NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Analysis of Electric Vehicle Battery Performance Targets

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Project #ES174

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

BOM Timeline

Project Start Date: 2010
Project End Date: 2015
Percent Complete: 60%

BOM Budget*

Total Project Funding:

DOE Share: $600,000
Contractor Share: $0

Funding Received in FY12:

$200,000

Funding for FY13:

$200,000 (anticipated)

Barriers

- **Battery Cost**
- **Battery Performance**

Partners

- United States Advanced Battery Consortium (USABC)
- Chrysler
- Ford
- GM
- NREL Vehicle System Analysis (VSA) Team

* NOTE: Budget and timeline are for the full scope of the Battery Ownership Model (BOM) project. The BEV battery performance target work is a subset of this effort.

Relevance: BOM

- NREL's Battery Ownership Model overall project objectives:
  - Quantify the total cost of ownership and fuel consumption of electric vehicle technologies under traditional and advanced operational strategies.
  - Identify optimal vehicle use strategies to meet DOE light duty vehicle goals.

- Specific Battery Ownership Model objectives in FY13:
  - Quantify impact of driver aggression, climate, HVAC, and battery thermal management on electric vehicle performance and costs.
  - Compare advanced range extension technologies for battery electric vehicles.
  - **Provide technical analysis to support updating USABC and DOE battery electric vehicle (BEV) battery technical targets.**

Relevance: BEV Technology Targets

- Battery technology targets are necessary to drive development towards commercially successful battery electric vehicles (BEVs) under DOE's EV Everywhere Grand Challenge and USABC projects
- The last USABC BEV battery technology target (right) was created in the early 90's, and its calculation is poorly documented.
- **NREL's Role:** Provide technical analysis support to USABC and DOE for updating BEV battery technical targets.

Parameter(Units) of fully burdened system	Minimum Goals for Long Term Commercialization	Long Term Goal
Power Density(W/L)	460	600
Specific Power – Discharge, 80% DOD/30 sec(W/kg)	300	400
Specific Power - Regen, 20% DOD/10 secW/kg	150	200
Energy Density - C/3 Discharge Rate(Wh/L)	230	300
Specific Energy - C/3 Discharge Rate(Wh/kg)	150	200
Specific Power/Specific Energy Ratio	2:1	2:1
Total Pack Size(kWh)	40	40
Life(Years)	10	10
Cycle Life - 80% DOD (Cycles)	1,000	1,000
Power & Capacity Degradation(% of rated spec)	20	20
Selling Price - 25,000 units @ 40 kWh($/kWh)	<150	100
Operating Environment(°C)	-40 to +50 20% Performance Loss (10% Desired)	-40 to +85
Normal Recharge Time	6 hours (4 hours Desired)	3 to 6 hours
High Rate Charge	20-70% SOC in <30 minutes @ 150W/kg (<20min @ 270W/kg Desired)	40-80% SOC in15 minutes
Continuous discharge in 1 hour - No Failure(% of rated energy capacity)	75	75

Relevance: NREL's History of Target Analysis

- **NREL has provided technical support and analysis to USABC and DOE for setting battery technology targets for multiple drivetrain architectures, including:**
  - 42 V Micro Hybrids
  - Fuel Cell Hybrid Electric Vehicles (HEVs)
  - 12V Start-Stop systems
  - Plug-in Hybrid Electric Vehicles (PHEVs)
  - Lower Energy, Energy Storage Systems (LEESS)

Milestones

Month / Year	Milestone or Go/No-Go Decision	Description	Status
3/2013	Milestone	Complete study on driver aggression, climate, HVAC, and battery thermal management	Completed
9/2013	Milestone	Complete study on range extension technologies	On-track
9/2013	**Milestone**	**Publish new BEV battery technology targets**	**On-track**

Relevant to the analysis for BEV battery technical target setting being reported in this presentation

Approach: Overview for Tech Target Analysis

- **After exploring multiple alternatives and considerable deliberation with the USABC BEV Battery workgroup and NREL System Analysis Team, we found the following approach to be the most justifiable:**
  - Select a conventional vehicle (CV) to benchmark against
  - Select vehicle mass factor to set total BEV mass
  - Simulate vehicle to calculate efficiency (kWh/mi), required motor power, and required battery power
  - Calculate allowable battery mass using mass of motor, power electronics and glider (includes mass compounding effects)
  - Specify required range, then use vehicle efficiency and mass properties to compute required specific energy and energy density
  - Compute battery cost that provides a simple 5 year payback versus a CV

