The MA^{3}T model: Market Adoption of Advanced Automotive Technologies

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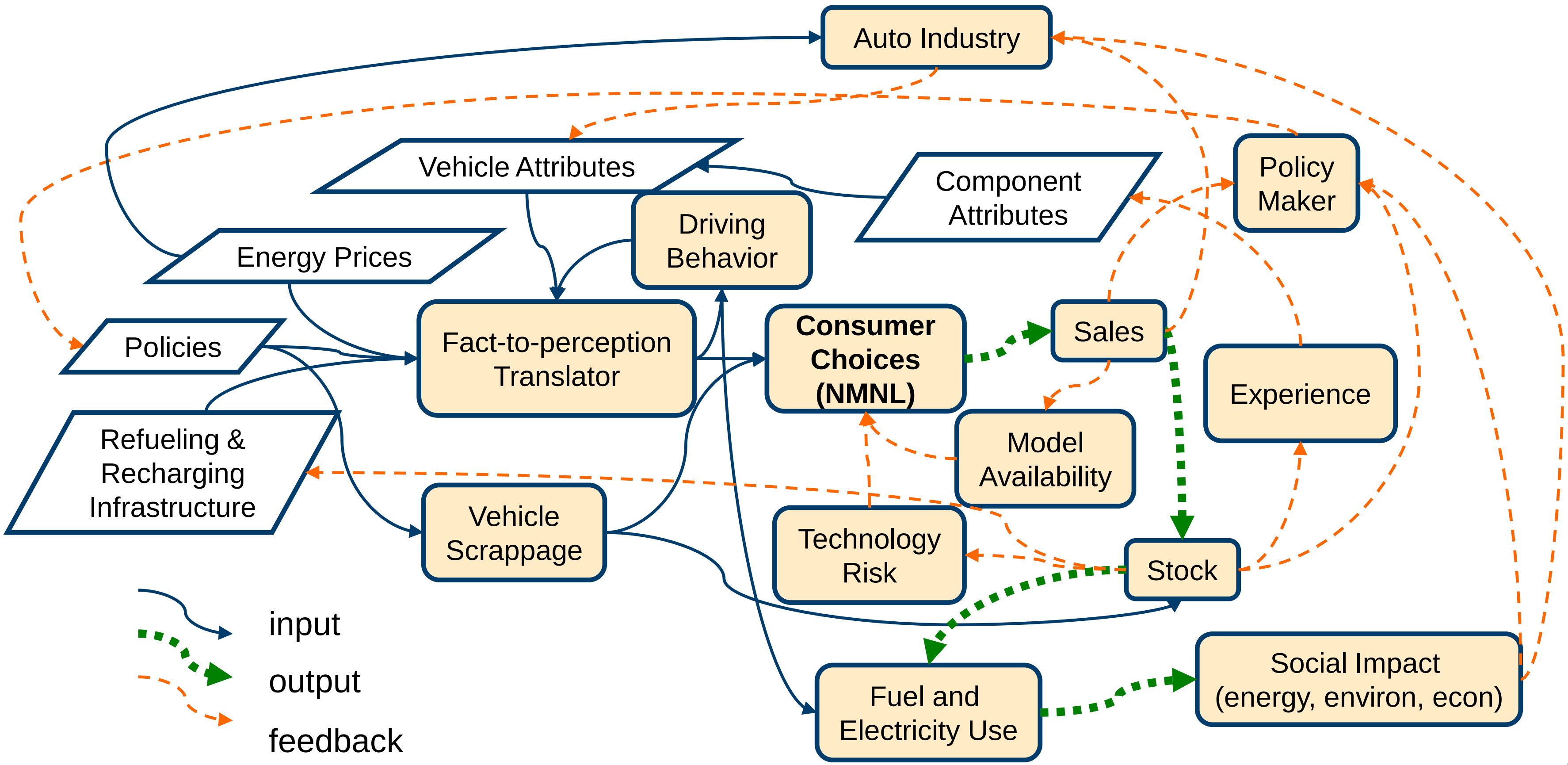
Outline

- **Purpose of Model**
- **Framework, Theory and Implementation**
- **Calibration and Validation**
- **Features and Capabilities**
- **Selected Results**
- **Areas for Improvement**
- **Conclusions**

MA3T was developed to allow DOE to analyze the transition of U.S. LDV powertrain mix and relevant policies.

- **Functional objectives**
  - **Assessment of social benefits and costs**
  - **Identifying barriers and drivers**
  - **Analysis of a wide range of policies**
  - **Analysis of stakeholder behavior**

MA3T simulates consumer choices and interactions between technologies, infrastructure, policies, and social impacts.



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for the Department of Energy

The MA3T model:
Market Acceptance of Advanced Automotive Technologies
Dr. David Greene, Dr.Zhenhong Lin

OAK RIDGE National Laboratory

MA3T is implemented in Excel/VBA. Three files are involved. Multi-run is convenient.

SAVE	Save the four input files "Scenario" "Segmentation" "EnergyPrices" and "Policy"
LOAD	Load the above four input files
SINGLE RUN	Run the model once with result files generated in the same folder; press ESC to abort the run
MULTI RUN	Select and run multiple scenarios
Calibrate	Calibrate to historical sales data

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The core NMNL consumer choice model assumes homogeneous preferences within each of the 1458 disaggregated market segments.

- Nested multinomial logit (NMNL) is commonly used for forecasting transportation demand
- Conditional probability of choice i in nest j = car/truck, k = Conv/H_2/EV and l = technology type is a function of a price sensitivity parameter β_{jkl} and generalized cost c_{ijkl}

$$p_{i|jkl} = \frac{e^{\beta_{jkl} \cdot c_{ijkl}}}{\sum_h e^{\beta_{jkl} \cdot c_{hjkl}}}$$

$$\sum_i p_{i|jkl} = 1$$

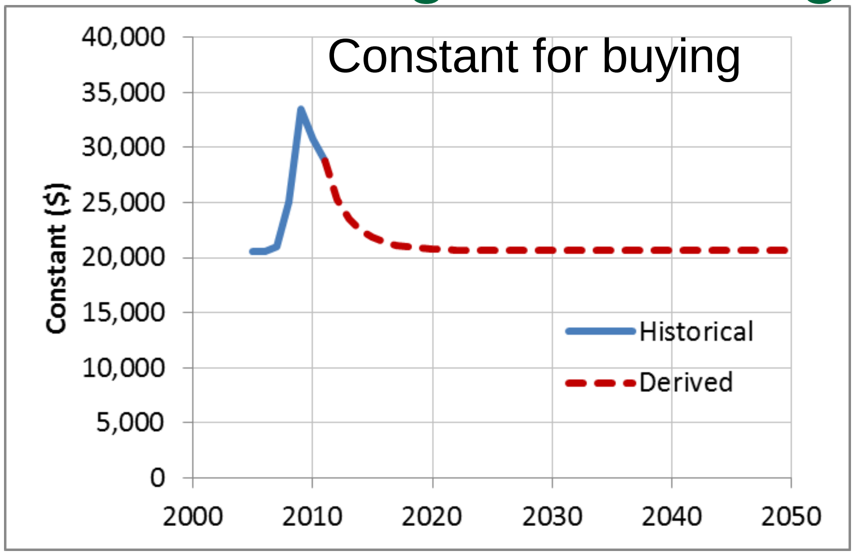
- the generalized cost c_{ijkl} is a function of technology attributes x_{zijkl} and the attribute weight (or value) w_{zjkl}

