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Evaluation of Technology Status Compared to Program Targets

Marc Melaina, Yuche Chen, Aaron Brooker
National Renewable Energy Laboratory

DOE Hydrogen and Fuel Cells Program 2016 Annual Merit Review and Peer Evaluation Meeting

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Project ID SA060

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Overview

Timeline	Barriers
Start: Sept, 2014 **End: Sept, 2016*** Percent complete: 80% * Annual project direction determined by DOE	**4.5 A. Future Market Behavior:** • Competition among advanced vehicles **4.5 B. Stove-piped/Siloed Analytical Capability** • Integrated comparison of multiple vehicle platforms **4.5 D. Insufficient Suite of Models and Tools** • Lacking simulation of specific makes and models (e.g. Toyota Mirai) competing on real-world attributes (e.g. acceleration)

Budget	Partners
Total project funding: $171k • FY15: $121k • FY16: $50k	• **External report peer reviewers** • **H2USA Automotive OEM members** • **Fuel Pathway Integration Tech Team (FPITT)**

Relevance (1)

FCTO Systems Analysis Framework

- Integration of techno-economic vehicle simulations (FASTSim) and market adoption (ADOPT)
- Approach combines real-world empirical data with projections of future cost and performance

- **USDRIVE Tech Teams** (GPRA, BaSCE)
- **NRC Transitions Study** (2013)

- **Fuel Cell Technologies Office**
- **H2USA Working Groups**

Analysis Framework
- Cost estimation
- Vehicle simulation and optimization
- Vehicle drivetrain evolution
- Market competition simulation

Models & Tools
- FASTSim
- ADOPT

Studies & Analysis
- Vehicle and component costs
- Market potential

Outputs & Deliverables
- Recommendations & reports
- Inputs to working groups

- FCTO and VTO Program Targets
- VTO models

__Acronyms__

ADOPT: Automotive Deployment Options Projection Tool

BaSCE: VTO Baseline and Scenario

FCTO: Fuel Cell Technology Office

FASTSim: Future Automotive Systems Technology Simulator

GPRA: Government Performance and Results Act

VTO: Vehicles Technology Office

Relevance (3)
Analysis Objective

Analysis establishes link between program targets and future market dynamics, including explicit policy drivers

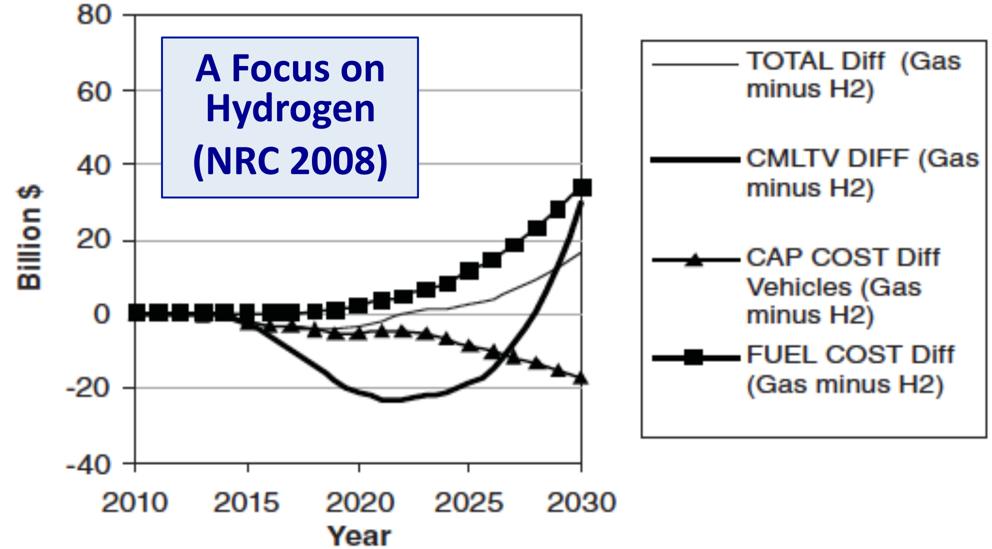
- **Objectives**
  - Understand the influence of meeting, exceeding, or falling short of DOE Fuel Cell Technology Office (FCTO) program goals on future market adoption of fuel cell electric vehicles (FCEVs)
  - Consider a wider range of uncertainties around future technology progress than considered in other studies
  - Combine techno-economic and consumer choice analysis of FCEVs in an integrated framework
- **Impacts on FCTO barriers during this reporting period**
  - Analyzed future FCEV competitiveness and market behavior under various scenarios **(Barrier A)**
  - Incorporated DOE Vehicle Technologies Office (VTO) analyses into FCEV simulations **(Barrier B)**
  - Updated FASTSim and ADOPT models (originally developed for VTO) to analyze FCEV technologies and markets **(Barrier D)**

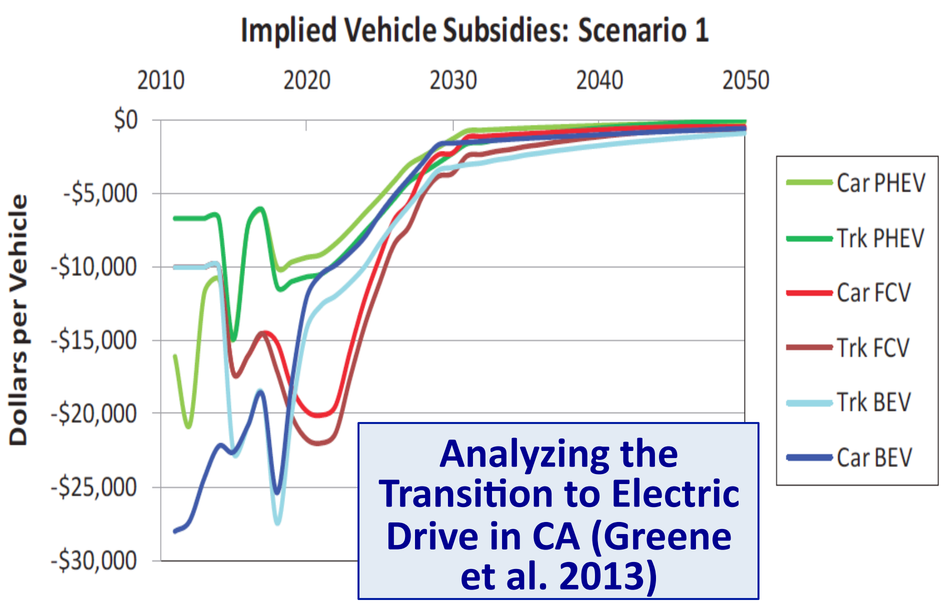
Relevance (3)

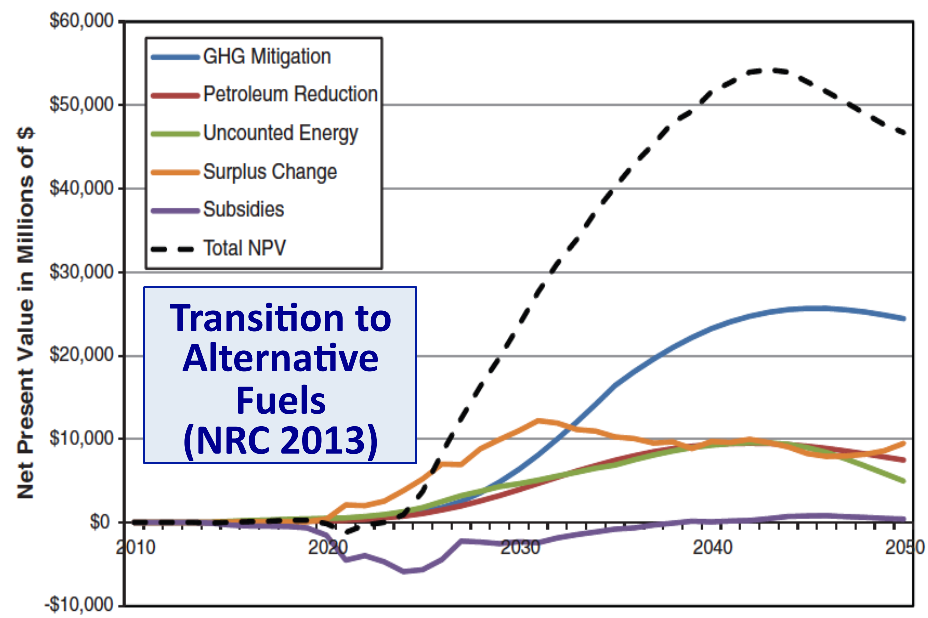
Building on previous transition analysis studies

Common and recurring themes

- Strong and continued policy support needed for successful FCEV market adoption
- Valley of death must be endured before achieving positive returns
- Extended vehicle subsidies required to establish growth trend







Approach (1)
Integrated Simulation

Novel analytic approach integrates vehicle simulation with market adoption potential

- **Develop analytical targets and scenarios**
  - Develop distinct technology trends (GPRA, NRC, other sources) to explore a wide range of potential vehicle technology development outcomes
  - Use targets to create Low, Base, and Accelerated scenarios for 2035
- **Analyze FCEV and other vehicle techno-economics (FASTSim)**
  - Simulate hybrid electric vehicle (HEV), conventional vehicle (CV), and FCEV with the same acceleration, range, and battery-to-total-power ratio
  - Model costs for vehicles in each scenario and identify the most influential parameters

- **Simulate future market shares (ADOPT + FASTSim)**
  - Create future market scenarios from base and accelerated scenarios
  - Explore vehicle tradeoffs to find most marketable powertrain sizing
  - Simulate future vehicle market shares based on vehicle attributes and consumer preferences

