VAN005

Consumer-Segmented Vehicle Choice Modeling: the MA3T Model

Principal Investigator(s):

Zhenhong Lin (Presenter)

Changzheng Liu

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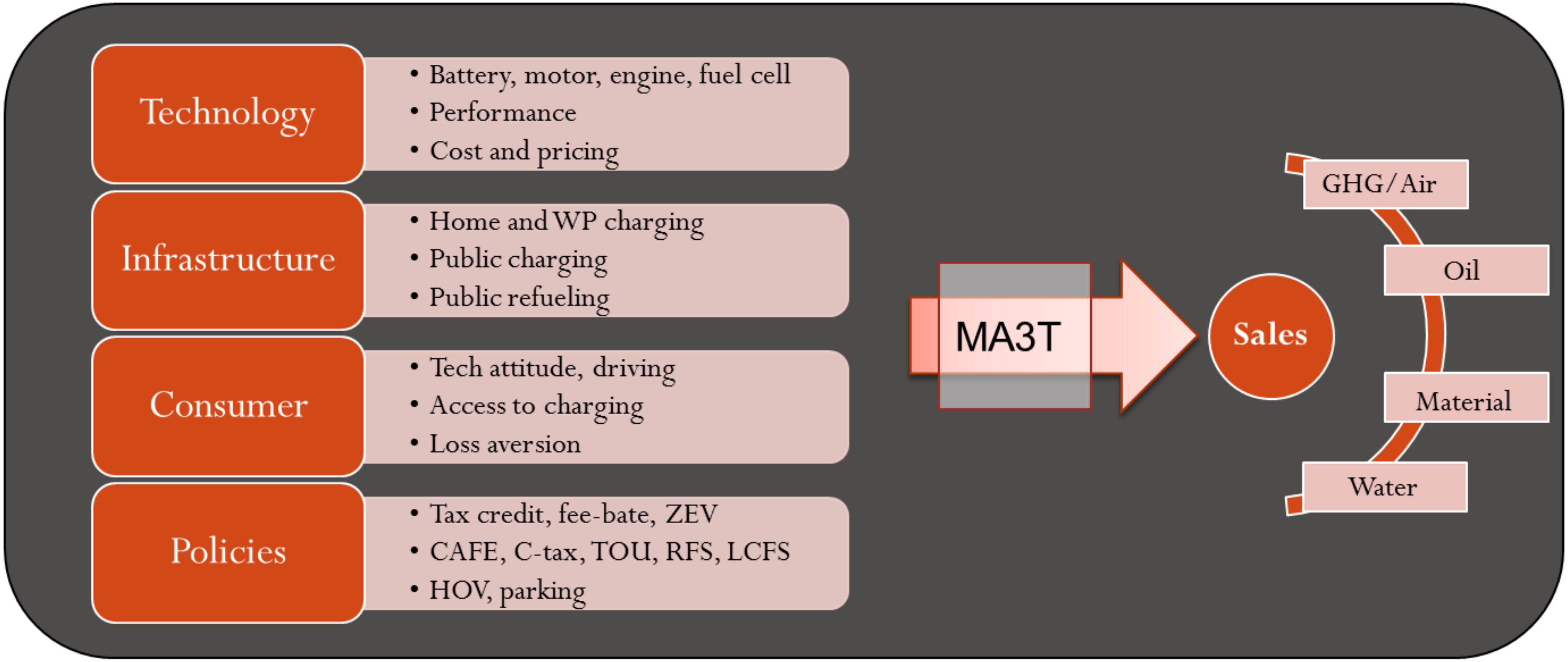
OVERVIEW

Timeline	**Barriers***
• Project start date: Oct. 2011 • Project end date: Continuing	• Costs of advanced powertrains • Behavior of manufactures and consumers • Infrastructure • Incentives, regulations and other policies **from 2011-2015 VTP MYPP*
Budget (DOE share)	**Partners**
• FY13 funding: $395k • FY14 (current expected) funding: $350k	• SRA International • Entergy Corporation • Argonne National Laboratory • Energy Information Administration • University of California, Davis • Iowa State University • University of Tennessee

MA3T—a scenario analysis tool for estimating market shares, social benefits and costs during LDV powertrain transitions, as resulting from technology, infrastructure, behavior, and policies

- Objective: improving the MA3T model on credibility, usefulness and user-friendliness.
- To address barriers in the VTO Multi-Year Program Plan: Costs of advanced powertrains; Behavior of manufactures and consumers; Infrastructure; Incentives, regulations and other policies



MA3T = Market Acceptance of Advanced Automotive Technologies

MA3T is calibrated, partially validated, fully-functional, and being officially used by DOE in GPRA analysis.

- Planning specifications
  - 2005-2050, annual basis, 7% discount rate, 10-year vehicle life (5 years for energy cost)
- Choice structure
  - NMNL: 2 LDV purchase decisions, 5 nest layers, 40 choices; SI, CI, HEV, PHEV, BEV, FCEV, CNG
- Consumer segmentation
  - 1458 US LDV consumer segments; 9 regions, 3 areas, 3 adopters, 3 drivers, 3 HC situations, 2 WP situations
- Vehicle attributes
  - vehicle price, fuel economies, refueling hassle, range limitation, acceleration, interior space, towing capability, etc.
- Infrastructure
  - hydrogen, natural gas, electricity, diesel; home, work, public charging
- Policy
  - ARRA PEV tax credit, general tax credit, instant rebate, HOV access, free parking, fee-bate, energy pricing
- Linked models and datasets
  - EIA/AEO 2012, Autonomie, GREET, TE Databook, NHTS 2001/2009, VISION, AHS, HPMS, historical sales/prices, etc.
- Output
  - By vehicle choice: sales, stock, fuel efficiency, fuel availability, recharge availability, purchase subsidy, fee-bate , vehicle MSRP, fuel demand, electricity demand, experience, tailpipe and WTW GHG emissions,
  - By segment: purchase probability by choice, utility components by choice
  - Fleet-wide: consumer surplus
- Integrated logics or theories
  - Learning by doing, R&D progress delay/acceleration, technology co-leaning, international spill-over, technology diffusion
  - Gamma daily distance variation, fuel-travel-back station location, path-dependent charging benefits,
  - Supply constraints, infrastructure utilization, ARRA PEV tax credit design, feebate design, endogenous infrastructure roll-out, automatic calibration

The core of MA3T is a nested multinomial logit (NMNL) model.

- **Discrete choice models**
  - Choice set
  - Choice probabilities
  - Consumer utility

$$Prob(i\ choosing\ j, j \in J) = \frac{e^{\beta X_{ij}}}{\sum_{k \in J} e^{\beta X_{ik}}}$$

Generalized Cost of choice k with M cost components:

$$X_{ik} = \sum_{m \in M} x_{ikm}$$

- **Types**
  - Binary choice
  - Multinomial choice without alternative correlation
    - Independence of Irrelevant Alternatives (IIA) property
  - Multinomial choice with alternative correlation
    - Nested multinomial logit (used in MA3T)
    - Generalized extreme value model
    - Mixed logit

