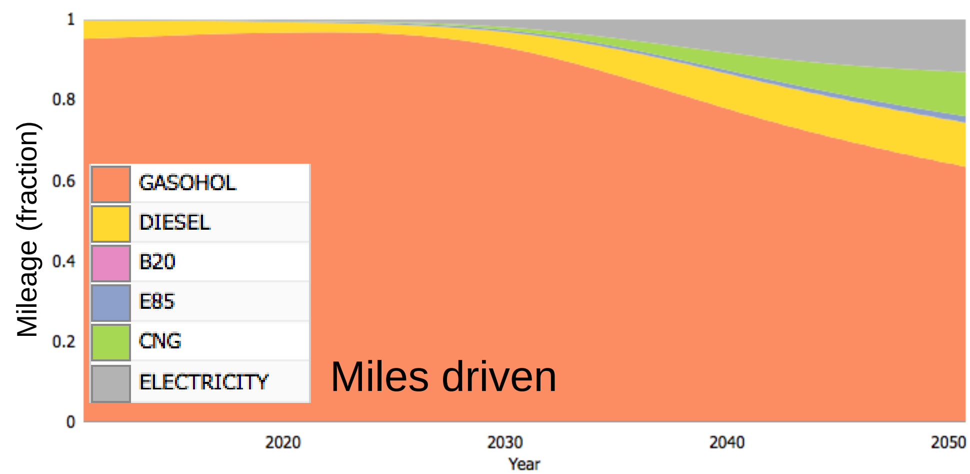
Accomplishments: 2050 Baseline Results for Stock, Sales, Miles Driven





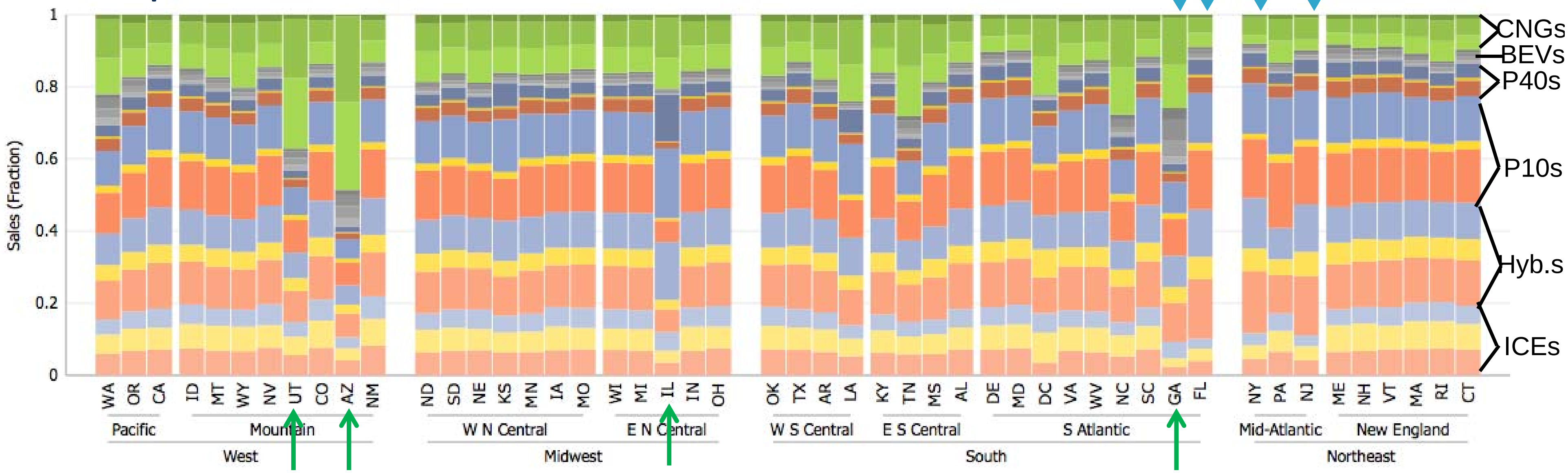


	% 2050 stock	% 2050 sales
ICE	34.2	16.3
Hybrid	25.8	27.7
PHEV10	21.6	27.8
PHEV40	6.1	8.1
BEV	3.2	4.1
CNG	9.1	16.1



Even with significant penetration of alternative vehicles, the majority of miles driven utilize petroleum fuels

Accomplishments: Examining 2050 sales by state illustrates impact of incentives



States with $1875 hybrid & PHEV incentive

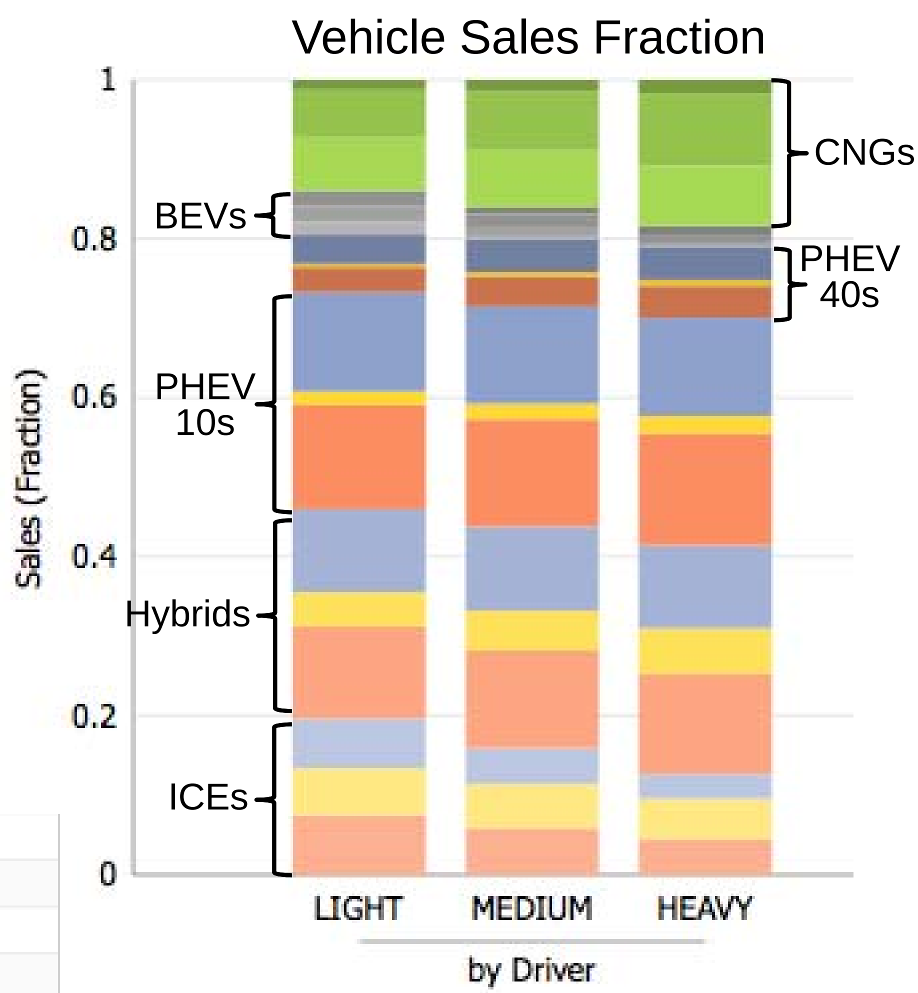
2050 Sales	Hybrid %	PHEV10 %	PHEV40 %
National Avg.	27.7	27.8	8.1
GA	24.0	20.3	5.1
FL	35.8	32.3	9.3
NY	37.4	31.7	8.5
NJ	36.4	31.5	8.4

