Electric Vehicle Technologies Workshop Session EV-08

Consumers – Vehicle Choice

Presented by

Thomas Stephens

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galvincenter for electricity innovation at ILLINOIS INSTITUTE OF TECHNOLOGY

About the Lecturer…

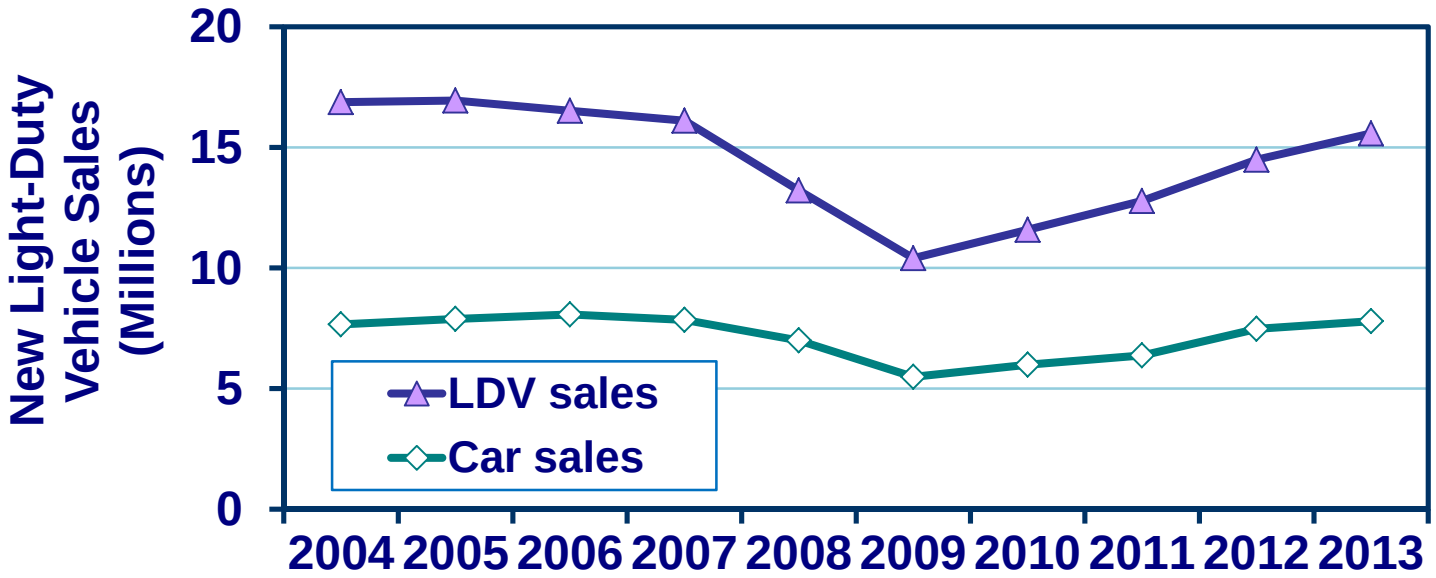
- Tom Stephens is a Transportation Systems Analyst at Argonne National Laboratory
- Education
  - PhD Chemical Engineering, University of Texas
  - MS Sustainable Systems, University of Michigan
- On assignment to the U.S. Department of Energy Vehicle Technologies Office
- Conducts assessments of advanced vehicle technology
  - Potential market adoption and energy implications

Outline

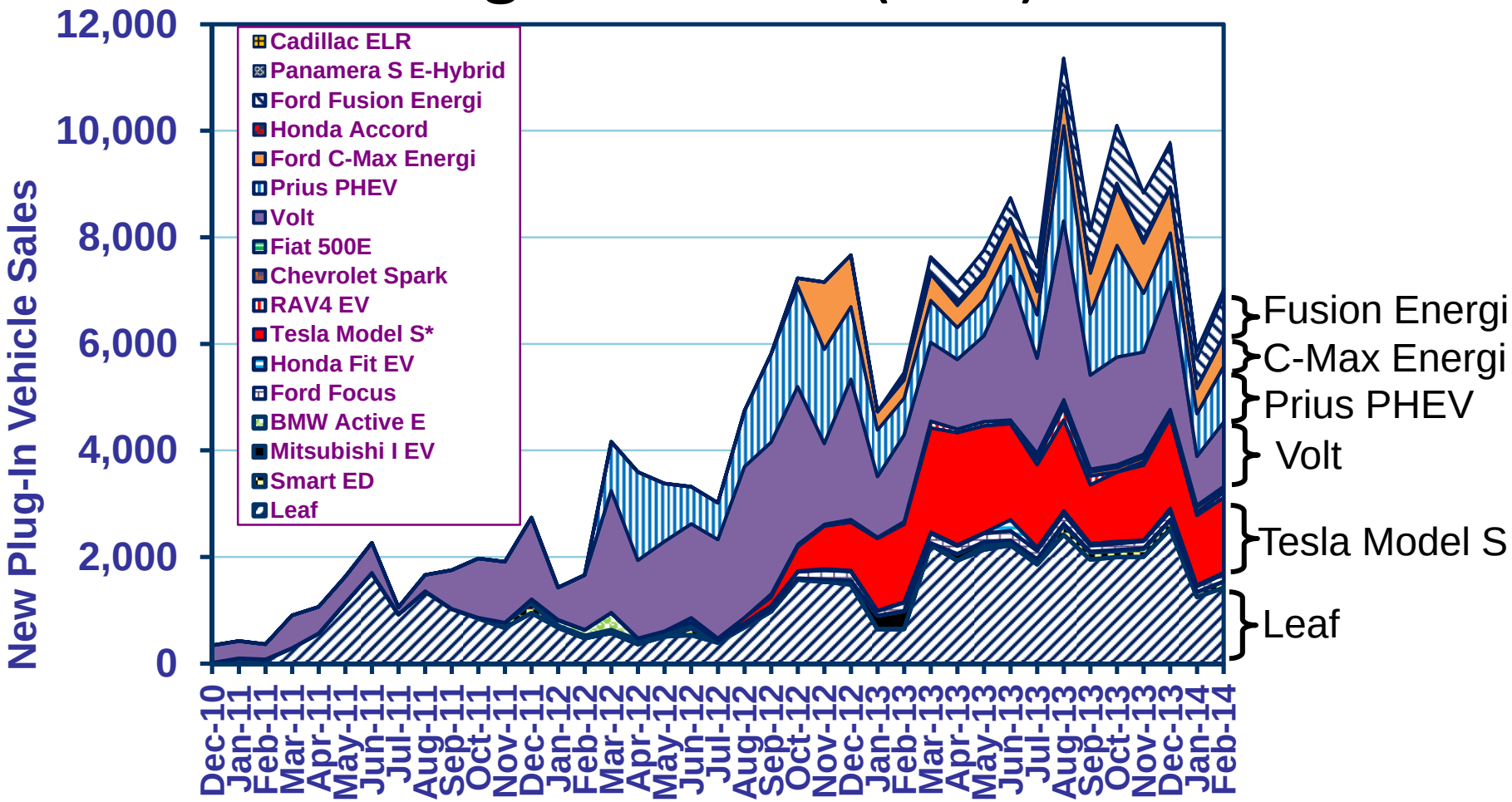
- Consumer demand for new vehicles
- Recent plug-in vehicles (PEVs) sales trends
- Factors that influence PEV adoption
- Projections of future sales, vehicle choice modeling
- What about
  - Commercial vehicles, fleets?
  - Fast charging, battery swapping, vehicle-to-grid?
  - Leasing, car sharing?