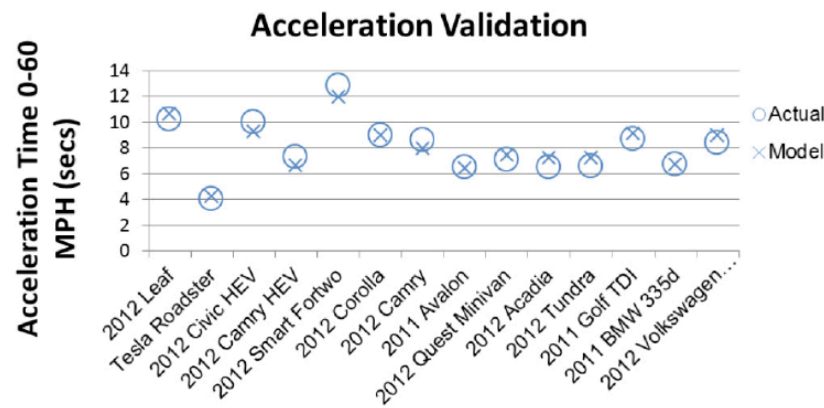
Approach (2)
FASTSim

User-friendly online model, validated against 100s of existing vehicles

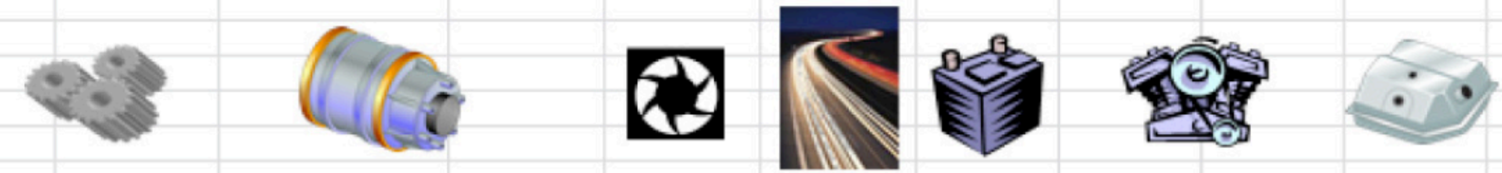
FASTSim Attributes

- Accessible, efficient, accurate, and robust tool for comparing vehicle powertrains
- Explicit and detailed modeling of major drivetrain components
- Efficiency, performance and cost are simulated on standard time-versus-speed drive cycles
- Results validated on hundreds of different vehicles and most existing powertrain options
- Beta version is robust; 1,800 unique downloads with no reports of errors or inaccuracies

Simulations are validated against real-world vehicle attributes by make and model.



FASTSim Drivetrain Components



Transmission power out achieved (kW)	Transmission power in achieved (kW)	Motor mechanical power out achieved (kW)	Motor elect. power in achieved (kW)	Auxiliary loads (kW)	Charger power out achieved (kW)	Battery power out achieved (kW)	Fuel converter power out achieved (kW)	Fuel converter power in achieved (kW)	Fuel storage power out achieved (kW)

Brooker, A., J. Gonder, L. Wang, E. Wood, S. Lopp and L. Ramroth (2015). FASTSim: A Model to Estimate Vehicle Efficiency, Cost and Performance, SAE World Congress, NREL/CP-5400-63623.

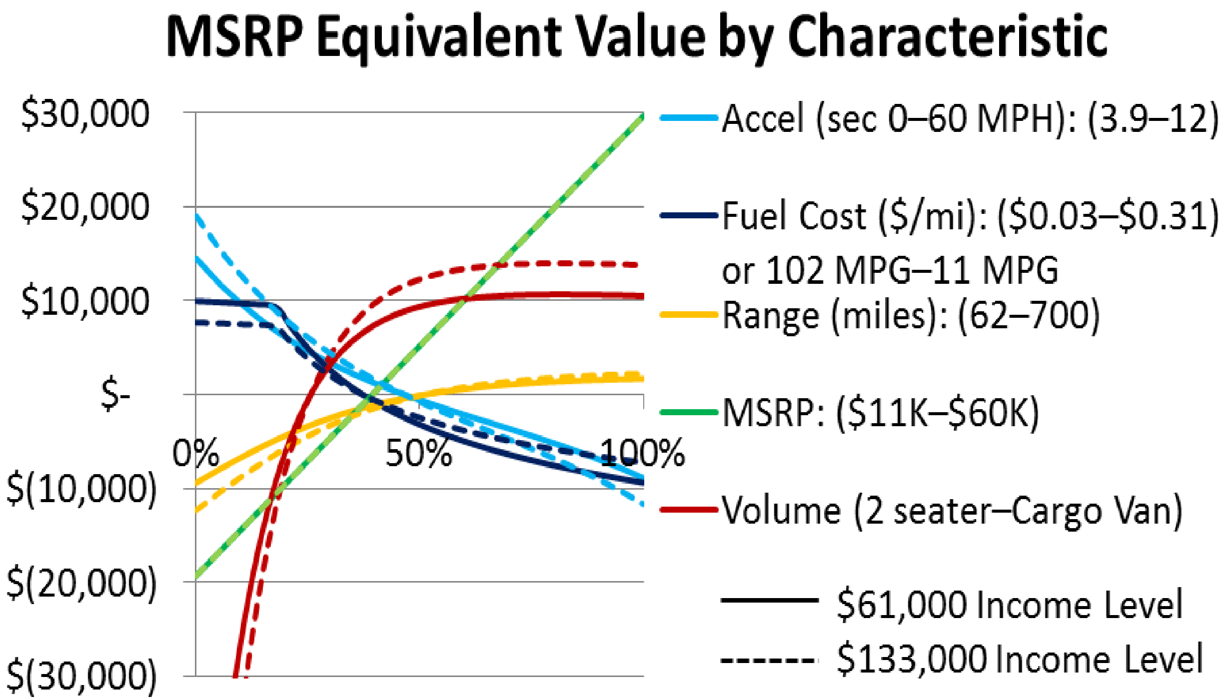
http://www.nrel.gov/transportation/fastsim.html

Approach (3)
ADOPT

Empirically validated against actual sales data for specific makes and models

ADOPT Attributes

- Validation is achieved by simultaneously matching sales against multiple attributes across multiple years: fuel economy, acceleration, price, vehicle size class, and powertrain.
- These consumer preferences trends vary with income. For example, fuel cost is less important to wealthy households, which acceleration is more valuable (see dotted lines in figure below).



Brooker, A., J. Gonder, S. Lopp, J. Ward (2015). ADOPT: A Historically Validated Light Duty Vehicle Consumer Choice Model, SAE World Congress, NREL/CP-5400-63608.

- Figure shows the value of changes in each attribute in terms of MRSP equivalent value
- 1-to-1 ratio for MSRP
- Lower acceleration add value
- Lower range reduces value, and higher range adds limited value
- Lower fuel cost or higher fuel economy adds value

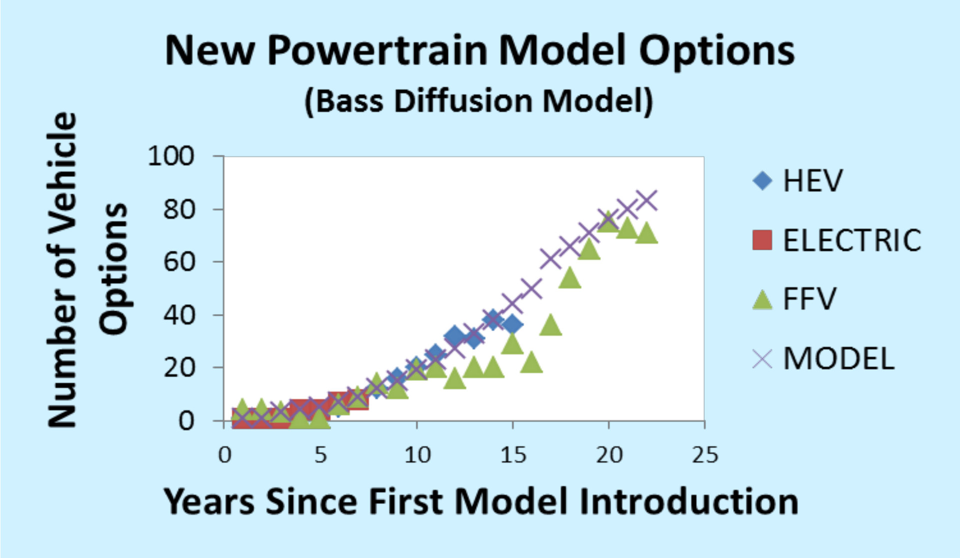
Approach (4)
ADOPT

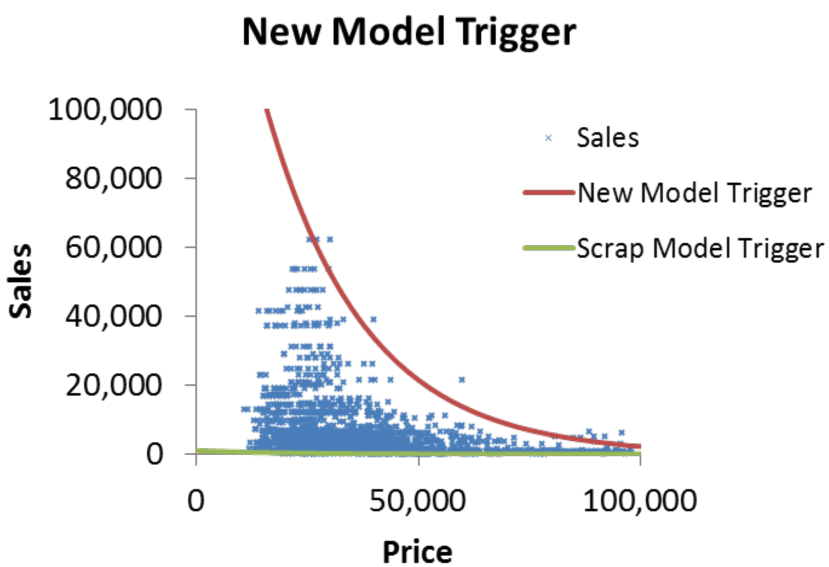
ADOPT simulates the introduction of new models for successful drivetrains

New Vehicle Options

Sales of novel vehicles can be limited due to a lack of models in the market

- Historical data exist on the number of new models introduced as novel drivetrain types are introduced
- Figure (right) shows new flex fuel vehicle (FFV), HEV and electric model options introduced into the LDV market.
- Model trend "X" is the ADOPT constraint.





