Applying the Battery Ownership Model in Pursuit of Optimal Battery Use Strategies



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NREL/PR-5400-54424 Project ID # ES123

Overview

Timeline

Project Start Date: 2009
Project End Date: 2015
Percent Complete: 35%

Budget

Funding Received in FY09: $200k

Funding Received in FY10: $200k

Funding Received in FY11: $200k

Anticipated Funding in FY12: $250k

Funding provided by Dave Howell of the DOE Vehicle Technologies office.

Activity managed by Brian Cunningham of the DOE Vehicle Technologies office.

Barriers

- Battery cost
- Battery life / durability
- Public acceptance of electric drive as central vehicle choice

Partners

- United States Advanced Battery Consortium (USABC)
- Better Place
- NREL internal teams:
  - *Vehicle Systems Analysis*
  - *Transportation Secure Data Center*
  - *Electric Vehicle (EV) Grid Integration*

Relevance/Objectives

VTP Light-Duty Vehicle Goals:

- **50** percent reduction in petroleum-based consumption by 2015
- **80** percent of energy from carbon-neutral sources by 2030

VTP Energy Storage Goals:

- Cost Targets: $270/kWh in 2015, $125/kWh in 2020
- Life Targets: 10+ years, 3,000-5,000 cycles

Battery Ownership Model Project Objectives:

- Quantify the total cost of ownership (TCO) and petroleum-based consumption of EV technologies under traditional and advanced operational strategies
- Identify **optimal battery use strategies** to meet VTP-light duty vehicle goals

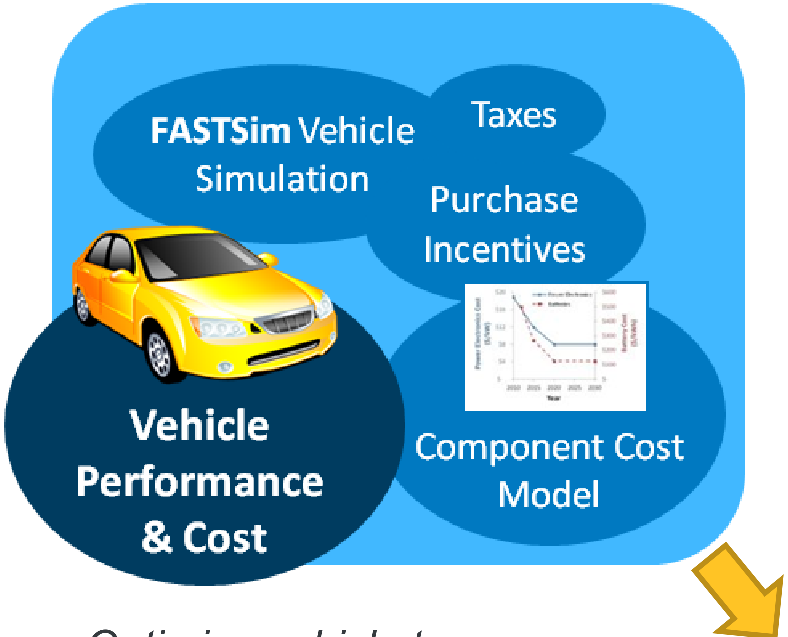
Battery Ownership Model FY12 Objectives:

- Assess the effect of *electric range, charge strategies, and drive patterns* on the TCO and petroleum-based consumption of plug-in electric vehicles (PEVs)
- Investigate the economics of *battery swapping* services for battery electric vehicles (BEVs)

Milestones

Date	Milestone	Status
8/31/2011	Complete technical and economic evaluation of various EV battery ownership concepts	Completed. Results highlighted the need for better battery degradation modeling and drive patterns.
3/31/2012	Complete analysis on the impact of driving patterns, electric range, and charge strategies	Completed.

Approach



Optimize vehicle to spec, calculate cost and fuel consumption

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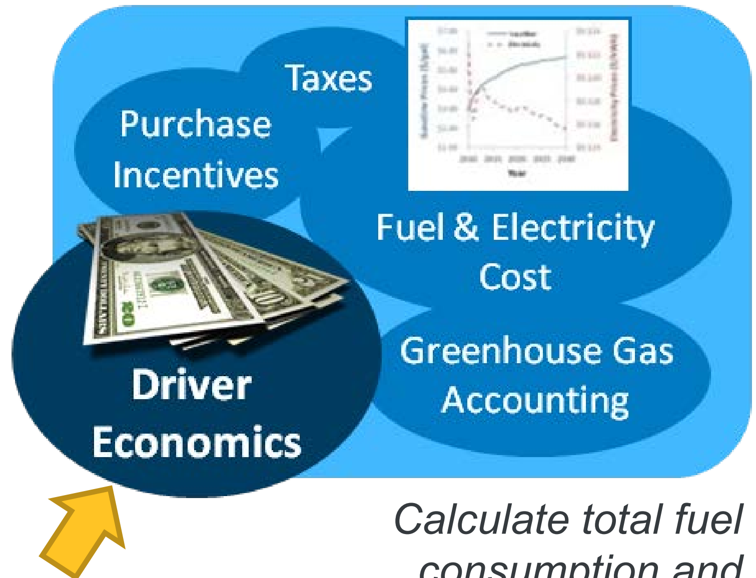
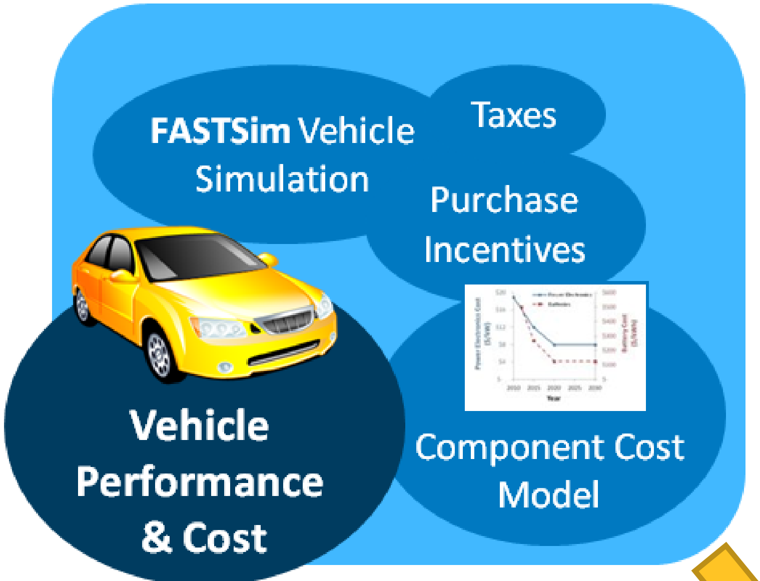