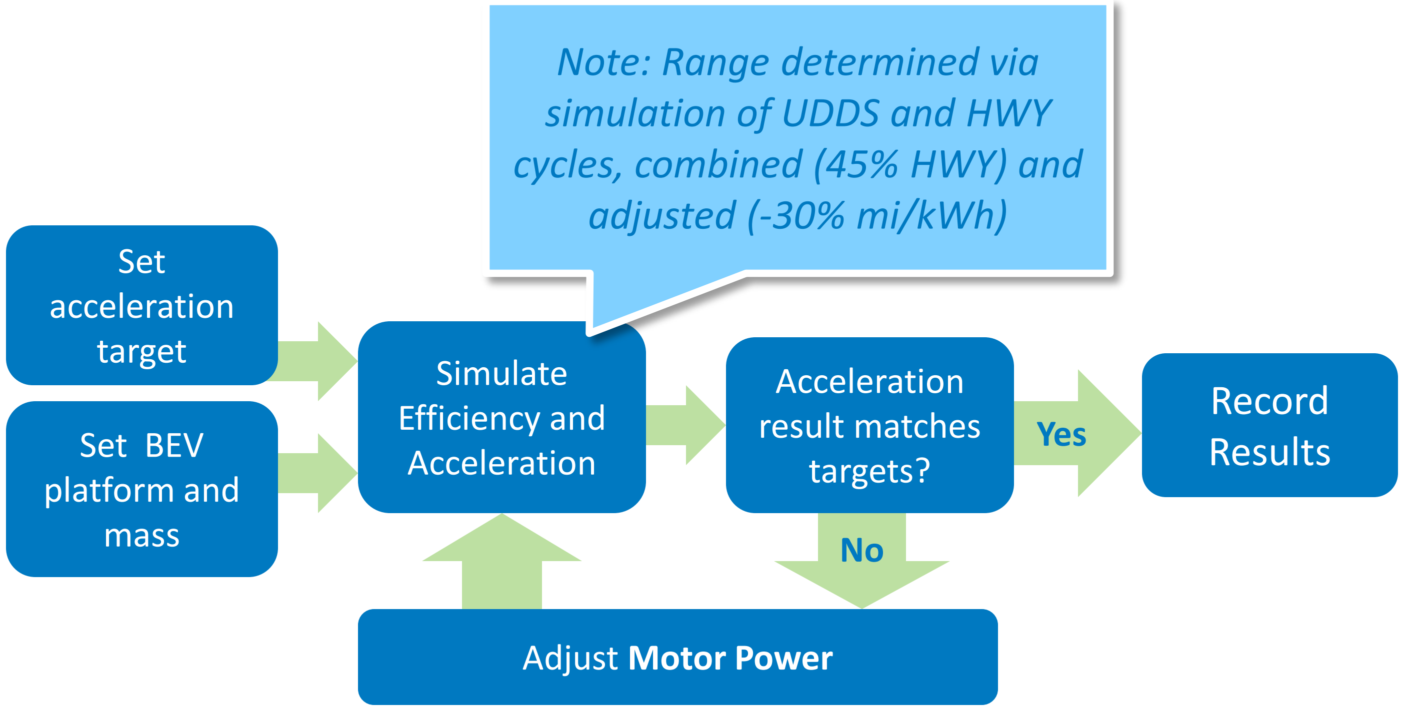
Approach: Benchmark Vehicles

- **OEM and DOE workgroup partners provided technical data for vehicle platforms to consider**
  - Two timeframes: 2015 & 2020
  - Three technology forecasts: Optimistic, Average, & Pessimistic
  - Obtained many important values for this analysis
    - Platform aerodynamics
    - CV mass and efficiency (miles per gallon)
    - BEV glider mass
    - Mass and cost coefficients for BEV motor and power electronics



	Compact	Mid-Size	Small SUV
Similar to...	Honda Civic, Ford Focus, etc.	Ford Fusion, Toyota Camry, etc.	Jeep Compass, Chevy Equinox, etc.