- ADOPT generates new model options (with similar drivetrains) when a specific model achieves significant sales.
- Figure (left) shows the new model trigger as a sales level that declines with increasing vehicle price.
- When a model reaches this trigger, new models are generated on the same drivetrain to compete in the LDV market.

Brooker, A., J. Gonder, S. Lopp, J. Ward (2015). ADOPT: A Historically Validated Light Duty Vehicle Consumer Choice Model, SAE World Congress, NREL/CP-5400-63608.

Accomplishments and Progress (1)

Techno-economic analysis: consumer perceived cost of ownership

In the Base scenario, the FCEV consumer cost is comparable to CV and HEV costs

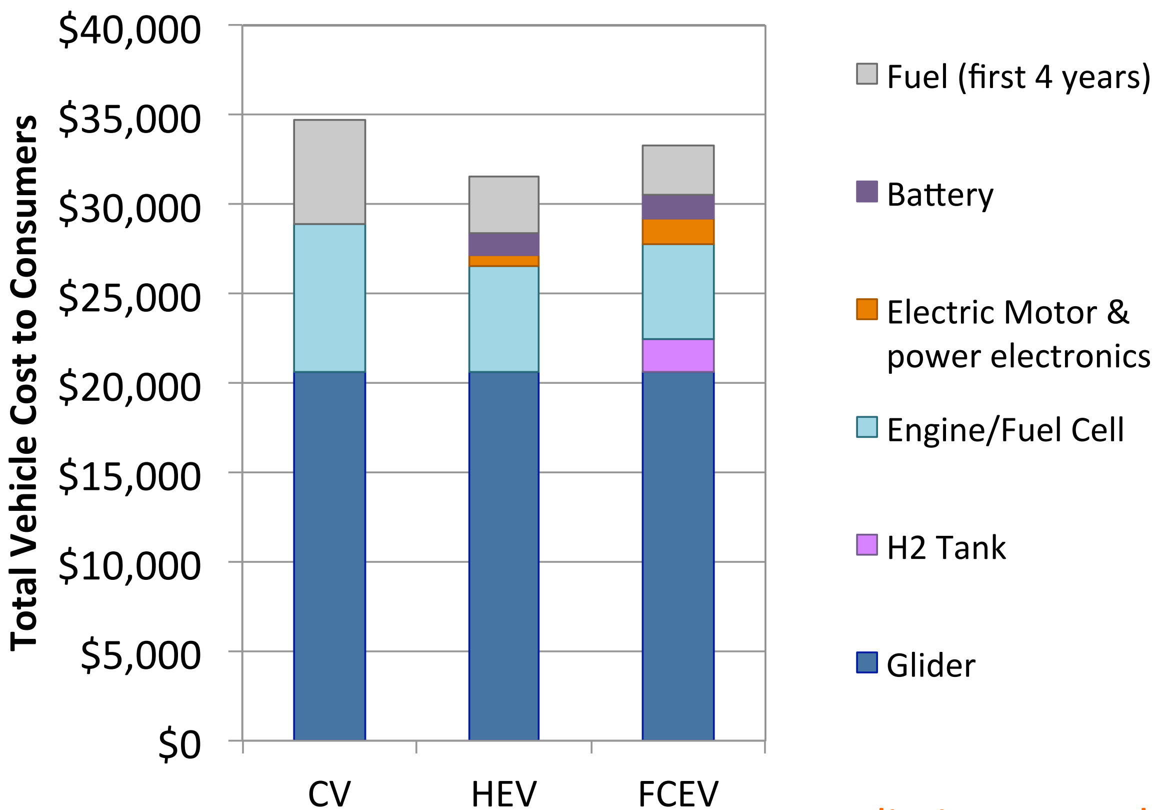
<u>Consumer perceived cost</u> = MSRP + first 4 years of fuel cost (no discounting)

- **Showroom 2035, Base scenario**
- **Perceived cost of FCEV lower than CV, higher than HEV**

	CV	HEV	FCEV
ICE/FC Size (kW)	165	114	118
Batt. Size (kW)	0	43	44
Fuel Economy (MPG)	30	56	81

<u>Simulation Details</u>

- 0-60 mph acceleration 5.9 s
- Same battery-to-total-power ratio (27%) for HEV and FCEV
- Range for FCEV > 350 miles
- Gasoline: $3.53 / gallon (2013 dollars)
- Hydrogen: $4.4 / GGE

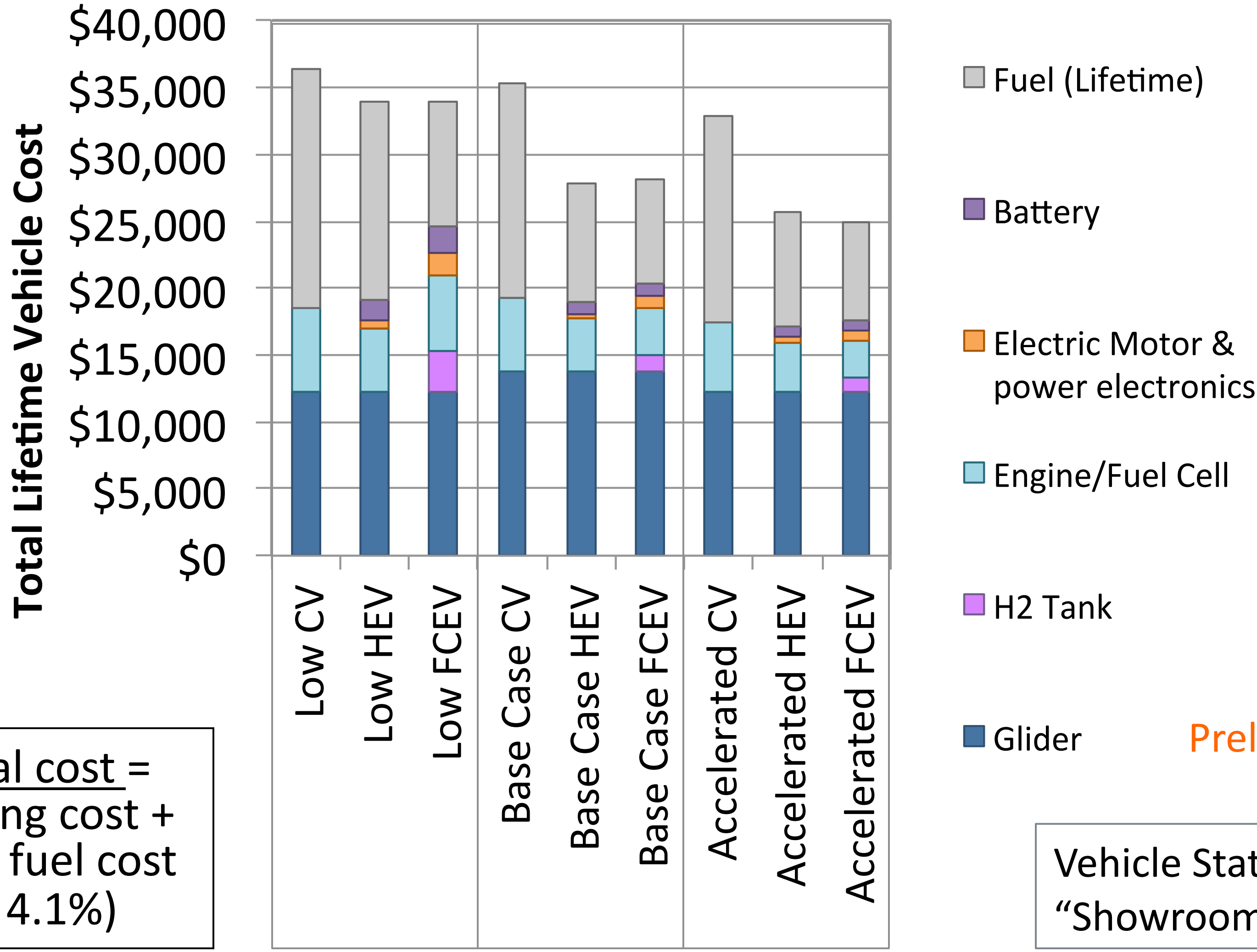


Preliminary Results

Accomplishments and Progress (2)

Techno-economic analysis: total vehicle costs with NPV of lifetime fuel

In all scenarios, CV cost is the highest and HEV and FCEV costs are comparable.