Calculate total fuel consumption and cost

Approach

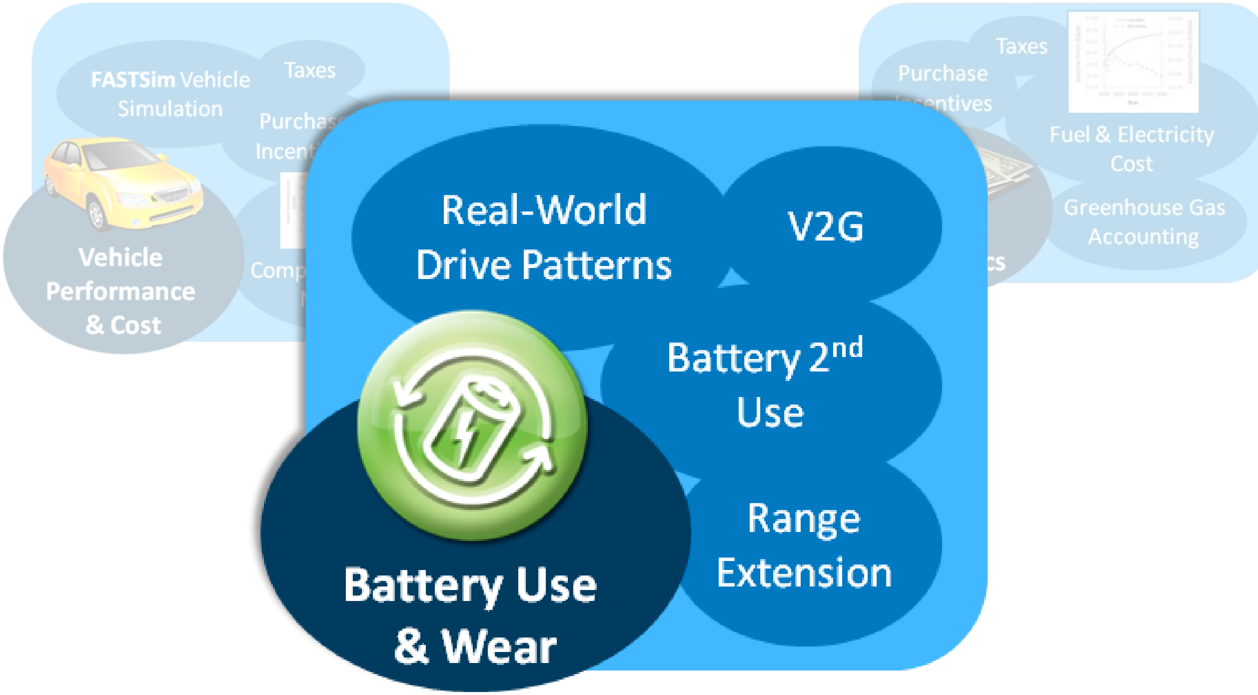


Optimize vehicle to spec, calculate cost and fuel consumption

Calculate total fuel consumption and cost

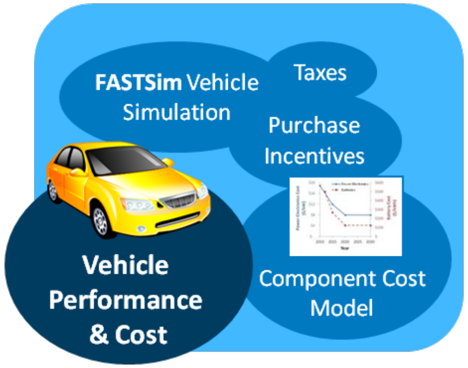
Apply drive pattern, calculate battery degradation through replacement period

Approach

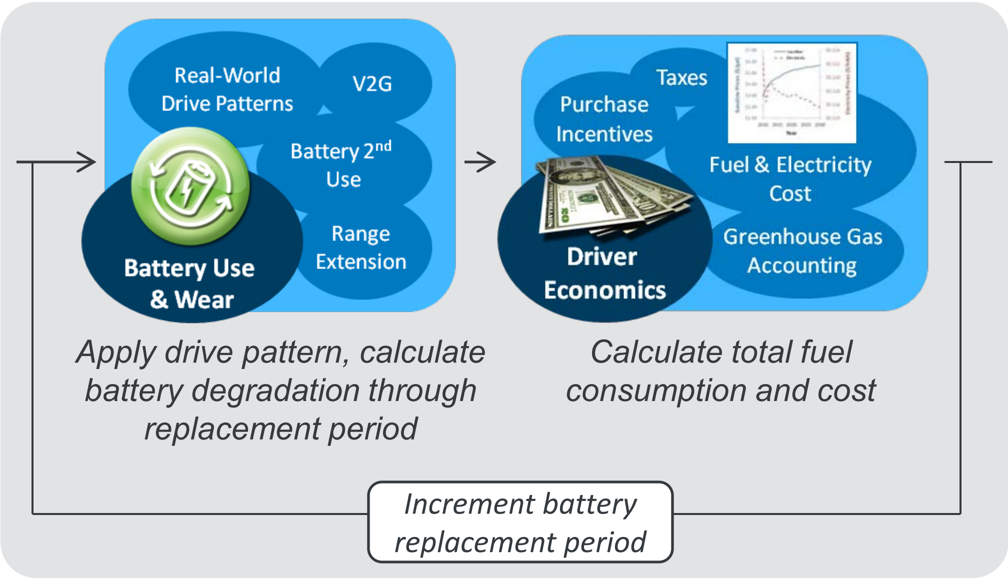


- **Semi-empirical, physically justified model based on laboratory life test data for a nickel cobalt aluminum (NCA) lithium (Li)-ion battery chemistry**
  - Calculates capacity loss and resistance growth in both operational and storage conditions
  - Considers effects of time, number of cycles, state of charge (SOC), voltage, temperature, and depth of discharge