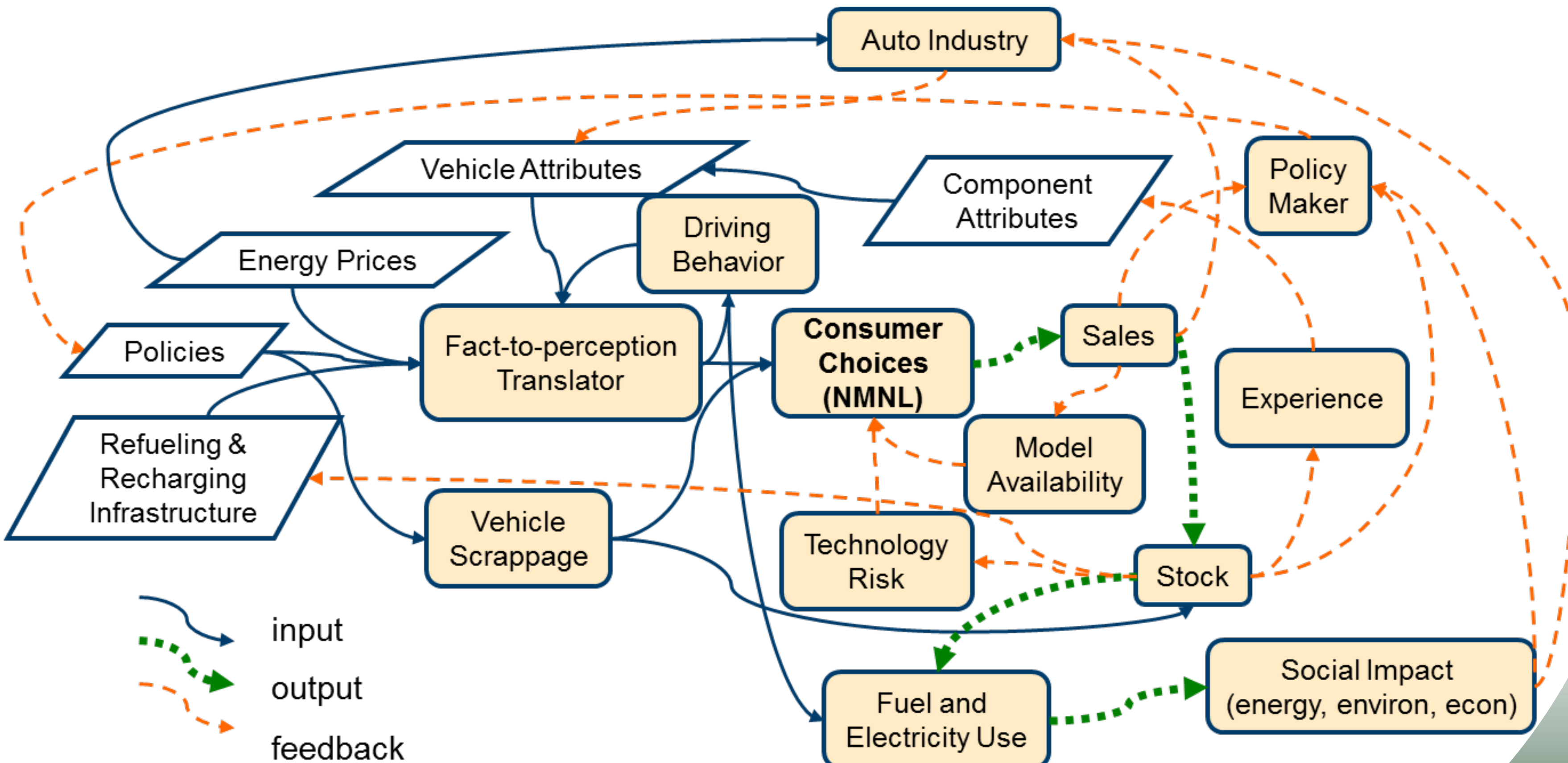
The coefficient β is a function of own-price elasticity η:

$$\beta = \frac{\eta}{X_{ij}(1 - P_j)}$$

- **Coefficient estimation**
  - MLE with revealed preference data
  - MLE with stated preference data
  - Assumed elasticity based on empirical studies

MA3T simulates consumer segment behavior and agent dynamics.

Consumer segment behavior: who will buy what, by how many, when, where, and why.
Agent dynamics: what you do affects what I do.

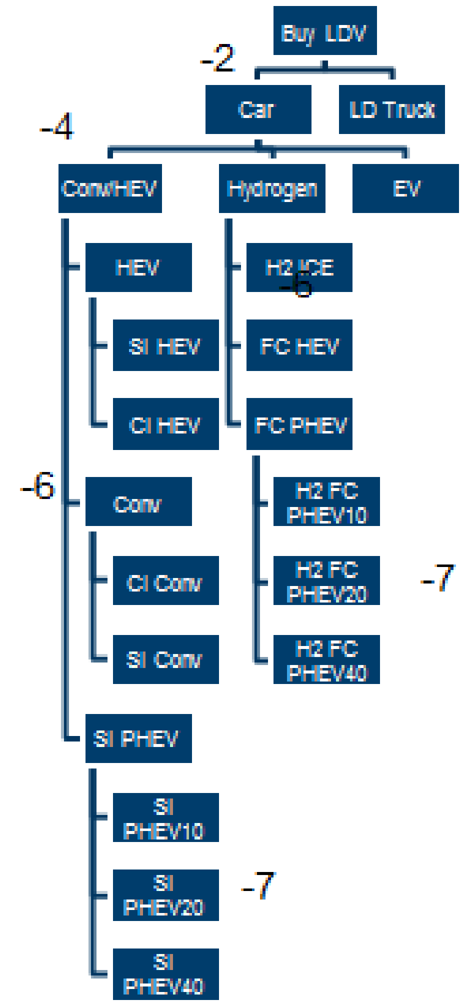


1,458 consumer market segments are characterized by a combination of data and assumptions.

- **Region**
  - 01_NewEngland 02_MiddleAtlantic 03_EastNorthCentral
    04_WestNorthCentral 05_SouthAtlantic 06_EastSouthCentral
    07_WestSouthCentral 08_Mountain 09_Pacific
- **Area**
  - 01_Urban 02_Suburban 03_Rural
- **Technology Attitude**
  - 01_Early-Adopter 02_Early-Majority 03_Late-Majority
- **Driver**
  - 01_Modest-Driver 02_Average-Driver 03_Frequent-Driver
- **Home Charging**
  - 01_Level-1 02_Level-1 03_Neither
- **Work Recharging**
  - 01_With Work Recharging 02_Without

The price slopes of the NMNL model are based on consensus estimates from previous studies.

- **competition among lower level nests/choices is more price sensitive than among the upper level nests**
- **price elasticity in the model can be modified**
- **20 Passenger Cars**
  - **SI/CI/NG Conv**: conventional powertrain powered by gasoline/di
  - **SI/CI/NG HEV**: hybrid vehicle by gasoline/diesel/natual gas
  - **SI PHEV10/20/40**: gasoline PHEV with 10/20/40-mile e-range
  - **H2 ICE**: conventional powertrain with hydrogen ICE
  - **H2 FC HEV**: hybrid vehicle with fuel cell (FC)
  - **H2 FC PHEV10/20/40**: FC PHEV with 10/20/40-mile e-mile
  - **BEV-100/150/200:** battery electric vehicle with 100/150/200-mile EV nest
- **20 Light-duty Trucks**
  - Same nest structure as passenger cars
  - Slightly less price elastic
- The current 2 classes to be expanded into small cars, midsize cars, large cars, SUV and pickup trucks



In FY14, six tasks to make MA3T more useful, credible and user-friendly

- **Structure upgrading**
  - Coherent representation of diverse charging technologies
  - Dynamic wireless charging
  - State incentives
  - Efficiency-cost curve
  - Technology co-learning
  - Phase-out of ARRA tax credit
  - Integration with @Risk
- **Data updating**
  - New Autonomie powertrain simulation data
  - Adopter share and value
  - Driver characterization and share
  - Update with AEO 2014
  - Historical sales data
- **Parameter calibrating**
  - Expand the calibration period to 2005-2012
- **Result validating**
  - Comparing predicted market shares to actual
- **Application**
  - GPRA analysis
  - DOE program goal impacts
  - Dynamic wireless charging impact
  - Fueleconomy.gov PHEV Calculator for utility factor analysis
- **Publication**

Implementing new mathematical relationships and improving algorithms of existing ones make MA3T more useful and user-friendly

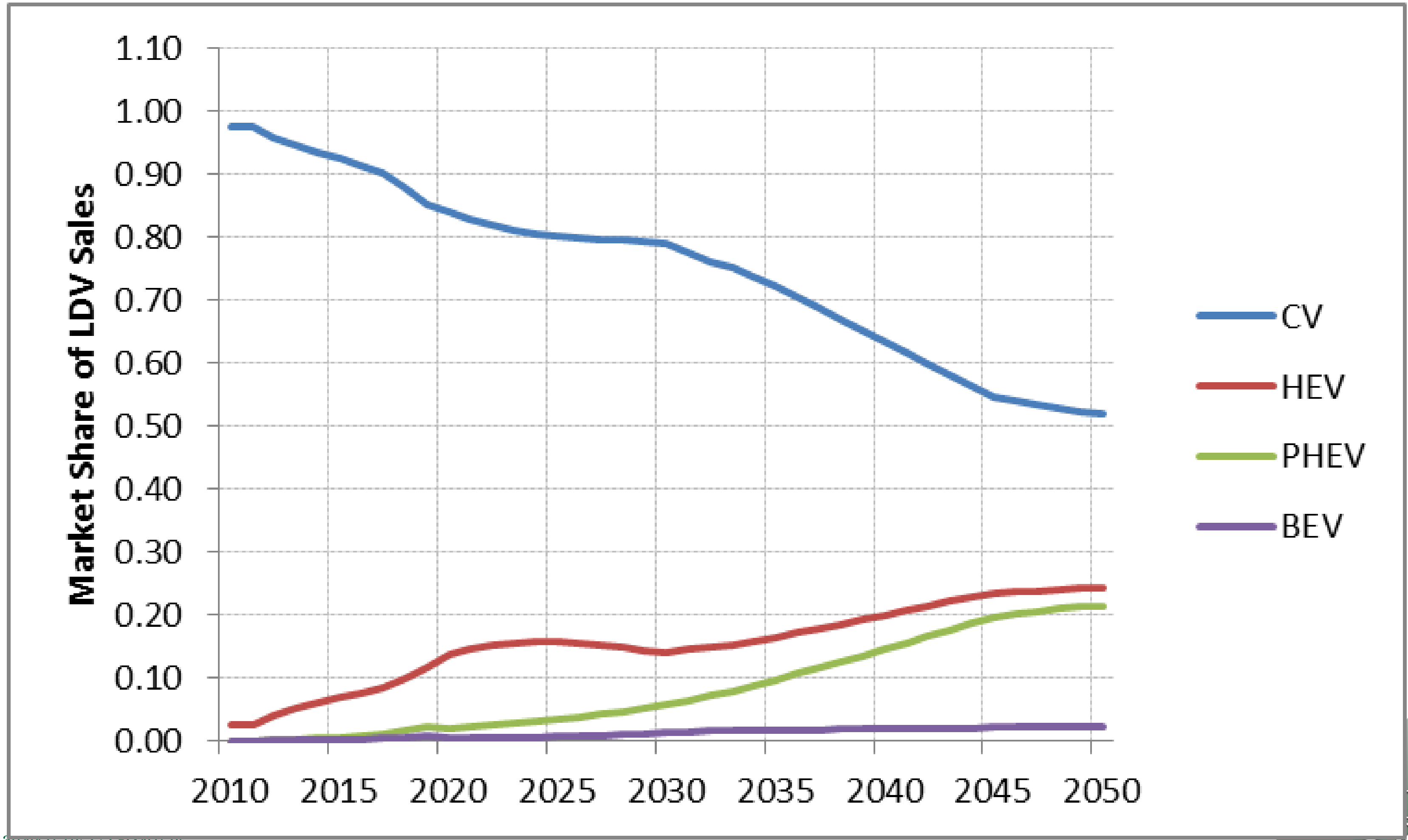
- **Coherent representation of diverse charging technologies** (new math, completed)
  - All in a coherent framework: home, workplace, public, and on-road warless charging
- **Dynamic wireless charging** (new math, completed)
  - Link DWC deployment and PEV sales
- **State incentives** (new math, ongoing)
  - Explain market share variance among states
- **Efficiency-cost curve** (new math, ongoing)
  - Allow gasoline vehicle tradeoff between fuel economy and price
- **Technology co-learning** (new math, completed)
  - Capture spillover effect between powertrains
- **Phase-out of ARRA tax credit** (new math, ongoing)
  - Avoid sudden drop of market shares on policy expiration