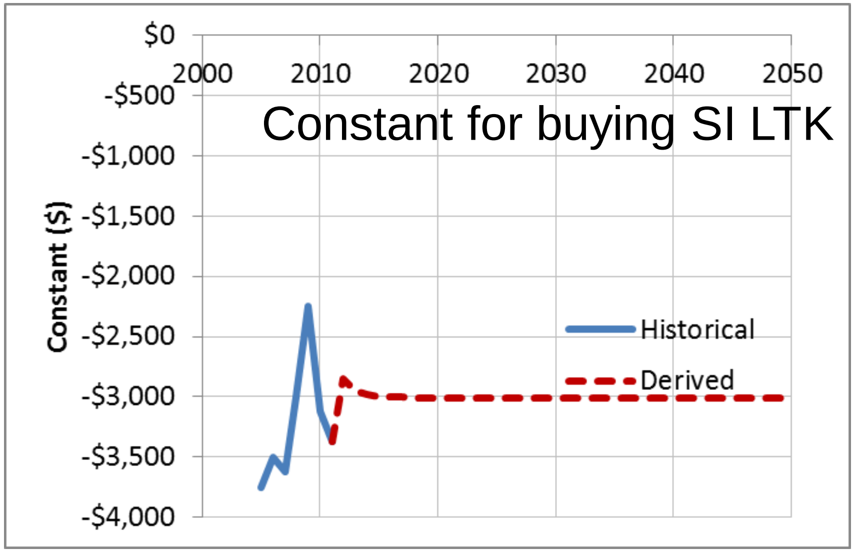
$$c_{ijkl} = \sum_z w_{zjkl} f_z\left(x_{zijkl}\right)$$

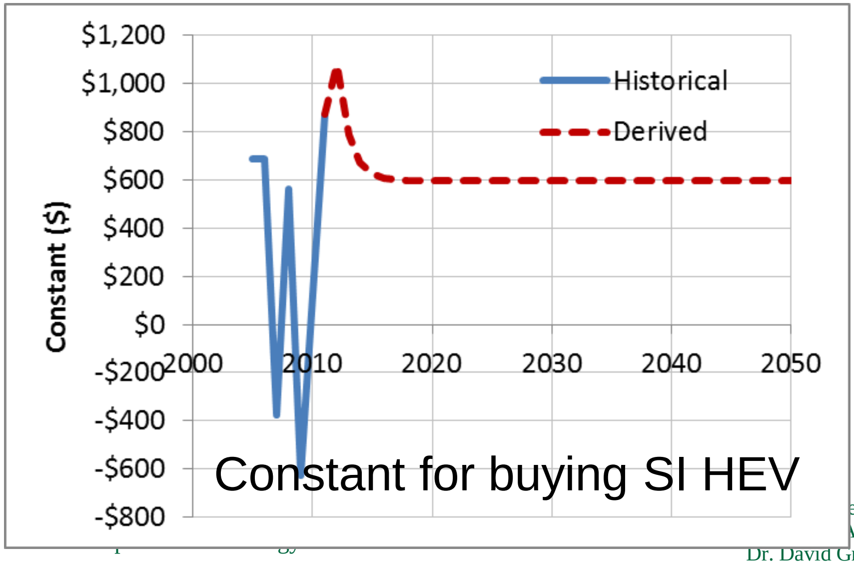
MA3T integrated NMNL with a wide range of knowledge. Some of the integrated theories are validated, but more need to be studied and learned

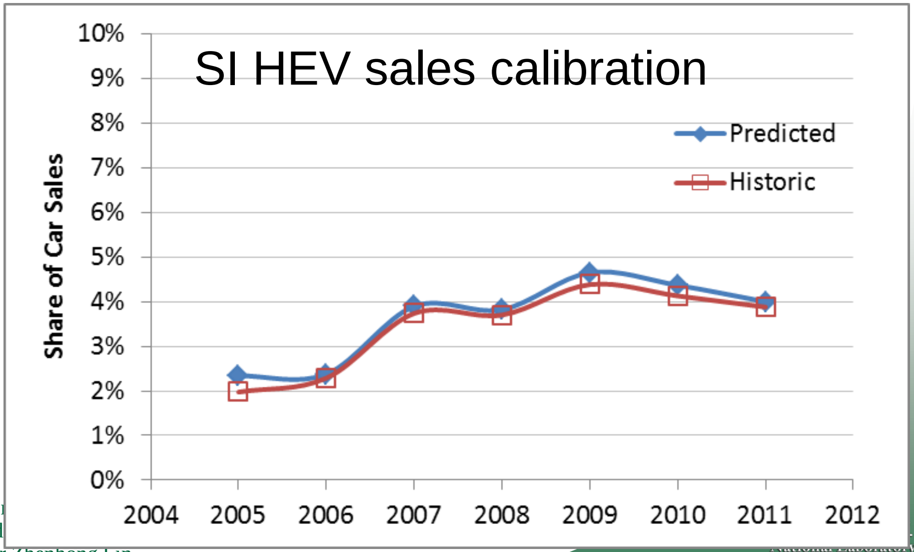
- Nested multinomial logit (NMNL)
- Learning by doing (LBD) and co-learning
- Economy of scale
- Gamma distribution for random daily distance
- Fuel-travel-back: optimal station locations
- Path-dependant charging benefit
- Supply constraint for new technologies
- Conflict: infrastructure availability and utilization
- Policy design, e.g. feebate parameters
- Calibration—learning from history
- Dynamic product design (being implemented)
- Optimal transition (to be implemented)

Calibration of NMNL constants aims at reducing bias. Precision can be improved by discovering/including more relevant factors.