Approach

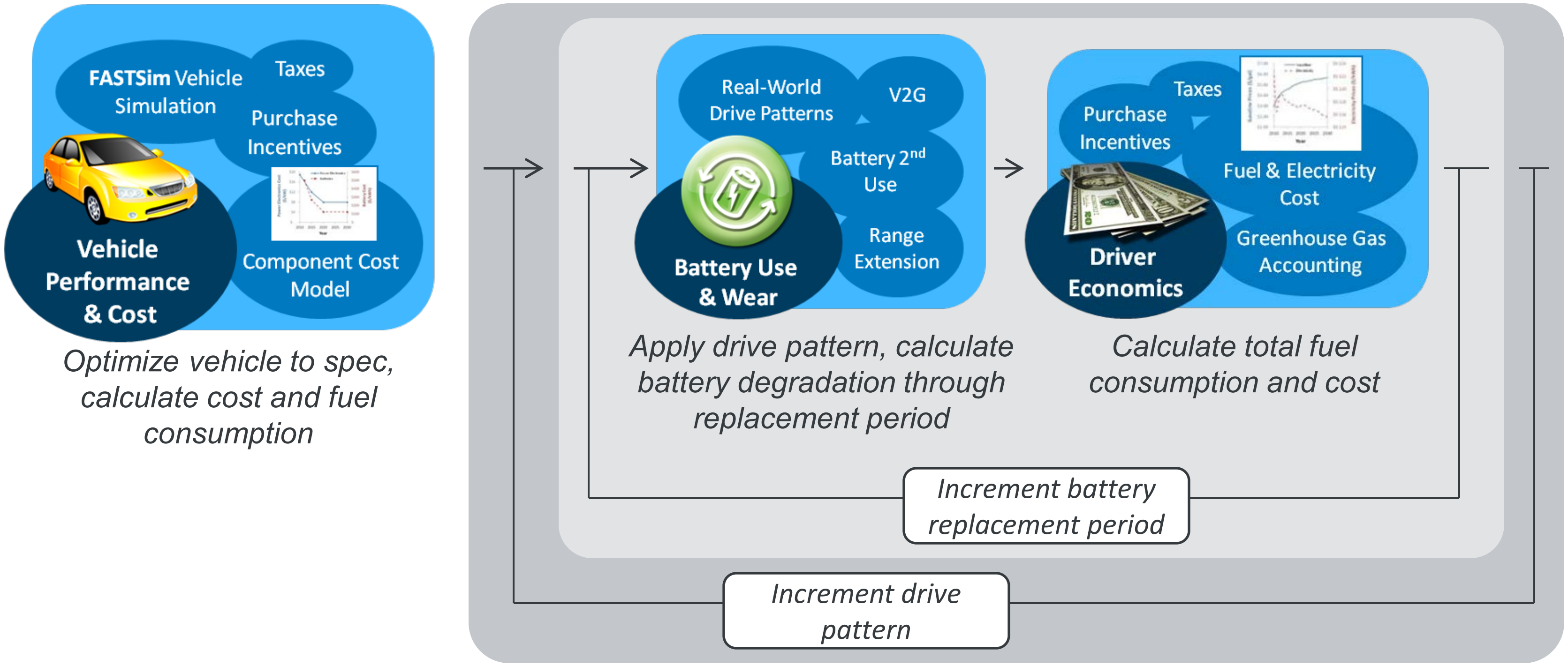


Optimize vehicle to spec, calculate cost and fuel consumption



- **Differentiators:**
  - High-fidelity battery degradation model
  - Cost-optimal battery replacement schedules