Approach: Vehicle Simulation



- **Provides vehicle efficiency and required motor power as a function of vehicle platform and mass**

Approach: Battery Mass and Volume

- **Parameters supplied from OEM and DOE workgroup partners and NREL VSA**
  - Electric motor and power electronics mass coefficient
  - CV vehicle and drivetrain mass
  - BEV glider mass
  - Allowable battery volume
- **Parameters from other sources**
  - Mass compounding factor (0.57*): scales glider mass with increases in battery, electric motor, and/or power electronics mass
- **Allowable Battery Mass Calculation:**

$$m_v = m_{mpcs} + m_b + m_g$$

$$m_g = m_{g,0} + 0.57\left(m_{mpcs} + m_b - m_{d,0}\right)$$

$$m_b = \left(m_v - 1.57 m_{mpcs} - m_{g,0} + 0.57 m_{d,0}\right)/1.57$$

m_v = total mass of vehicle
m_{mpcs} = mass of motor and power electronics
m_b = mass of battery
m_g = mass of BEV glider
$m_{g,0}$ = mass of CV glider
$m_{d,0}$ = mass of CV drivetrain

**From D. Malen and K Reddy, "Preliminary Vehicle Mass Estimation Using Empirical Subsystem Influence Coefficients," prepared for the FGCP-Mass Compounding Project Team of the Auto/Steel Partnership, May 2007.*

Approach: Cost Calculations

$$MSRP_{CV} + S_{fuel} = MSRP_{BEV}$$

S_{fuel}= 5 yr simple fuel savings
$MSRP_{BEV}$ = price of BEV

$$MSRP_{BEV} = G + m \times \left(C_{mpcs} \times P_{motor} + C_{batt} \times E_{batt}\right)$$

G = price of glider
m = mfg-to-retail markup factor = 1.5****
C_{mpcs} = cost of motor and power electronics = $8/kW*****
P_{motor} = motor power
C_{batt} = allowable battery cost
E_{batt} = battery energy

$$MSRP_{CV} = G + m \times \left(C_{CV1} + C_{CV2} \times P_{engine}\right)$$

G = price of glider
m = mfg-to-retail markup factor = 1.5****
C_{CV1} = non-scaling engine cost = $531*
C_{CV2} = scaling engine cost = $14.5/kW*
P_{engine} = engine power

Note: we assume the glider cost for the CV and BEV to be equivalent

$$S_{fuel} = VMT_5 \times \left(P_{gas} / mpg - P_{elec} \times kpm\right)$$

VMT_5 = 5 year vehicle miles travelled= 60,000
P_{gas}= average price of gas = $5.32/gal **
mpg = miles per gallon of CV***
P_{elec} = average price of electricity = $0.117/kWh **
kpm= kWh per mile of BEV