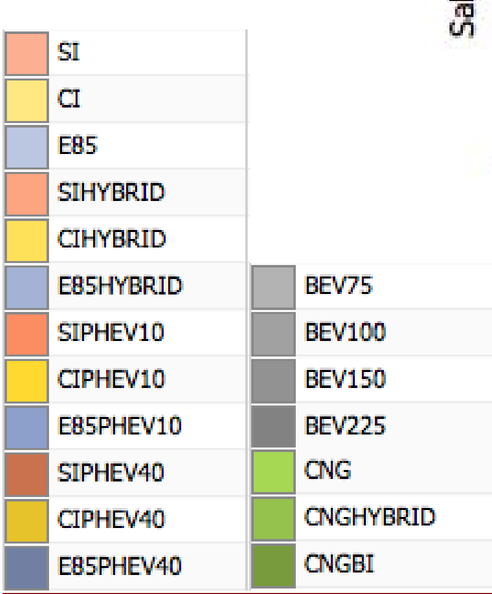
Other notable incentives

	2050 Vehicle incentives
UT	HOV incentive (worth $625/year) for CNG & BEV
AZ	CNG charger discount; tax credits & HOV incentive for CNG & BEV
IL	Many E85 fuel & vehicle incentives
GA	Elec. discounts; tax credits & HOV for CNG, PHEV, & BEV

Accomplishments: 2050 sales broken down by driver demographics – Driving intensity

Light drivers have the highest fraction of BEVs.



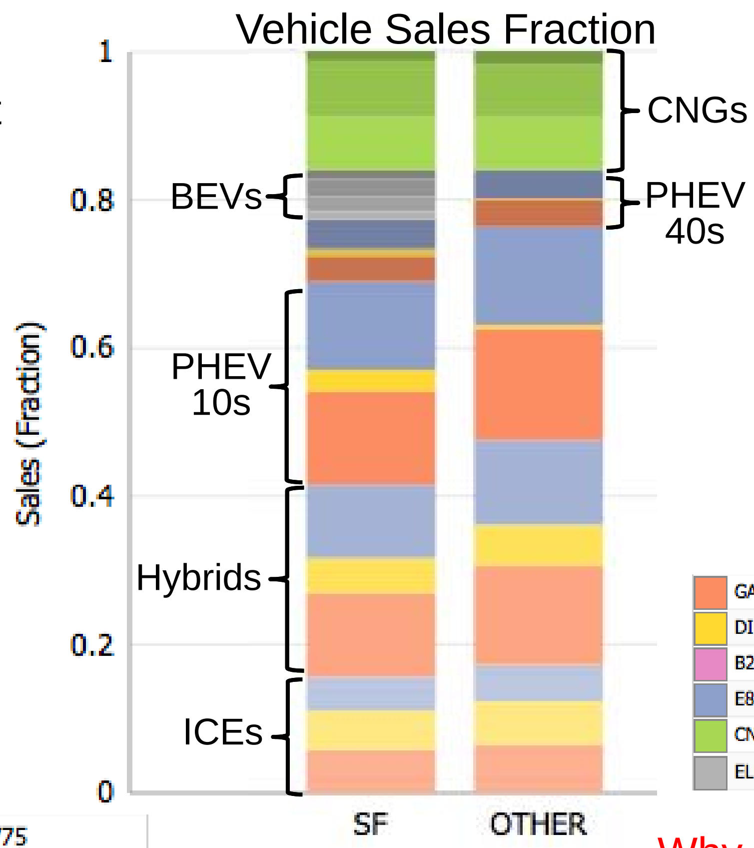


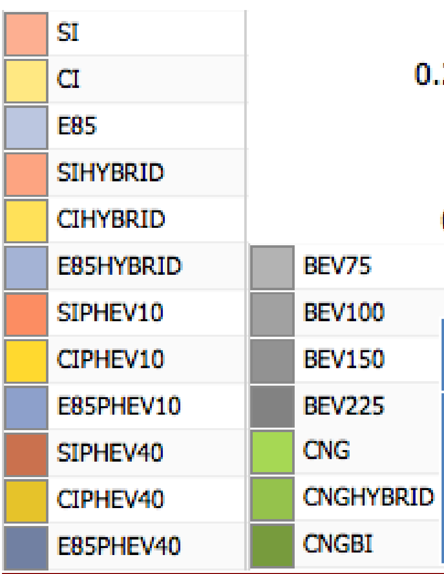
Heavy drivers have the highest fraction of CNGs.

Heavy drivers have a greater fraction of PHEVs and hybrids than lighter drivers. They also tend towards longer range BEVs.

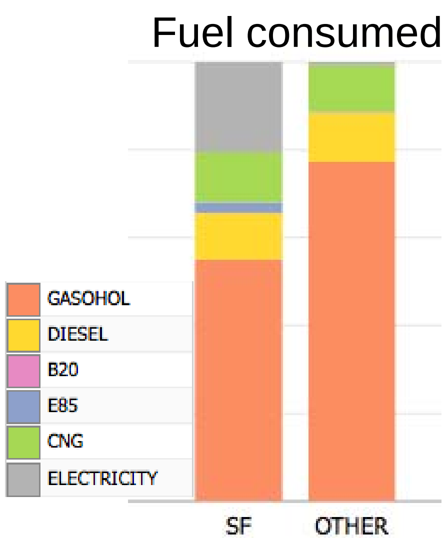
Accomplishments: 2050 sales broken down by driver demographics – Single family versus multi-unit

BEVs are almost exclusively found in single family homes where dedicated charging is available.