Approach



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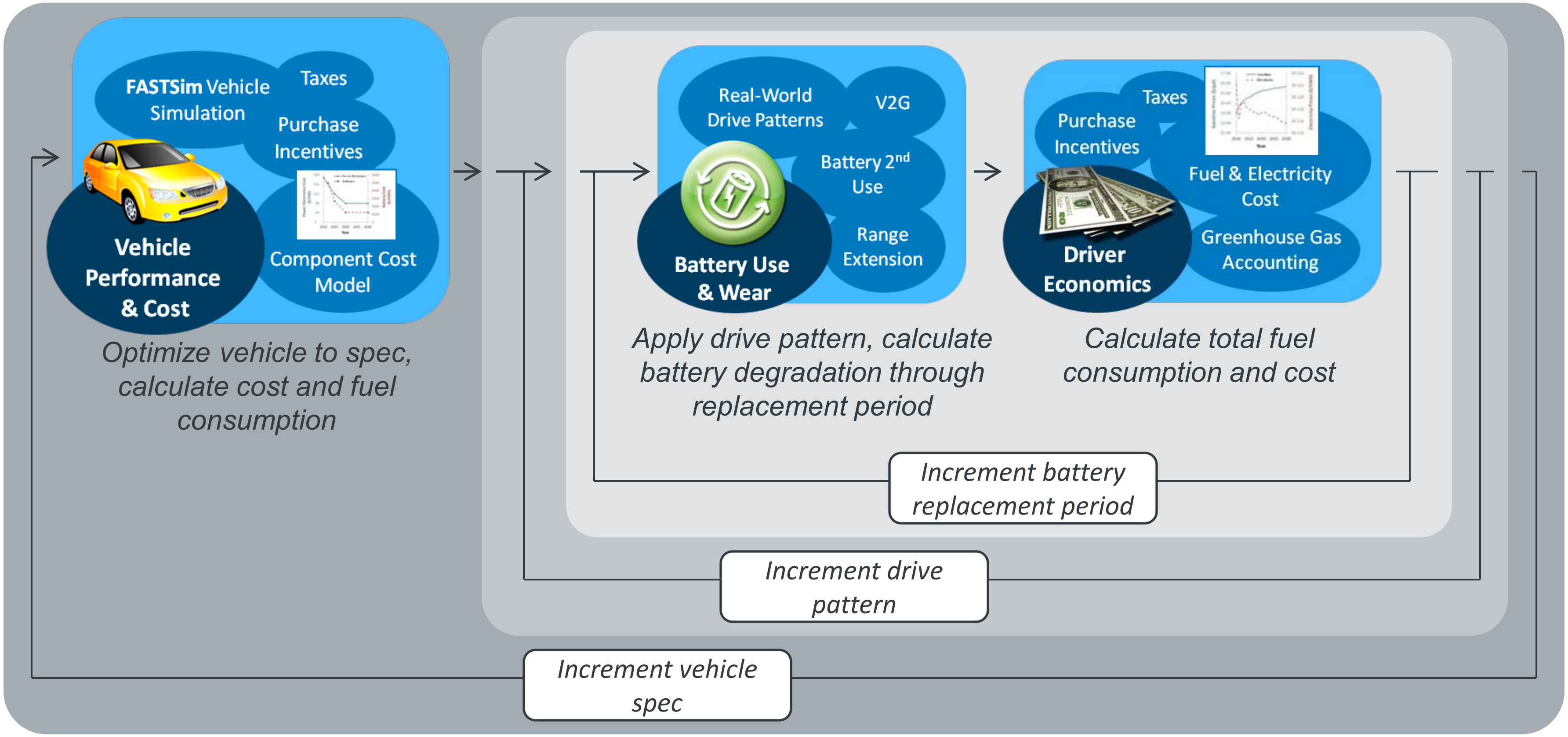
  - Cost-optimal battery replacement schedules
  - Analysis of hundreds of real-world longitudinal drive patterns

Approach



- **Differentiators:**
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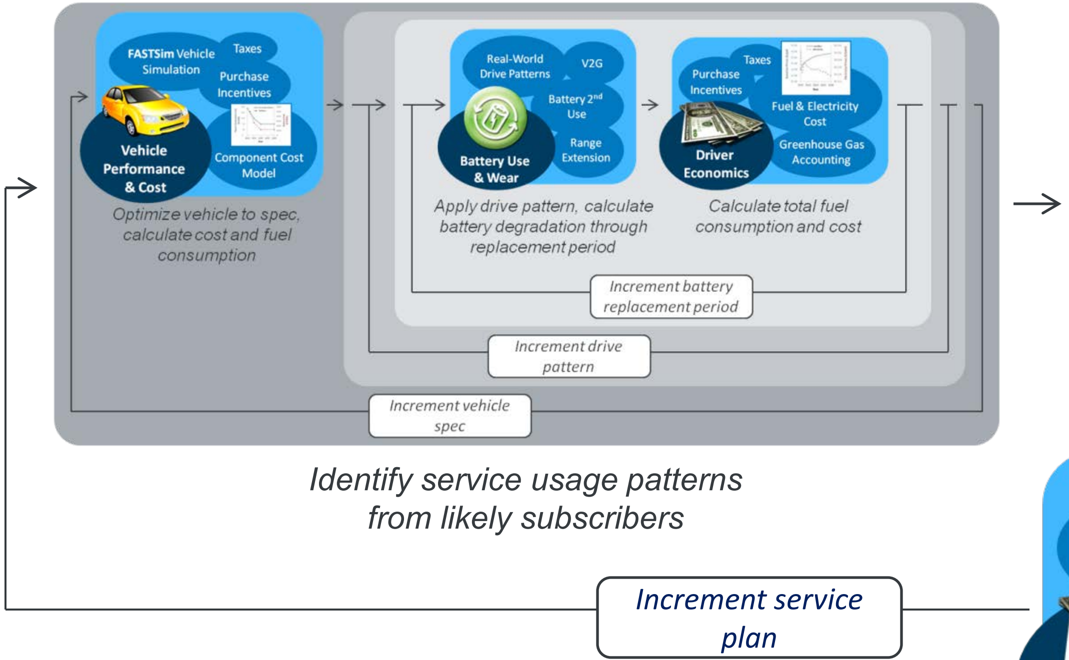
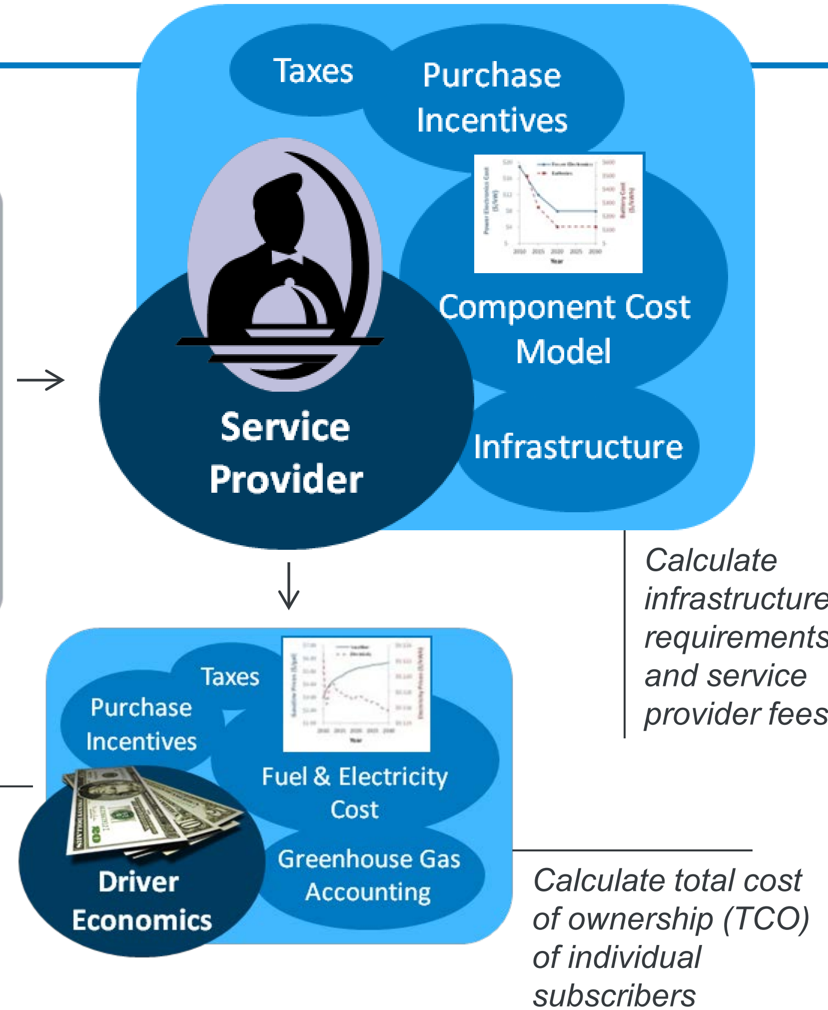
  - Analysis of hundreds of real-world longitudinal drive patterns
  - Study trends of cost and fuel use with different vehicle types, configurations, and use strategies