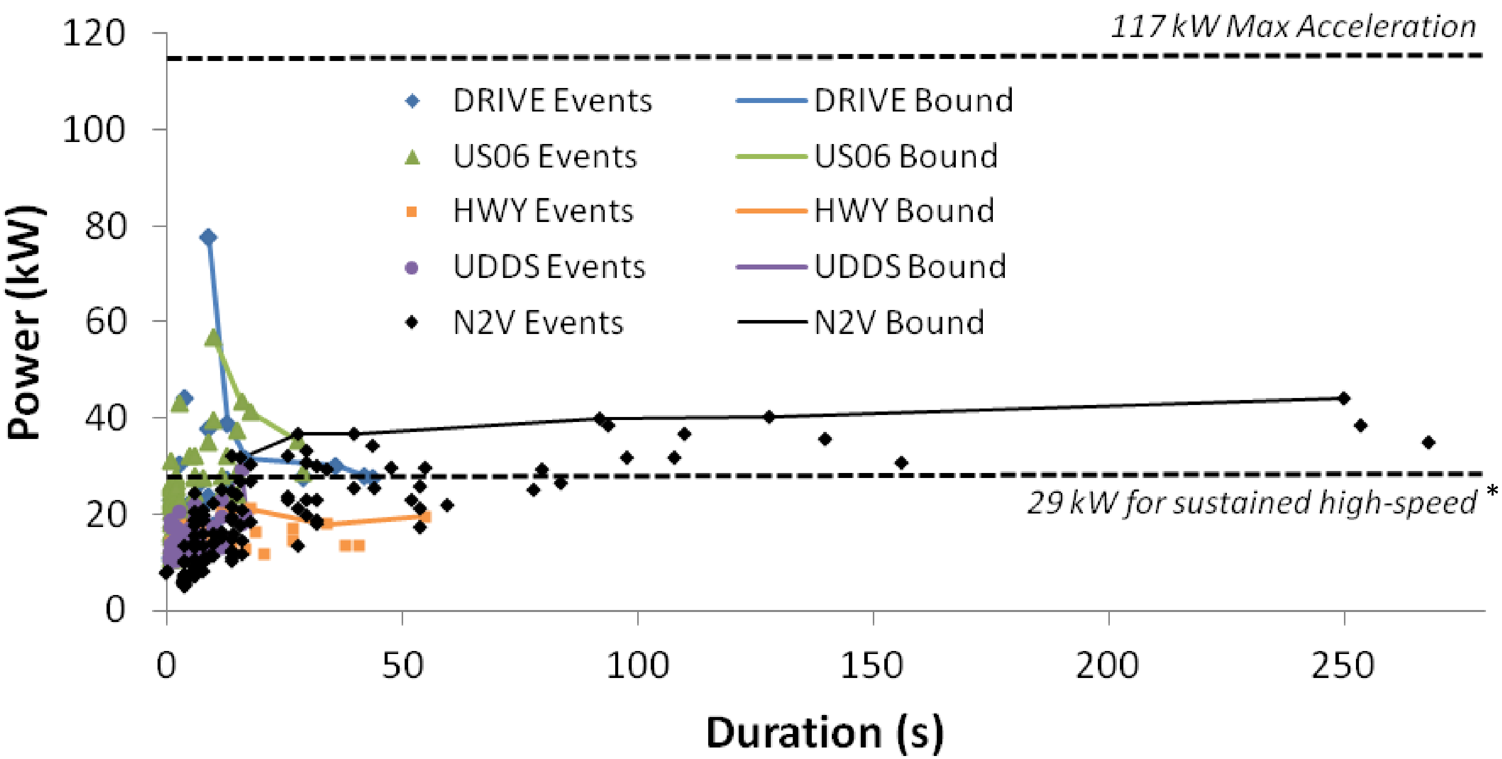
- **Identifying cost is challenging, as there are many approaches – some of which are rather complex.**

- **We propose a simple approach that sets the upfront cost of the BEV equal to the upfront cost of a comparable CV plus five years of (undiscounted) fuel savings.**

* Results of separate NREL study
** Average of prices reported in 2012 dollars from EIA's 2011 high oil price scenario from 2020 to 2025
*** Data from OEM and DOE workgroup partners
**** Reference available upon request
***** DOE cost target for 2020 cost of automotive motors and power electronics

