

Battery Ownership Model: A Tool for Evaluating the Economics of Electrified Vehicles and Related Infrastructure



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**25th Electric Vehicle
Symposium
Shenzhen, China**

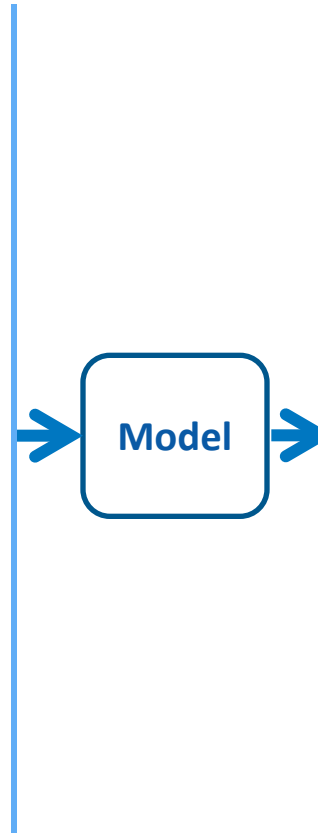
November 5–9, 2010

NREL/PR-5400-50356

Many New Vehicle Technologies, Power Sources, Infrastructure Technologies, and Business Models Are Being Proposed for Transportation

How Do We Make Sense of These Options as They Relate to Component Development, Economics, Energy Use, Greenhouse Gases, and the Role of Government?

Solar Power **Wind Power**
Swap Stations **City Charge Points**
Aggregators **Charge Service Provider**
Traditional EVs **PHEVs** **Smart Grid**
Location **Drive Profile**
Battery Life **V2G** **Vehicle Characteristics**
Cost of Money **Charging Algorithms**
Subsidies **Battery Specific Power & Specific Energy**
Job Creation **Battery Secondary Use**
Consumer Behavior **Future Cost of Gasoline**