Approach





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  - High-fidelity battery degradation model
  - Cost-optimal battery replacement schedules
  - Analysis of hundreds of real-world longitudinal drive patterns
  - Study trends of cost and fuel use with different vehicle types, configurations, and use strategies
  - Accounting for the added utility, battery wear, and infrastructure costs of range-extension techniques (battery swap, fast charge, public charging, etc.)
  - Allow creative ownership and financing options that mitigate risks to consumers

Collaboration and Coordination

- **Working with industry and heavily leveraging other DOE-funded projects**
  - Work directly with USABC on battery electric vehicle (BEV) target analyses
  - Input from Better Place on battery swapping analyses
  - Utilize NREL Vehicle Systems Analysis group's FASTSim for vehicle simulation and optimization
  - Drive patterns and processing from NREL's Transportation Secure Data Center
  - Battery degradation model provided by NREL's Energy Storage team
  - Employing ANL's GREET model for greenhouse gas accounting
  - Development of unique capabilities has been supported by NREL battery second use, EV grid integration, and Clean Cities projects.

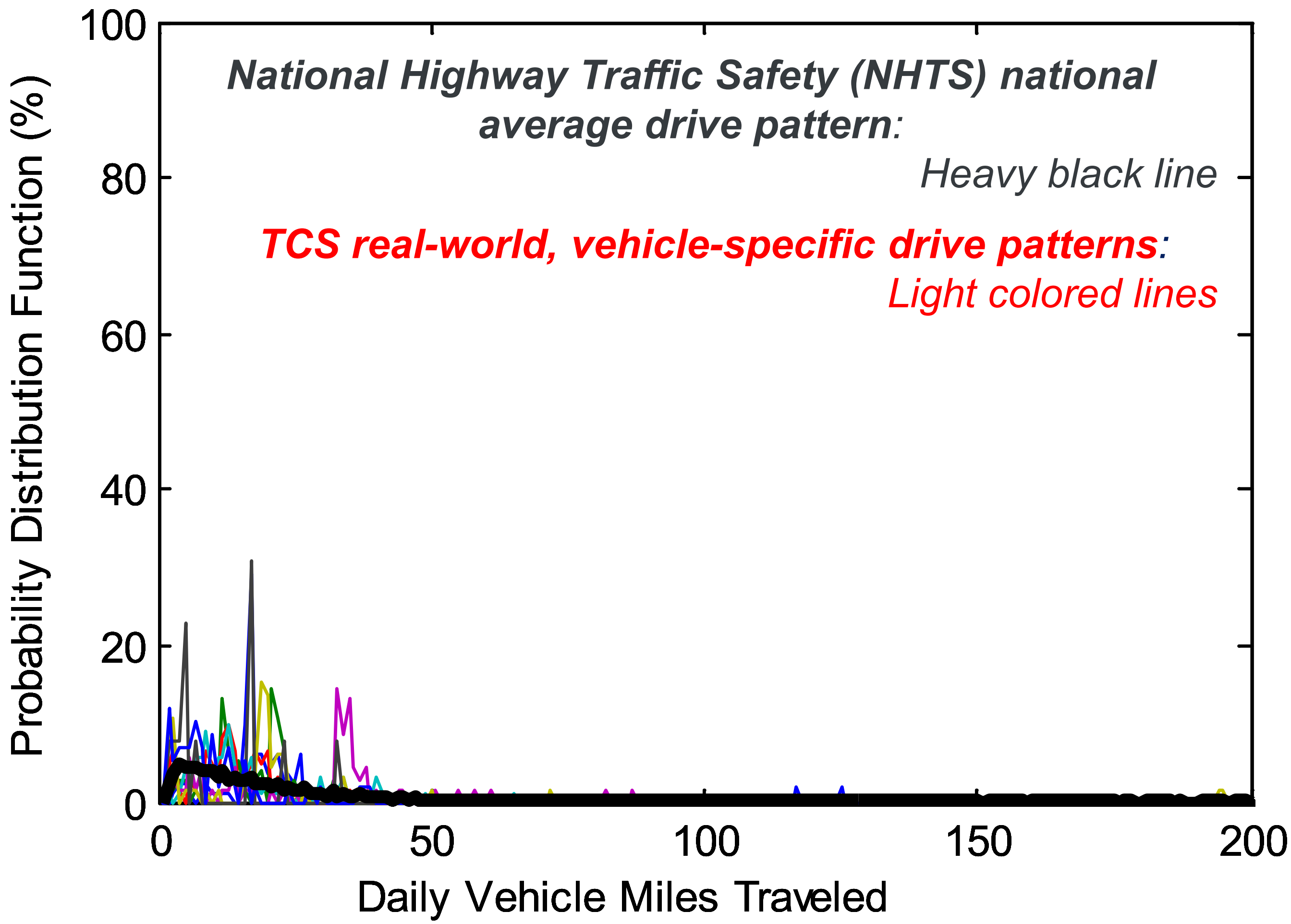
FY11 Accomplishments

- **Identified the need for more advanced modeling capabilities and began integrating them**
  - Performed BEV target analyses, battery swapping investigations, and lithium availability studies using version 1.0 software
  - Identified a strong sensitivity to battery degradation and the potential for strong sensitivity to drive patterns
  - Began version 2.0 development, restructuring software architecture for new battery degradation model and large numbers of longitudinal drive patterns
  - Incorporated and tested NREL's high-fidelity battery degradation algorithm

FY12 Accomplishments

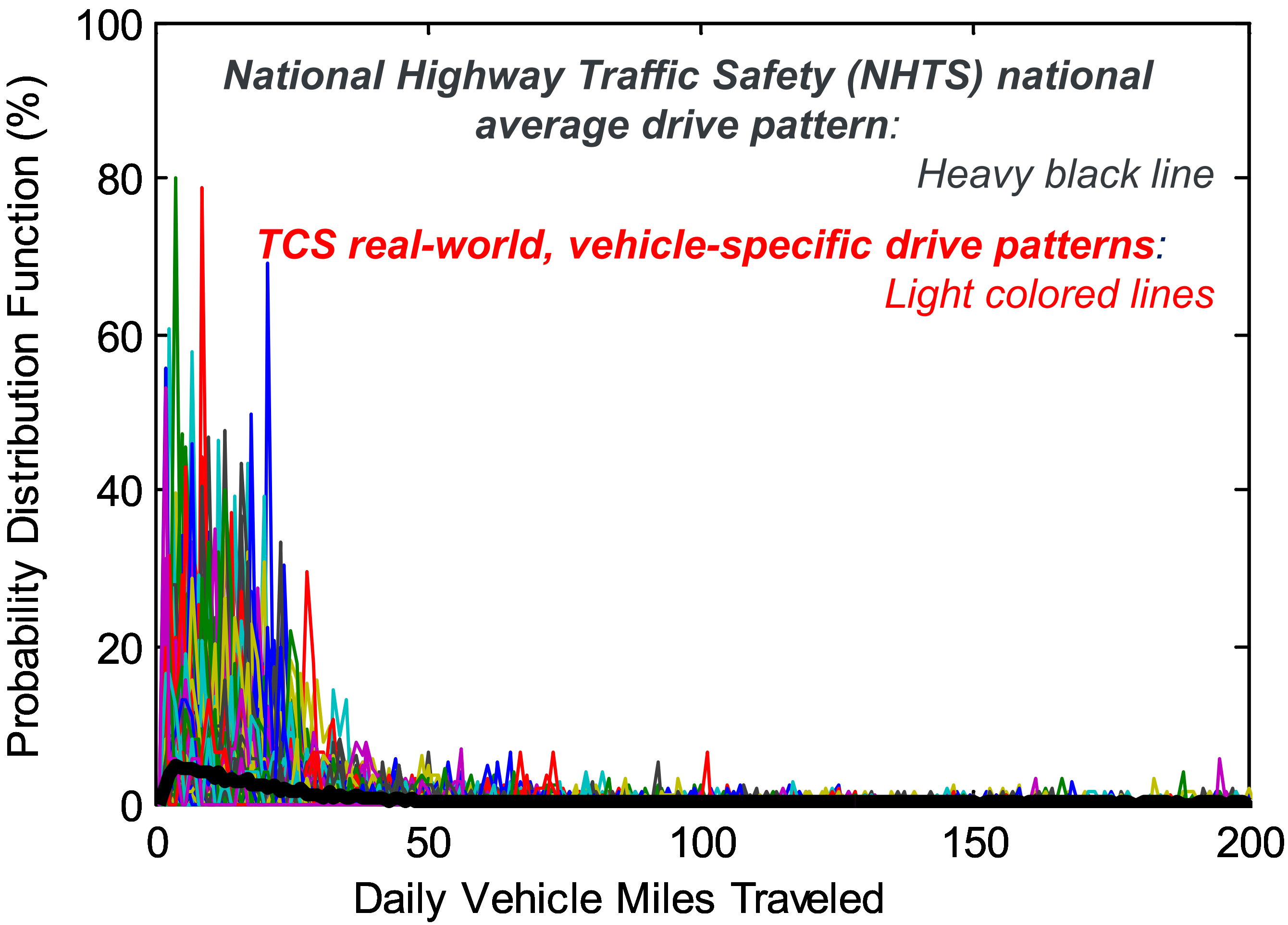
- **Major software upgrades in FY12**
  - Incorporated 398 longitudinal drive patterns from Puget Sound Regional Council Travel Choices Study (TCS)
  - Accounted for a BEV's unachievable vehicle miles travelled (VMT) by two different means
  - Developed a cost-optimal battery replacement algorithm
  - Developed a battery SOC window expansion control algorithm
  - Made significant updates to service provider submodel
  - Added battery second use and vehicle-to-grid (V2G) capability