Progress: Discharge Power Requirements

Example: 2020 Mid-Size Sedan, 1.2 times the mass of a comparable CV

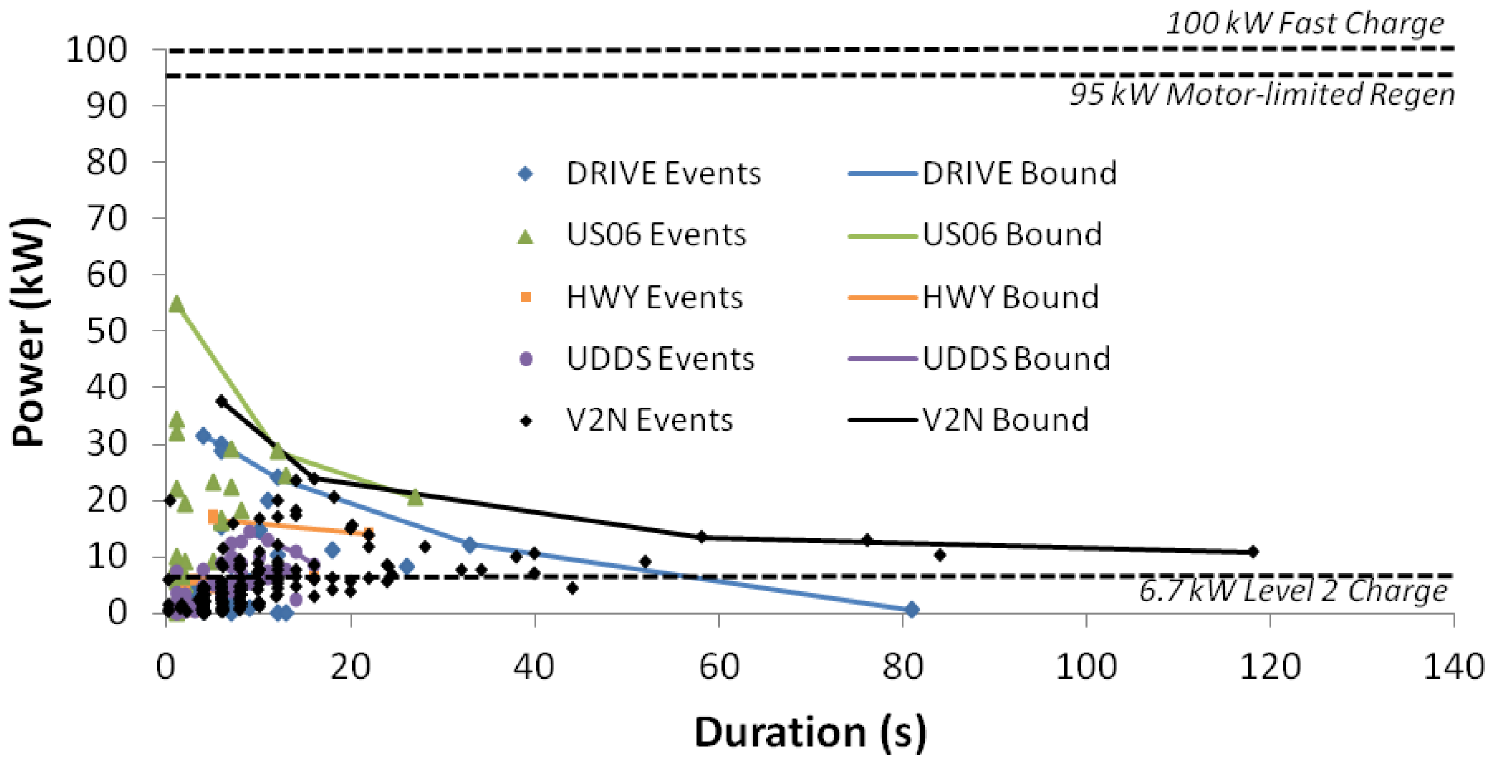


- **Required discharge power is a strong function of duration, highly sensitive to drive cycle**