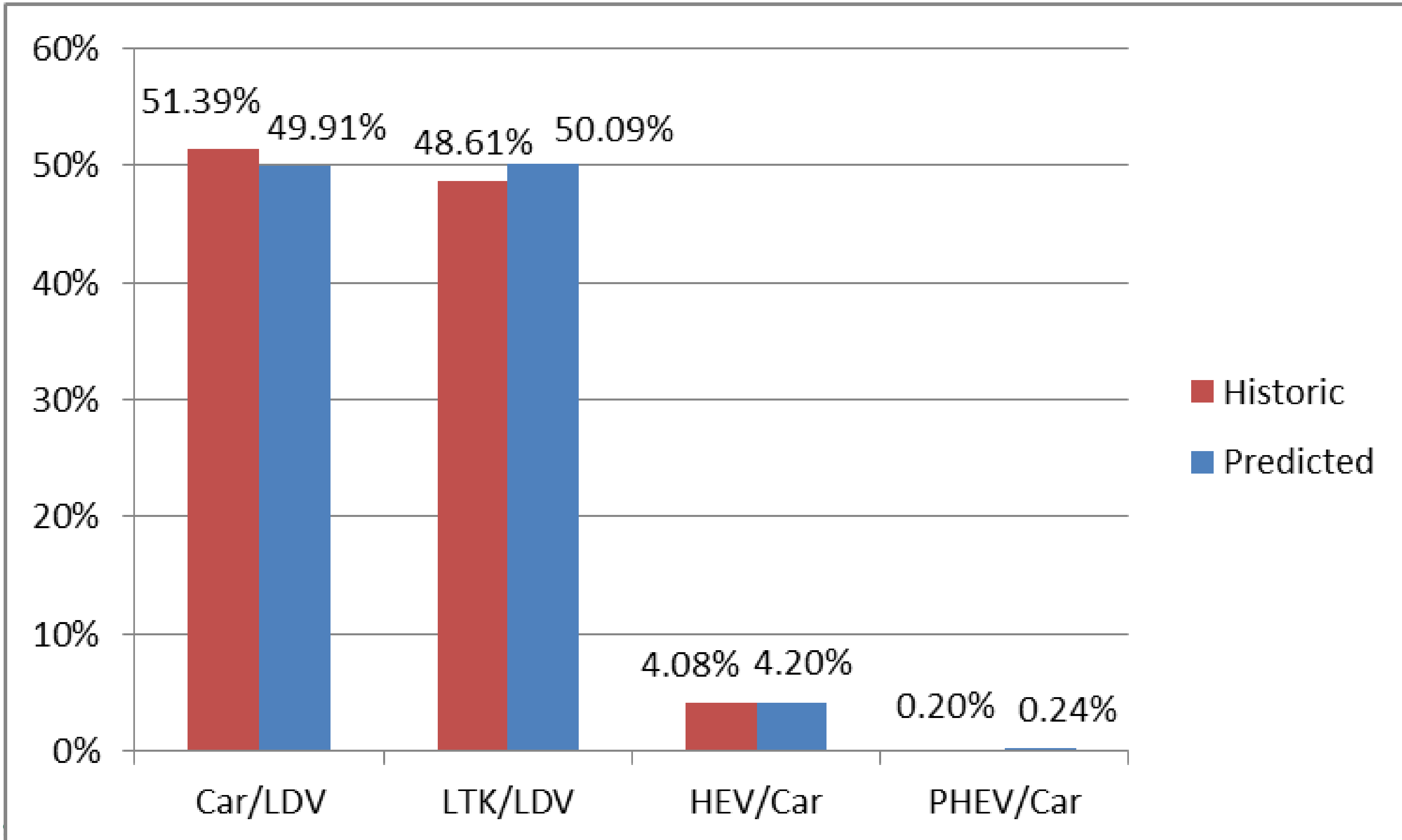








Extrapolation of GC constants based on weighted history learning seems to produce close estimates for year 2012.



MA3T simulates 1458 U.S. consumer segments choosing among 40 LDV choices

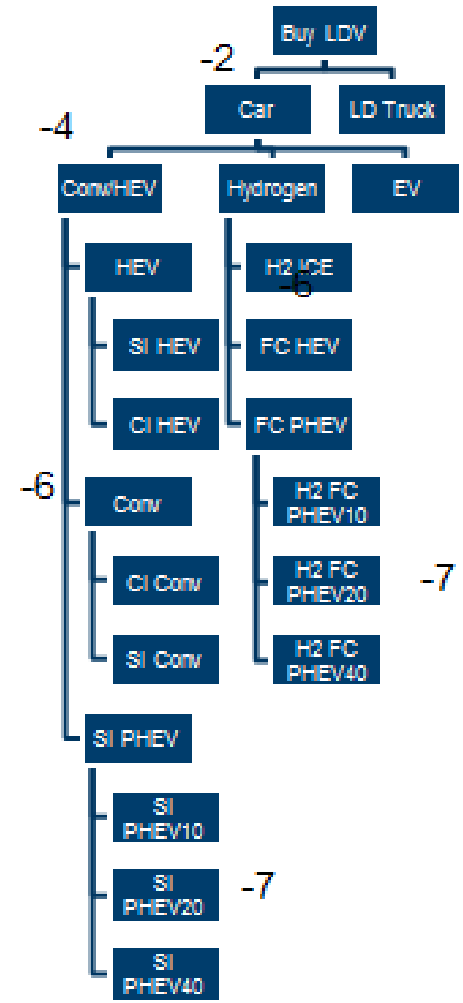
- **U.S. LDV market divided into 1458 seg., 2005-50**
- **Buy or no buy decision is now endogenous**
- **20 powertrain technologies, cars and light trucks, to be expanded into small cars, midsize cars, large cars, SUVs and pickup**
- **Vehicle attributes: retail price, fuel economies, acceleration, refueling hassle, range limitation cost, etc**
- **Infrastructure: hydrogen, natural gas, electricity, diesel; home, work, public charging**
- **Policies: fuel/carbon tax, feebate, parking or HOV incentives, tax credit or rebate**

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 parameters of the NMNL model are calibrated based on consensus estimates from previous studies, theory, and assumptions.

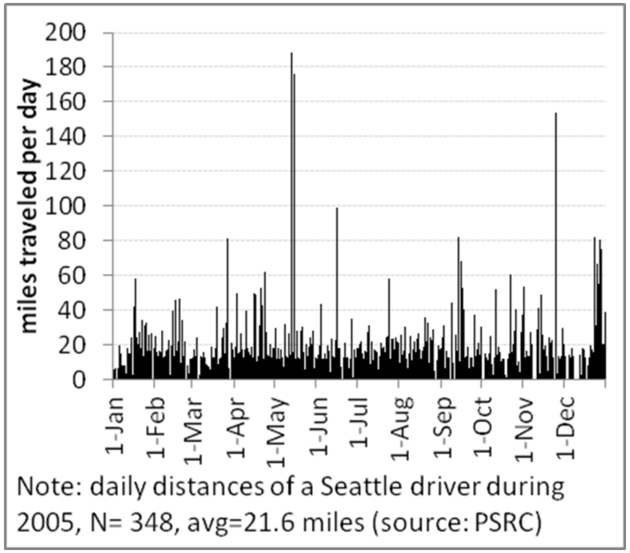
- **competition among lower level nests/choices is more price sensitive than among the upper level nests**
- **price elasticities in the model can be modified**
- **20 Passenger Cars**
  - **SI/CI/NG Conv**: conventional powertrain powered by gasoline/diesel/natural gas
  - **SI/CI/NG HEV**: hybrid vehicle 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 range. **EERV**, in the 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