FY12 Accomplishments



- **There's a lot of variability between drive patterns**

FY12 Accomplishments



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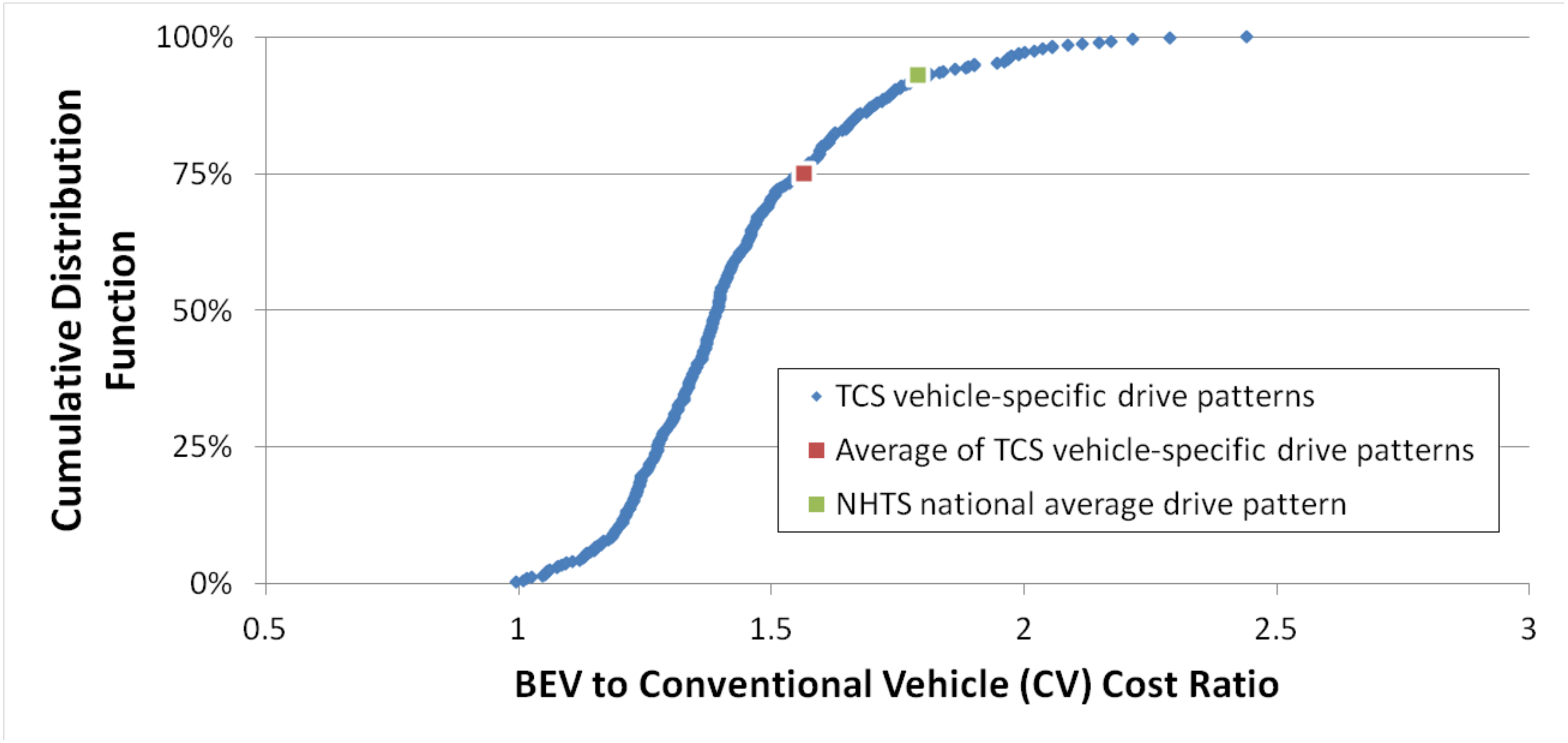
FY12 Accomplishments



- **Drive pattern variability impacts cost, life, and other factors**

**Results assume a mid-size sedan vehicle platform, 2012 start year, 15-year vehicle life & analysis period, availability of current federal purchase incentives, achievement of DOE battery cost targets ($500/kWh in 2012 to $125/kWh by 2020), 2010 Energy Information Administration (EIA) high-oil-price scenario gasoline and electricity cost projections, a 75-mile range, just-in-time charging from home, 100% maximum SOC, high cost of unachievable VMT, and several other important factors not listed here.*