Battery Ownership Model Multi-Disciplinary Team



Jeremy Neubauer
battery secondary use, project subtask lead



Aaron Brooker
vehicle systems analysis, optimization & programming



Michael Mendelsohn
economics & financing



Caley Johnson
carbon markets, policy analysis & fueling stations



John Rugh
vehicle ancillary loads reduction & driving statistics



Michael O'Keefe
power electronics, EV grid integration & programming

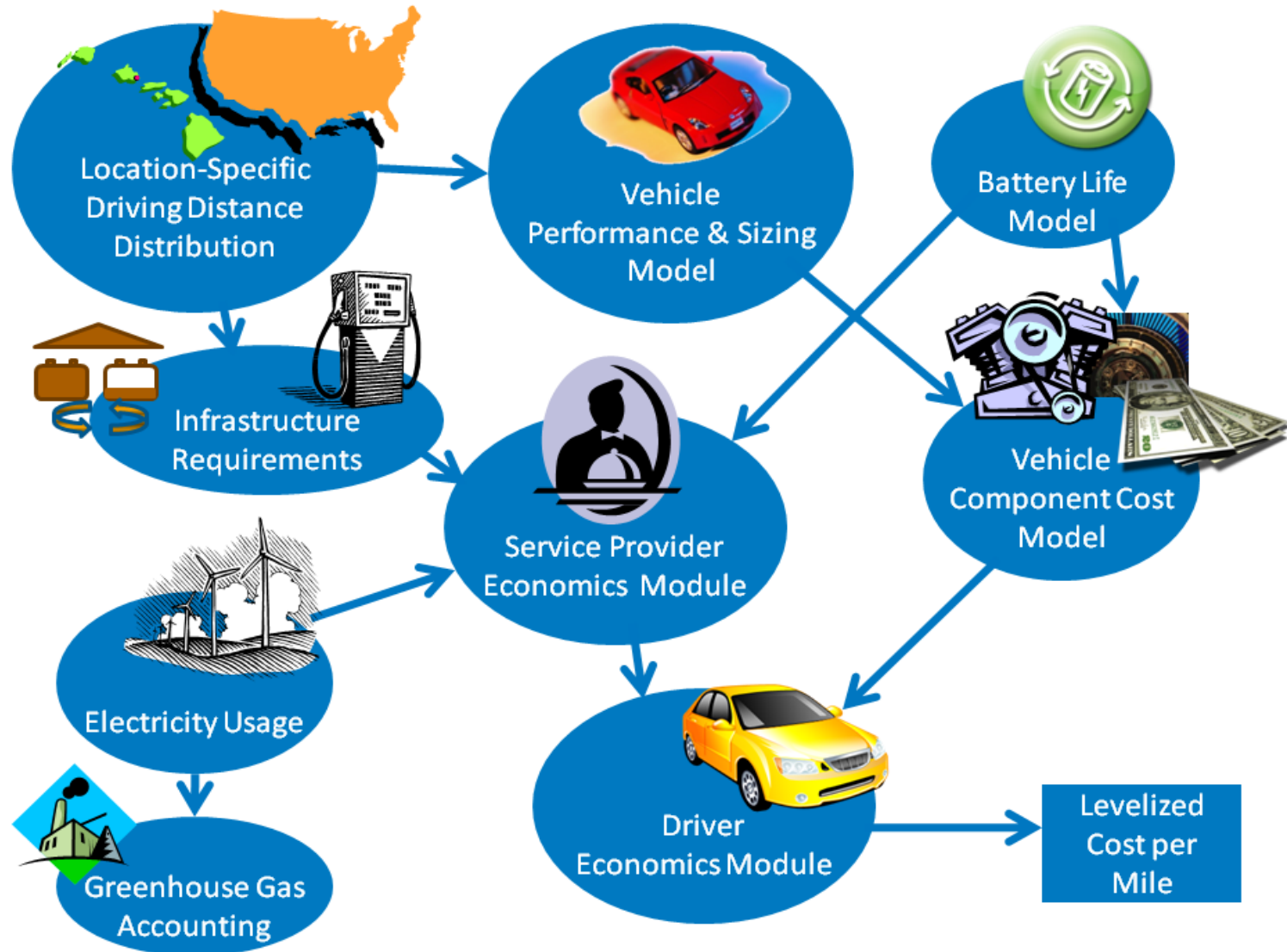


Terry Penney
advisor on project direction



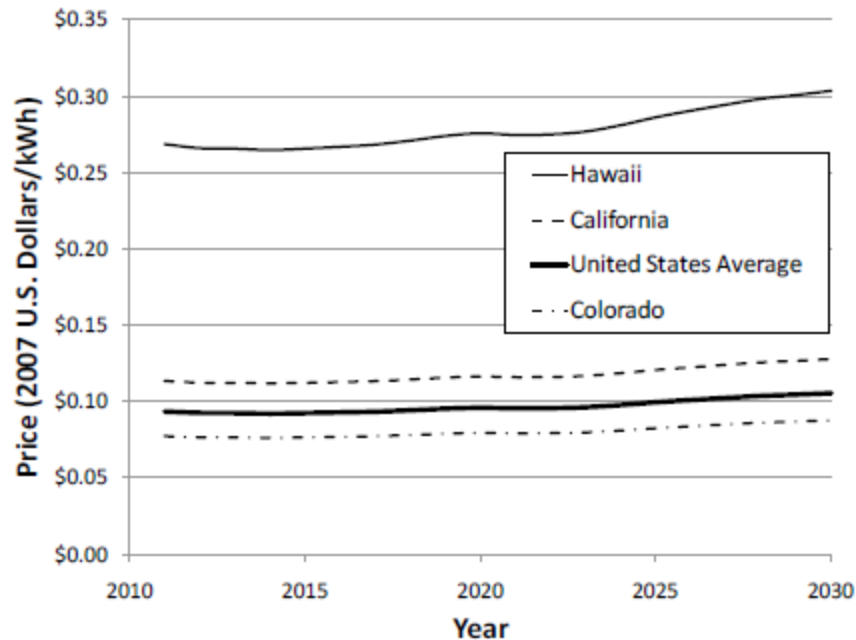
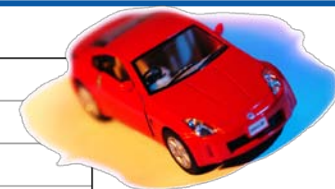
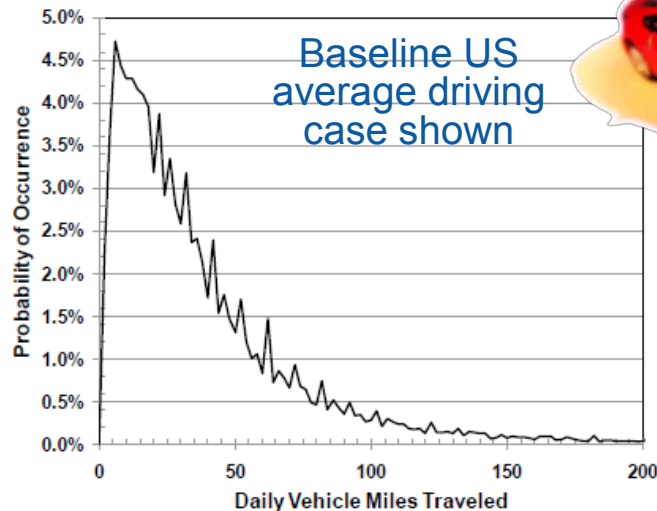
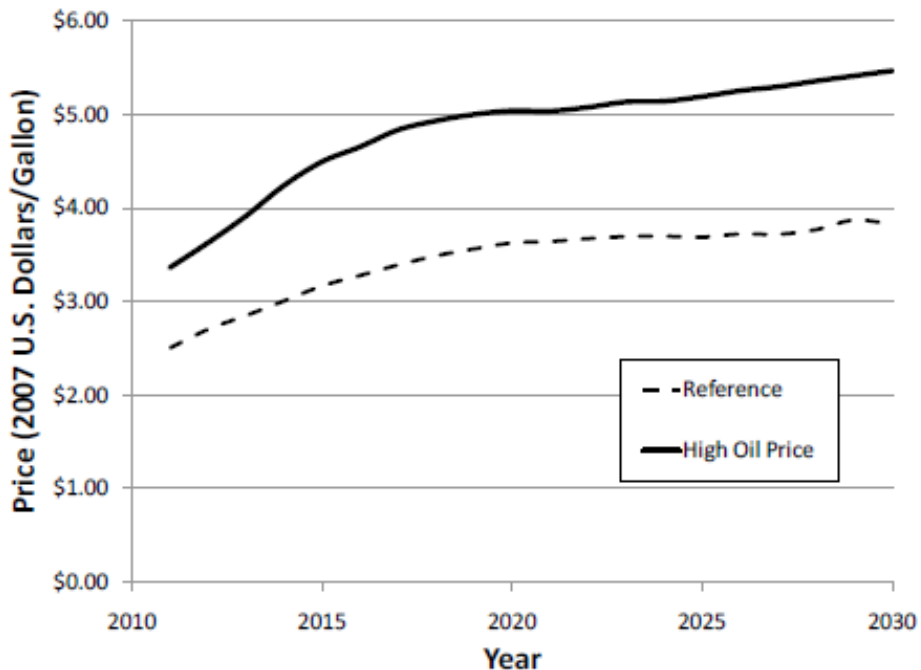
Ahmad Pesaran
energy storage system task lead