- CNG adoption is similar across dwelling types.
- PHEV adoption is also remarkably similar.



- We assume serial driving for PHEVs in SF – a large fraction of PHEV miles electrified.
- Charge-sustaining driving for PHEVs in other yields few electrified miles.

Why is PHEV adoption so similar?

		ICE	Hybrid	PHEV10	PHEV40	BEVs	CNGs
% of 2050 sales	SF	15.7	26.0	27.3	8.4	6.7	16.0
	Other	17.2	30.3	28.7	7.8	0.0	16.0

Vehicle efficiency (in charge sustaining mode) is driving PHEV adoption among multi-unit dwellers

	SI	SIHybrid	SIPHEV10	SIPHEV40	BEV150
2045 CS efficiencies (mpg)	29.38	48.60	50.16	40.74	NA
2045 CD efficiencies (Wh/mi)	NA	NA	159.5	222.4	234.2
2045 veh. price over conventional	$0	$1,251	$1,912	$5,400	$5,229

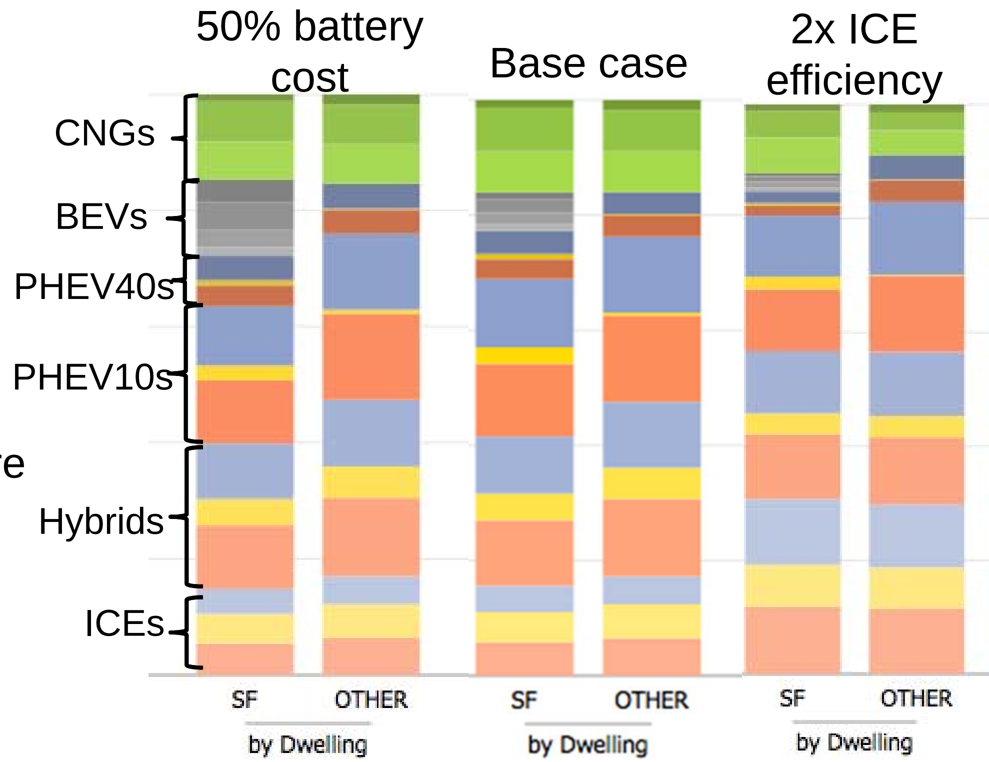
Assuming midsize vehicles, Autonomie 2011
Prices converted to 2012 dollars.
Price mark-ups do not include charger costs.

What factors influence PHEV adoption and electrified mileage in this population segment?

1. Battery costs (up-front vehicle price)
2. Vehicle ICE efficiency (cost per mile)
3. Public charging infrastructure (number of electrified miles and cost per mile)

How do battery cost and ICE efficiency influence adoption?

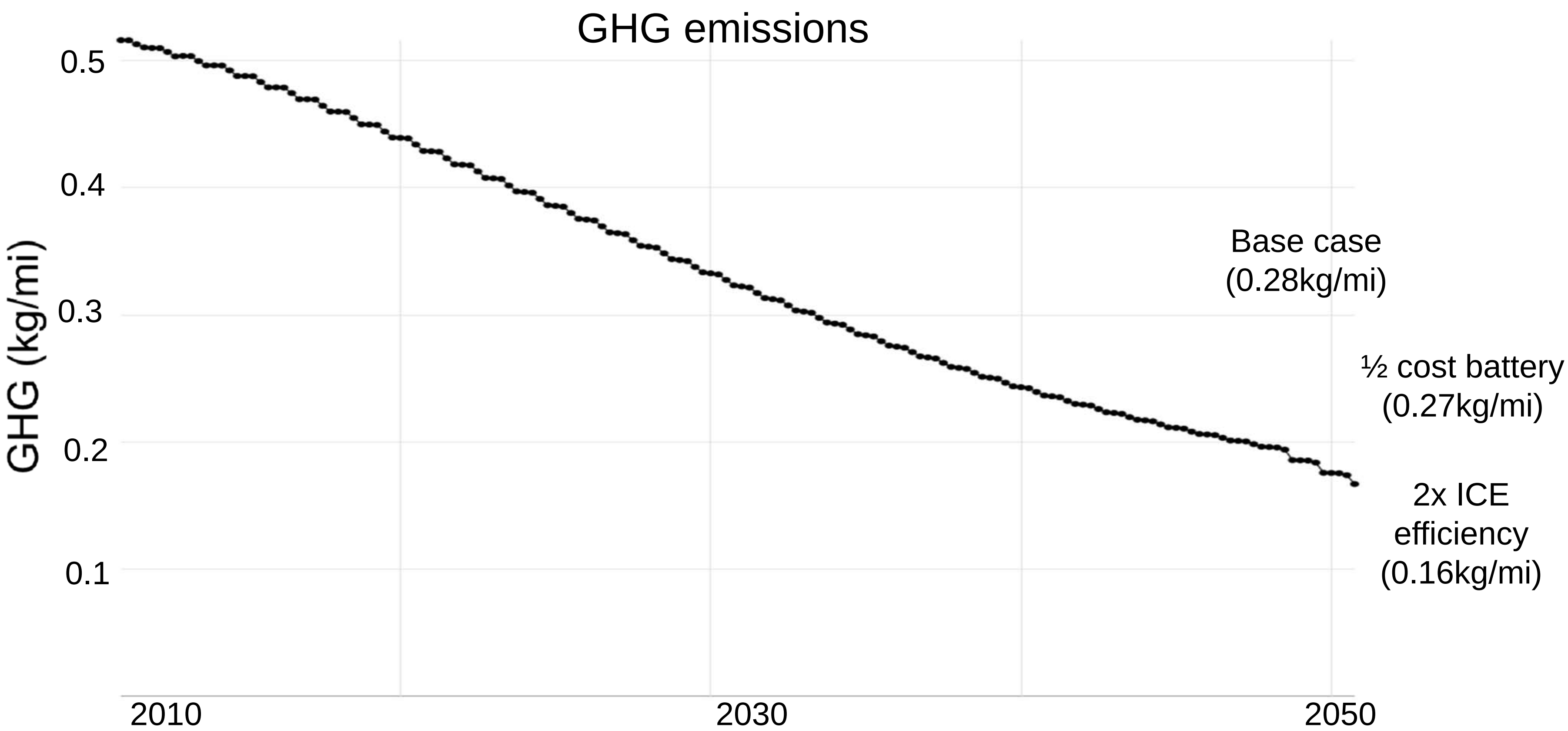
- Decreasing battery cost lowers prices of BEVs & PHEVs; highest electric range vehicles gain market share especially in SF homes.