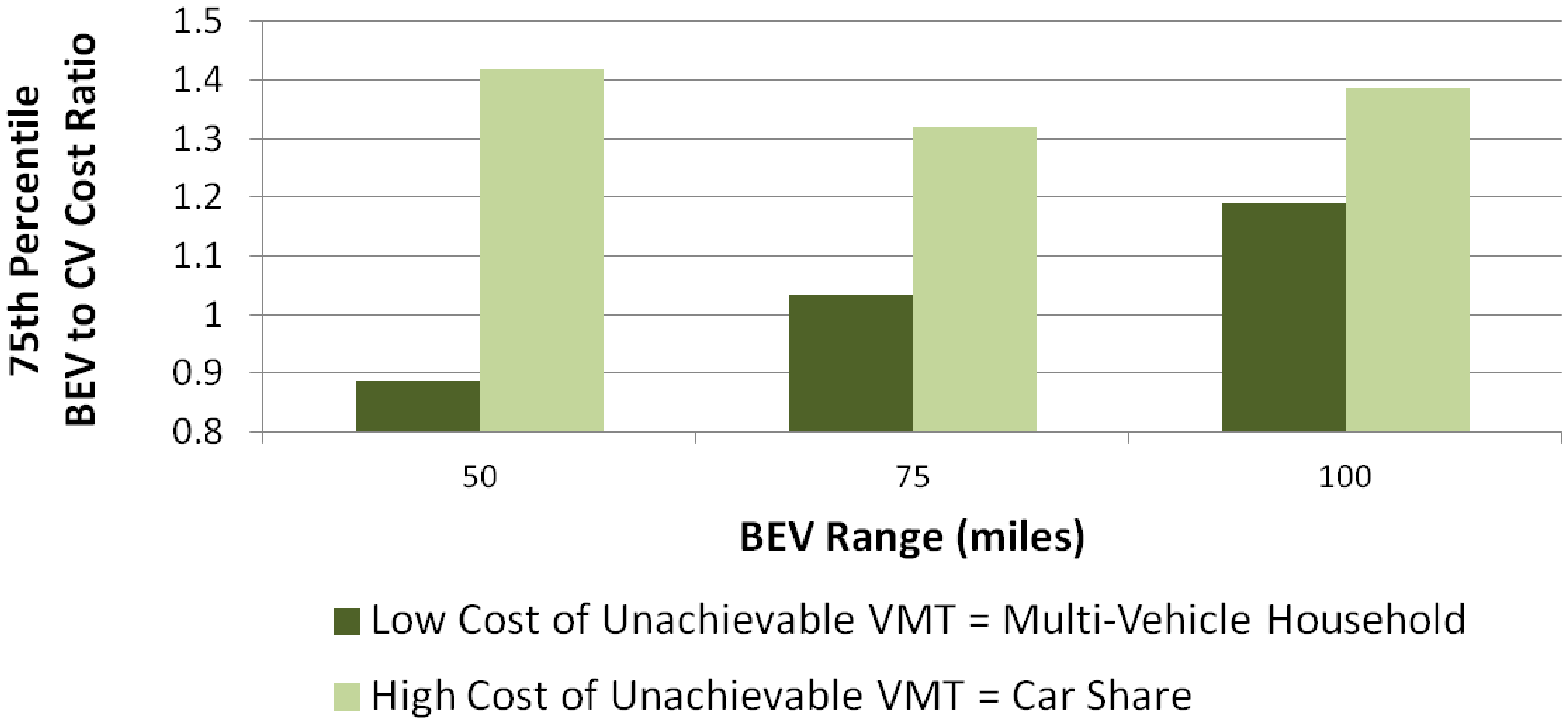
FY12 Accomplishments

- **Large quantities of data require new ways to present results**

  - BEV study of range, charge strategy, and drive patterns: **42,876** cases simulated
  - Plug-in hybrid electric vehicle (PHEV) study of range, charge strategy, and drive patterns: **76,416** cases simulated
  - We propose the **75^{th} Percentile Cost Ratio**, which bounds the top 25% of the most cost-effective drive patterns.

FY12 Accomplishments

- **Unachievable VMT has a big effect on cost, optimal vehicle configuration, and use strategies**



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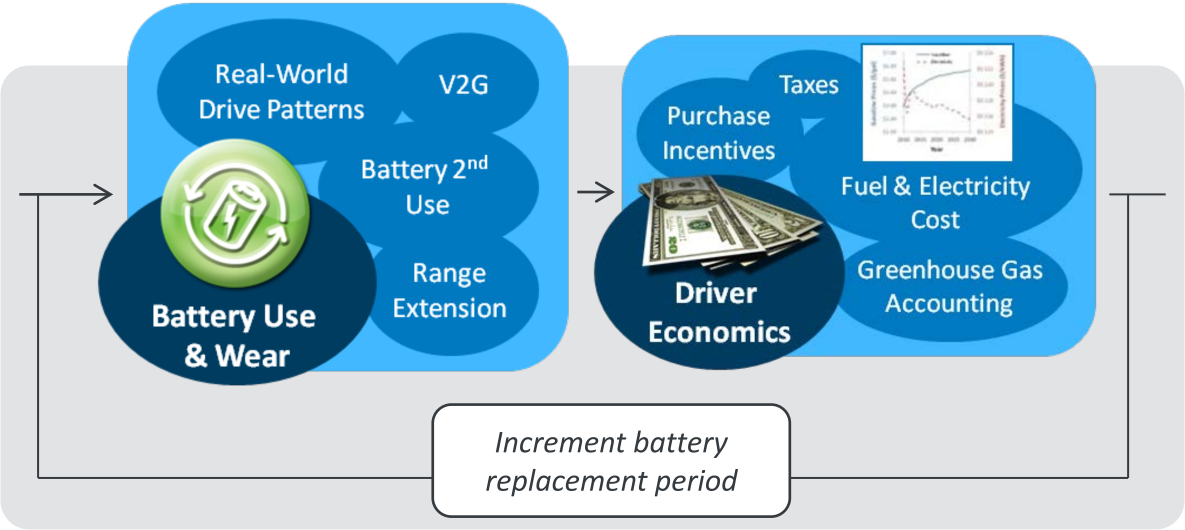
FY12 Accomplishments

- **Plug-in electric vehicle battery replacements are rarely financially justified**
  - Cost-optimal battery replacement algorithm trades the cost of a replacement battery against the savings due to increased electric VMT
  - Only BEVs under the high cost of unachievable VMT produce significant numbers of financially motivated battery replacements



Proposed Future Work

- **FY12**
  - Complete battery swapping study
  - Perform BEV target analysis for USABC

- **FY13**
  - Scope and complete fast charge study
  - Scope and complete V2G analysis
  - Scope and complete vehicle-to-building analysis
  - Scope and complete battery second use analysis
  - Compare all study results to identify cost- and fuel-optimal implementation strategies for EVs and future research avenues
  - Add degradation models for other battery chemistries
  - Integrate ANL's battery cost model (BatPaC)

Summary

- **The Battery Ownership Model is an advanced TCO tool for EVs that:**
  - Uses a unique approach to enable analysis of vehicle and use strategy combinations that other calculators cannot
  - Integrates modeling tools funded by other DOE-funded projects
  - Is being applied to identify pathways to the VTP's short- and long-term goals of reducing petroleum use and carbon footprint by optimizing the use of energy storage systems

- **FY12 findings show us that:**
  - The use of real-world, vehicle-specific drive patterns in place of multi-vehicle "averaged" drive patterns is very important
  - Accounting for the cost of unachievable travel in range-limited BEV analyses has a strong impact on cost-optimal vehicle specification and use strategies
  - PHEV and BEV battery replacements are rarely financially justifiable

- **FY13 work will begin identifying cost- and fuel-optimal EV configurations, use strategies, and business models**