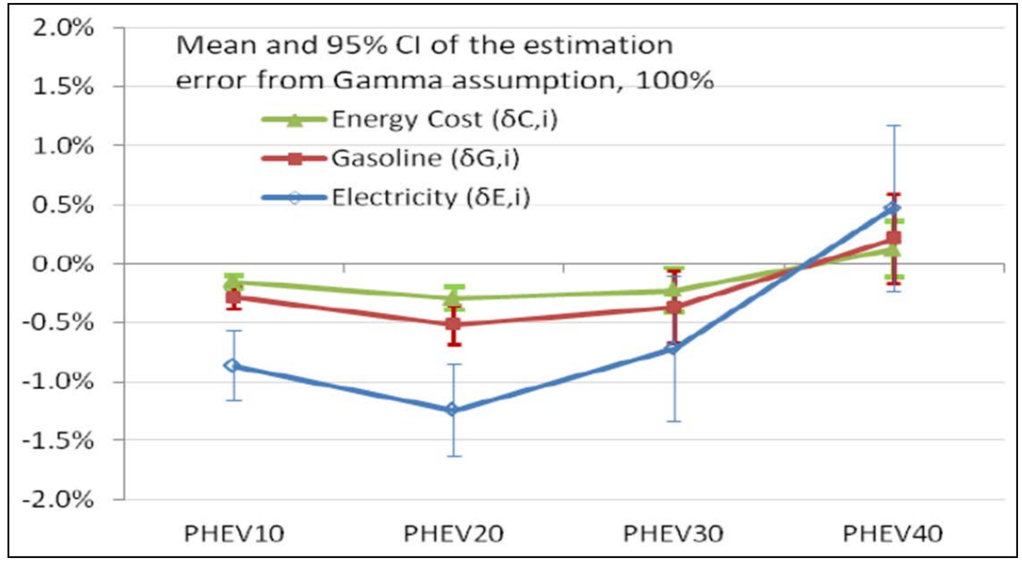


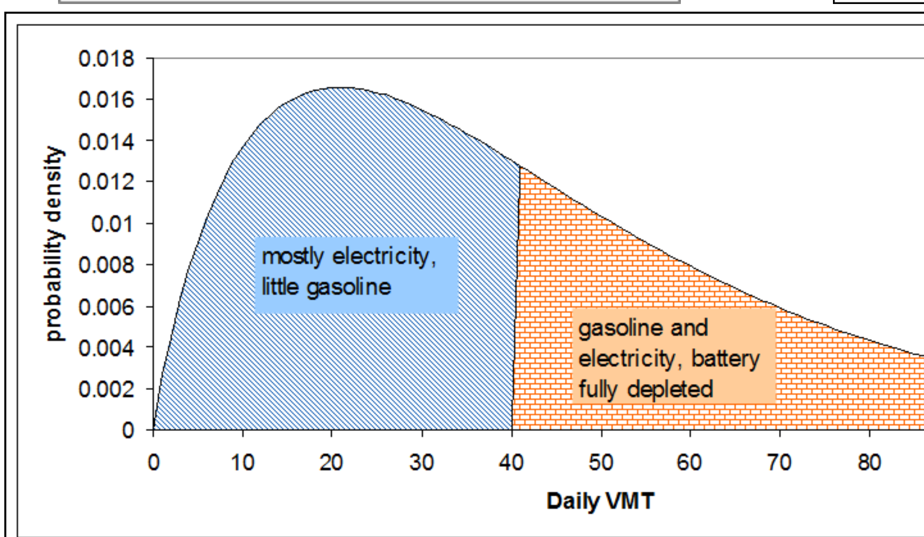
Choice attributes included (or planed to) are intended to reflect factors that will influence choices relatively predictably in the long run.

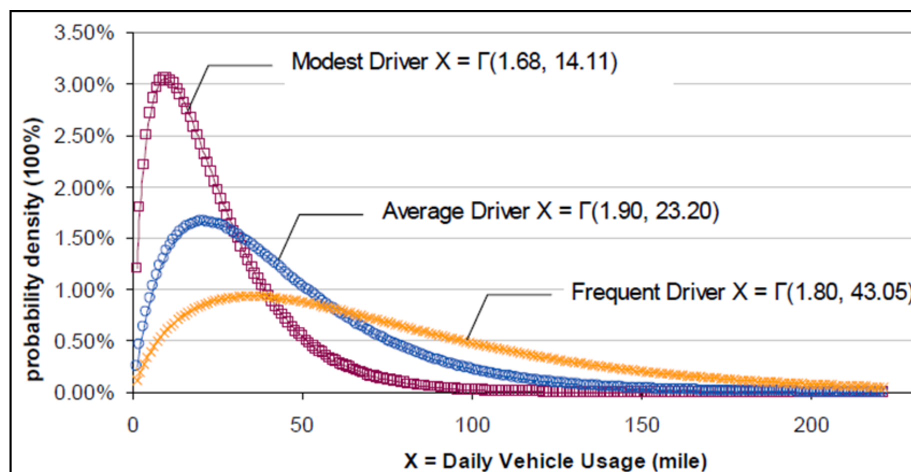
- **vehicle retail price**
- **fuel and electricity cost**
  - **affected by daily VMT distribution and driving behavior, varying by region, area and driver type**
- **battery replacement cost**
- **acceleration**
- **cargo space**
- **towing**
- **range**
- **home backup power**
- **refueling and recharging accessibility cost**
- **model availability**
- **technology risk**
- **vehicle-to-grid costs and revenues**
- **Maintenance cost**
- **greenness (placeholder)**
- **<u>can be expanded to include more items</u>**

The validated ORNL Gamma method allows more accurate estimation of PHEV energy use/cost. Three types of drivers are represented in MA3T.