Vehicle total cost = Manufacturing cost + NPV lifetime fuel cost (discount 4.1%)

Preliminary Results

Vehicle Status for "Showroom 2035"

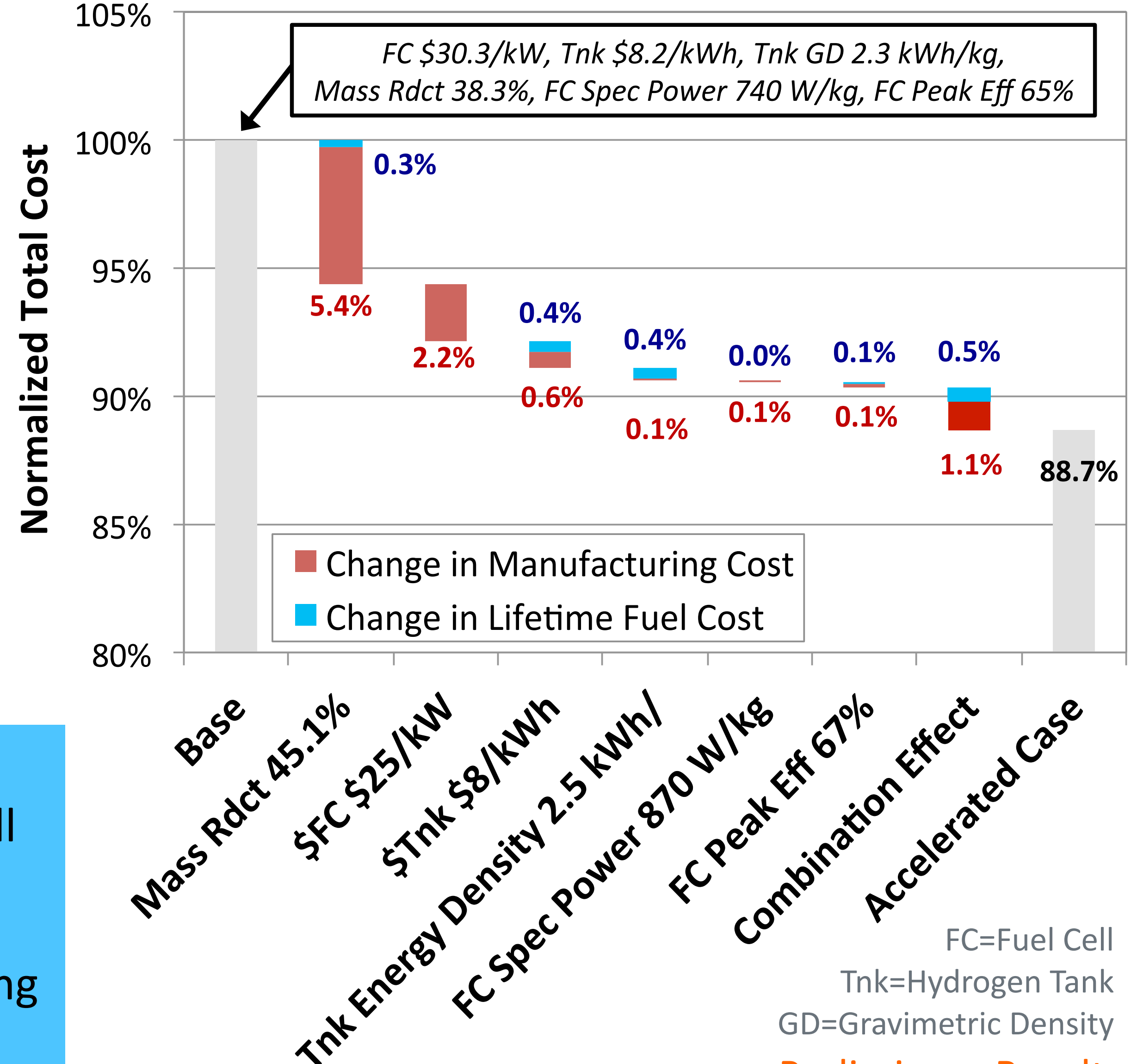
Accomplishments and Progress (3)

Techno-economic analysis: Impact of surpassing technical targets

Improving one attribute at a time, moving from the Base Case to the Accelerated Case, the total cost improvement is about 11%.

Mass Reduction (5.7%) has a greater effect than fuel cell cost (2.2%) or tank cost (1.0%).

- Tank density, fuel cell specific power, and fuel cell peak efficiency are all less than 1%.
- Combined effect of changing all attributes is 1.6%



FC=Fuel Cell
Tnk=Hydrogen Tank
GD=Gravimetric Density

Preliminary Results

Accomplishments and Progress (4)

Range of input assumptions for market adoption scenarios

ADOPT models allows for variations in technology progress and support policies

Technology progress trends

- Base Case and Accelerated Case
- Low Case: does not result in significant FCEV market share
- FCEV Targets Only: Accelerated trends for FCEVs only
- Early FCEV Targets: Targets are met sooner, by 2025

Tech Progress

Policy Incentives

- Federal Incentive: $8,000 per FCEV, max. of $7,500 for BEVs/PHEVs
  Limit on incentives allowed per automaker
  - 200,000 per automaker (Base Case)
  - 2 million per automaker (Extended Incentives)
- State Incentives: $5,000 per FCEV, $2,500 per BEV, $1,500 per PHEV

Fed & State Incentives

High Oil Price

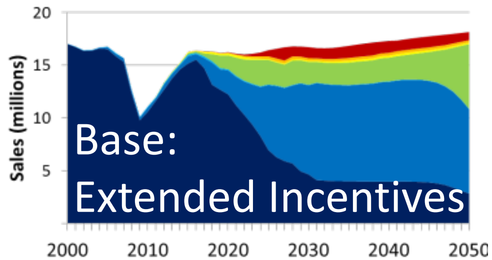
- Shift in projection from $3.53 to $5.64 per gallon by 2035
- EIA's Annual Energy Outlook Reference and High Oil cases

Price of Oil (gasoline)

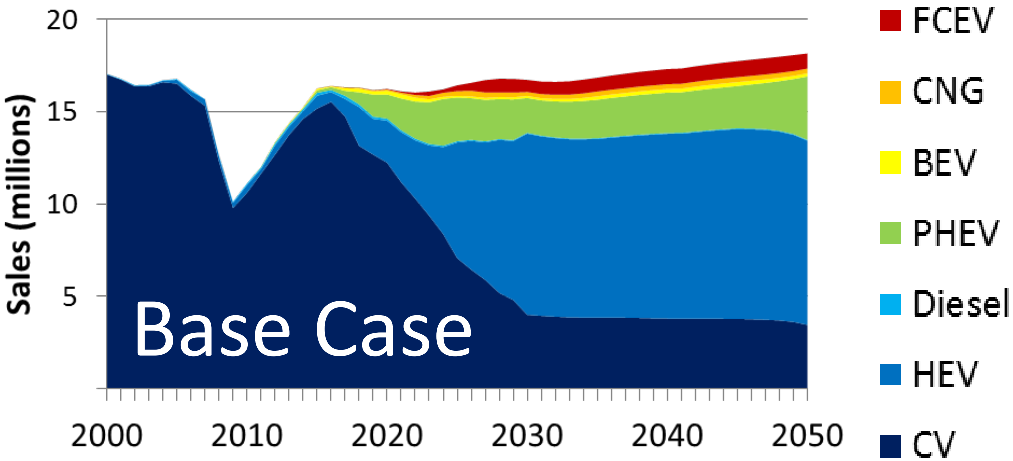
CAFE is also an important policy driver for advanced vehicles, but FCEV markets tend not to mature quickly enough to benefit significantly from CAFE credits

Accomplishments and Progress (5)

Base Case with Extended Incentives or High Oil Price

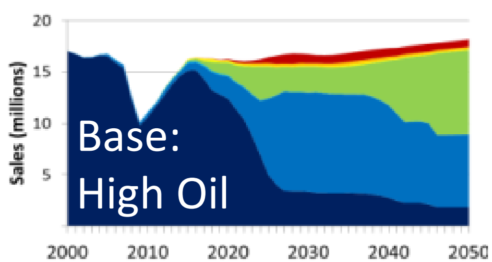


Base Case with Extended Incentives
Little effect on FCEV market share without make/model diversity.



Base Case

- Limited FCEV market share.
- Cost parity does not lead to accelerated adoption.
- Restricted make/model diversity limits market share growth.
- CAFE requirements fulfilled before FCEV niche market is established.



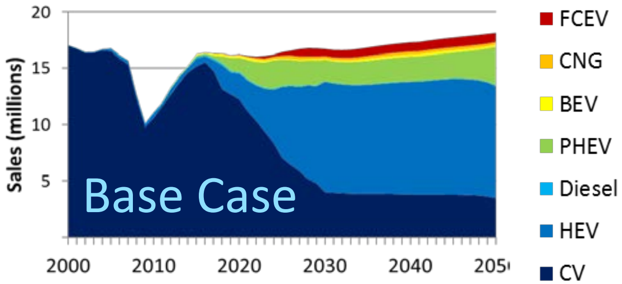
High Oil Price Case
Little effect on FCEV market share, but significant increase in PHEVs around 2040.

Preliminary Results

Similarity of program goals at CV cost parity for FCEVs, BEVs and PHEVs results in relatively fixed market shares when CAFE requirements are met by 2025-2030.