Sales of new vehicles in the U.S.

- Consumer demand for new cars is subject to
  - Economic conditions (employment, income)
  - Automaker incentives (discounts, financing)
  - Policies (government rebates, tax credits)



U.S. Plug-in vehicle (PEV) sales



http://www.transportation.anl.gov/technology_analysis/edrive_vehicle_monthly_sales.html

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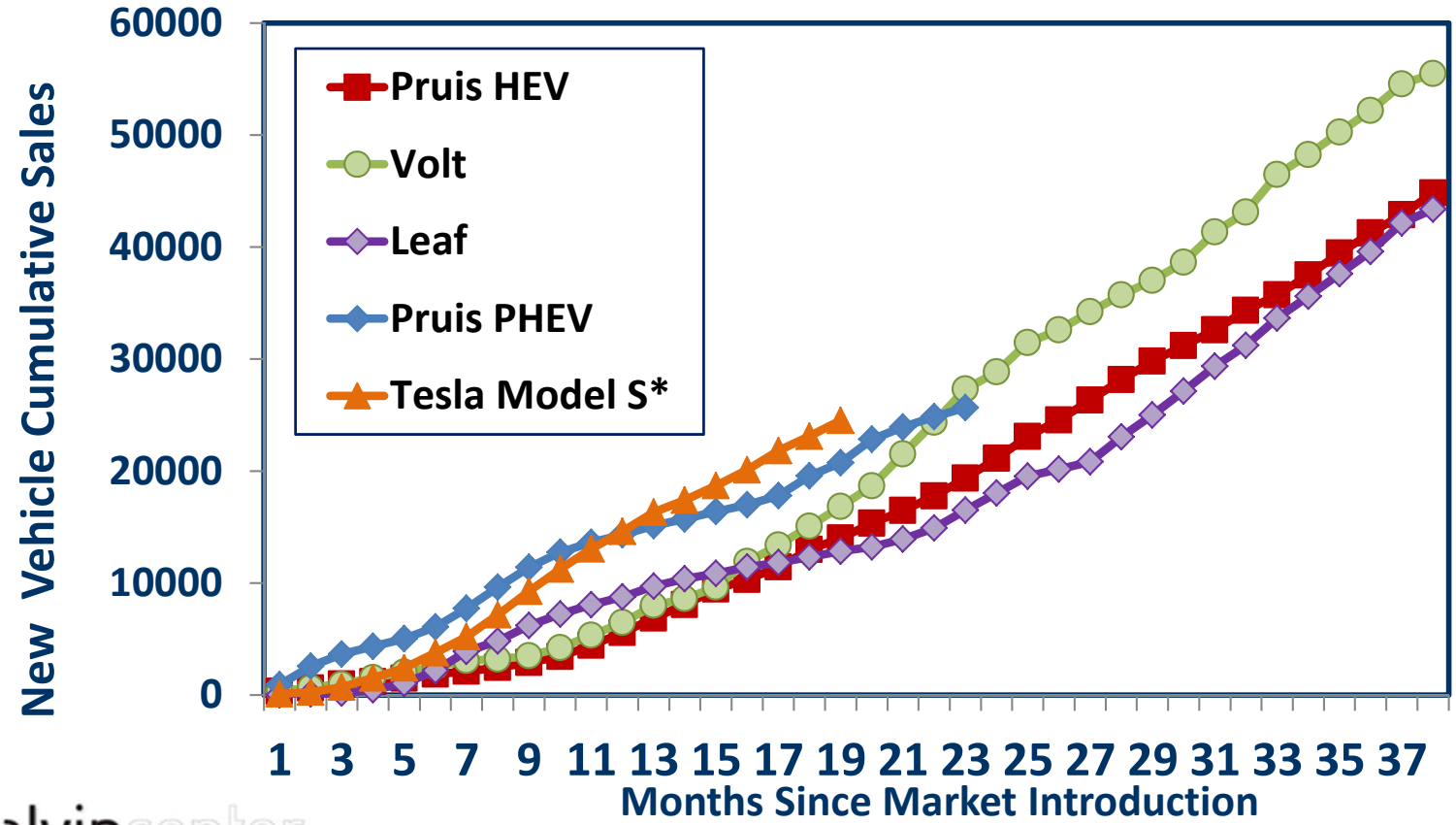
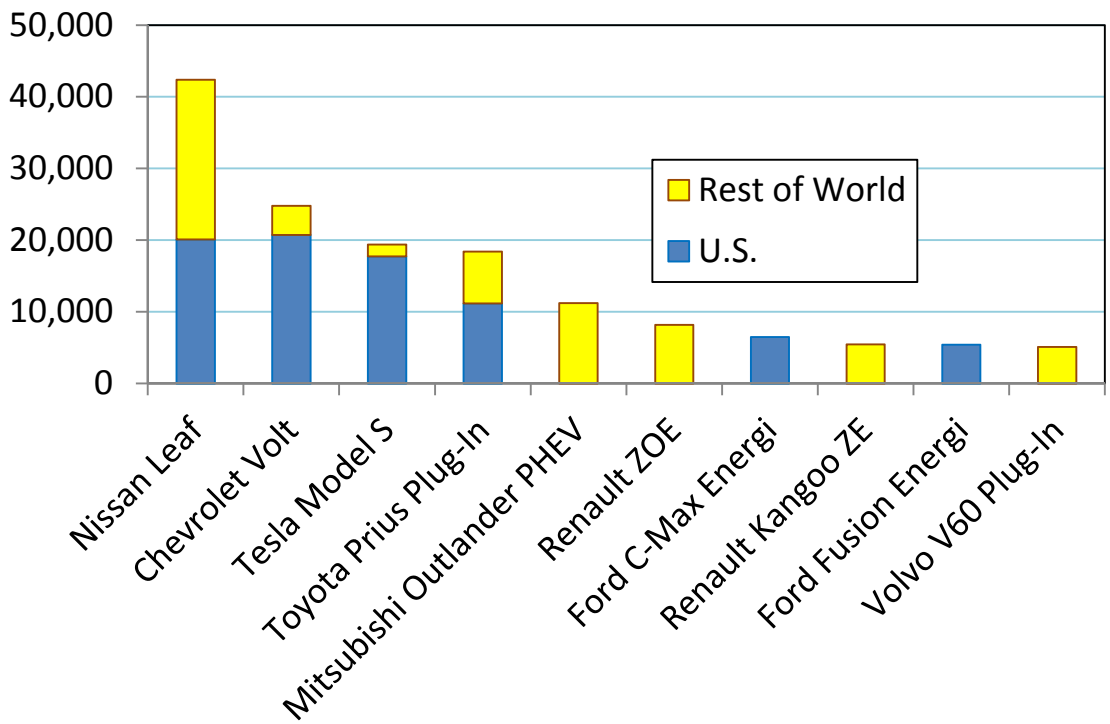
PEVs sales in the U.S. show sales growth comparable to or faster than historic HEV sales