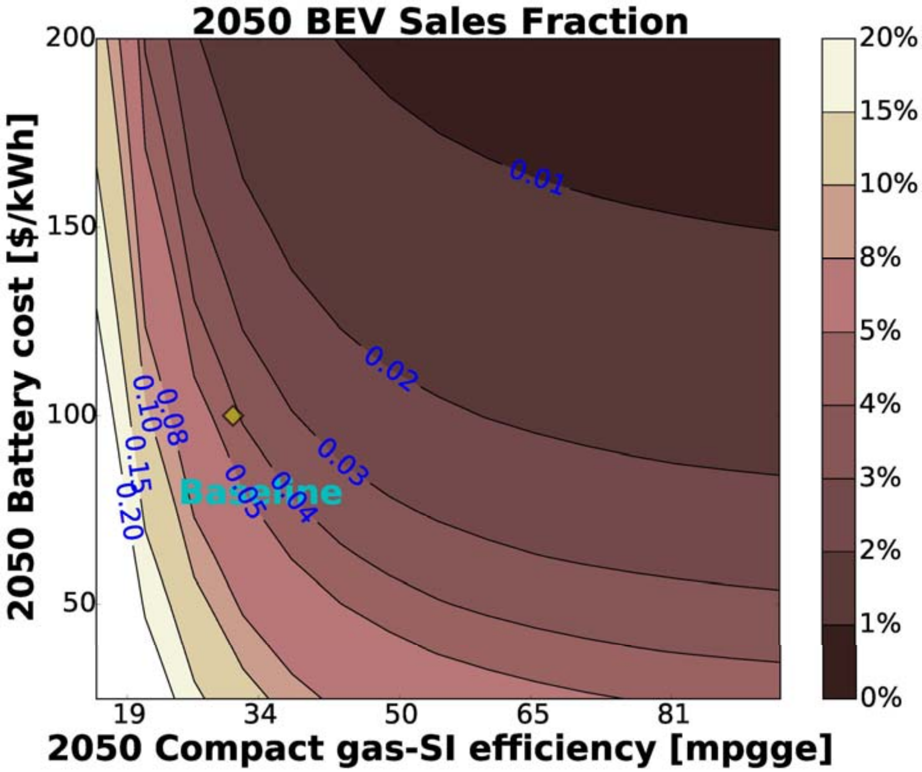
- Dramatically increasing ICE efficiency causes market share of alternatives other than conventional ICEs to decrease.

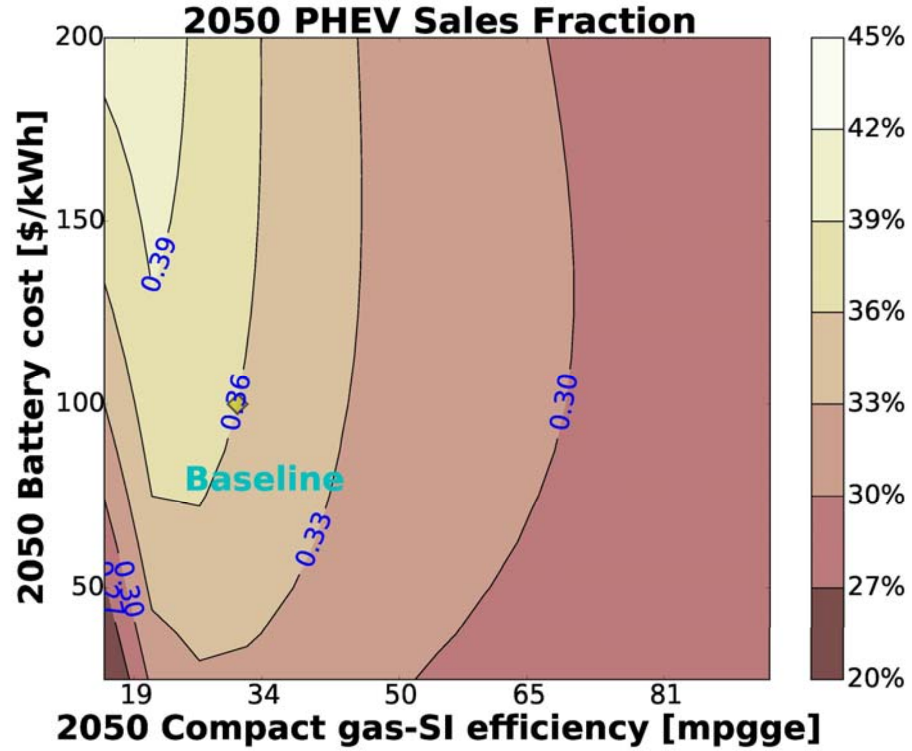
% of 2050 sales		ICE	Hybrid	PHEV10	PHEV40	BEV	CNG
Single Family	base	15.7	26.0	27.3	8.4	6.7	16.0
	½ cost battery	14.8	25.1	23.7	8.7	13.2	14.8
	2x ICE eff.	30.7	26.0	23.8	4.3	3.2	12.0
Other	base	17.2	30.3	28.7	7.8	0.0	16.0
	½ cost battery	17.0	30.4	28.5	8.7	0.0	15.3
	2x ICE eff.	29.9	26.7	26.1	8.1	0.0	8.8