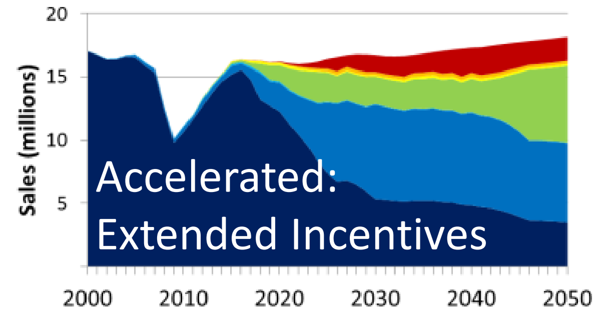
Accomplishments and Progress (6)

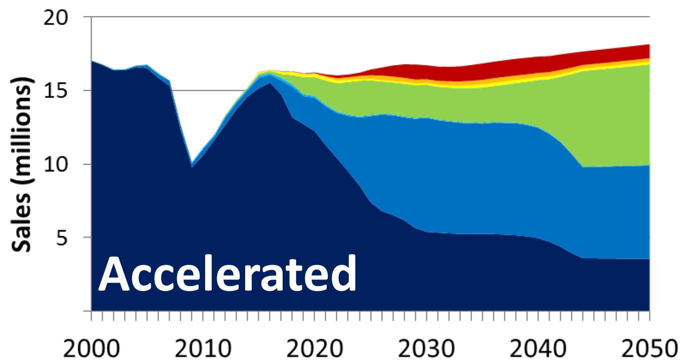
Accelerated Case with Extended Incentives or High Oil Prices



Accelerate Case with Extended Incentives

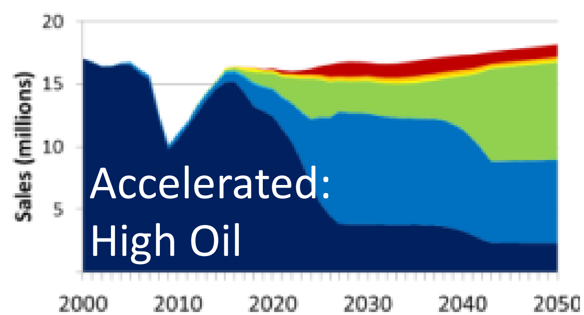
Moderate increase in FCEV market share.





Accelerated Case

- Limited FCEV market share
- Increase in PHEVs around 2040



High Oil Price Case

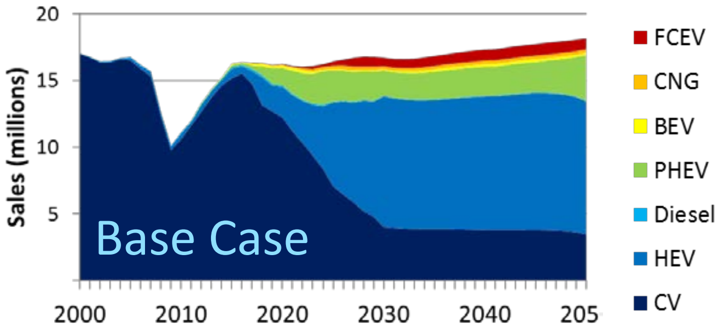
Little effect on FCEV market share; significant increase in PHEVs around 2040.

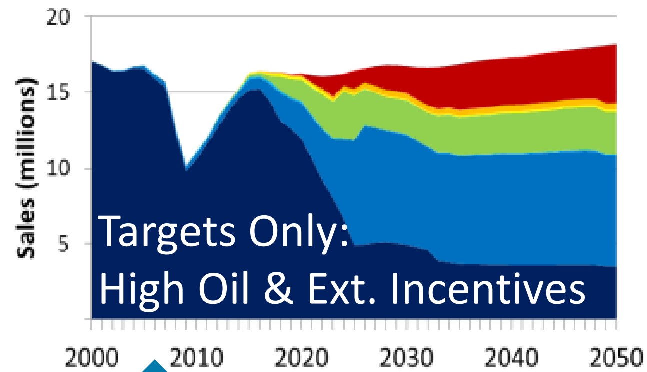
Preliminary Results

Limited niche market is not sufficient to diversify FCEV make/model availability. Extended incentives support FCEVs while high oil prices favor PHEVs.

Accomplishments and Progress (7)

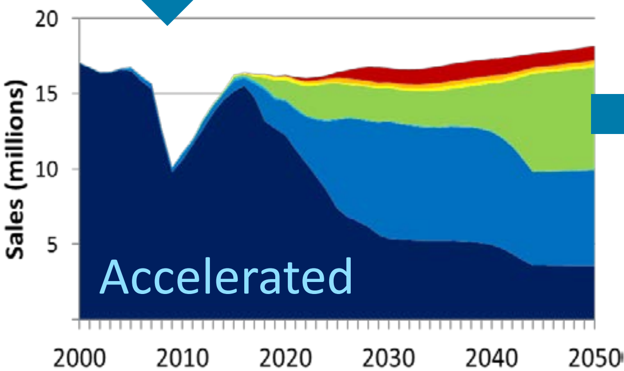
FCEV Targets Only, with Extended Incentives or High Oil Prices

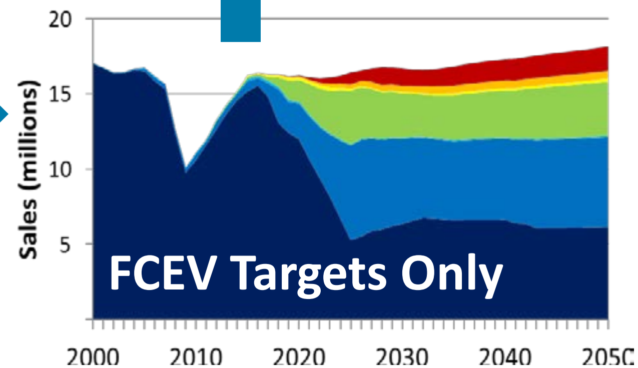




High Oil & Extended Incentives

Significant increase in FCEV market share.

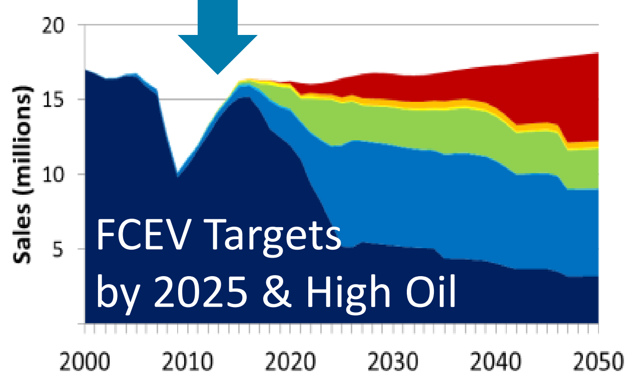




FCEV Targets Only Case

- Moderate increase in FCEV market share.
- More limited BEV & PHEV sales.

This scenario does not require extended incentives to achieve large market share



High Oil & FCEV Targets met by 2025

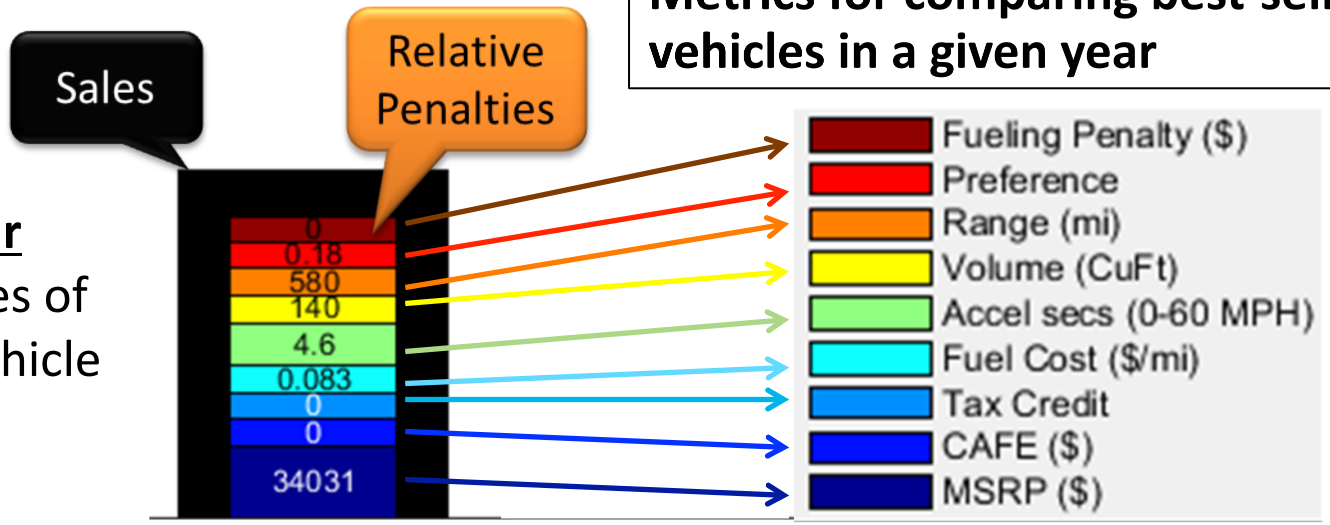
- Significant effect on FCEV market share.
- CV market share as low as Base Case by 2050.