- Incentives are higher for PEVs than HEV incentives
- PEV model diversity is growing rapidly



Sales of PEVs are increasing globally

- PEVs are selling in Japan, Norway, France, Germany, and the Netherlands (First 11 months of 2013)



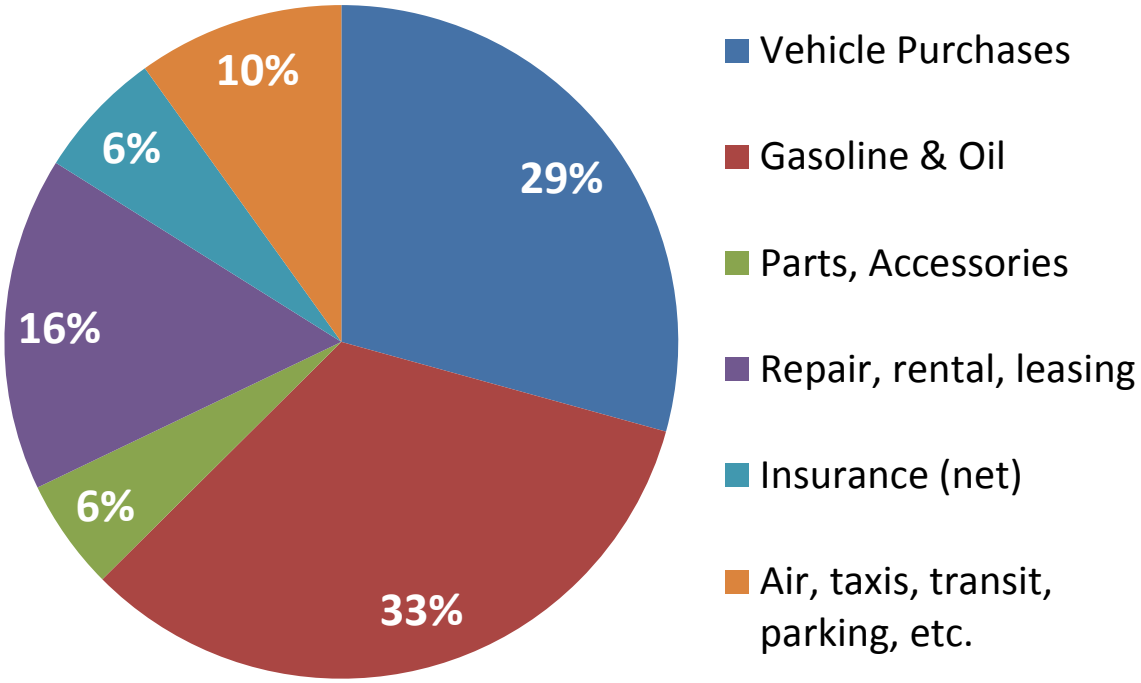
https://www1.eere.energy.gov/vehiclesandfuels/facts/2014_fotw815.html
http://insideevs.com/global-sales-of-top-10-plug-ins-already-above-20000-units-a-month/

Many factors influence vehicle purchase decisions

- Vehicle price (and incentives)
- Size class/type (compact, midsize, SUV, pickup)
- Operating costs (fuel, maintenance, repair, insurance, registration)
- Resale Value
- Safety
- Performance
- Reliability
- Other (interior space, styling, color, …)
- Social and emotional values (symbolism, image)

Vehicle and fuel purchases are the largest transportation expense for the average U.S. household

2010: $999 billion, 10% of Total U.S. Personal Expenditures



Ward's Motor Vehicle Facts & Figures 2011

PEVs Offer Advantages to Consumers

- Lower cost per mile
  - For example, compare 2014 Nissan Leaf with Nissan Versa

Leaf

$28,980 – 35,020 MSRP

30 kWh/100 mi

$550 per year for electricity*

Versa

$11,900 – 16,890 MSRP

535 mi/gal

$1550 per year for gasoline*

* www.fueleconomy.gov
45% highway, 15,000 mi/year
$3.58/gal gasoline, 12¢/kWh electricity