While increasing ICE efficiency decreases market share of alternative vehicles, GHG emissions decrease



Parameterizing ICE efficiency and battery cost shows their relative impact on PHEV and BEV sales

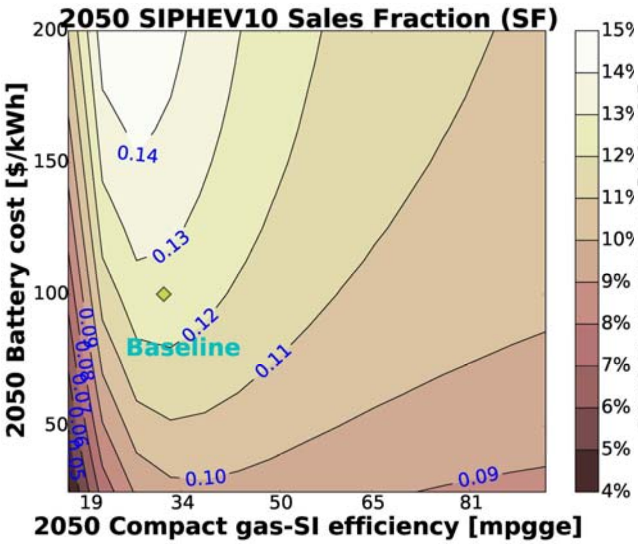


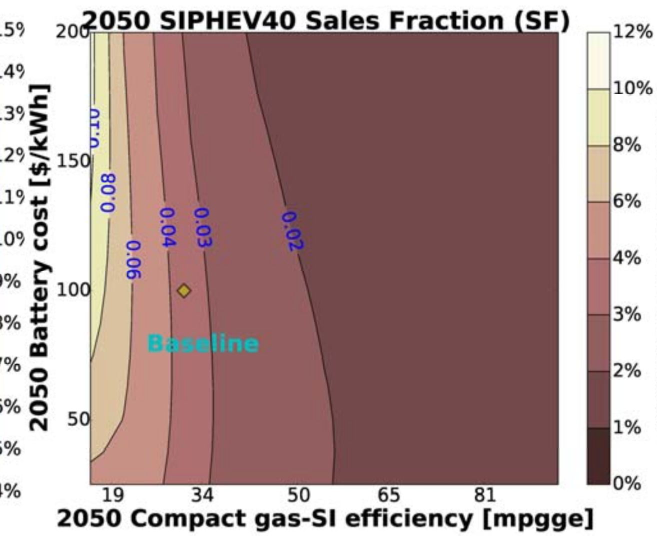


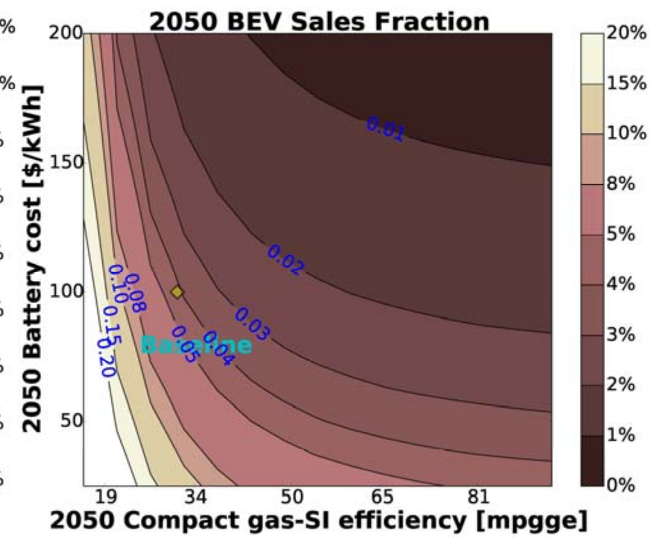
- 2050 BEV sales are less than 10% for all scenarios where conventional SI efficiency is better than 34 mpgge in 2050.

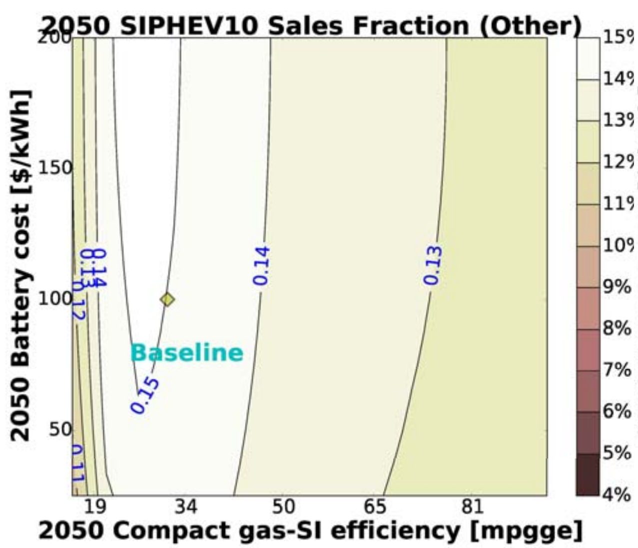
- PHEVs generally lose market share to conventionals & hybrids as ICE efficiencies increase.
- For very low ICE efficiencies, PHEVs lose market share to BEVs.

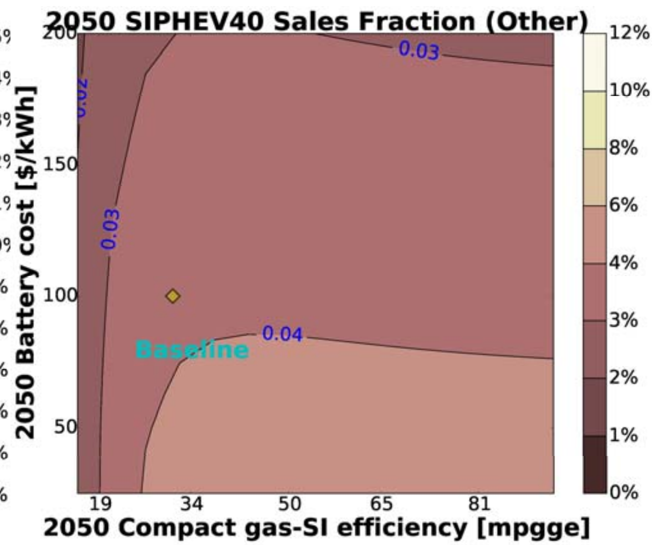
Parametric analysis illustrates impact of dwelling type on PHEV10 vs. PHEV40 sales