NREL developed the **Battery Ownership Model** to answer this question



Location-Specific Driving Distance Distribution

Price of Gasoline



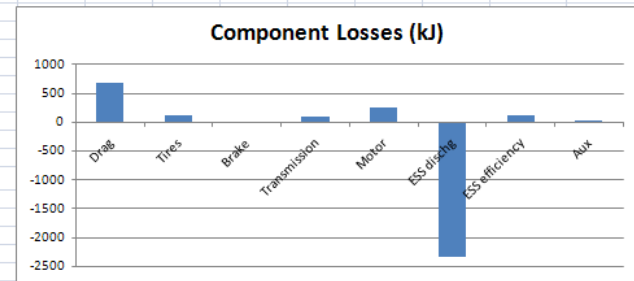
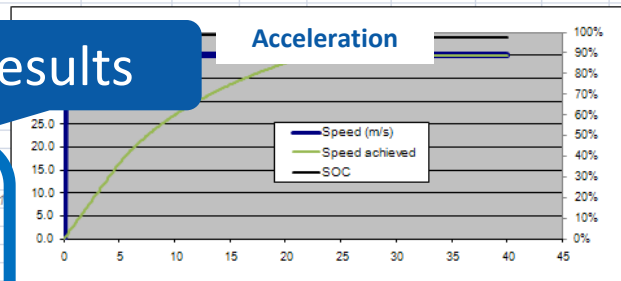
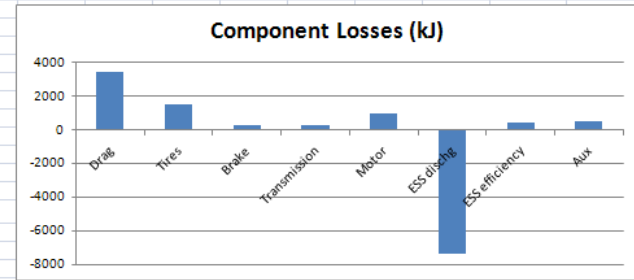
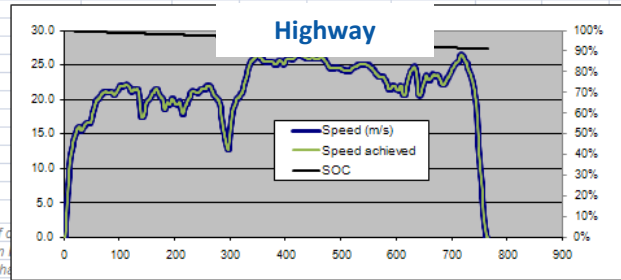
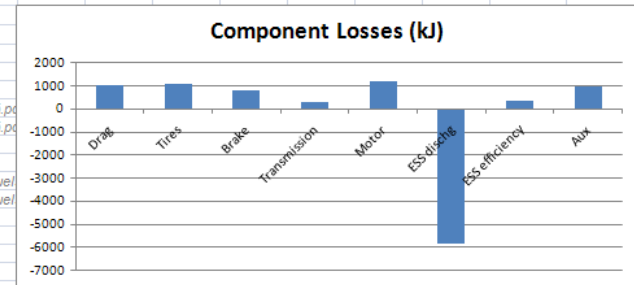
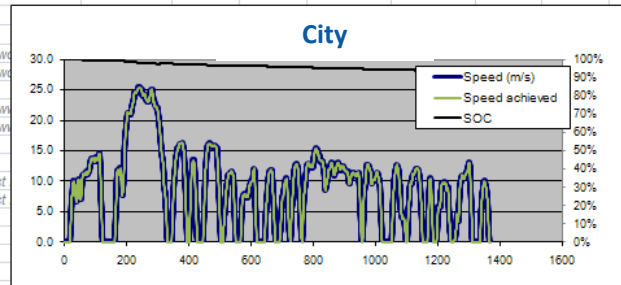
Vehicle Performance and Sizing Model



Inputs

Components		
Battery power (kW)	80	
Battery energy (kWh)	24	
Battery mass (kg/kWh)	7.8	See ES Chars w
Battery base mass (kg)	43.0	See ES Chars w
Battery round trip efficiency	90%	
Battery life coefficient A (product)	157.29	VART http://www
Battery life coefficient B (power)	-0.6844	VART http://www
Max motor power (kW)	80	
Motor time to full power (s)	1	
Motor controller mass (kg/kW)	0.833	A. Simpson, Cost
Motor controller base mass (kg)	21.6	A. Simpson, Cost
Transmission efficiency	95%	
Transmission mass (kg)	114	
Drag coefficient	0.32	
Frontal area (m ²)	2.1	
Wheel inertia (one wheel) (kg*m ²)	0.815	
Number of wheels	4	
Rolling resistance coefficient	0.007	
Wheel radius (m)	0.282	
Wheel coefficient of friction	0.7	
Auxiliary loads (kW)	0.7	
Vehicle glider mass (kg)	900	
Vehicle center of gravity height (m)	0.53	
Drive axle weight fraction	0.55	
Wheel base (m)	2.67	
Regen braking percent	60%	
Controls		
Min SOC	20%	Used s depth of d
Percent usable SOC passing buffer	0.1	Must be between
Max SOC	100%	Must be higher th
Assist kW per percent SOC off target	0.2	
Charge kW per percent SOC off target	0.2	
Min SOC target speed (MPH)	50	
Max SOC target speed (MPH)	0	
Balance SOC		
Run (if calc opts =man)		
Results		
Total mass (kg)	1331	1180 kg ~Civic, 2008
SOC setpoint	50%	
Battery life (miles)	1,038,629	
Range (miles)	77	
CAFÉ Sticker		
City (mpgge)	0.217	0.242
Highway (mpgge)	0.200	0.257
Combined	0.210	0.248