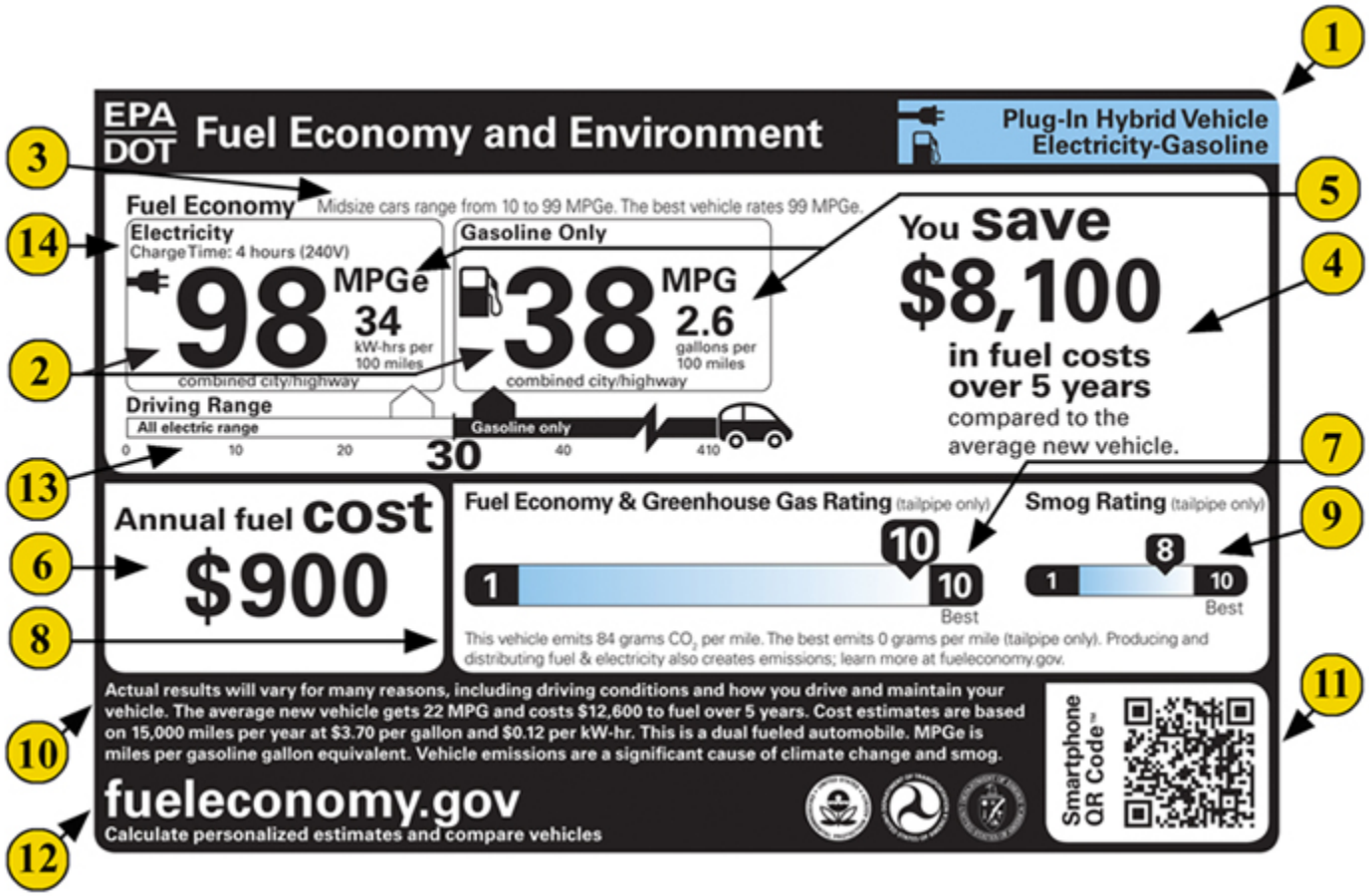
For some advanced-technology vehicles, additional factors matter

- Unfamiliarity
- Uncertainty of benefits
- Driving range (e.g., for some BEVs and some alt fuel vehicles)
- Availability of fuel (electricity)
- Availability with other features (make/model diversity)
- Incentives
- Continued improvements in conventional vehicles

Consumers and dealers may be unfamiliar with PEVs

- Consumers unfamiliar with PEVs may be hesitant to consider purchasing one
  - What will it cost to own (charging, maintenance, repair)?
  - Will I need an expensive charger?
  - Will I need to upgrade my electricity service?
  - What will my electric bill be?
  - Can I get a special electricity rate?
  - Where can I charge up away from home?
  - How long will the battery last? And what would a replacement cost?
- Auto dealership sales staff may have limited information about PEVs and electricity rates, service upgrades

Window-sticker fuel economy label is good for comparing vehicles, but "Your mileage may vary"



http://www.fueleconomy.gov/feg/label/learn-more-PHEV-label.shtml

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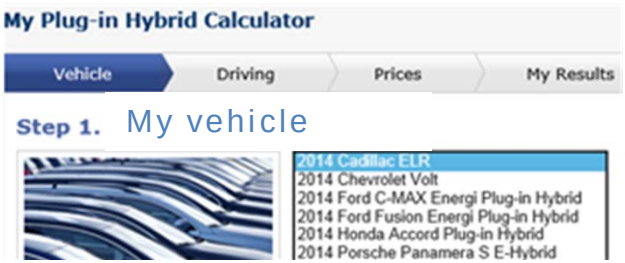
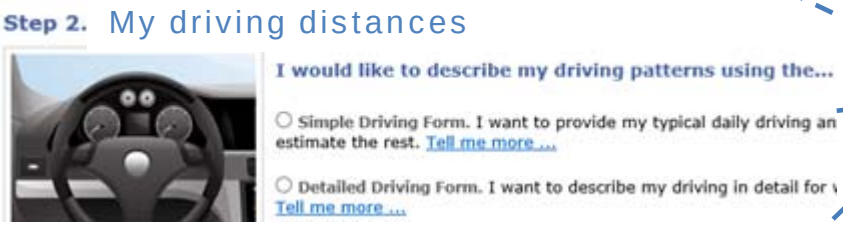
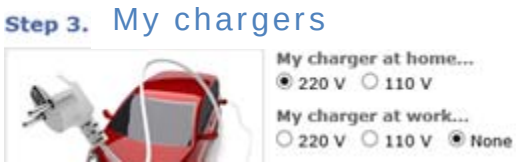
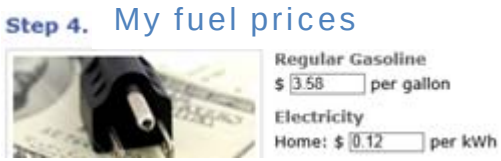
My Plug-in Hybrid Calculator
www.fueleconomy.gov

- Allows personal estimates of fuel and electricity use









Annual Estimated Fuel Use and Costs

	Gasoline	Electricity	Total
Fuel Costs	$274	$227	$501
Miles	3,259	6,741	10,000
Fuel Used	76 gallons	2,272 kWh	—

Estimated number of gas station visits per year: **about 6.**

http://www.fueleconomy.gov/feg/Find.do?action=phev1Prompt

Uncertain future fuel savings

- PEV energy use is variable, depending on
  - Driving style, accessory use (A/C, heating)
  - Charging frequency (distance between charging)
- No one knows the future
  - Future fuel prices
  - Relocation
  - Other household changes in vehicle use
- Consumers are often risk-averse
  - Potential losses are weighted more than potential gains
  - Willing to pay less for uncertain fuel savings

Greene, DL (2011) "Uncertainty, loss aversion, and markets for energy efficiency," *Energy Economics*, **33**, 608.
related presentation: http://emf.stanford.edu/files/docs/250/GREENE8-4.pdf