Gamma distribution can be specified by the mean and mode, i.e. average and typical daily distances

- **Expected daily fuel use (gge/day)**

$$E_g = C_{g,cd} \cdot \int_0^{R_{cd}} x \cdot p(x) \cdot dx + C_{g,cs} \cdot \int_{R_{cd}}^{M} x \cdot p(x) \cdot dx + (C_{g,cd} - C_{g,cs}) \cdot R_{cd} \cdot (1 - \int_0^{R_{cd}} p(x) \cdot dx)$$

- **Expected daily electricity use (kWh/day)**

$$E_e = C_{e,cd} \cdot \left(\int_0^{R_{cd}} x \cdot p(x) \cdot dx + R_{cd} \cdot (1 - \int_0^{R_{cd}} p(x) \cdot dx) \right)$$

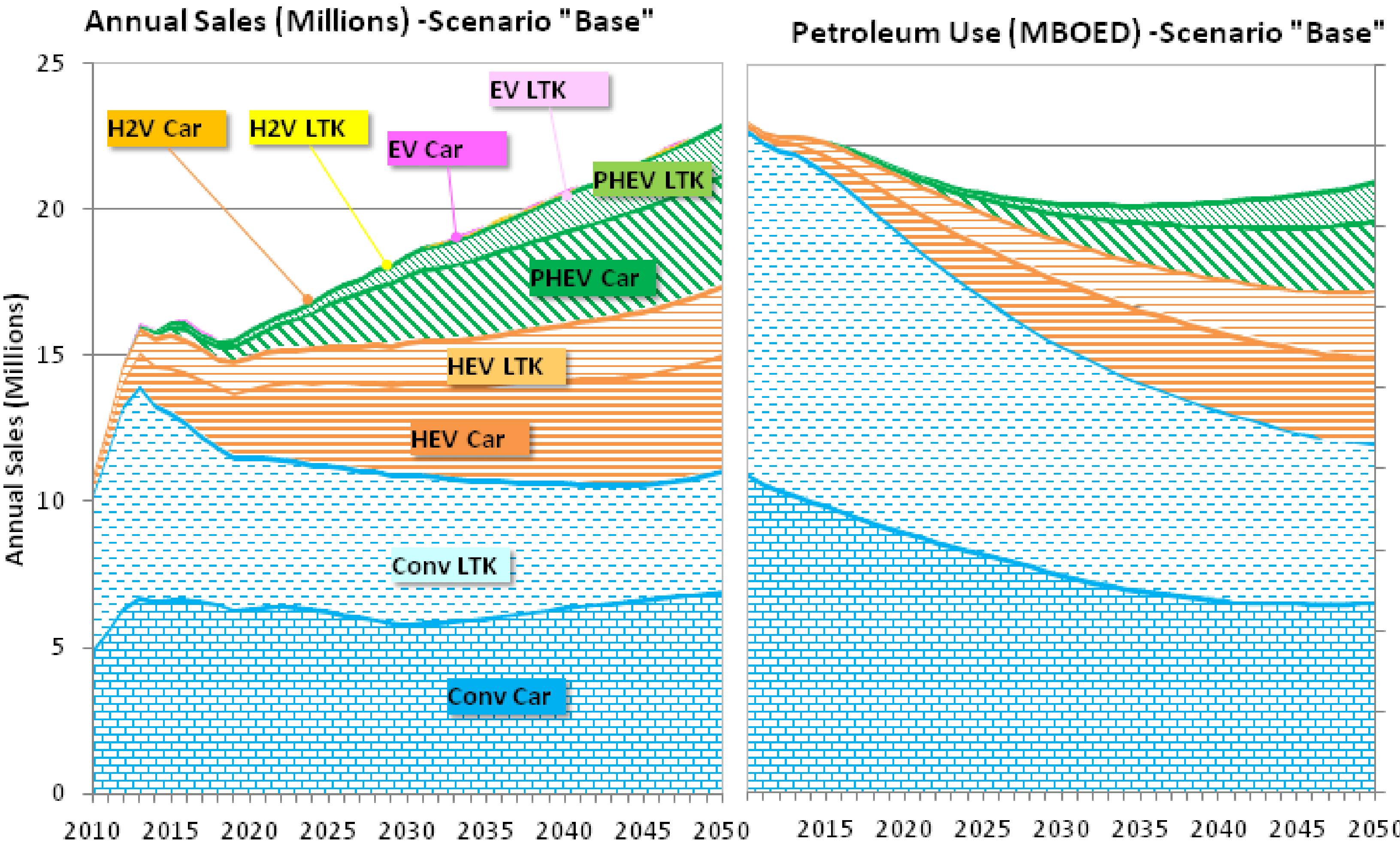
- **Gamma distribution of daily distance**

$$p(x; k, \theta) = x^{k-1} \frac{e^{-x/\theta}}{\theta^k \Gamma(k)}, \qquad k\theta = x_{avg}, \qquad (k-1)\theta = x_{md}$$

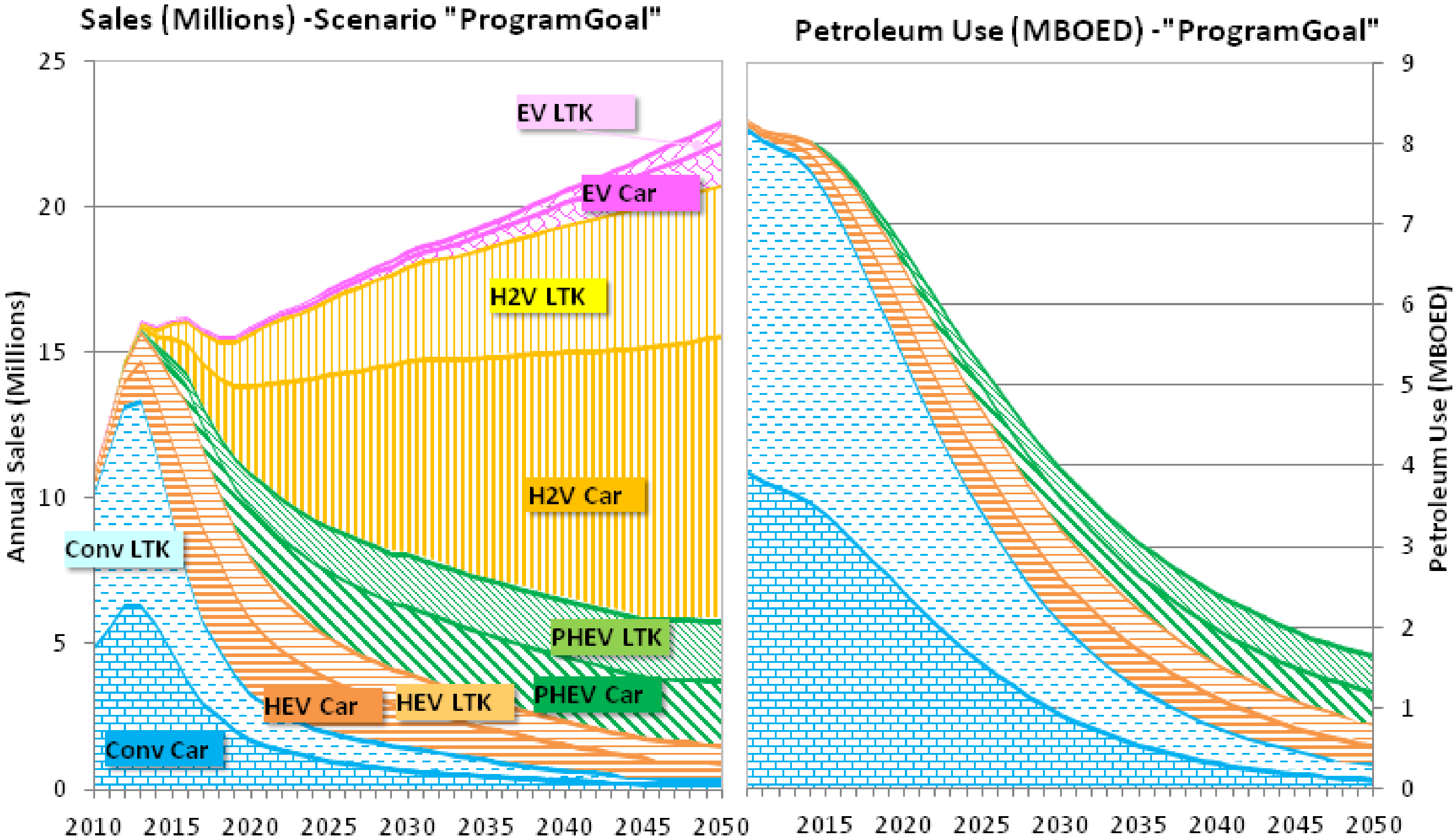
References:

Lin, Z., & Greene, D. L. (2011). Assessing Energy Impact of Plug-In Hybrid Electric Vehicles: Significance of Daily Distance Variation over Time and Among Drivers. *Transportation Research Record, 2252*(1), 99-106.

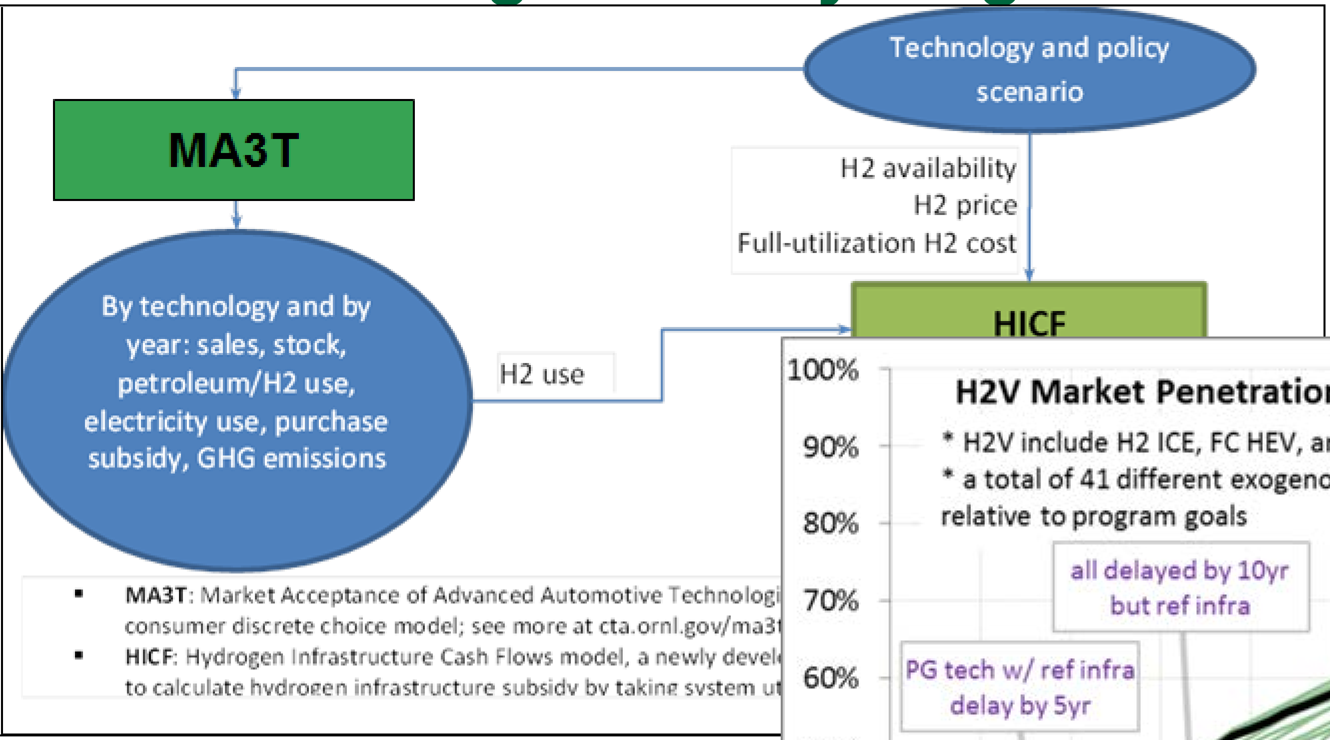
Base scenario: moderate technology progress; no expansion of charging or hydrogen refueling infrastructure