**40 minute selection of sustained high-speed climbing*

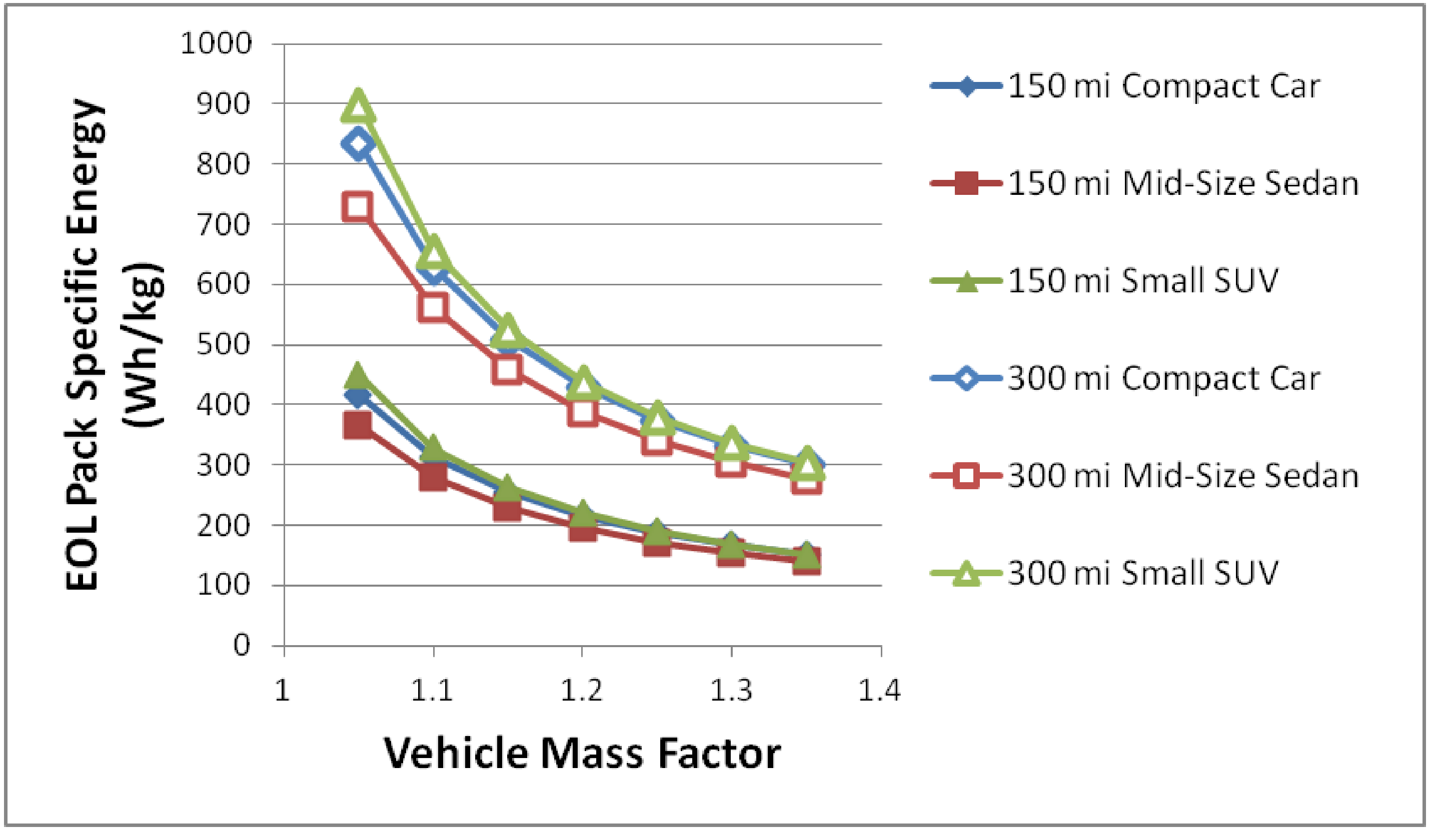
Progress: Charge Power Requirements

Example: 2020 Mid-Size Sedan, 1.2 times the mass of a comparable CV