Results



Vehicle Component Cost Model

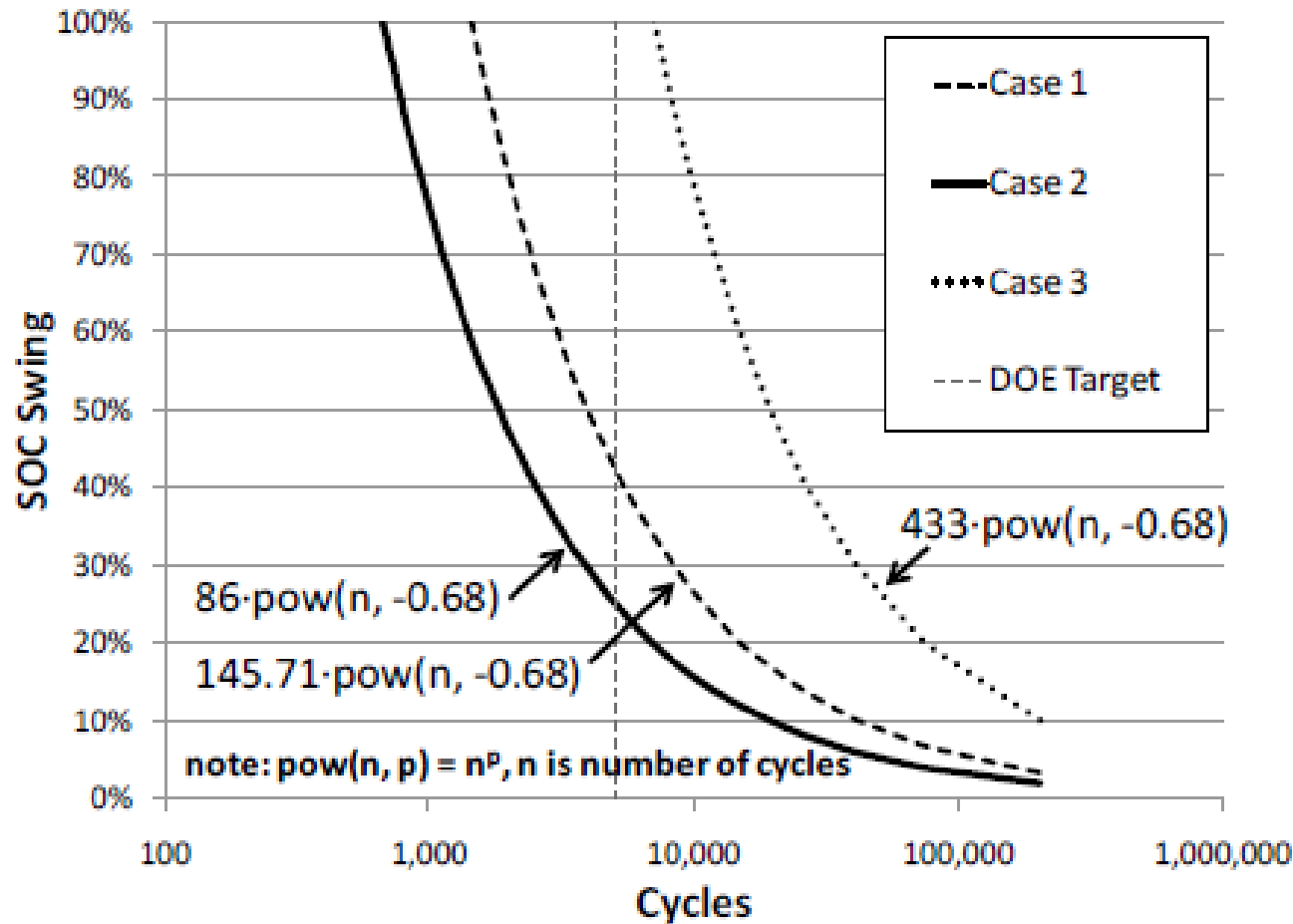
Baseline technology costs have been calibrated against currently available vehicles