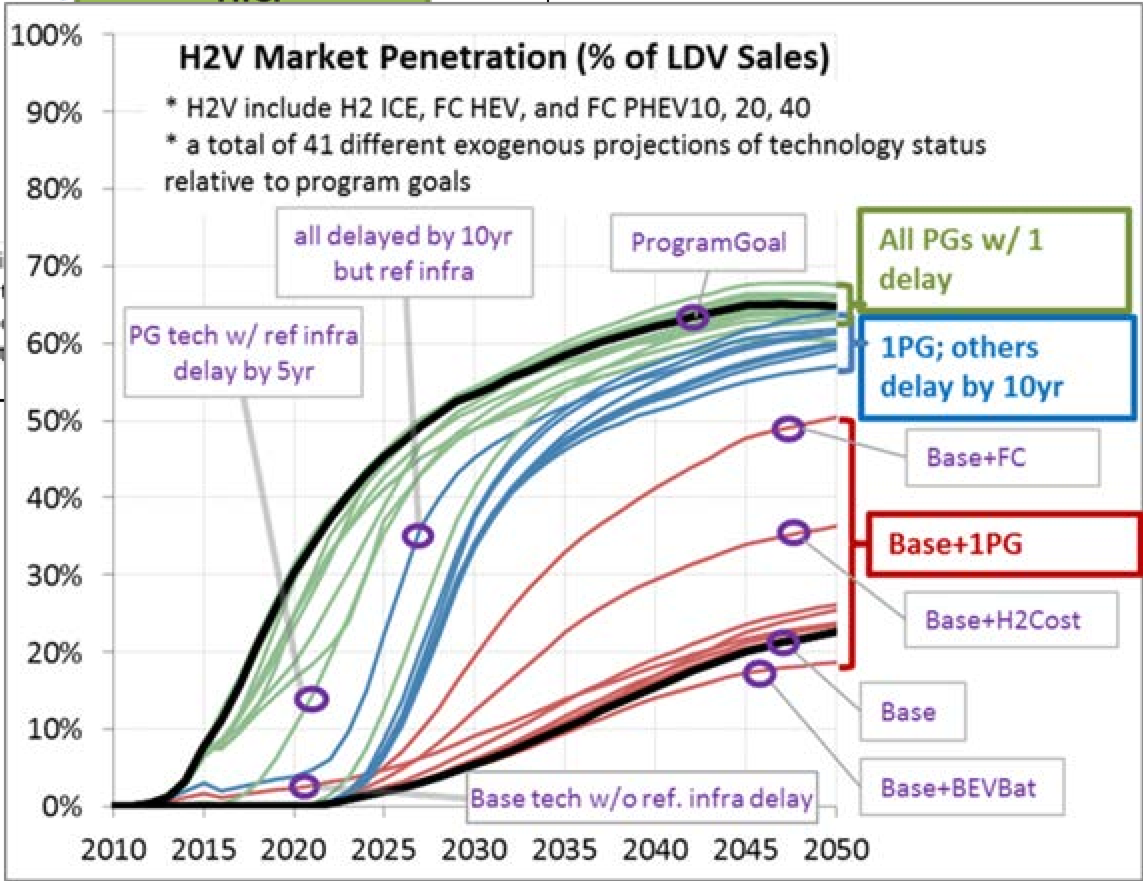


ProgramGoal: all vehicle components meeting DOE program goals on time; fast expansion of both charging and hydrogen infrastructure

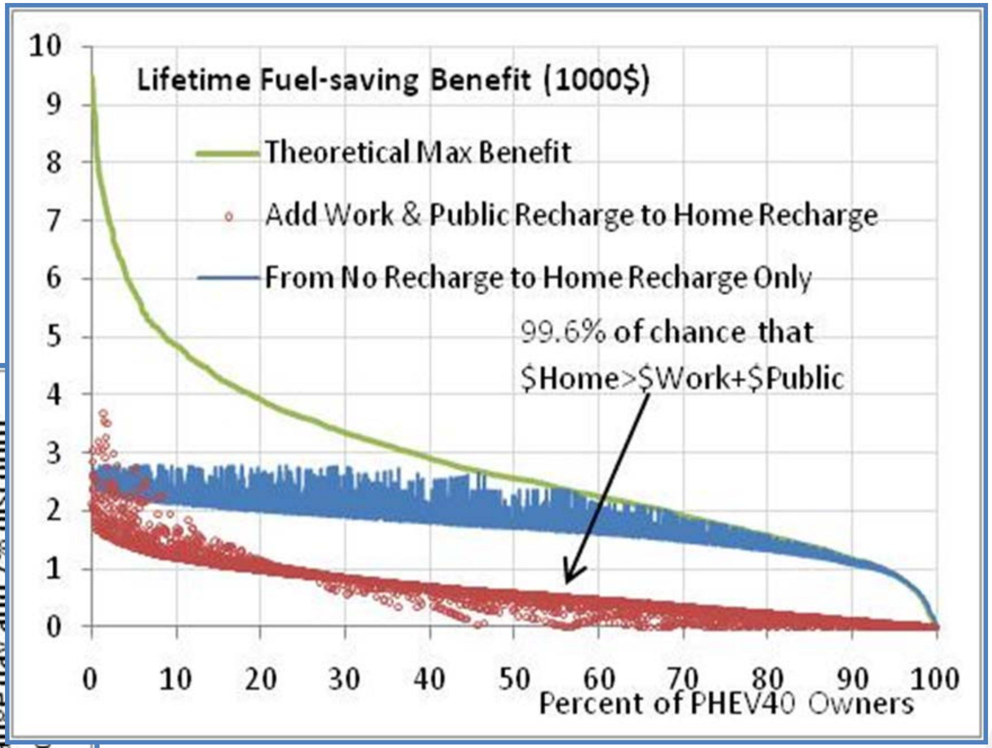


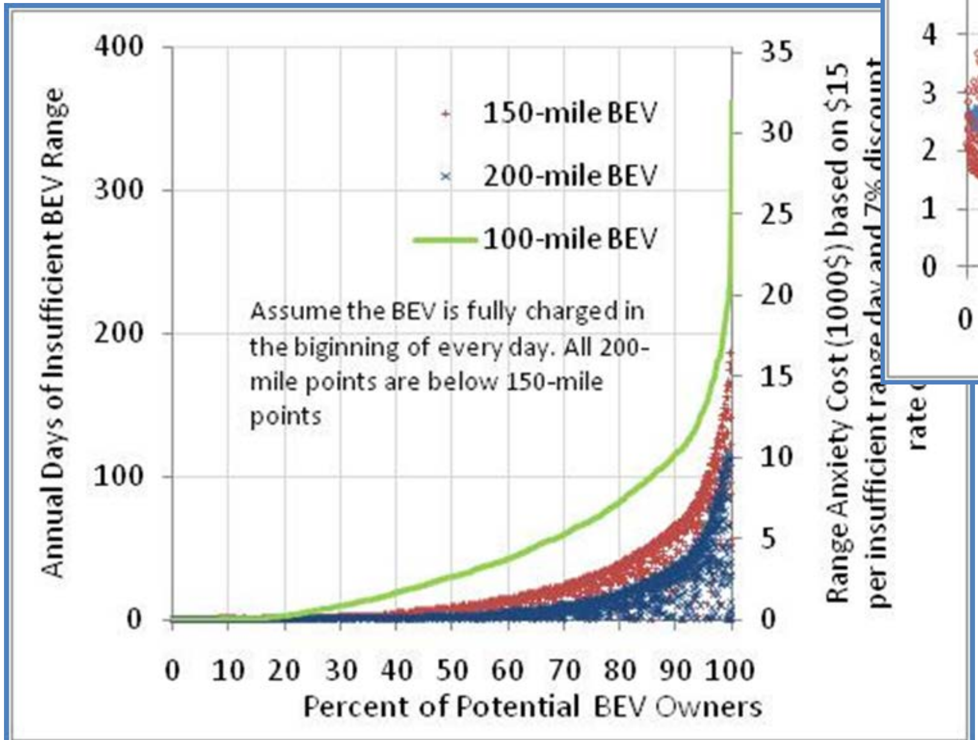
MA3T has been used to analyze the effect of DOE technical targets on hydrogen vehicle market