Familiarity grows with exposure

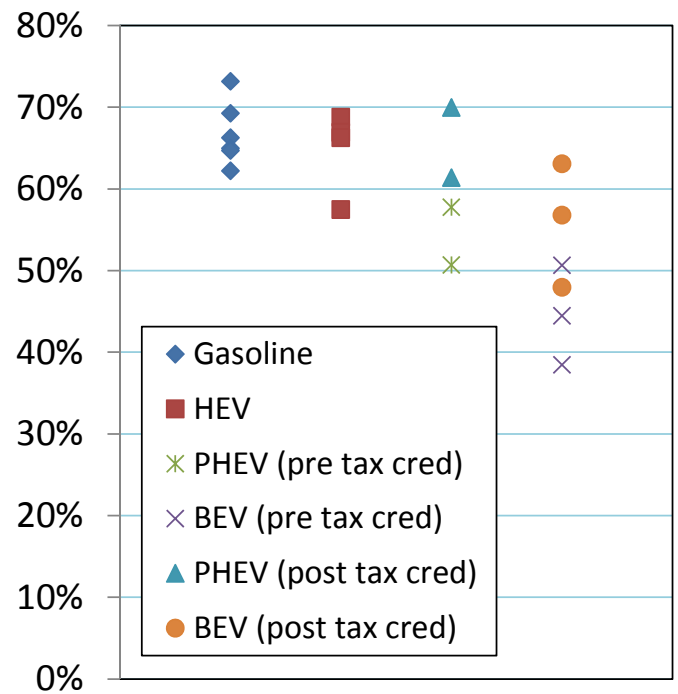
- Potential car buyers see PEVs
  - When friends or coworkers buy one
  - At auto shows, ride-and-drive demos, in advertisements
- Personal contact and direct experience with vehicles are important
  - Trusted information sources
  - Driving a PEV
- PEV adoption appears to be geographically clustered
  - Favorable policies in some areas
  - Favorable market segments (niches)

Tal G et al., (2013) "Who Is buying electric cars in California? Exploring household and vehicle fleet characteristics of new plug-in vehicle owners," Institute for Transportation Studies, Research report – UCD-ITS-RR-13-02, University of California at Davis, http://www.its.ucdavis.edu/research/publications/publication-detail/?pub_id=1839

PEVs may depreciate faster than conventional vehicles

- BEV resale value is a smaller fraction of MSRP and of (MSRP – tax credit), based on only 15 vehicles (MY 2011, 2012)

MY	Make/Model	Drivetrain	Resale / MSRP	Resale / (MSRP – Tax Cr)
2012	Honda Civic	Conv	73%	
2012	Toyota Corolla	Conv	69%	
2012	Honda Insight	HEV	69%	
2012	Toyota Prius	HEV	67%	
2012	Chevrolet Cruze	Conv	66%	
2012	Chevrolet Volt	PHEV	58%	70%
2012	Nissan Leaf	BEV	51%	63%
2012	Mitsubishi i	BEV	38%	48%



NADA "Q2 2013 Plug-in Electric Vehicles: Market Analysis and Used Price Forecast", http://automotivedigest.com/wp-content/uploads/2013/06/Q2-2013-NADA-Plug-In-Electric-Report.pdf
Values from Apr 2013

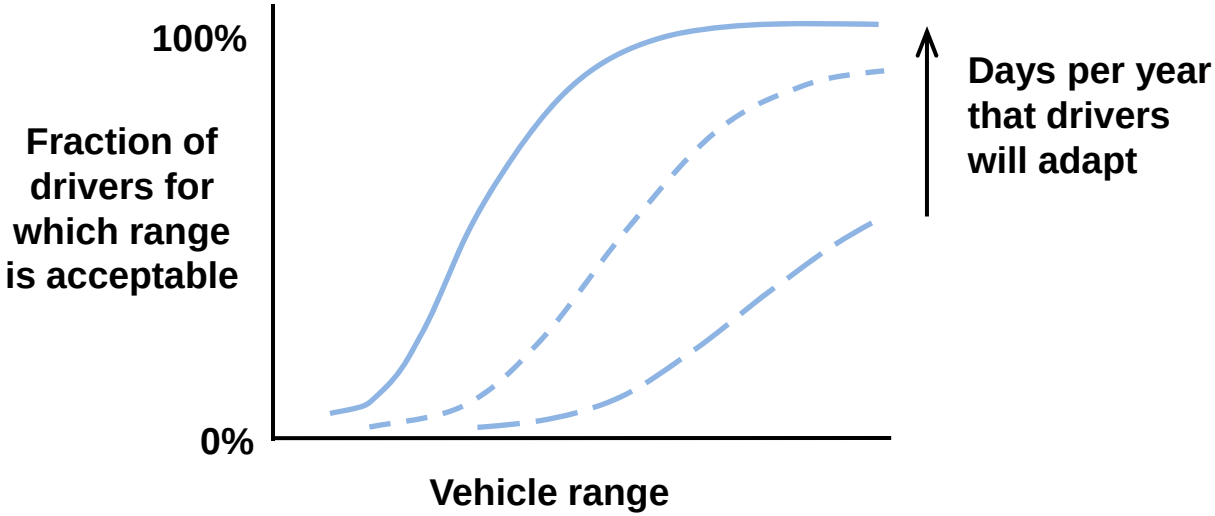
Several Factors Influence Resale Value

- Discounting (but with delayed effect)
  - One study found that a 10% discount on new cars led to 6.5% decrease in price of 3-year old cars (Holweg & Kattuman)
- Supply and demand of used cars
- Model upgrades
- Model reputation/public perception
- General economic/market conditions
- The market for new PEVs is just developing, the used PEV market is just beginning

Holweg M and PA Kattuman. "The Incentive Whiplash,"
http://www.eea-esem.com/files/papers/EEA-ESEM/2006/2414/IncentiveWhiplash.pdf

Limited range of some BEVs can limit adoption by some drivers

- What range is needed? How often?



- If the vehicle has insufficient range for a few days per year, some drivers will adapt (e.g., use a different car)
- How many days per year depends on the daily driving distance distribution over the year

Figure adapted from:
Tamor MA, C Gearhart, C Siro (2013), "A statistical approach to estimating acceptance of electric vehicles and electrification pf personal transportation" *Transportation Research Part C* 26, 125-134.