Preliminary Results

Accomplishments and Progress

How to read ADOPT outputs on relative vehicle competitiveness

Metrics for comparing best-selling vehicles in a given year



Height of **black bar** indicates total sales of the best-selling vehicle

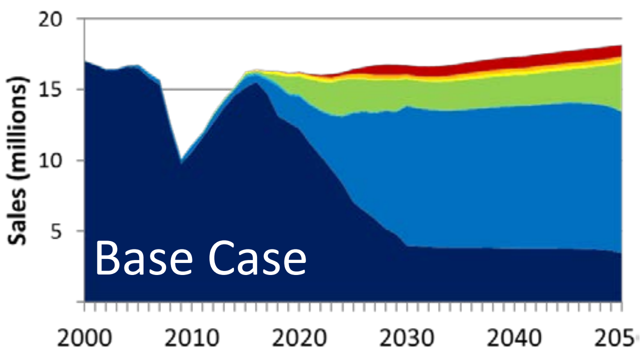
Stacked **color bars** indicate penalties to consumers

- MSRP and incentives are shown in units of $ per vehicle
- Other vehicle attributes are shown with physical units (e.g. range in miles)
- Bar height is roughly proportional to the MSRP-equivalent penalty value
- *Preference* is a consumer attribute for specific make/model (non-powertrain)
- Fueling penalty is for limited station/charging availability (assumed to be negligible for ZEVs in this study: $9/FCEV)

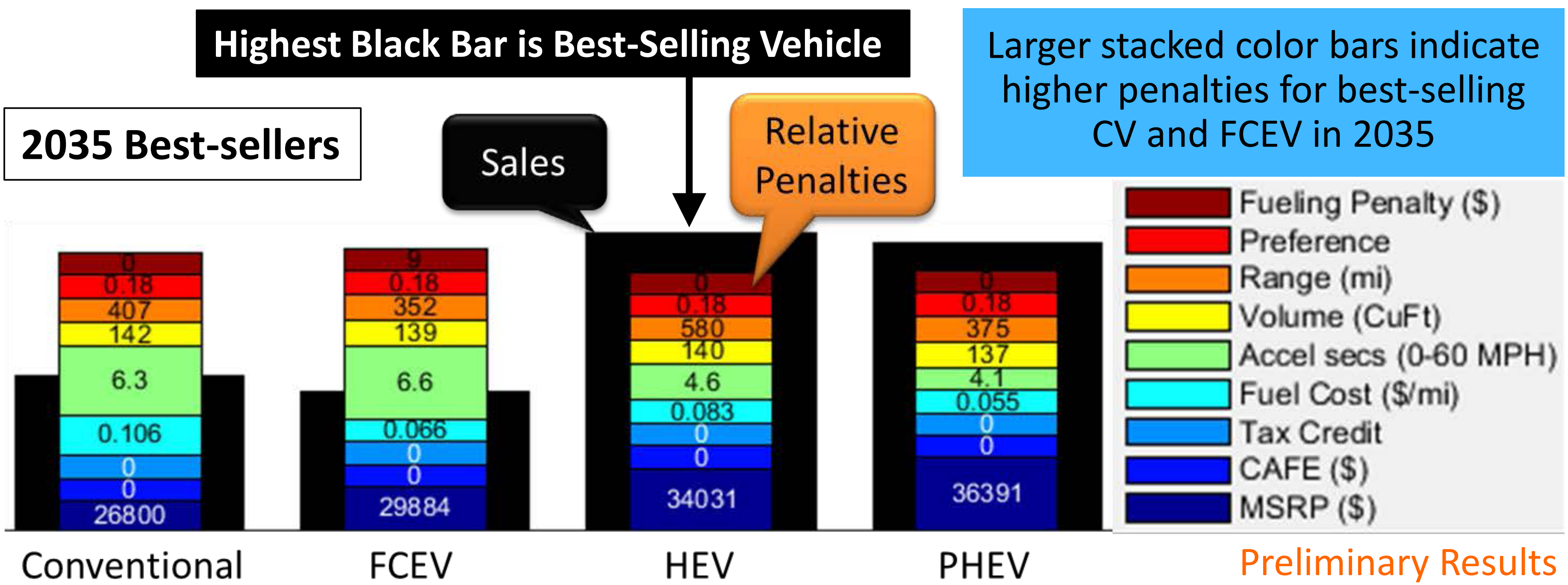
ADOPT output allows for detailed comparison of factors contributing to the relative competitiveness of best-selling vehicle platforms

Accomplishments and Progress (8)

Details of vehicle competition in the Base Case



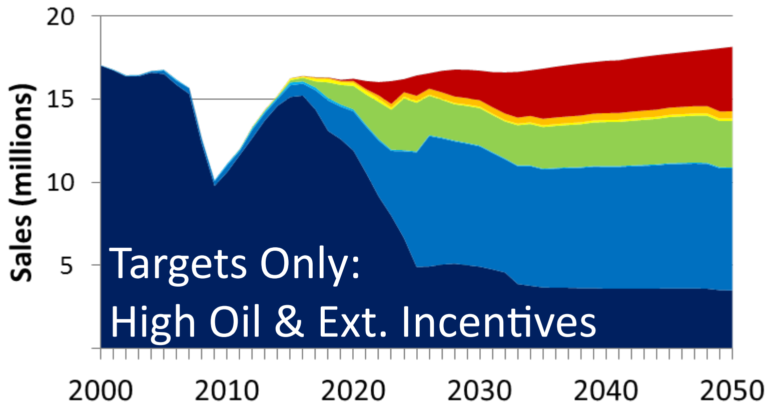
- Combination of lightweighting and battery progress results in improved acceleration for HEVs and PHEV: 0-60 mph in less than 5 sec for best-selling models
- Consumer preference for acceleration compensates for higher MSRP of HEVs and PHEVs
- FCEV acceleration limited by technology improvements



Competitive vehicle platforms involve tradeoffs to increase acceleration

Accomplishments and Progress (9)

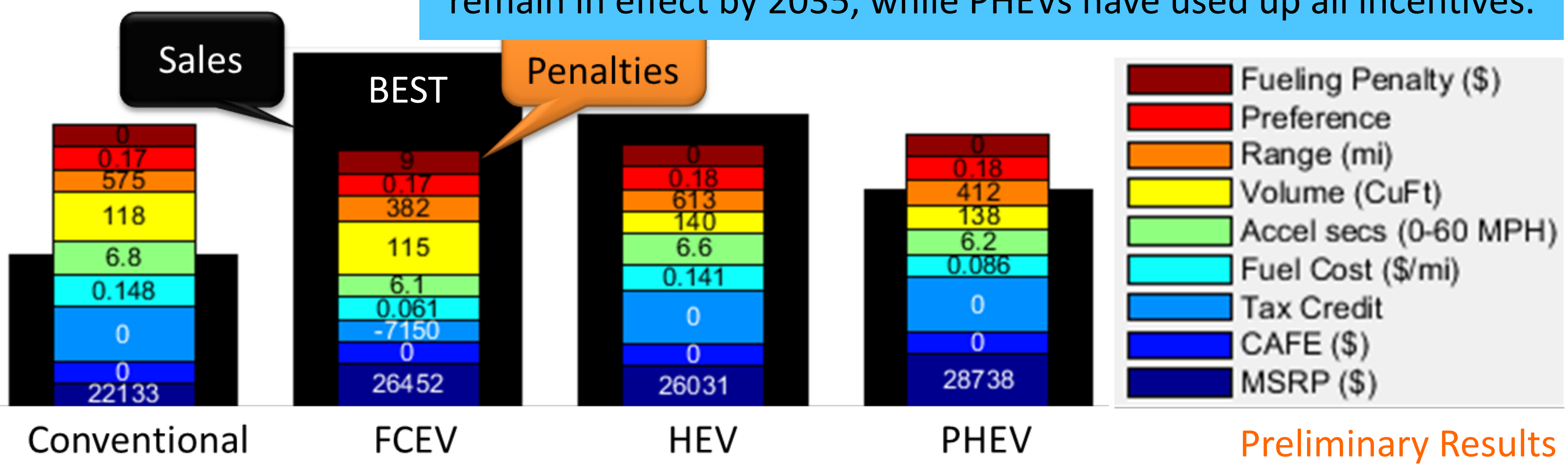
Best-selling vehicles for FCEV Targets Case: High Oil & Extnd. Incentives



- Incentives and lower fuel costs make FCEVs top-selling vehicles by 2035
- Accelerated component progress improves FCEV acceleration
- Moderated battery improvements and light-weighting limit acceleration in HEVs & PHEVs

2035 Best-sellers

$13,000 in tax credits (at 55% effectiveness, or $7,150) per FCEV remain in effect by 2035, while PHEVs have used up all incentives.