For result relevancy and credibility, MA3T keeps up with new data and projections of technologies, behavior, infrastructure and policies.

- **Adopter share and value** (completed)
  - Technology diffusion theory; industry information
- **Driver characterization and share** (completed)
  - NHTS 2001/2009
- **Powertrain price, efficiency, and range data** (on-going)
  - Automomie
- **Demographics and energy prices** (on-going)
  - AEO 2014
- **Historical sales data** (on-going)
  - ORNL Transportation Energy Databook, ANL PEV Sales Data, WardsAuto, Autonews.com, Hybriddashboard.com

The new Base case of MA3T: new vehicle data leads to lower predicted sales of PEVs.

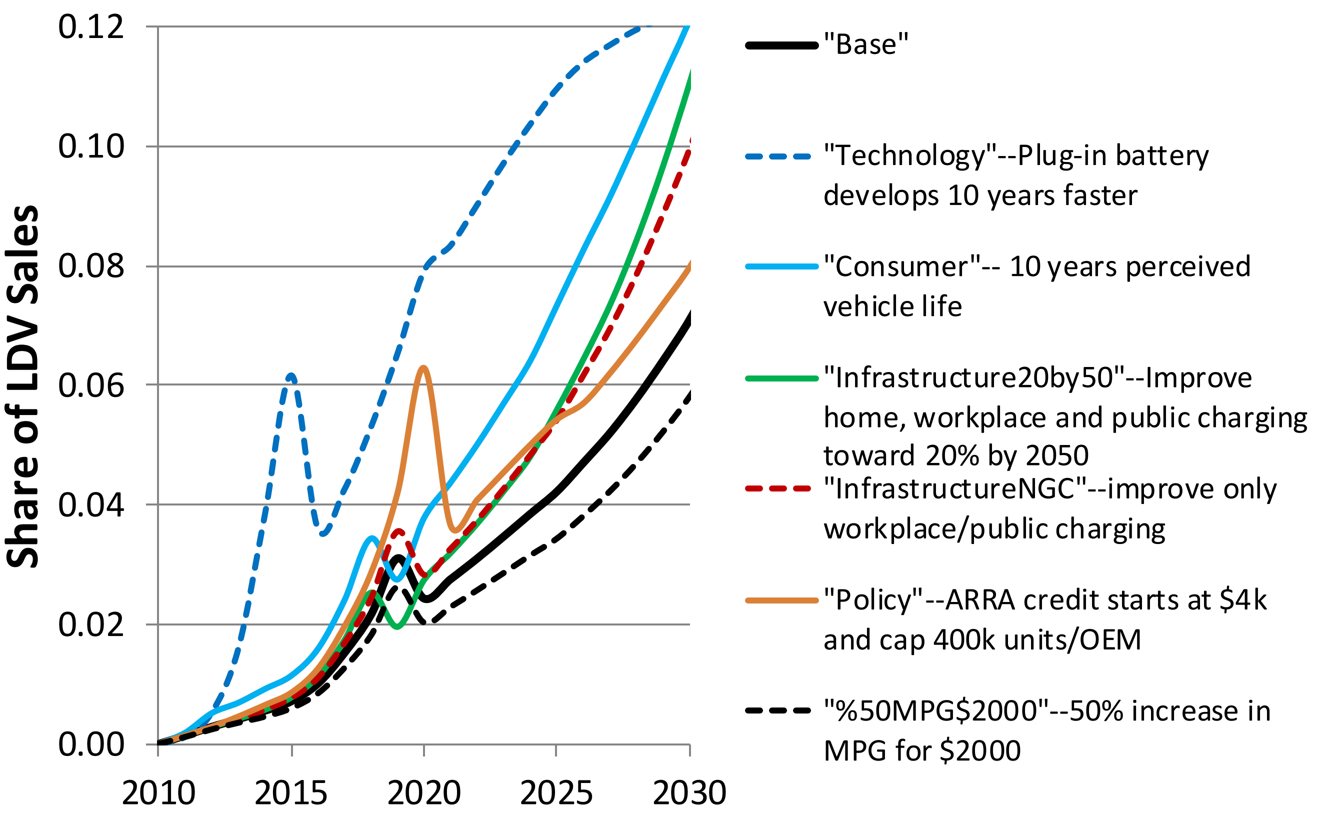
If the new Autonomie data reflects the new CAFE, one question is if the new CAFE make it easier or more difficult for PEVs to compete.



A typical example of using MA3T

The sudden drops due to expiration of ARRA tax credit and will be eliminated with implementation of the ARRA phase-out mechanism.

Notice 2009-89: *New Qualified Plug-in Electric Drive Motor Vehicle Credit*". Internal Revenue Service. 2009-11-30. Retrieved 2014-04-11.