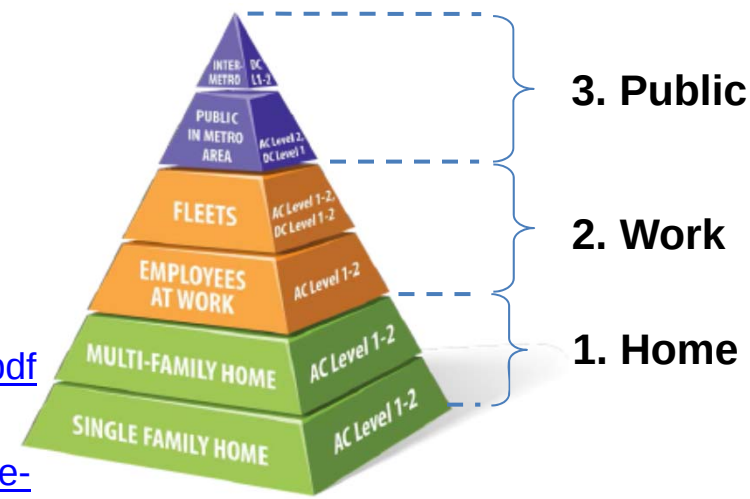
Range of BEVs and "electric" range of PHEVs

- We can roughly estimate the cost of BEV range from considering the value of time to find a charging station or the cost of substitute transportation
  - Value of time implies cost of range is proportional to a 1/R
  - Cost of substitute transportation is proportional to the days when a substitute is needed
- The "electric" (or "charge-depleting") range of PHEV allows operation on cheaper electricity
  - From fuel prices, electricity rates, and distance driven between charging, we can estimate fuel and electricity costs
- Such estimates are only rough approximations unless trip-by-trip distance distributions s are known

Lin Z (2012) "Battery electric vehicles: Range optimization and diversification for the US drivers." *Transportation Research Board 91st Annual Meeting*. Paper No. 12-4477, http://info.ornl.gov/sites/publications/files/Pub32211.pdf

Availability of charging stations is important (but how important?)

- Both PHEVS and BEV need charging stations
  - Absolute requirement for BEVs
  - Most PEV owners want to charge at home
  - Workplace charging can add value
  - Public charging can enable long distance BEV travel
- Influence of charger availability on vehicle adoption depends on
  - Driving needs of each driver/household
  - Vehicle range, charging time
- Charging stations needed

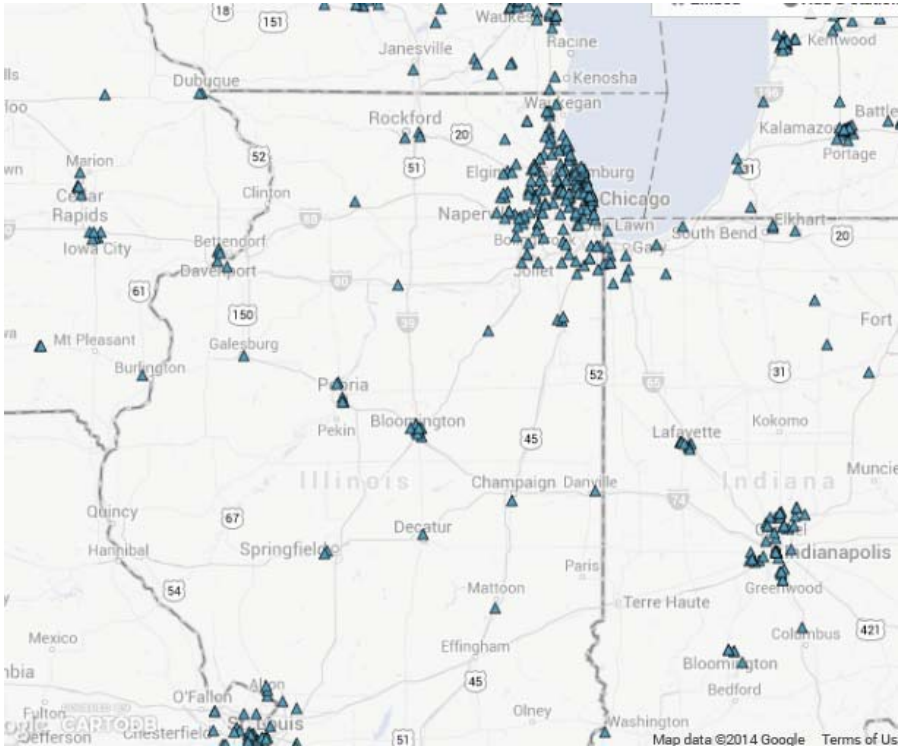


Frades M, *A Guide to the Lessons Learned from the Clean Cities Community Electric Vehicle Readiness Projects, Feb 2014.* http://www.afdc.energy.gov/uploads/publication/guide_ev_projects.pdf

Motovalli J, *Fast-Charging Networks for Electric Cars: A State-by-State Guide*, http://www.plugincars.com/fast-charging-networks-state-state-guide-129469.html

Existence of and knowledge of charging stations

- U.S. DOE EERE Alternative Fuels Data Center Alternative Fueling Station Locator
- Electric charging stations
- Other fuels (NG, E85, etc.)
- Over 7000 electric charging stations in U.S.
  - Physical location, address
  - Phone number
  - Status (planned or operational)
  - Power level, connector type, number of ports
  - Network (if applicable)
- Proprietary networks provide station info



http://www.afdc.energy.gov/locator/stations/

Market niches for BEVs and PHEVs

- Both BEVs and PHEVs must be driven a lot for the fuel savings to exceed the incremental price (relative to a conventional or hybrid vehicle)
- However, range-limited BEVs aren't convenient (or usable?) for long-distance trips, depending on locations of charging stations
- Since PHEVs cost less to drive on electricity, they are more economical if they are driven
  - Consistently far enough to deplete the battery but not much farther
  - Charged more than once per day
- Interplay between vehicle price, range , driving pattern, and charging

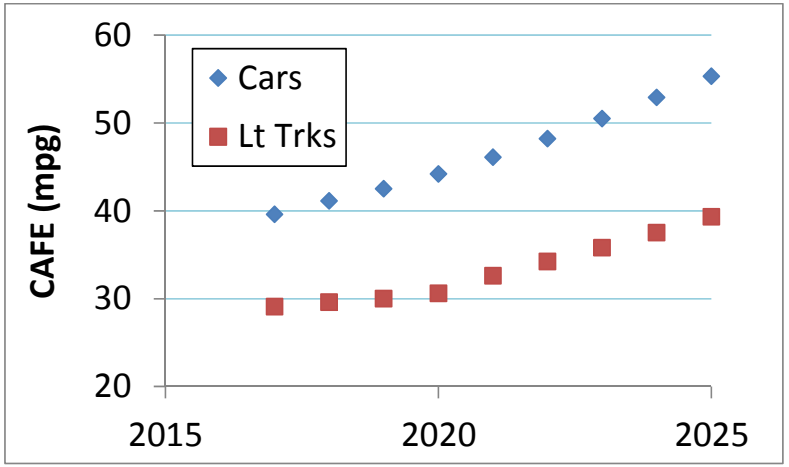
Santini et al., *Plug-in Hybrid Electric Vehicles*, IA-HEV 2013 Task 15 Report, International Energy Agency, to appear.