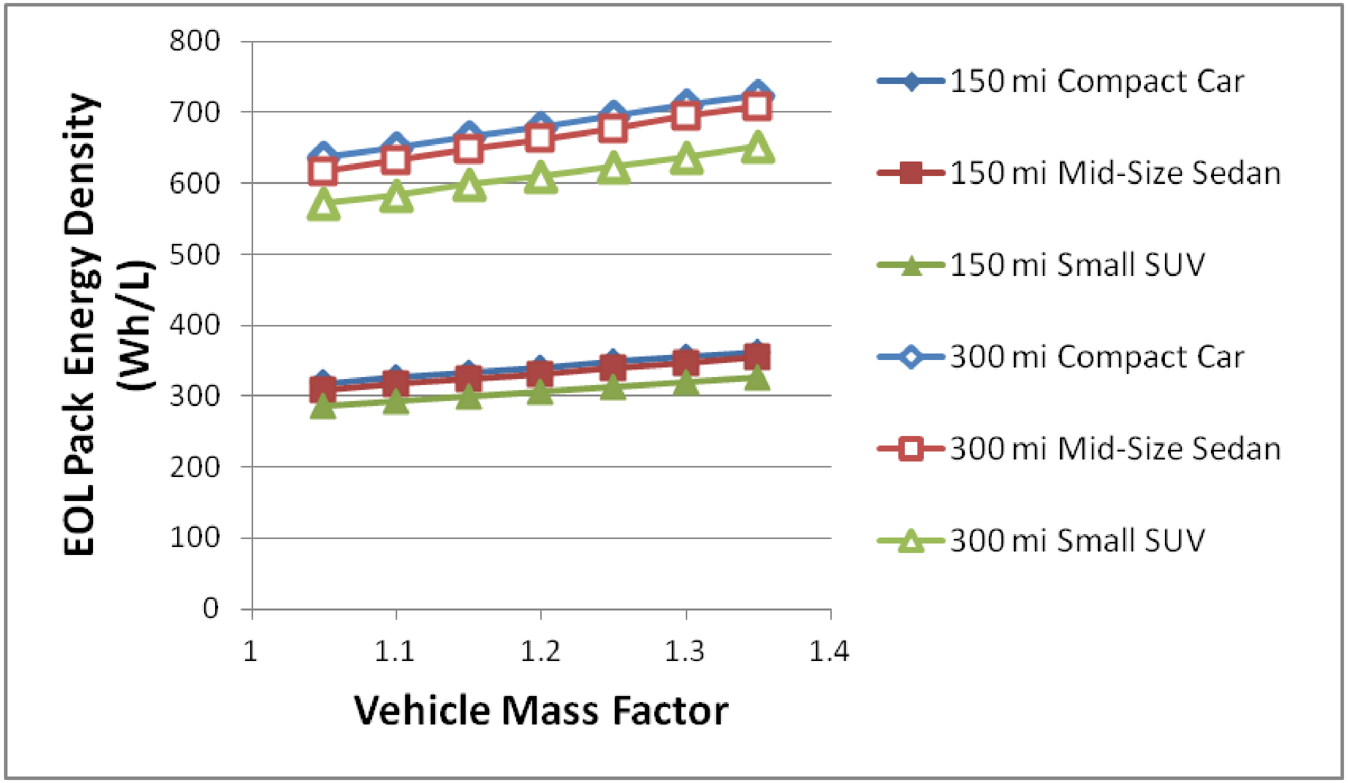
- **Regen requirements are also a function of duration, but high rate charging requirements (i.e. fast charge) can negate the need to consider regen in detail.**