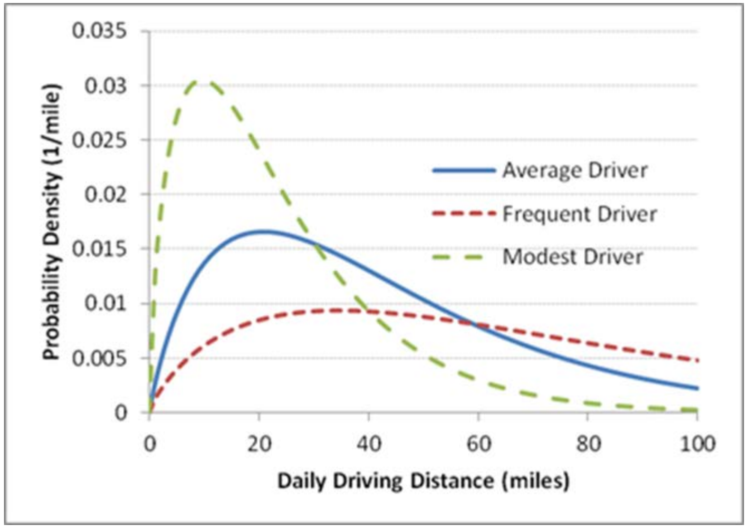


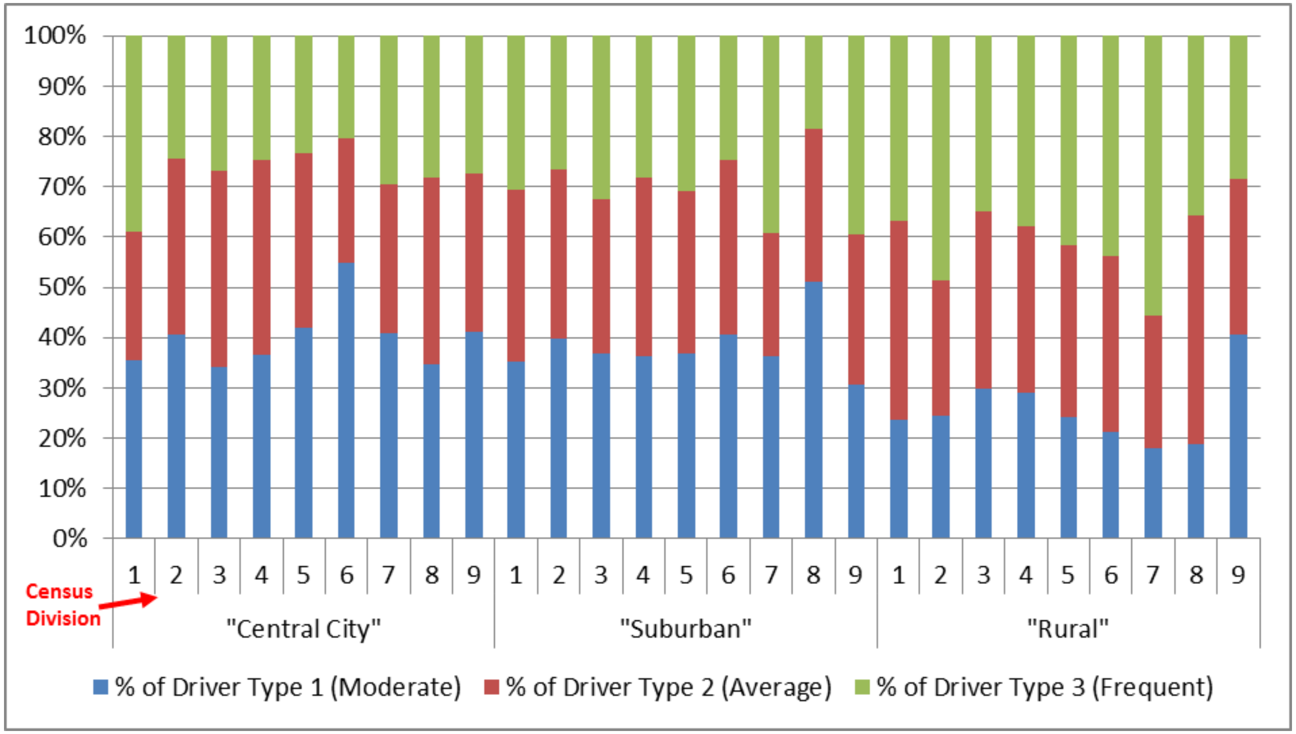
Different powertrains share similar components (e.g. battery). MA3T captures technology co-learning between powertrains.

Component Cost Ratio								
	SI HEV	**P10**	**P20**	**P40**	**FCV**	**FCV P10**	**FCV P40**	**BEV100**
Motor	0.31	0.26	0.22	0.17	0.17	0.17	0.12	0.08
FC	0.00	0.00	0.00	0.00	0.48	0.38	0.26	0.00
Battery	0.16	0.27	0.40	0.54	0.11	0.21	0.47	0.86
H2 Storage	0.00	0.00	0.00	0.00	0.09	0.09	0.06	0.00

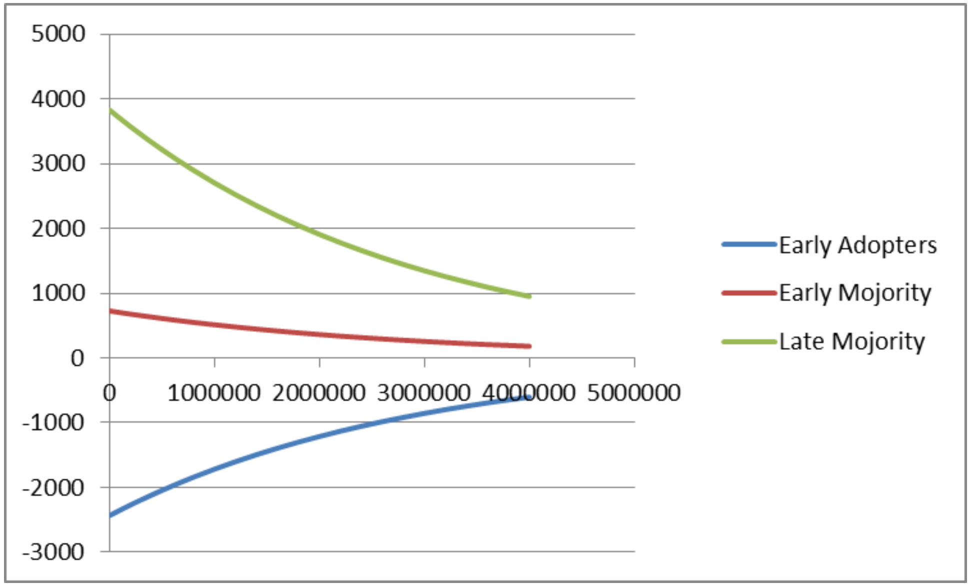
Component Size Index								
	SI HEV	**P10**	**P20**	**P40**	**FCV**	**FCV P10**	**FCV P40**	**BEV100**
Motor	0.66	0.70	0.71	0.74	0.97	1.00	1.05	1.24
FC	0.00	0.00	0.00	0.00	1.21	1.00	1.04	0.00
Battery	0.27	0.96	1.81	3.70	0.28	1.00	4.00	15.04
H2 Storage	0.00	0.00	0.00	0.00	0.96	1.00	1.00	0.00

Driving pattern heterogeneity captured with three Gamma distributions of daily driving distance based on NHTS data.

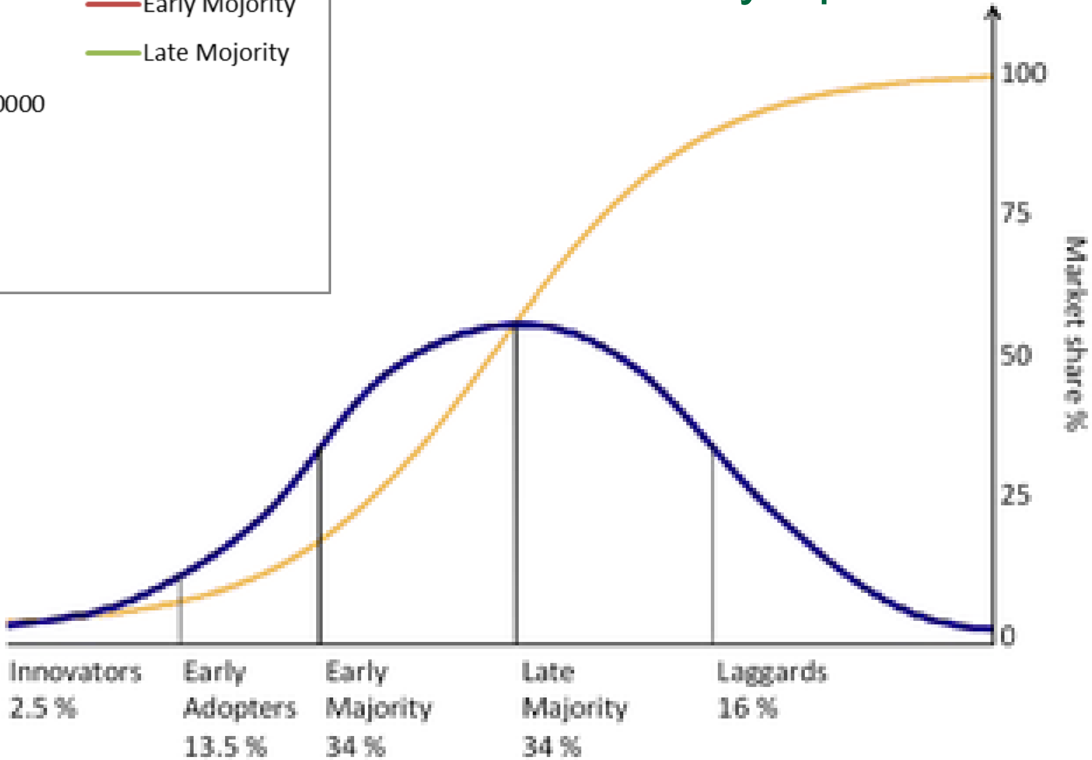




For new technologies, early adopters are willing to pay a premium, while late majority require compensation.



Combining Rodger's logistic function of adopter share and industry input.