Zhou J, A Vyas, D Santini (2013) "Tracking national household vehicle usage by type, age, and area in support of market assessments for plug-in hybrid electric vehicles," *Journal of Transportation Technologies* **3**, 174-183, http://dx.doi.org/10.4236/jtts.2013.32017

Santini et al., (2013) "Cost effective annual use and charging frequency for four different plug-in powertrains," SAE Paper 2013-01-0494. SAE World Congress, Detroit, MI, April 16–18.

Consider an automaker's perspective

- How fast should PEV production capacity be ramped up?
  - Tooling up assembly plants and establishing supply chains take time and money
  - Car models are redesigned only every 4 – 5 years
  - New technologies are introduced gradually in selected models and markets
  - Conventional technologies continue to improve
- Standards and regulations
  - Most automakers meet CAFE standards
  - California and seven other states require a certain sales share of "zero-emission vehicles"—approx. 10% by 2020



Plotkin S, T Stephens, W McManus (2013). *Vehicle Technology Deployment Pathways: An Examination of Timing and Investment Constraints*, DOE/GO-102013-3708.

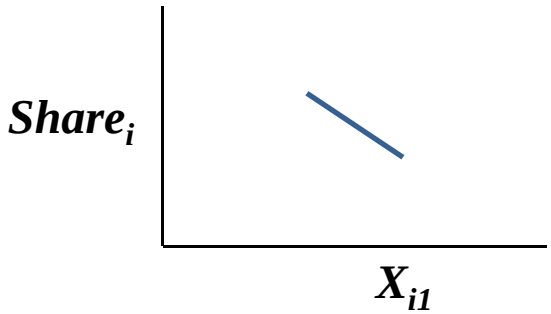
NHTSA/EPA, *2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards*, Federal Register / Vol. 77, No. 199 / Oct 15, 2012.

CARB, "ZEV Tutorial," www.arb.ca.gov/msprog/zevprog/factsheets/zev_tutorial.pdf.

Making projections of future sales

- Short term (a few years) projections can be based on
  - Market trends, automaker announcements, surveys, focus groups, expert judgment
  - Regression models

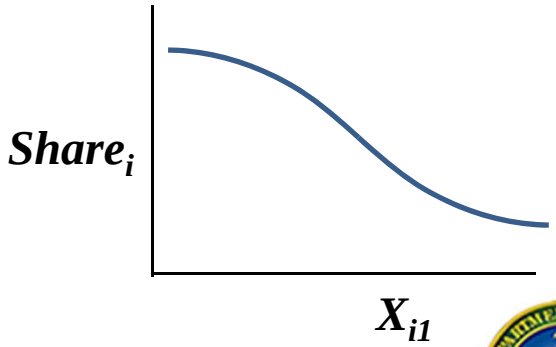
$$Share_i = c_1 X_{i1} + c_1 X_{i1} + \cdots + \varepsilon$$



- For longer-term projections, more sophisticated models, e.g., discrete choice models that use a utility function

$$Share_i = f(U_i)$$

$$U_i = \beta_1 X_{i1} + \beta_1 X_{i1} + \cdots + \varepsilon$$



Consumer choice models

- Consumer choice models give the probability that consumers will choose a given product, e.g., vehicle type, in terms of
  - Vehicle price
  - Fuel economy or fuel cost per mile (and other operating costs)
  - Other vehicle attributes
    - Vehicle range
    - Availability of fuel
    - Size class
    - Performance
    - Diversity of makes/models
    - Other ...
  - Consumer characteristics
    - Annual distance driven
    - Early adopter
    - Income
    - Other …

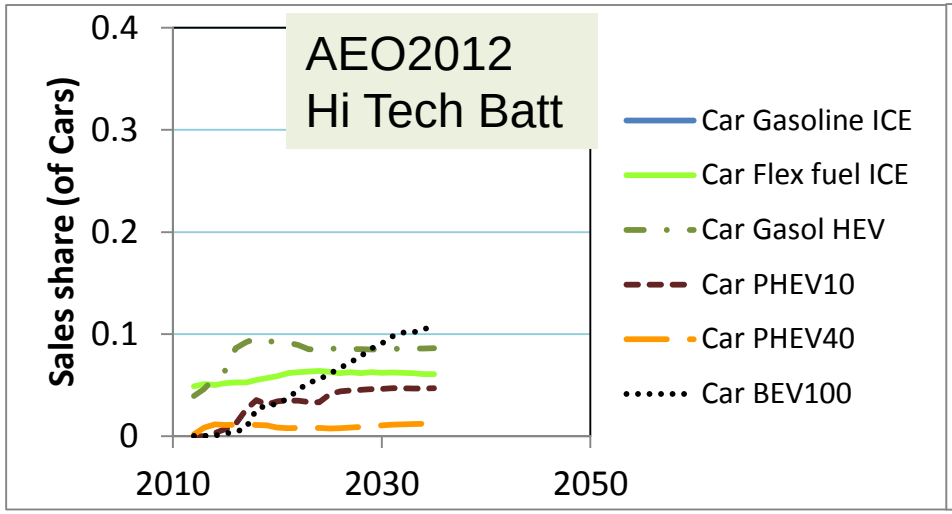
See, e.g.,

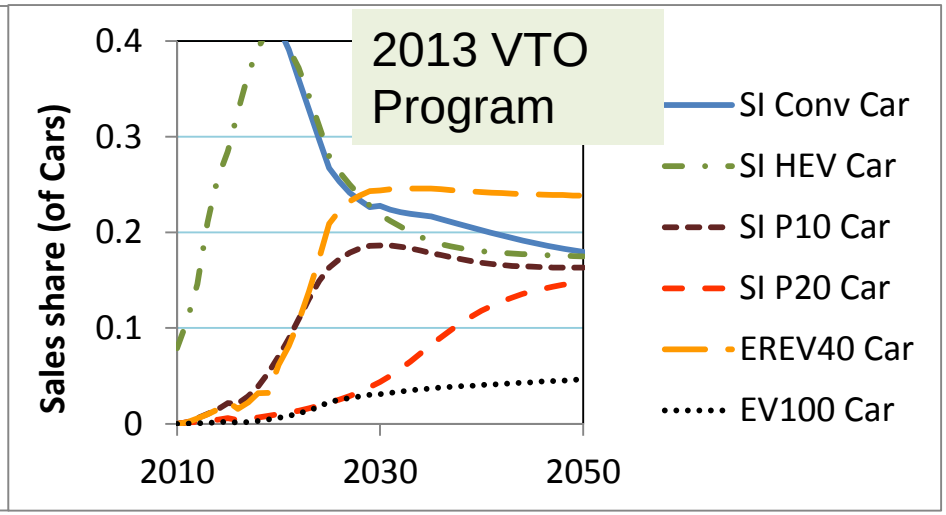
Train, K (2009) *Discrete Choice Methods with Simulation*, http://elsa.berkeley.edu/books/choice2.html