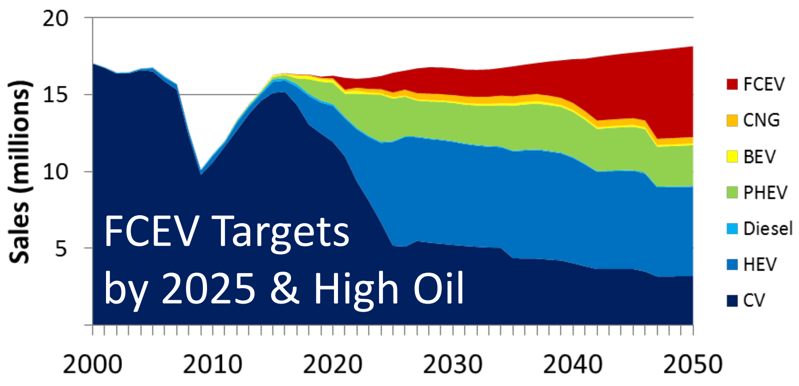


Preliminary Results

FCEVs achieve competitive balance of range, acceleration and volume

Accomplishments and Progress (10)

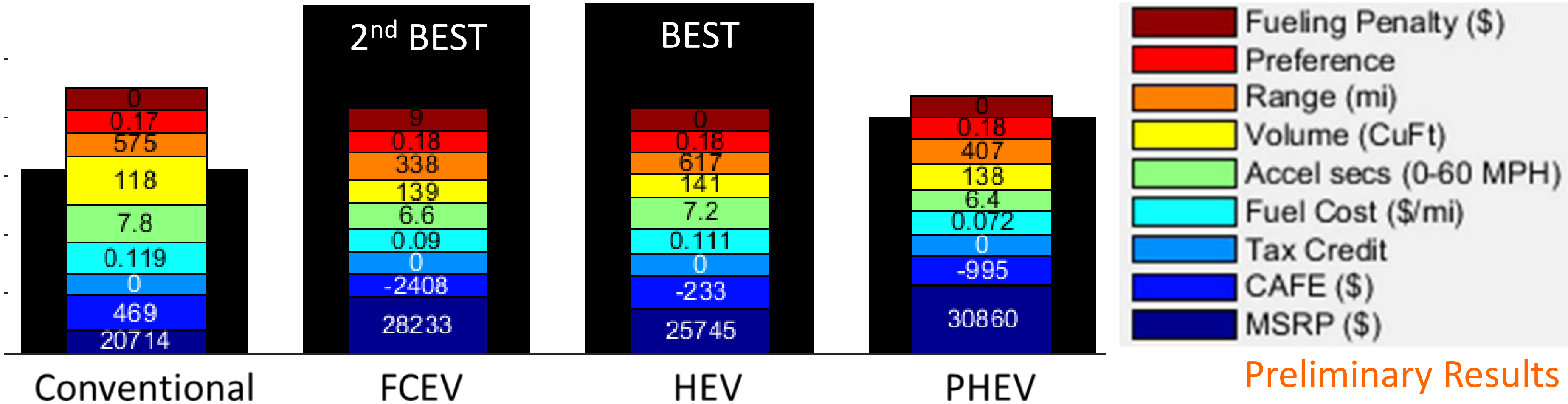
FCEV targets met by 2025, high oil best-selling vehicles



- Meeting targets by 2025 allows FCEV sales to to increase due to CAFE credits
- Example below show $2408 in CAFE credits for the FCEV; lower credits for best HEV and PHEV
- "Plateau" effects for FCEV sales (left figure) in the 2040-2050 timeframe are result of specific autos meeting 20 million Federal vehicle cap

2025 Best-sellers

Best-selling FCEV has similar sales as best-selling HEV in 2025



Preliminary Results

Early progress results in continually increasing FCEV sales, though total sales are limited by competition with other evolving, advanced vehicles

Collaborations and Previous AMR Reviews

- **Preliminary results were reviewed by the Fuel Pathway Integration Tech Team (FPITT)**
- **Report Peer Review involves key stakeholders**
  - FCEV Auto Representatives
  - H2USA Stakeholders
- **FASTSim and ADOPT have been documented and reviewed through earlier VTO projects**

<u>Responses to previous Annual Merit Review Comments</u>

This is the first year the project has been reviewed at AMR

Remaining Challenges and Barriers

Modeling Vehicle Systems

- Mass Reduction: The representation of mass reduction cost as a function of total mass reduction could be improved to develop better estimates of tradeoffs with component size, vehicle acceleration, and net cost.
- Global Learning: A more comprehensive analysis would account for effect of FCEV sales worldwide on learning rates for fuel cell components.
- Alternative FCEV Drivetrains: Plug-in or novel powertrain configurations.

Policy Drivers

- ZEV Mandate: Accounting for both CAFE and the ZEV Mandate (in select states) would improve the realism of policy influences on vehicle sales.

Consumer Choice

- Electric Drive: A better understanding of consumer preferences for electric drive vehicles and novel or green technologies would improve consumer adoption realism.
- Fueling Availability: Accounting for the influence of fueling/charging availability on consumer choice at higher levels of geographic resolution.

Proposed Future Work

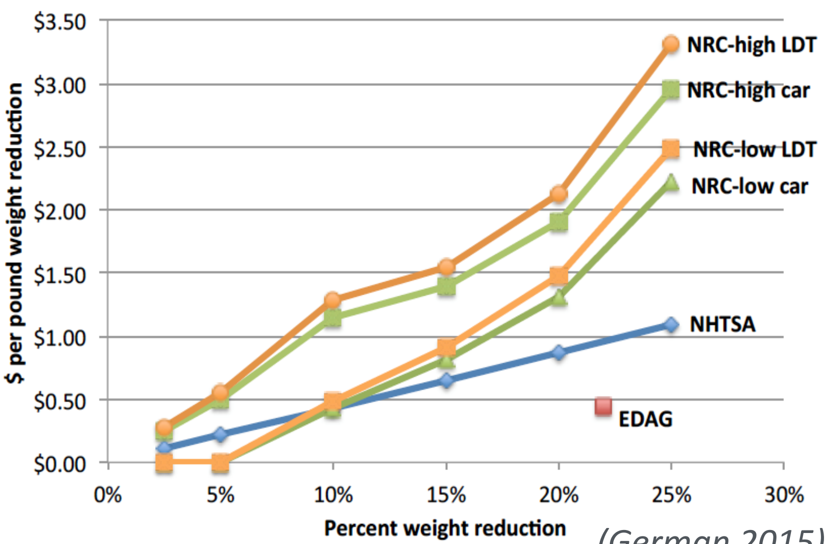
Modeling Vehicle Systems

- Develop improved mass reduction cost curve to better represent tradeoffs in component sizes and acceleration.

Policy Drivers

- Incorporate ZEV Mandate influence by simulating credit system.
- More explicit representation of station support policies (see below).

Example of Mass Reduction Cost Curve



(German 2015)

Consumer Choice and Fueling Availability

- Rely on results from previous and ongoing studies to account for cost penalties associated with limited fueling availability.
- Requires disaggregation of ADOPT simulations to "neighborhood" level of market analysis and integration of feedback from spatial refueling network representations in the SERA model.
- This approach will enable more realistic representation of the influence of hydrogen station support policies on FCEV market adoption.

Summary

Relevance

- FCEV market potential is dependent upon technology improvement trends across multiple advanced vehicle drivetrain components (PHEVs, etc.)
- Policy mechanisms must be understood in greater detail

Approach

- Integration of techno-economic (FASTSim) and market potential (ADOPT) modeling capabilities developed within VTO analysis framework
- Cases compare results of meeting, exceeding or falling short of program goals

Technical Accomplishments and Progress

- Lifetime cost for FCEVs is lower than CVs and comparable to HEVs
- Technological improvements (e.g., mass reduction, fuel cell cost reduction, and combined effects) are critical for reducing FCEV costs and increasing adoption.
- HEVs and PHEVs are more competitive than FCEVs, especially with CAFÉ
- FCEV success is dependent upon supportive policies driving consumer adoption

Collaboration

- Peer reviews with multiple key stakeholders

Proposed Future Research

- Improved vehicle modeling, policy driver representations, and consumer choice

Questions?

Contact Information

Marc.Melaina@nrel.gov

Technical Back-Up Slides

Technical Backup (1)
References

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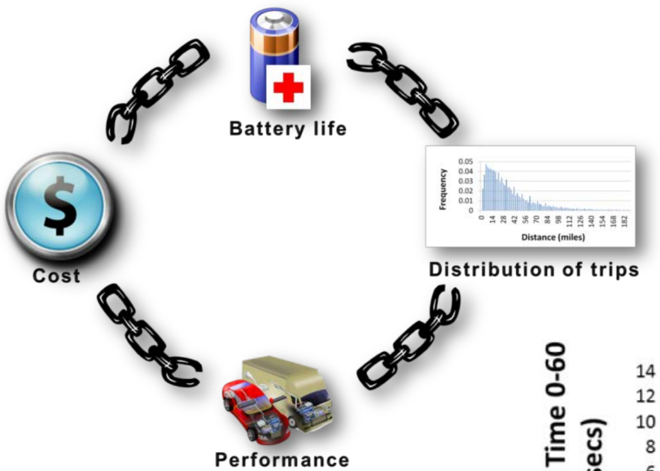
Technical Backup (2)

FASTSim Overview

Compare

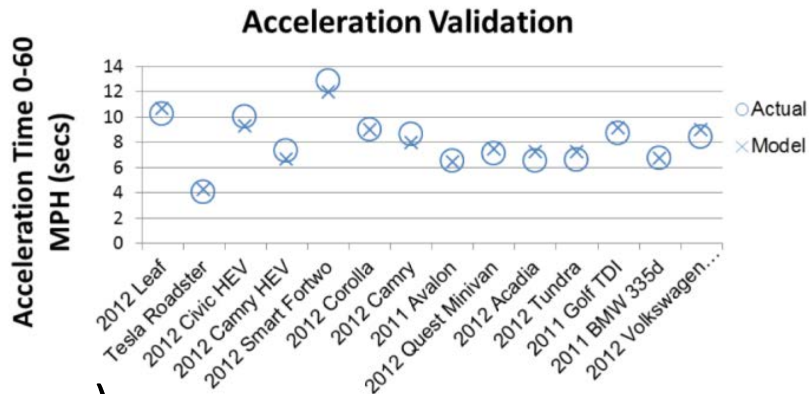
- Efficiency
- Cost
- Performance

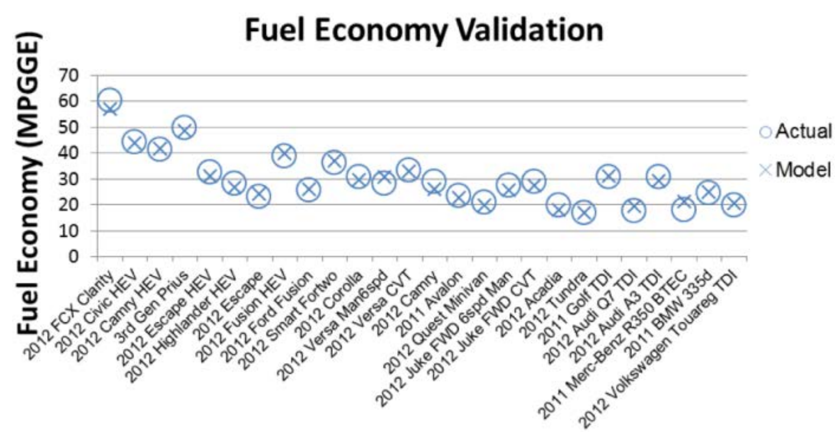


Systems approach

Benefits

- Fast: 2.5 seconds (City/Hwy + SOC balance)
- Includes data for most vehicle types
- Validated
- Easy to use





Brooker, A., Gonder, J., Wang, L., Wood, E. et al., "FASTSim: A Model to Estimate Vehicle Efficiency, Cost and Performance," SAE Technical Paper 2015-01-0973, 2015, doi:10.4271/2015-01-0973.