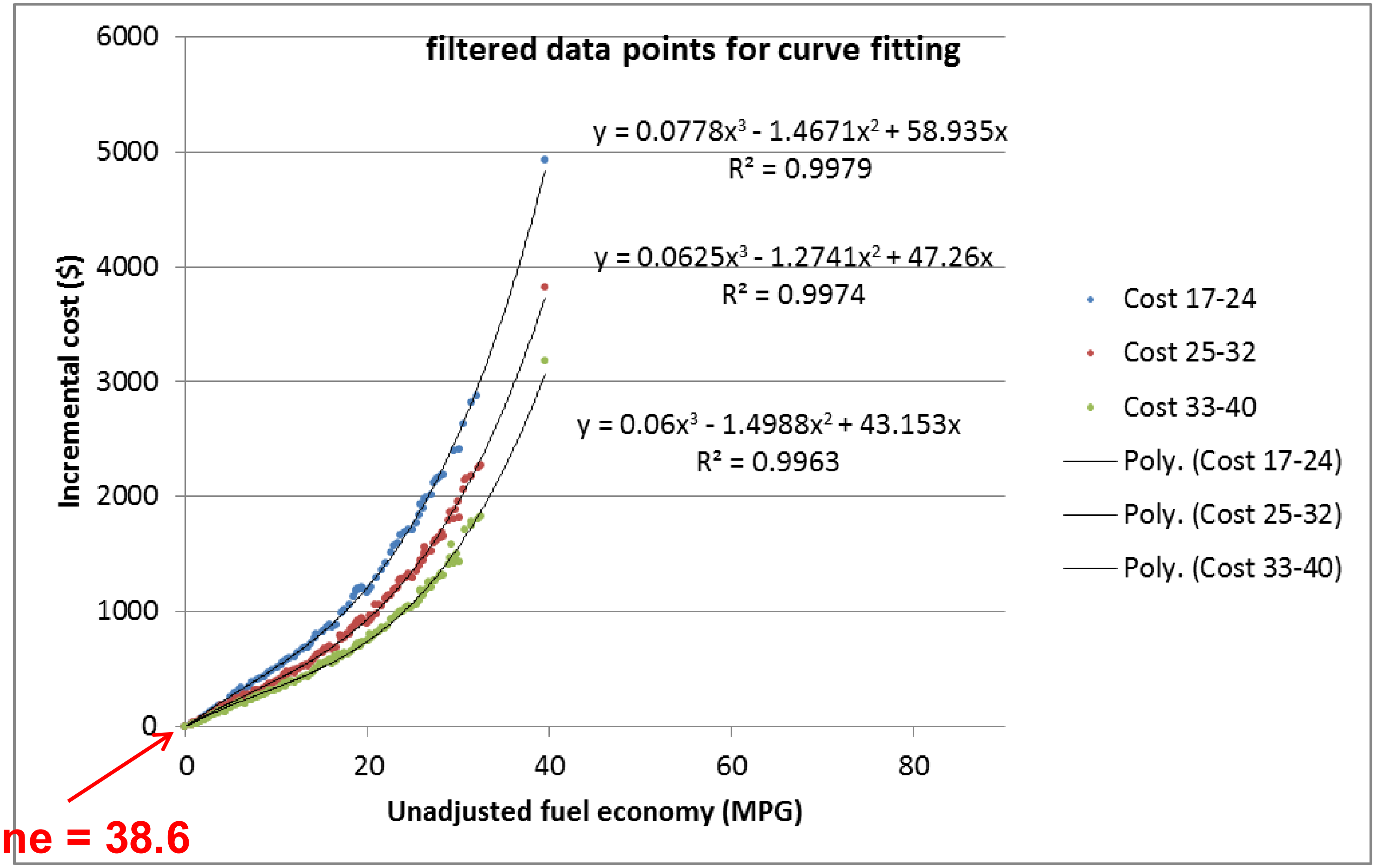
White house is proposing to increase the federal tax credit from $7.5k to $10k and remove the OEM eligibility cap. State incentives vary widely.

State	PHEV incentive	PHEV HOV	BEV incentive	BEV HOV
AZ	$560	No	$560	Yes
CA	1500	Yes	2500	Yes
CO	$6,000	No	$6,000	No
DC	$2,800	No	$2,800	No
GA		No	$5000	Yes
IA	$389	No	$389	No
IL	$4,083	No	$4,083	No
LA	$3,000	No	$3,000	No
MD	$2,000	Yes	$2,000	Yes
NJ	$2,800	Yes	$2,800	Yes
OK	$1,500	No	$1,500	No
PA	$3,000	No	$3,000	No
SC	$2,000	No	$2,000	No
TN	$2,500	Yes	$2,500	Yes
TX	$2500	No	$2500	No
UT	$605	Yes	$605	Yes
WA	120	No	$2600	No
WV	$7,500	No	$7,500	No
FL		No		Yes
HI	$4500	Yes	$4500	Yes
NJ		Yes		Yes
NC		Yes		Yes
RI	$1875	No	$1875	No
VA		Yes		Yes

ARRA tax credit phase-out mechanism is being implemented.

ARRA PEV Incentive Parameters		
	All Years	
Starting Year	2010	when the incentives start to apply
Vehicles per OEM (1000)	200	the maximum cumulative number of subsidized vehicles per OEM
Number of OEM	6	the number of OEM assumed to produce eligible PEVs
Min Battery Size (kWh)	2	the mimimum battery size of eligible vehicles
Minimum Incentive ($)	2,500	the minimum subsidy per eligible vehicle
Maximum Incentive ($)	7,500	the maximum subsidy per eligible vehicle
Incre. Incentive ($/kWh)	417	the incremental subsidy per kWh beyond the Size Threadhold
Size Threadhold (kWh)	4	the battery size beyond which each additional battery capacity earns the incremental incentive
note:		

Efficiency-cost curves allow more realistic competition from conventional vehicles



Baseline = 38.6 mpg
Intermediate car

MA3T coherently models the effect of a wide range of charging options.

$$R_e = \frac{E_h + E_w + E_p}{\max(e_e - e_w, 0^+)}$$

- R_e: Effective electric range
- E_h: Home charging energy
- E_w: Work charging energy
- E_p: Public charging energy
- e_e: On-road discharge rate
- e_w: On-road charging rate

$$e_w = \eta P_w O_w / V_w$$

- ηP_w: On-road charging efficiency and power
- V_w: Vehicle speed

$$O_w = k(A_w)$$

- O_w: On-road charging opportunity
- A_w: On-road charging availability

On dynamic wireless charging in MA3T, users can modify spatial relationship, deployment rate, vehicle speed and effective power.

Dynamic Wireless Charging Availability-Opportunity Spatial Relationship

Select ->	Average

San Diego
San Francisco
Average

note:4 metropolitan are … *xamined--San Diego, San Francisco-Oak Lan*

DWC Vehicle Speed (mph)	2005	2006	2007	2008
01_NewEngland	55	55	55	55
02_MiddleAtlantic	55	55	55	55
03_EastNorthCentral	55	55	55	55
04_WestNorthCentral	55	55	55	55
05_SouthAtlantic	55	55	55	55
06_EastSouthCentral	55	55	55	55
07_WestSouthCentral	55	55	55	55
08_Mountain	55	55	55	55
09_Pacific	55	55	55	55

note: speed limit 60-85 mph among states. Lower speed allows more c

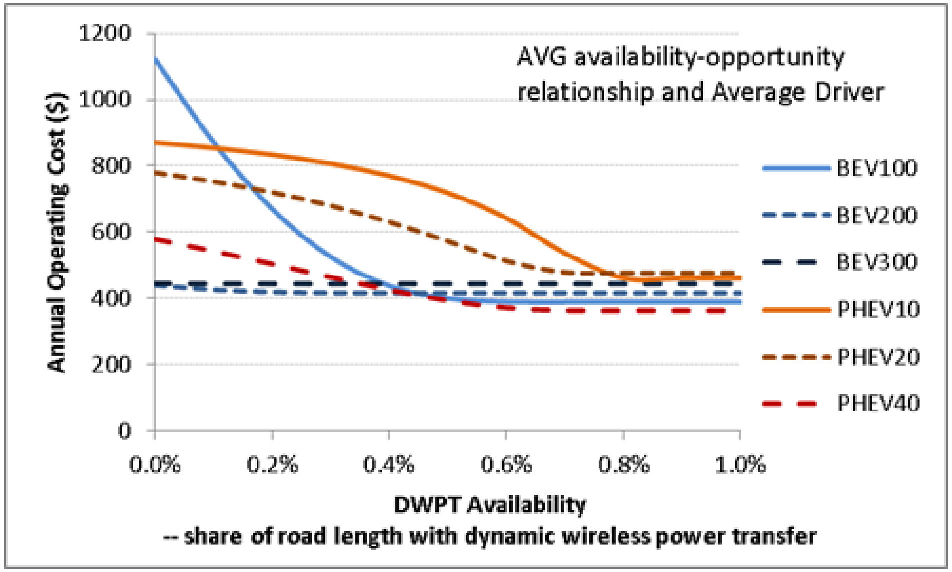
DWC Availability = % of candidate road lengh with DWC	2005	2006	2007	2008
01_NewEngland	0.0%	0.0%	0.0%	0.(
02_MiddleAtlantic	0.0%	0.0%	0.0%	0.(
03_EastNorthCentral	0.0%	0.0%	0.0%	0.(
04_WestNorthCentral	0.0%	0.0%	0.0%	0.(
05_SouthAtlantic	0.0%	0.0%	0.0%	0.(
06_EastSouthCentral	0.0%	0.0%	0.0%	0.(
07_WestSouthCentral	0.0%	0.0%	0.0%	0.(
08_Mountain	0.0%	0.0%	0.0%	0.(
09_Pacific	0.0%	0.0%	0.0%	0.(

note:

DWC Effective Power (kW)	2005	2006	2007	2008
01_NewEngland	-	-	-	-
02_MiddleAtlantic	-	-	-	-
03_EastNorthCentral	-	-	-	-
04_WestNorthCentral	-	-	-	-
05_SouthAtlantic	-	-	-	-
06_EastSouthCentral	-	-	-	-
07_WestSouthCentral	-	-	-	-
08_Mountain	-	-	-	-
09_Pacific	-	-	-	-

note: according to John Miller's paper, Pmax=100 kW, Pavg=75kW

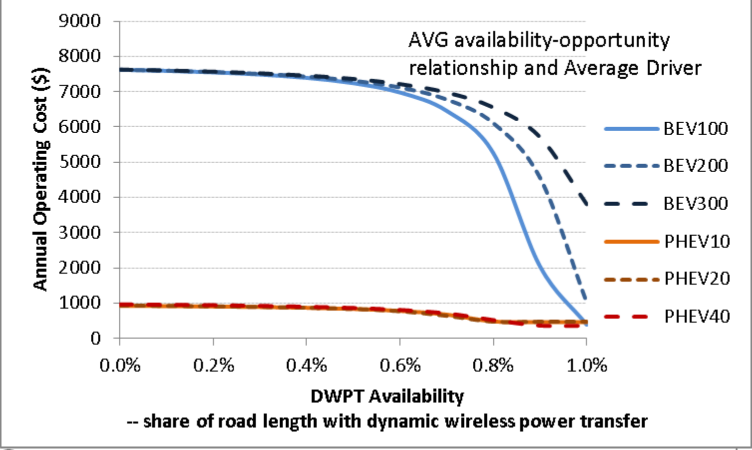
DWC decreases energy cost and range assurance cost for BEVs.
-- average driver

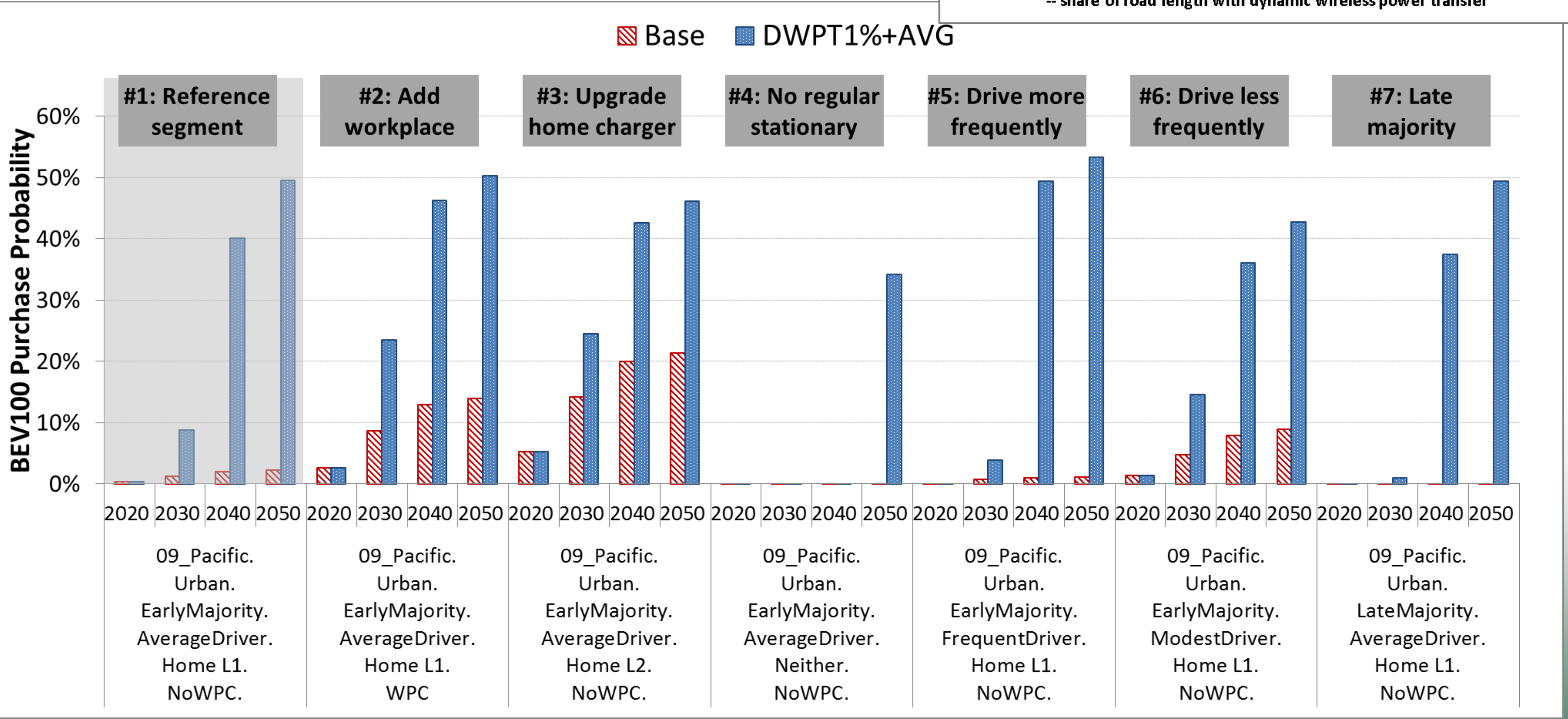


DWPT Availability		0.0%	0.1%	0.2%	0.3%	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%	1.0%
DWPT Opportunity1		0.0%	2.6%	5.0%	7.5%	9.8%	12.1%	14.4%	16.5%	18.6%	20.7%	22.7%
PHEV Annual Gasoline Use (gallons)2	PHEV10	227	219	210	197	180	155	119	69	34	33	33
	PHEV20	184	171	156	137	114	87	59	42	41	41	41
	PHEV40	94	78	61	44	27	13	4	0	0	0	0
PHEV Annual Electricity Use (kWh)2	PHEV10	758	864	999	1176	1417	1756	2252	2946	3441	3444	3444
	PHEV20	1364	1537	1748	2007	2324	2698	3082	3306	3321	3321	3321
	PHEV40	2487	2681	2888	3100	3304	3478	3593	3635	3638	3638	3638
BEV Annual Electricity Use (kWh)2	BEV100	3741	3799	3841	3869	3884	3889	3891	3891	3891	3891	3891
	BEV200	4164	4166	4167	4167	4167	4168	4168	4168	4168	4168	4168
	BEV300	4444	4444	4444	4444	4444	4444	4444	4444	4444	4444	4444
BEV Range-limited Frequency (days/year)2	BEV100	22.8	14.2	7.8	3.5	1.2	0.2	0.0	0.0	0.0	0.0	0.0
	BEV200	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	BEV300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

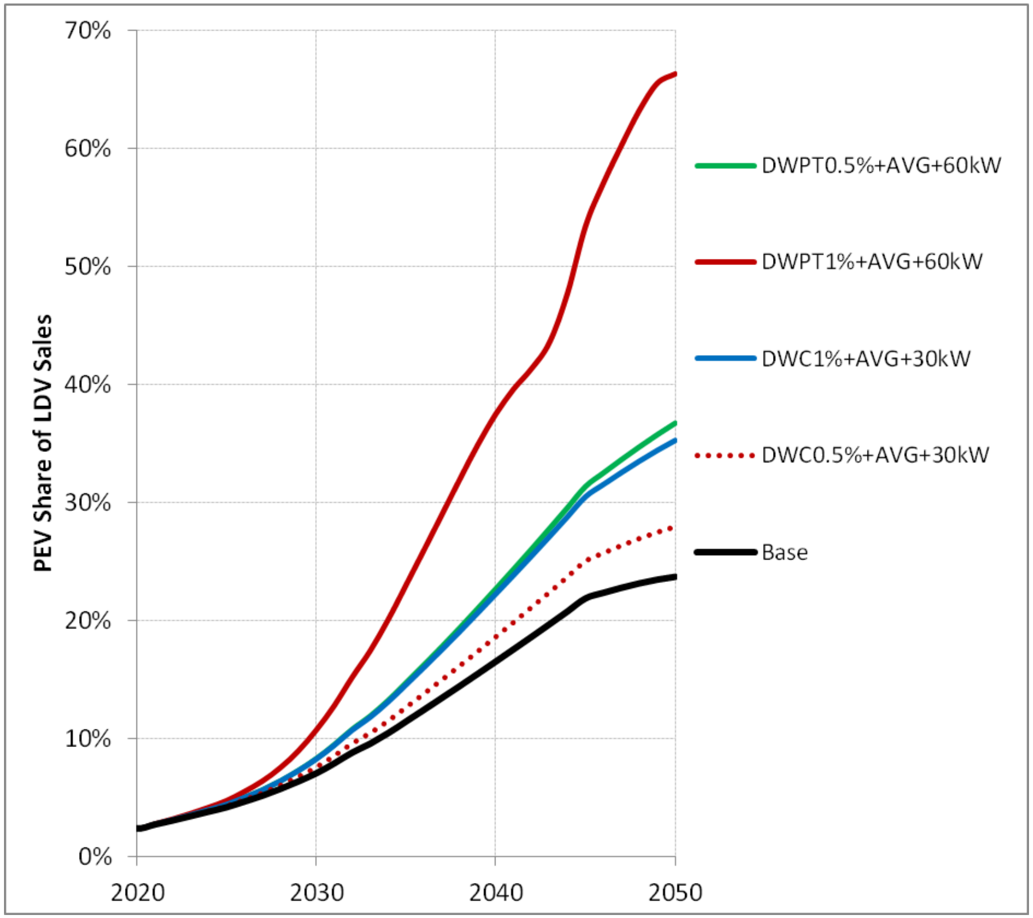
1. based on the AVG availability-opportunity relationship.
2. based on Average Driver's driving pattern.