Progress: End-of-Life Pack Specific Energy



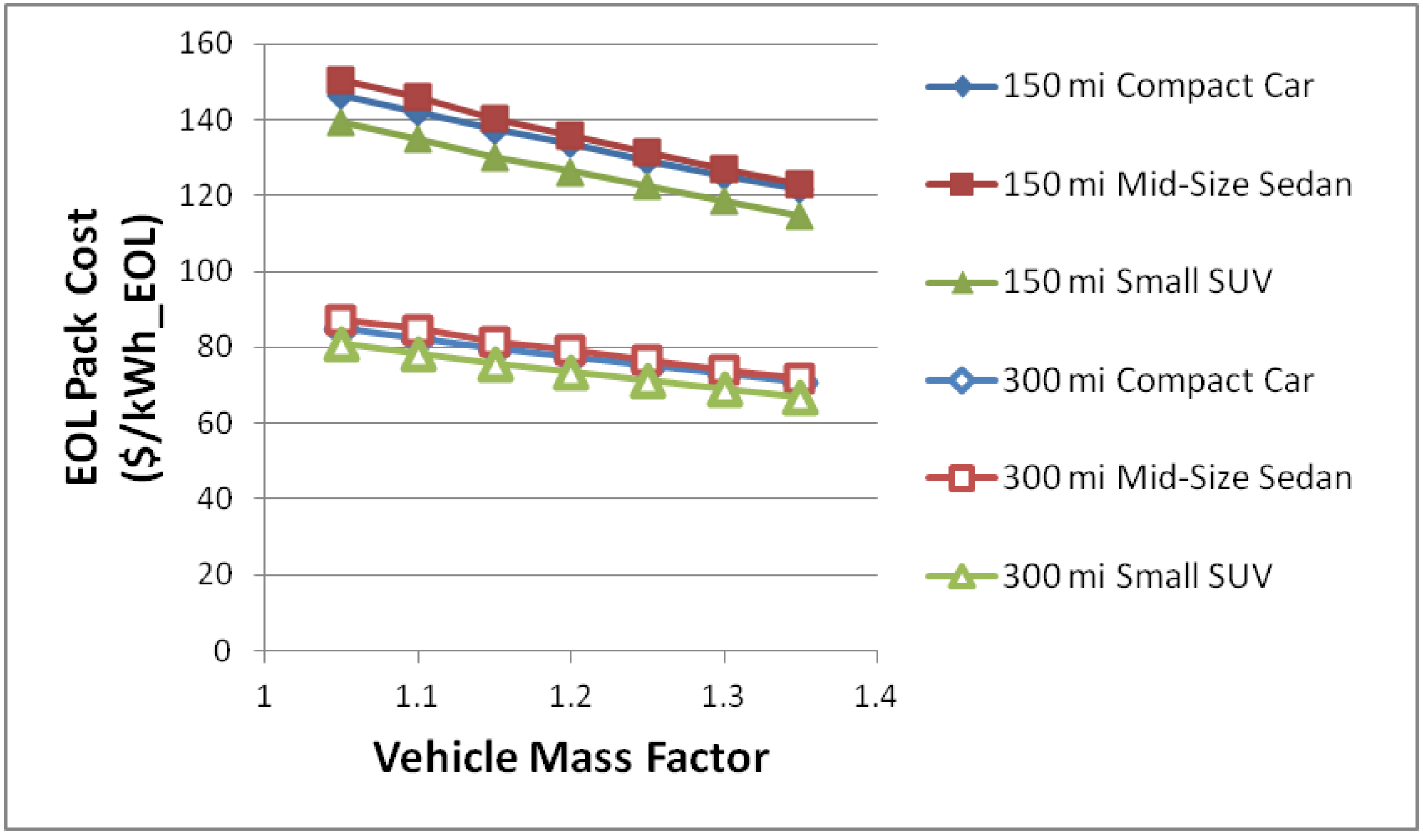
- **Mid-size sedan offers least aggressive target for a given range and vehicle mass factor**
  - Compact car platform has a small battery mass budget for a given VMF
  - Small SUV requires a lot of battery due to mass and aerodynamics

Progress: End-of-Life Pack Energy Density



- **Small-SUV offers least aggressive target for a given range and vehicle mass factor**
  - Allowable volume for each vehicle (125 L for compact car, 140 L for mid-size sedan, and 175 L for small SUV) needs confirmation though

Progress: Pack Cost



- **Mid-size sedan offers least aggressive target for a given range and vehicle mass factor**
  - Fuel economy of compact car is high, lowering the potential savings of a BEV
  - Small SUV requires a lot of battery

Progress: Translating Requirements

- All discussion of battery energy is with respect to AVAILABLE ENERGY at END-OF-LIFE. As such, our results are time, environment, and chemistry agnostic. Considerations for SOC windows less than 100%, thru-life degradation, temperature sensitivity, etc. must be made separately.
- All calculations are for the complete battery PACK, encompassing cells, structure, battery management system, thermal systems, etc. Results must be scaled separately to acquire cell-level requirements/test conditions.
- In context of BEGINNING-OF-LIFE CELL performance, these considerations can double the aggressiveness of end-of-life pack level values reported here. For example:
  - A pack level end-of-life specific energy requirement of 200 Wh/kg may require cells with a beginning-of-life specific energy of 400 Wh/kg
  - A pack level cost requirement of $140/Wh may require a cell that costs $70/Wh

Future FY13 Work: Down Select for Targets

- Analyze vehicle utility factor as a function of range
- Workgroup selection of vehicle platform, range, and other properties to be used for target calculation
- Obtained feed back from stakeholders (USABC MC, DOE VTP, etc,)
- Calculation of target values based on these selections
- Journal publication of methods and results

Summary

- **Worked closely with stakeholders to define approach for updating battery targets for the USABC and DOE EV Everywhere Grand Challenge battery R&D**

- **Provided technical analysis and support to USABC and DOE for updating BEV battery technical targets within the scope of NREL's broader Battery Ownership Model project.**

  – Developed a framework to calculate BEV battery technology target

  – Calculated targets as a function of vehicle platform, mass, range, and other parameters

  – Currently reviewing results with the USABC workgroup and DOE en route to finalizing targets and publishing our findings