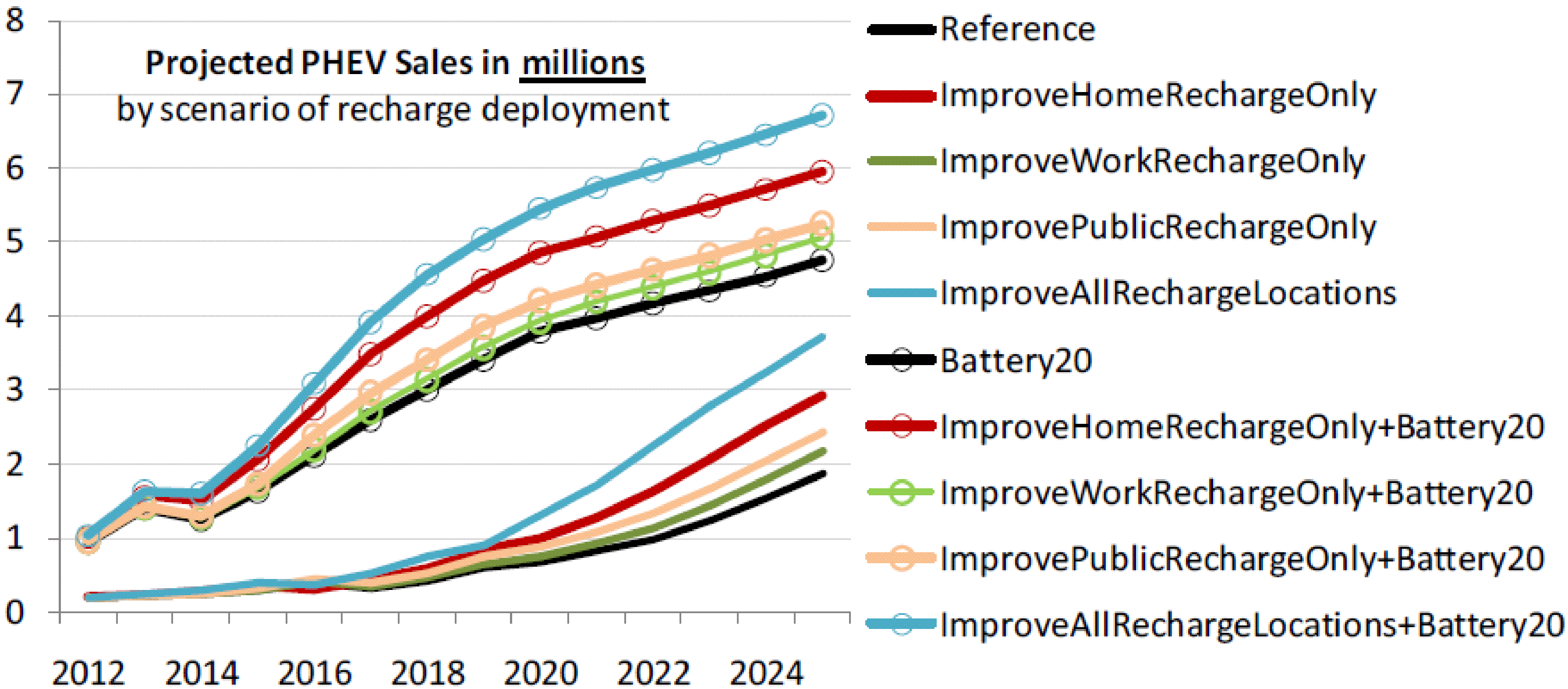


Improved charging infrastructure increases fuel savings for PHEV and improve range assurance for BEV, but to what extent will it facilitate PEV adoption?





The contribution of infrastructure improvement to PEV market adoption can be amplified by battery cost reduction or prevented by high battery cost.



Note: 1. Reference assumes existing policites, recharge availability and moderate technology progress. 2. Battery20 stands for 20 years earlier reduction of battery cost. 3. Deployment of each recharge option is assumed to be aggressive during 2017-2025. 4. Projections generated by ORNL *MA³T* model. 5. the temporary kinks are due to expiration of the ARRA PHEV subsidies.

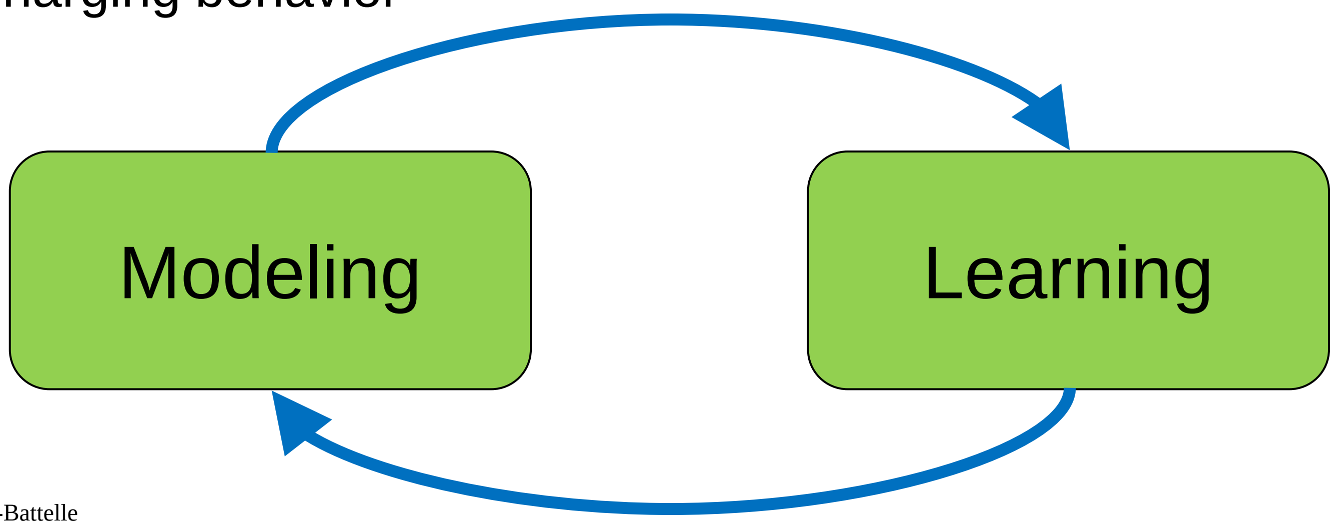
Figure 5 Impact of Recharge Availability on PHEV Penetration, Conditional on Battery Cost

Areas for future improvement

- **Vehicle and energy data update**
- **Calibration and validation**
- **Parameterization**
  - Price elasticity
  - Value of fuel savings; risk aversion
  - Value of refueling and recharging convenience
  - V2G
  - Charging behavior and services
- **Market segment data**
  - Early adopters
  - Driver and driving distributions
  - Home vehicle flexibility
  - Duty cycle

MA^{3}T provides a flexible modeling framework that can be improved as we learn more about how markets respond to advanced automotive technologies.

- **NMNL core plus logical structure that can be populated with best available information.**
- **Detailed market disaggregation important for representing early market penetration.**
- **Need better data in several areas, especially**
  - Early adopters
  - Charging behavior



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Thank you !