DWC benefits all consumers, but particularly those with charging challenges, e.g. w/o home or workplace charging.





DWC can significantly increase PEV (mainly BEV) sales by expanding the consumer base, but uncertainties warrant more research.

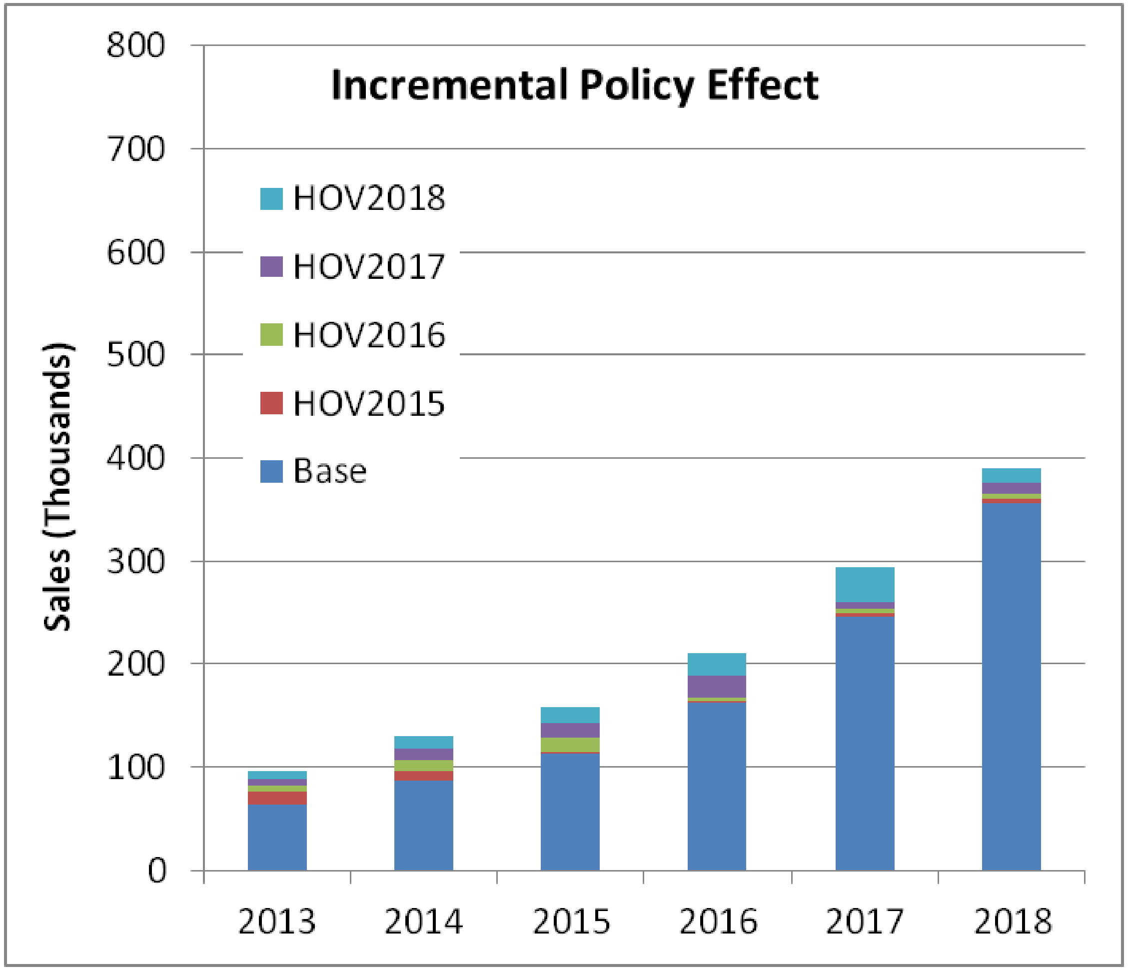


- **Uncertainties**
  - **Receiving power**
  - **Traffic concentration (or, deployment efficiency)**
  - **Availability of other charging options**

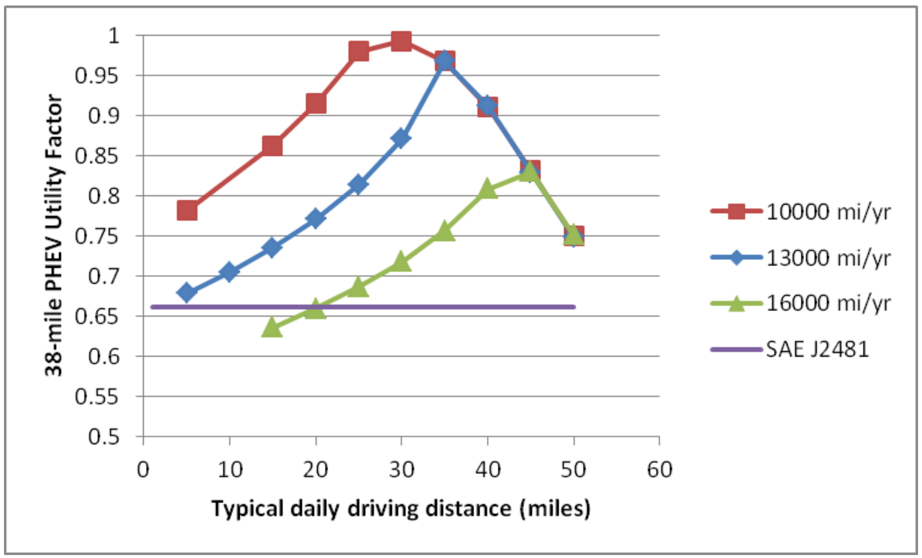
Zhenhong Lin, James Li, Jing Dong. Dynamic Wireless Power Transfer: Potential Impact on Plug-in Electric Vehicle Adoption. SAE Technical Papers 2014-01-1965.

MA3T shows significant but decreasing effect of HOV access on PEV sales.

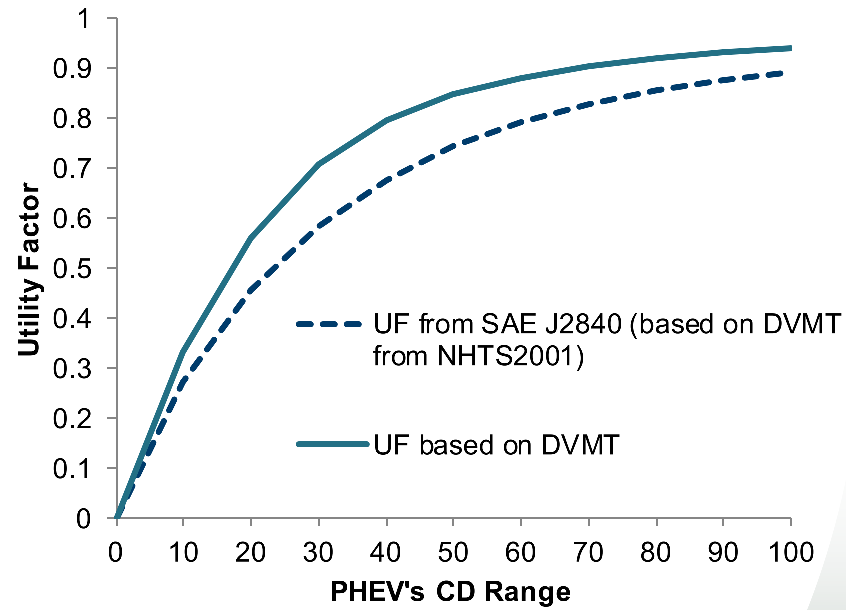
The value of HOV access is measured by region-specific per-motorist congestion cost estimated by TTI's Urban Mobility study.



Daily distance variation significantly affects PHEV electrified share of distance.