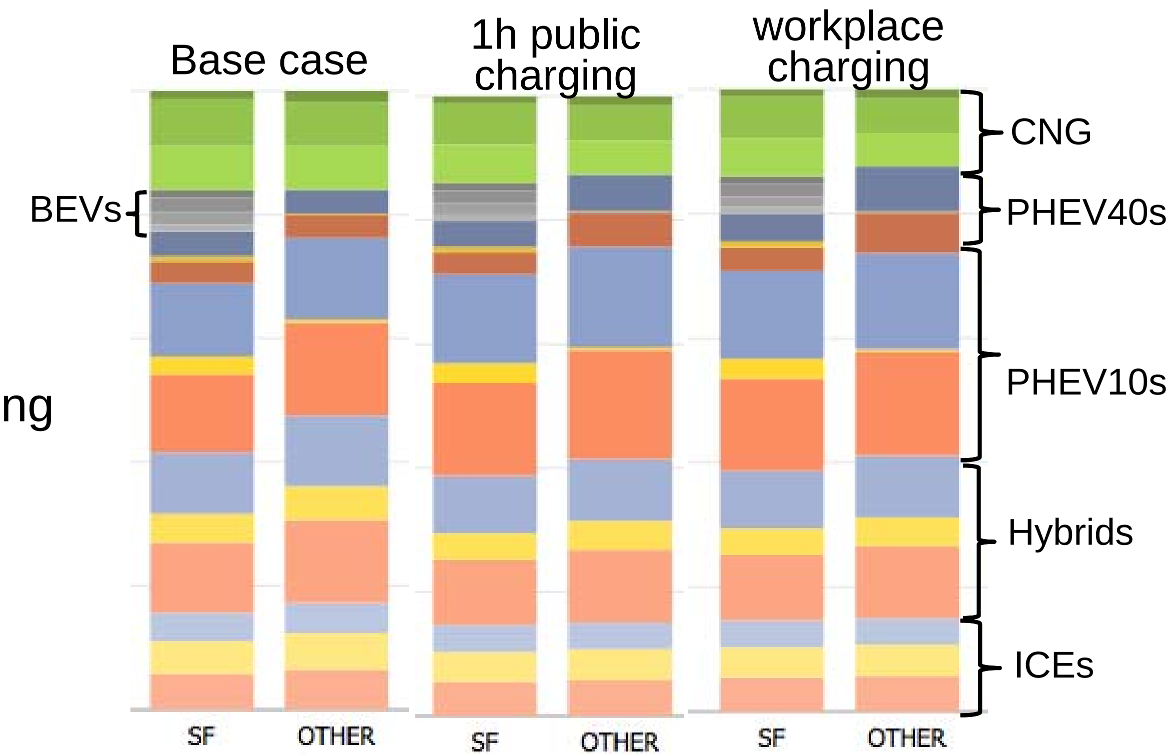




- SF – Sales of PHEVs and BEVs are strongly influenced by ICE efficiency. BEVs and PHEV40s are viable alternatives at low efficiencies.
- Non-SF – When ICE efficiency decreases, BEVs and PHEV40s are not viable alternatives. Hybrids become more prevalent when ICE efficiency is very low.

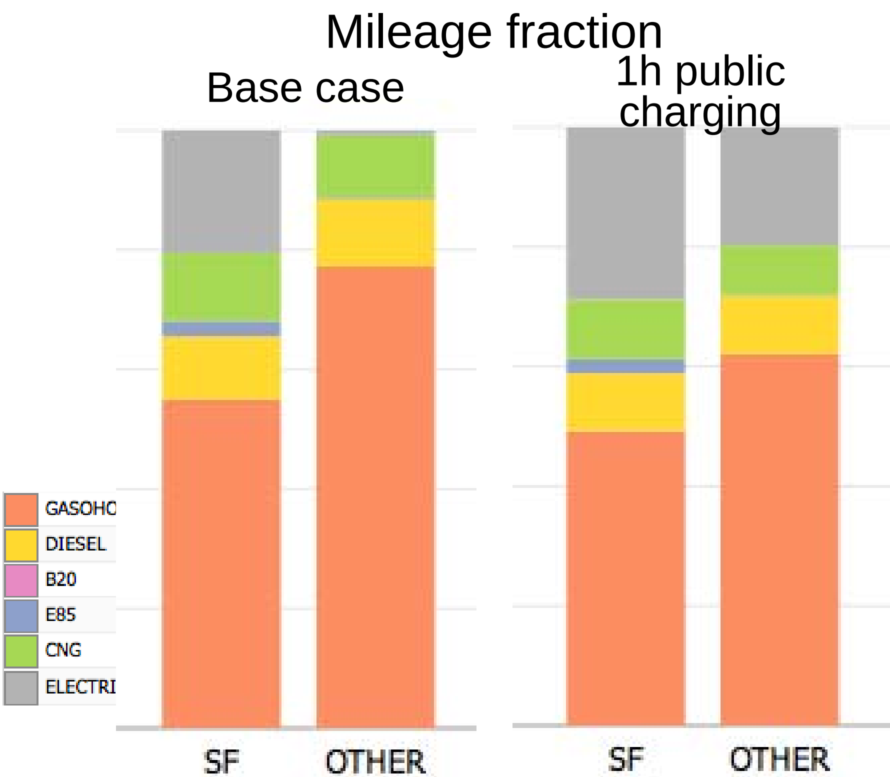
Availability of public charging can significantly influence PHEV adoption