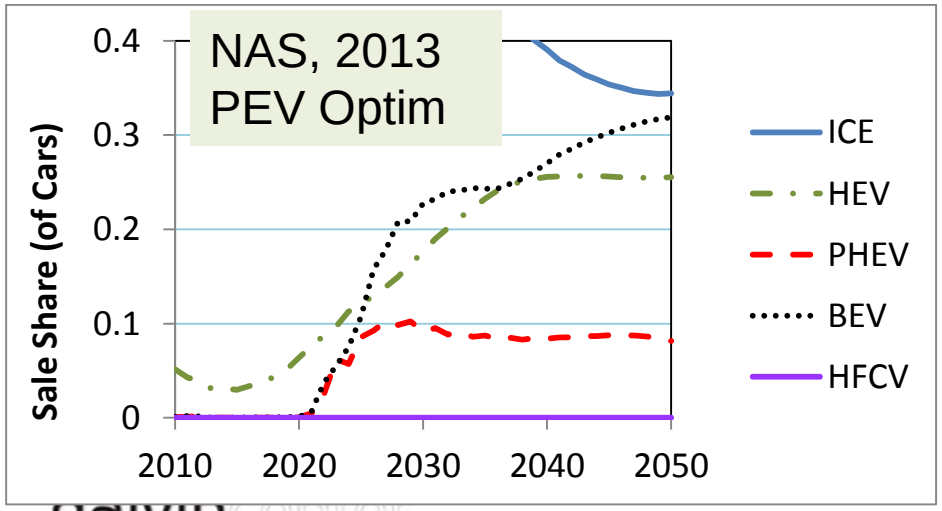
Al-Alawi & Bradley (2013) *Renewable and Sustainable Energy Reviews* **21**, 190-203.

Projections of future market shares of advanced-technology vehicles vary widely

Different models using different inputs give different results



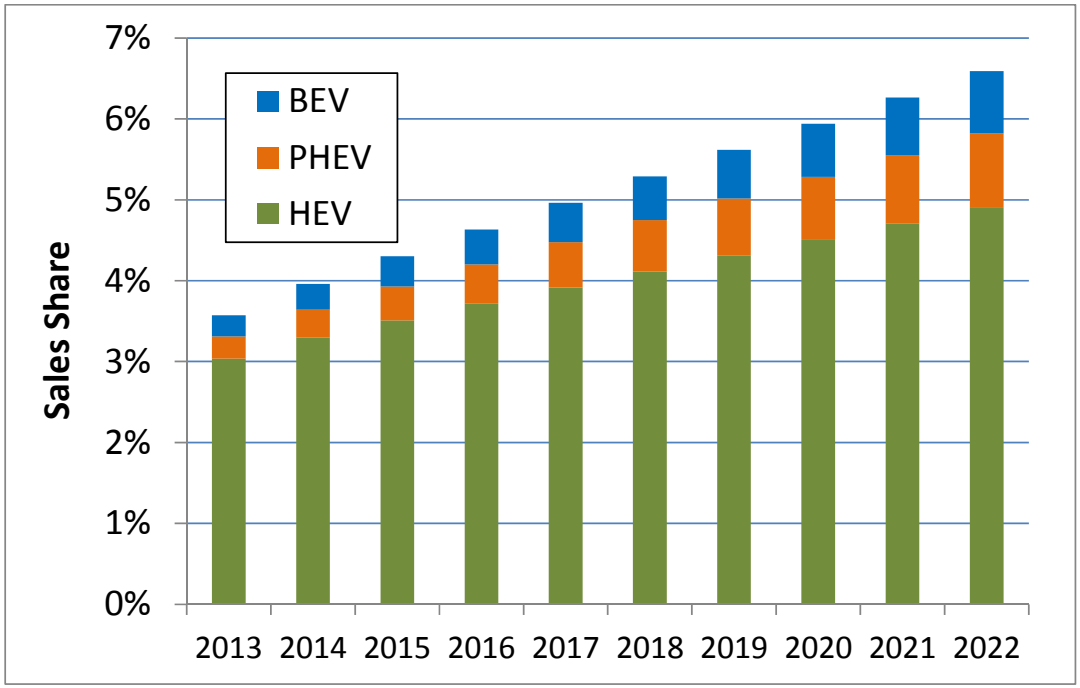




- AEO2012 High Technology Battery Case
- VTO Program Benefits Analysis Program Success Case
- NAS, 2013 Transitions to Alt Veh & Fuels Optimistic PEV Case

Projections of PEV and HEV sales shares from Navigant Research

North America, Light-duty vehicles



N America:

- Steady growth, but probably won't meet ZEV targets

Global trends:

- Increasing HEV, PEV availability
- Decreasing price
- Continuing incentives
- Increasing fuel prices
- Recovery of N American and Asian LDV markets

Sources: "Electric Vehicle Market Forecasts, Global Forecasts for Light Duty Hybrid, Plug-In Hybrid, and Battery Electric Vehicle Sales and Vehicle Parc: 2013-2022," Navigant Research Report, Published 4Q 2013.

"Electric Vehicles: 10 Predictions for 2014," Navigant Research White Paper, www.navigant research.com research/electric-vehicles-10-predictions-for-2014

We can't predict the future but can make projections of how sales shares might change with technology and market conditions

- Sales projections are highly uncertain
- Projections are useful for examining
  - Possible futures
  - Sensitivities to
    - Vehicle technology (electric drive and all other vehicle technologies)
    - Fuel prices
    - Vehicle prices (and purchase incentives)
    - Other policies, conditions
- Projections must be developed and interpreted with care
- Developing and comparing vehicle choice models is ongoing
  - Market segmentation
  - Market maturation
  - Consumer behavior

What about ...

- Fleets
  - Potentially attractive early market niche
  - Awareness of cost of ownership (fuel, maintenance, reliability)
  - Purchase decision based on numerous factors, e.g. who pays for fuel
  - Some fleets, e.g., taxis need quick refueling
- New mobility business models
  - Leasing (popular for PEVs)
  - Car sharing (multiple business models)
- Fast charging, battery swapping
  - Fast charging may decrease battery life
  - Battery swapping requires more batteries per vehicle
- Vehicle-to-grid (or vehicle-to-home) integration
  - Technology and business cases are in flux