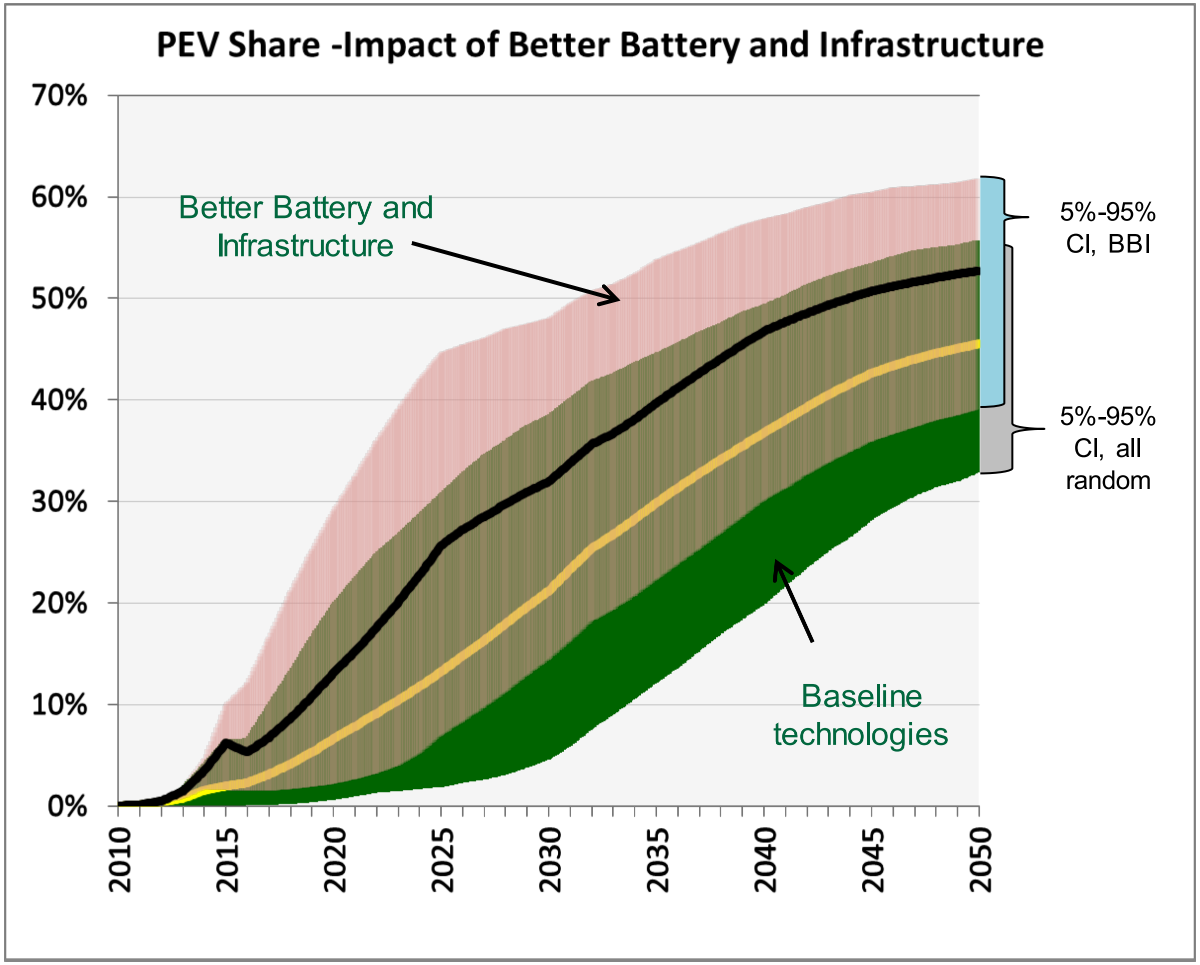


Based on *My Plug-in Hybrid Calculator* on fueleconomy.gov. Assume one full charge per day.



Based on *longitudinal GPS-tracked travel data in Seattle*

Improving battery and infrastructure can ensure robustness of market success in face of many uncertainties.



Changzheng Liu, Zhenhong Lin, Analyzing Uncertainty of PEV Market. Working paper.

- **Better Battery and Infrastructure**
  - **5-year battery cost reduction acceleration**
  - **By 2050, public charging 75%, WPC 75%, L2 home charging 75%**
- **Sources of uncertainty**
  - **Fuel prices**
  - **Learning by doing rates**
  - **Choice elasticity**
  - **Model supply behavior**
  - **Value of model diversity**
  - **Range assurance cost**
  - **Perceived vehicle lifetime**
  - **Share of early adopter**
  - **Technology risk**

13 peer-reviewed articles resulted from the MA3T project (7 during FY14)

1. Lin, Z., Li, J., & Dong, J.. (2014). Dynamic Wireless Charging: Potential Impact on Plug-in Electric Vehicle Adoption. *Society of Automotive Engineers Technical Papers 2014-01-1965 .*
2. Dong, Jing, Lin, Zhenhong, Liu, Changzheng, and Liu, Yanghe. (2014). "Assessing Grid Impact of Plug-in Electric Vehicle Charging Demand Using GPS-Based Longitudinal Travel Survey Data." *SAE Technical Papers* 2014-01-0343.
3. Dong, J., & Lin, Z.. (2014). Stochastic Modeling of Battery Electric Vehicle Driver Behavior: The Impact of Charging Infrastructure Deployment on BEV Feasibility. *Transportation Research Record (accepted)*.
4. Lin, Z. (2014). Battery Electric Vehicles: Range Optimization and Diversification for U.S. Drivers. *Transportation Science (accepted)*.
5. Wu, X., Dong, J., and Lin Z.. (2014). "Cost Analysis of Plug-in Hybrid Electric Vehicles Using GPS-Based Longitudinal Travel Data." *Energy Policy* 68: 206–17
6. Dong, J., Liu, C., & Lin, Z. (2014). Charging infrastructure planning for promoting battery electric vehicles: An activity-based approach using multiday travel data. *Transportation Research Part C: Emerging Technologies*, *38*(0), 44 – 55.
7. Greene, D. L., Lin, Z., & Dong, J. (2013). Analyzing the sensitivity of hydrogen vehicle sales to consumers' preferences. *International Journal of Hydrogen Energy*, *38*(36), 15857 – 15867.
8. Lin, Z., Dong, J., and Greene, D.L., 2013. Hydrogen Vehicles: Impacts of DOE Technical Targets on Market Acceptance and Societal Benefits. International Journal of Hydrogen Energy, Vol 38, Issue 19, Pages 7973-7985
9. Lin, Z., Dong, J., Liu, C., & Greene, D. (2012). Estimation of Energy Use by PHEVs: Validating Gamma Distribution for Random Daily Driving Distance. Transportation Research Record, 2287(1), 37-43.
10. Lin, Z. (2012). Optimizing and Diversifying the Electric Range of Plug-in Hybrid Electric Vehicles for U.S. Drivers. International Journal of Alternative Powertrains, 1(1), 108-194.
11. Dong, J., & Lin, Z. (2012). Within-day recharge of plug-in hybrid electric vehicles: Energy impact of public charging infrastructure. Transportation Research Part D: Transport and Environment, 17(5), 405-412.
12. Lin, Z., & Greene, D. L. (2011). Promoting the Market for Plug-In Hybrid and Battery Electric Vehicles: Role of Recharge Availability. Transportation Research Record, 2252(1), 49-56.
13. Lin, Z., & Greene, D. L. (2011). Assessing Energy Impact of PHEVs: Significance of Daily Distance Variation over Time and Among Drivers. Transportation Research Record, 2252(1), 99-106.

Working papers under the MA3T project.

1. Changzheng Liu, Zhenhong Lin. Analyzing the uncertainty of the plug-in electric vehicle market using MA3T and @Risk.
2. Documentation for the Market Acceptance of Advanced Automotive Technologies (MA3T) model. Working paper.
3. Cost-effectiveness Comparison of a wide range of charging infrastructure options.
4. Re-thinking the utility factor of PHEVs.
5. Linking charging availability and charging opportunity.

The progress of the MA3T project relies on collaboration with industry, universities and government agencies.

- SRA International
  - Input data processing, state incentive, result processing, historical sales data
- Entergy Corporation
  - Electricity demand profile, grid impact analysis
- Argonne National Laboratory
  - Vehicle attribute data, application, PEV sales data, coefficient estimation
- National Renewable Energy Laboratory
  - Infrastructure roll-out scenario, infrastructure costs
- Energy Information Administration
  - Energy prices, grid carbon intensity
- University of California, Davis
  - Consumer survey findings, infrastructure analysis
- Iowa State University
  - Infrastructure analysis, scenario file processing, policy analysis
- University of Tennessee
  - Coefficient estimation, model upgrades

We need a better understanding of consumer behavior and industry behavior. FY15 will focus on consumer segmentation and supply behavior.

- **Continued vehicle attribute and energy price updates**
- **Improved consumer segmentation**
- **Improved representation of state and local incentives**
- **Representing supply-side behavior**
  - Optimizing fuel economy of conventional vehicles
  - Infrastructure business model and endogenous deployment
- **Comparison of various charging options**

Summary

- The goal of MA3T is to provide a useful, user-friendly and credible tool for scenario analysis.
- Toward this goal, we made FY14 progress on structuring upgrades, data updates, calibration, validation, application and publication
- FY15 will focus on consumer segmentation and supply behavior.