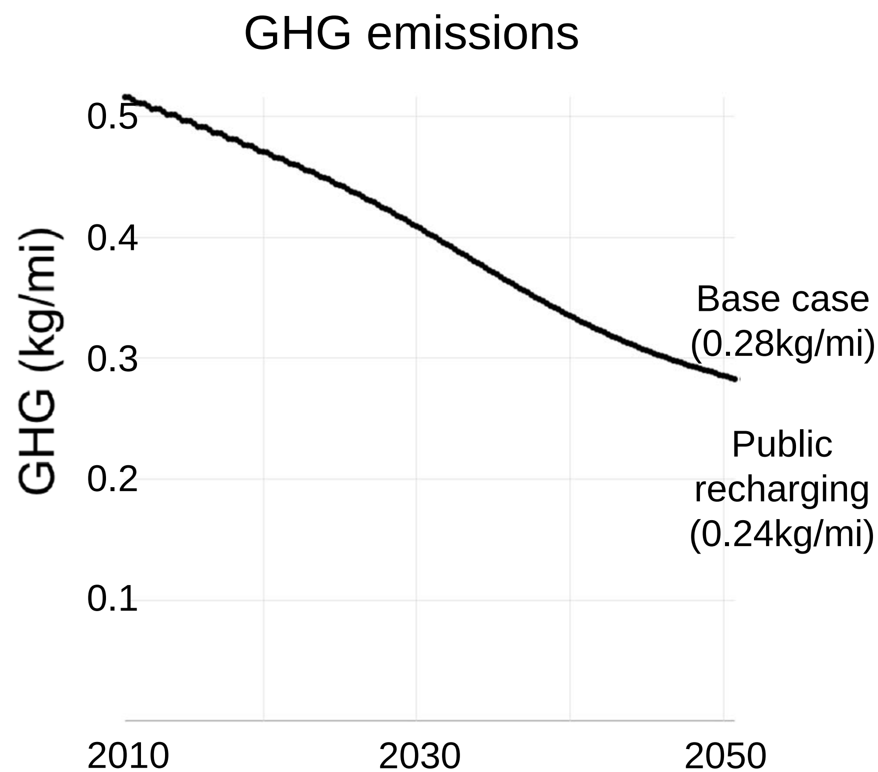
- Access to 1 hour of public charging increases PHEV attractiveness
- Access to 1 'tank' of fully electrified mileage provides additional impact but diminishing returns



			ICE	Hybrid	PHEV10	PHEV40	BEV	CNG
% of 2050 sales	SF	base	15.7	26.0	27.3	8.4	6.7	16.0
		1h public charging	14.7	25.0	32.5	8.6	6.1	14.0
		full public charge	14.6	24.0	32.2	9.1	6.1	14.0
	Other	base	17.2	30.3	28.7	7.8	0.0	16.0
		1h public charging	15.0	26.4	34.3	11.7	0.0	12.6
		full public charge	15.0	26.2	32.5	13.9	0.0	12.4

Public charging can potentially have a large impact on electric miles driven by residents of non-single family housing





			Gasohol	Diesel	E85	CNG	Electricity
% of 2050 miles	SF	base	55.0	10.6	2.5	11.4	20.5
		1h public charging	49.3	9.6	2.3	10.1	28.7
	Other	base	77.3	11.3	0.2	10.4	0.8
		1h public charging	62.1	9.7	0.0	8.3	19.7

Technical Accomplishments

Peer-reviewed Publications

- Barter GE, Tamor MA, Manley DK, West TH. *The implications of modeling range and infrastructure barriers to battery electric vehicle adoption*. Accepted for publication in *Transportation Research Record* (2015).
  - Recipient of the Transportation Research Board 2015 Barry McNutt Award
- Previous work: Peterson MB, Barter GE, Manley DK, West TH. *A parametric study of light-duty natural gas vehicle competitiveness in the United States through 2050*. *Applied Energy*, 125, 206-217 (2014).
- Previous work: Westbrook J, Barter GE, Manley DK, West TH. *A parametric analysis of future ethanol use in the light-duty transportation sector: Can the US meet its Renewable Fuel Standard goals without an enforcement mechanism?* Energy Policy, 65 , 419-431 (2014).

Technical Report

- Manley DK, Barter GE, West TH. *Transitioning the Transportation Sector: Exploring the Intersection of Hydrogen Fuel Cell and Natural Gas Vehicles.* Sandia Technical Report SAND2015-0437.

Presentations

- Manley D, Barter G, Peterson M, Askin A, Westbrook J, West T. *Opportunities in Transportation – Short and Long Term Strategies*. U.S. Department of Transportation Climate Adaptation and Mitigation Workshop, Washington DC, February 25-26, 2015.
- Barter, GE, Tamor, ME, Manley, DK, West, TH. *The implications of modeling range and infrastructure barriers to battery electric vehicle adoption*. Transportation Research Board 94th Annual Meeting, Washington, DC, January 11-15, 2015.
- Manley D, Clay K, Joseck F, Scott C, Ward J, West T. *Transitioning the Transportation Sector: Exploring the Intersection of Hydrogen Fuel Cell and Natural Gas Vehicles*. American Institute of Chemical Engineers Alternative Natural Gas Applications Workshop, Alexandria, VA, October 8-9, 2014.
- Manley DK, Barter GE, *Parametric Sensitivities to Alternative Fuel and Vehicle Model Factors*. U.S. Department of Energy Vehicle Choice Modeling Workshop, Davis, CA, October 1, 2014.

Collaboration with other institutions

- Incorporation of real world driving cycles in collaboration with Ford
- Model input and review from ANL, ORNL, NREL, Energetics
- Technical critiques on modeling and analysis:
  - DOE
  - DOT
  - Ford Motor Company
  - General Electric
  - American Gas Association
- Workshop Organizing Committee
  - Toyota
  - American Gas Association
  - DOE

Remaining Challenges and Barriers

- Availability of alternative fuel and charging infrastructure
  - Deeper understanding of impact of refueling infrastructure availability
- Availability of AFVs and electric drive vehicles
  - Impact of additional technology options, including hydrogen fuel cell electric vehicles
- Uncertainty in vehicle choice models and projections
  - Characterize factors that lead to different projections
- Identification of largest leverage points for reducing petroleum consumption and greenhouse gas emissions
- Role of alternative fuels, technologies, and infrastructure on heavy duty vehicle emissions and petroleum consumption

Future work

- Challenge: Availability of alternative fuel and charging infrastructure
  - FW: Conduct deeper tradeoff analyses that explore refueling infrastructure availability
- Challenge: Availability of AFVs and electric drive vehicles
  - FW: Include hydrogen fuel cell electric vehicles in tradeoff analyses. Initial modeling of hydrogen production pathways & FCEVs in **Project SA055 – Hydrogen Analysis with ParaChoice Model,** presented 6/9/15, 3:15pm, Crystal City, Room/Salon F
- Challenge: Uncertainty in vehicle choice models and projections
  - FW: Characterize factors that lead to different projections
  - FW: Compare results with other models in VTO analysis portfolio
- Challenge: Identification of largest leverage points for reducing petroleum consumption and greenhouse gas emissions
  - FW: Conduct parametric analyses that more deeply explore fuel infrastructure availability, vehicle model availability, impact of lower cost or higher performance technological advances
- Challenge: Role of alternative fuels, technologies, and infrastructure on heavy duty vehicle emissions and petroleum consumption
  - FW: Expand parametric modeling & analyses to consider heavy duty vehicles