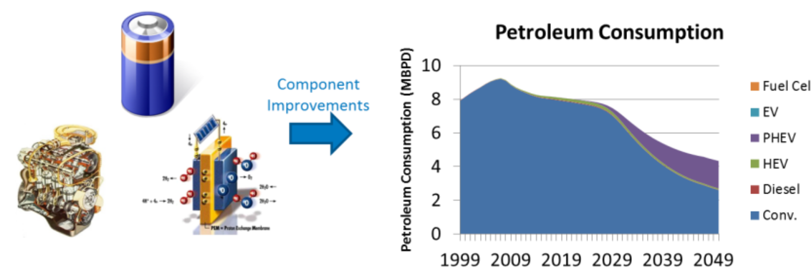
Technical Backup (3)
FASTSim Modeled Vehicles

- **Base vehicle platform: 2016 Camry HEV**
  - Battery power: 43 kw
  - Battery energy: 1.6 kWh
  - ICE power: 116.3 kW
  - Battery-power-to-total-power ratio: 27%
  - 0-60 mph acceleration speed: 7.2s
- **Development of CV, HEV, and FCEV in 2035 Showroom**
  - Apply technology advances to vehicle components for FASTSim vehicle simulation, resulting in the following attributes:
    - 0-60 mph acceleration speed 5.9s
    - Same battery-to-total-power ratio (27%) for HEV and FCEV
    - Range for FCEV > 350 miles
  - Calculate and compare costs

Technical Backup (4)
ADOPT Overview

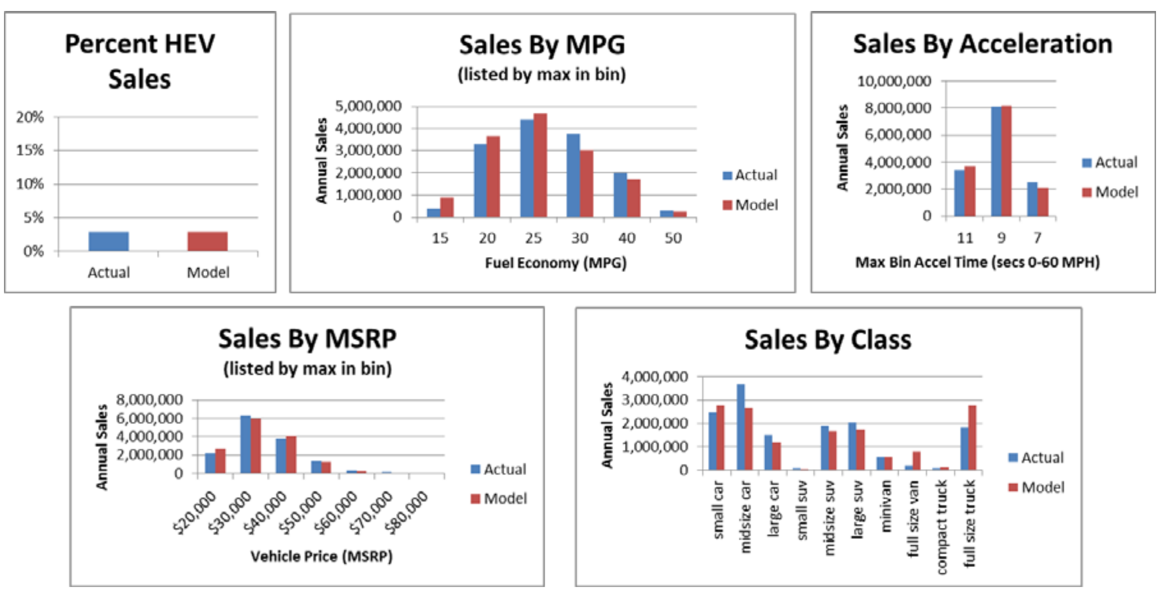
Estimates advanced technology impact on U.S. light duty (LD) vehicles

- Petroleum use
- GHG emissions



ADOPT's choice model

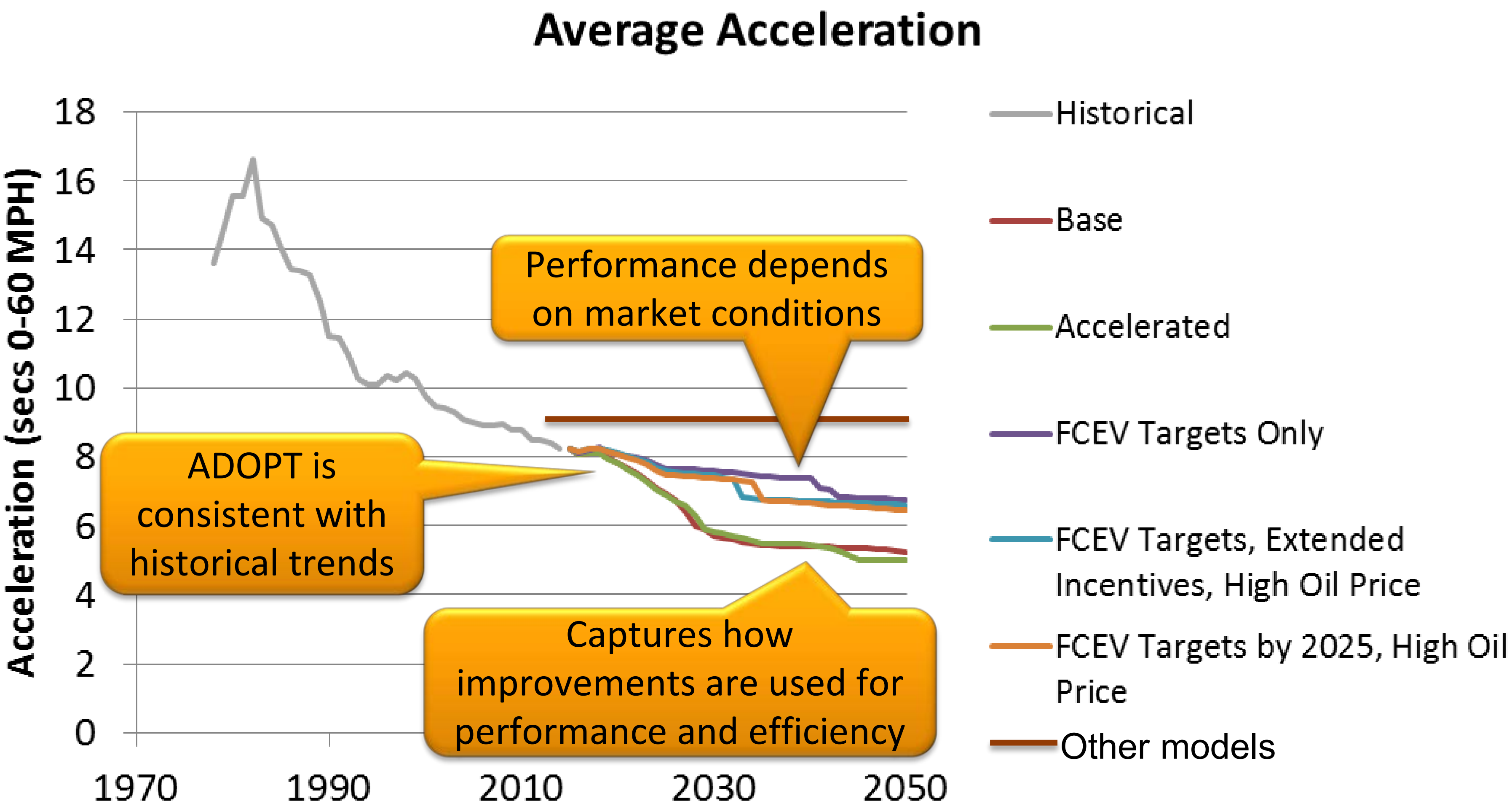
- Uses a mixed logit function
- Includes all existing makes, models, and trims
- Enforces CAFE standards
- Validates well with historical sales



Technical Backup (5)

ADOPT Vehicle Evolution with Respect to Acceleration

Choice model: captures vehicle option trends



https://www.edmunds.com/nissan/leaf/2011/road-test-specs2.html