Summary

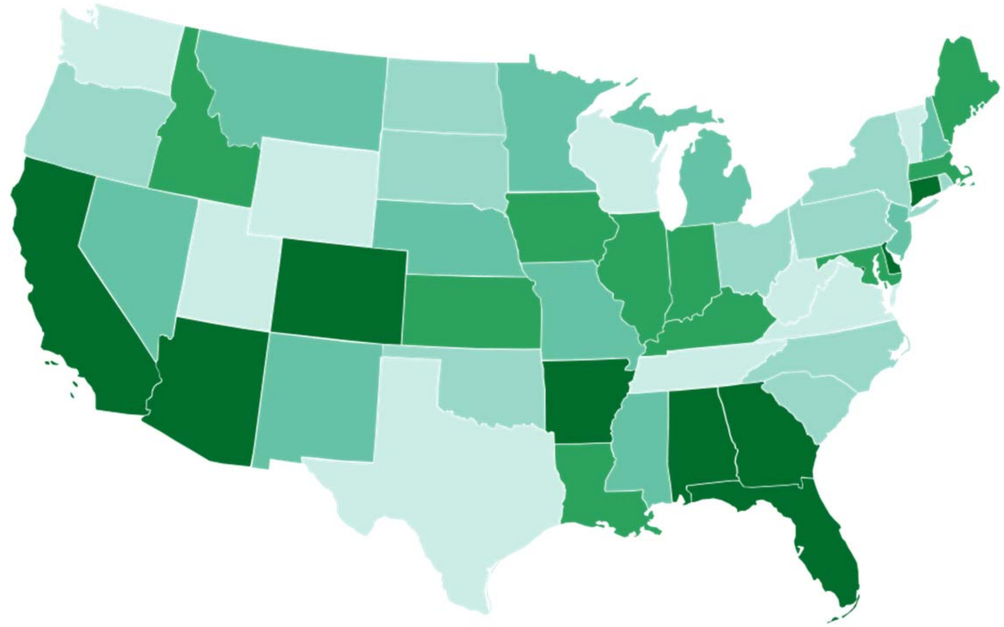
- Engagement with diverse stakeholders provides context for key questions & issues to focus analysis
- ParaChoice provides a parametric approach to vehicle choice modeling that includes feedback loops to fuel production and raw energy stocks
- Parametric approach reveals the sets of conditions that must be true to reach performance goals and the tradeoffs present in the uncertainty space.
- Analyses with this model have led to peer-reviewed publications focusing on NGV competitiveness, EV competitiveness, and the Renewable Fuel Standard.
- Segmentation by vehicle type and driver demographics illustrates factors that influence alternative technology adoption and fuel use. Work this year focused on how dwelling type, ICE efficiency, battery cost, and charging infrastructure influenced PHEV and BEV adoption and electrified miles.

TECHNICAL BACK-UP SLIDES

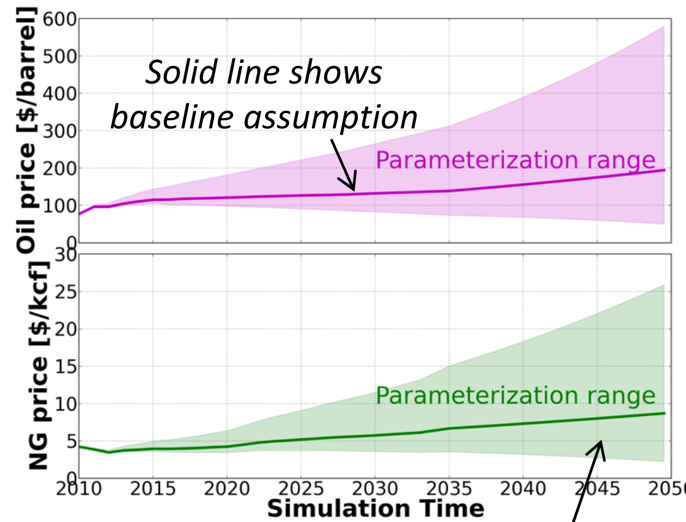
Modeling Approach: Energy supplies, fuels, and vehicle mixes vary by state

State-level Variations

- Vehicles
  - Numbers, sizes, drive-train mixes
- Driver demographics
  - VMT intensity, urban-suburban-rural divisions, single-family vs. other home rates
- Fuels
  - Costs, electricity mix, taxes & fees, alternative fuel infrastructure
- Energy supply curves (as appropriate)
  - Biomass, natural gas
- Policy
  - Consumer subsidies and incentives



Modeling Approach: Model inputs are taken from published sources when possible, and many are parameterized



Filled range shows growing scope of uncertainty which is parameterized

Energy sources

- Oil: Global price EIA Annual Energy Outlook (2014)
- Coal: National price EIA AEO (2014)
- NG: Regional price EIA AEO (2014)
  - Differential prices for industrial, power, & residential
- Biomass: State supply curves ORNL's Billion Ton Study
  - Price corrected to match current feedstock markets

Fuel conversion and distribution

- Conversion costs and GHG emissions derived from ANL GREET model
- RFS grain mandate is satisfied first, then cellulosic (but not enforced)
  - Gasohol blendstock allowed to rise from E10 to E15
- Ethanol can be transported from one region to another for cost or supply balance
- Electricity grid
  - State-based electricity mix, allowed to evolve according to population growth and energy costs
  - Intermittent and "always-on" sources assumed to supply base load first
  - Vehicles assumed to be supplied by marginal mix

Modeling Approach: Model inputs are taken from published sources when possible, but many are parameterized

Vehicle model

- Consumers do not change vehicle class (size)
- VMT varies by model segmentation, but does not change over time
- LDV stock growth rate is the same as population growth rate (per capita vehicles is constant)
- Consumers have baseline 3 year required payback period with no discounting
- Vehicle efficiency, cost, and battery capacity taken from ANL *Autonomie* 2011 model analysis
- CAFE requirements are satisfied
- Consumer choice model is nested, multinomial logit type (like MA3T)
  - Sale shares depend on amortized consumer *utility cost* = vehicle purchase price – subsidies + fuel operating costs + penalties (range and fuel availability)
- Bi-fuel vehicles (E85 FFVs and CNG bi-fuel vehicle) dynamically choose fuel use rate breakdown using:

(Probability of visiting a station with CNG) * (Willing-to-pay price premium)

Changes as new pumps are added in response to vehicle sales → (Probability of visiting a station with CNG)

Responds to market conditions (price sensitivity is parameterized) → (Willing-to-pay price premium)

Modeling Approach: The vehicle sub-model is focused on tracking LDV stock evolution and capturing the elements of consumer choice