Equation coefficients can be varied to explore sensitivities and future scenarios

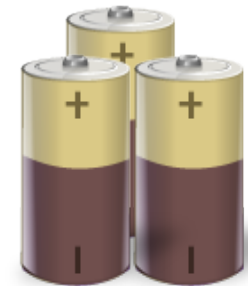


Battery	$\frac{\$22.00}{kW} \cdot P_b + \frac{\$700.00}{kWh} \cdot E_b + \680.00
Motor & Power Electronics	$\frac{\$21.70}{kW} \cdot P_m + \425.00
Engine	$\frac{\$14.50}{kW} \cdot P_e + \531.00

Battery Life Model



A simple model for battery degradation has been tied to the driving profile



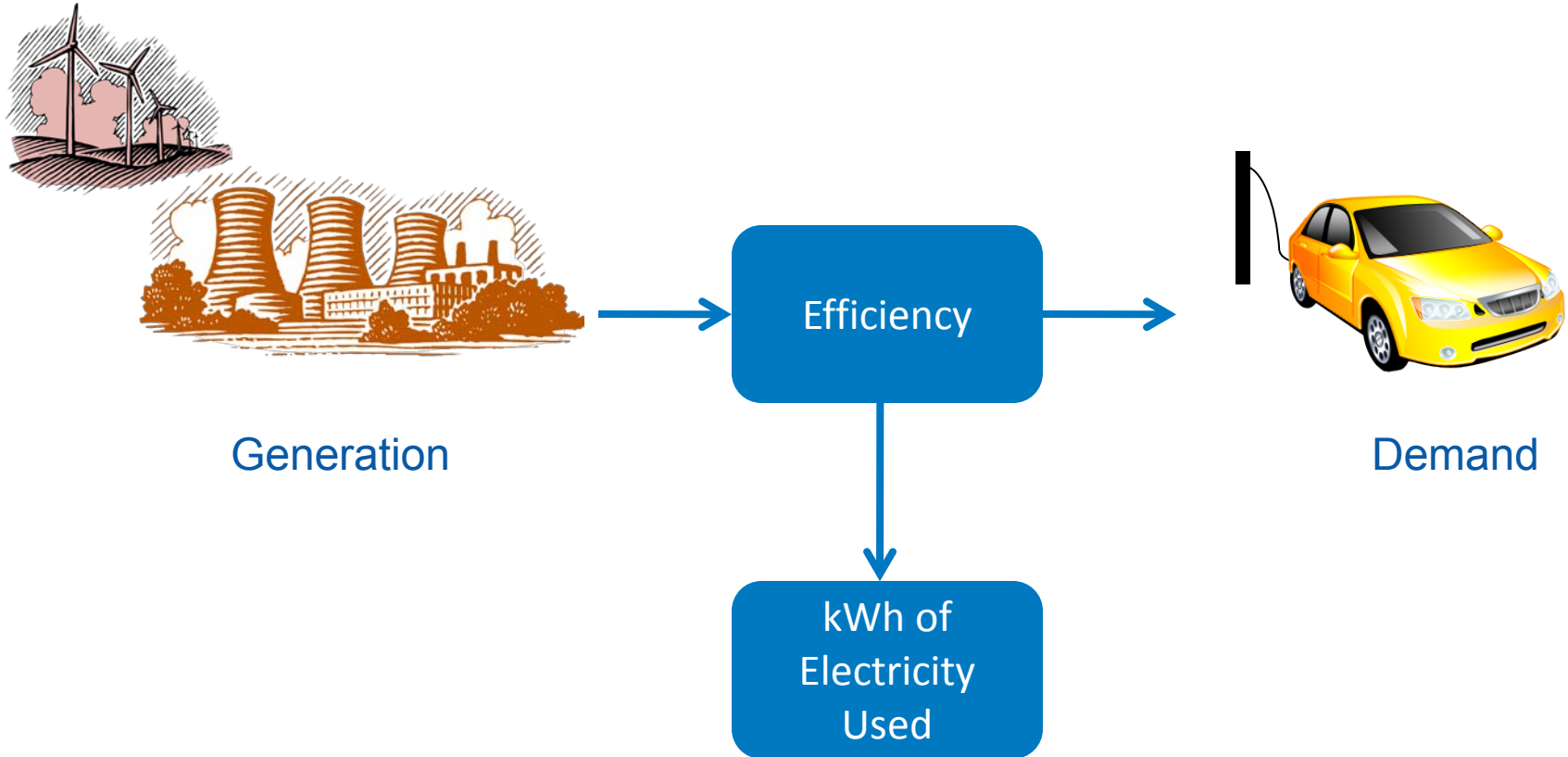
Infrastructure Requirements

Swap Fraction	Swap Stations per 10,000 Cars
11%	11
09%	9
01%	1

For reference: ~6.4 gasoline stations (~54.7 pumps) per 10,000 cars

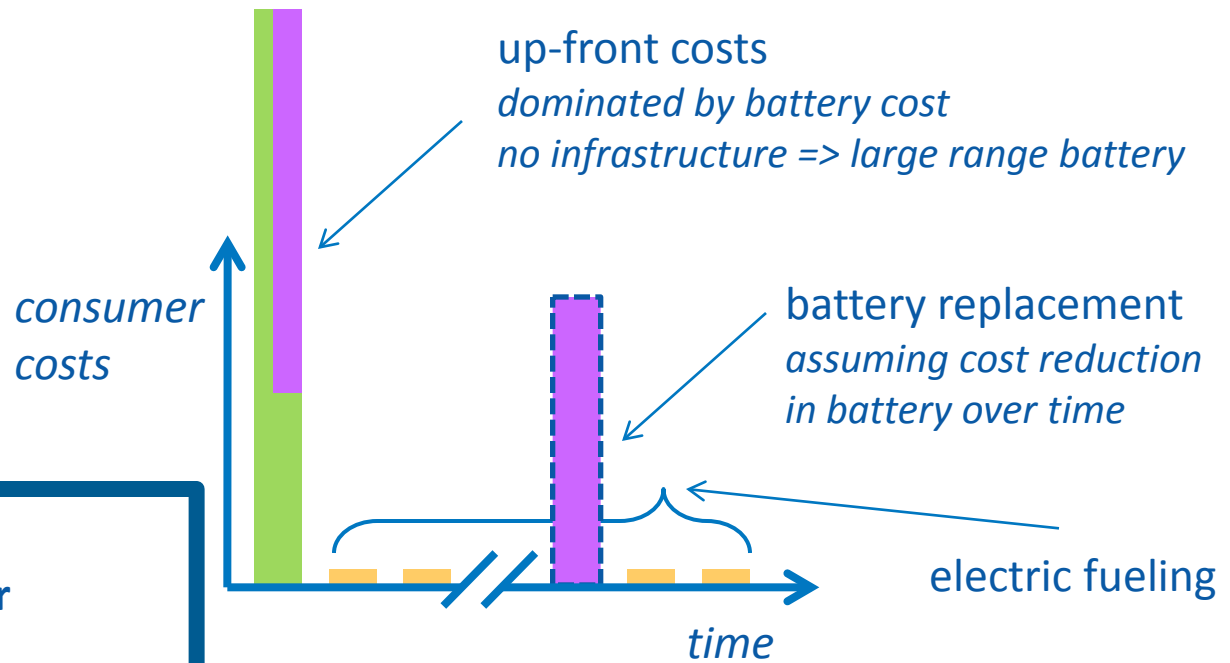
Assuming: same “level of convenience” for swap station as gasoline station in terms of cars per “pump” & time per fueling

Electricity Usage

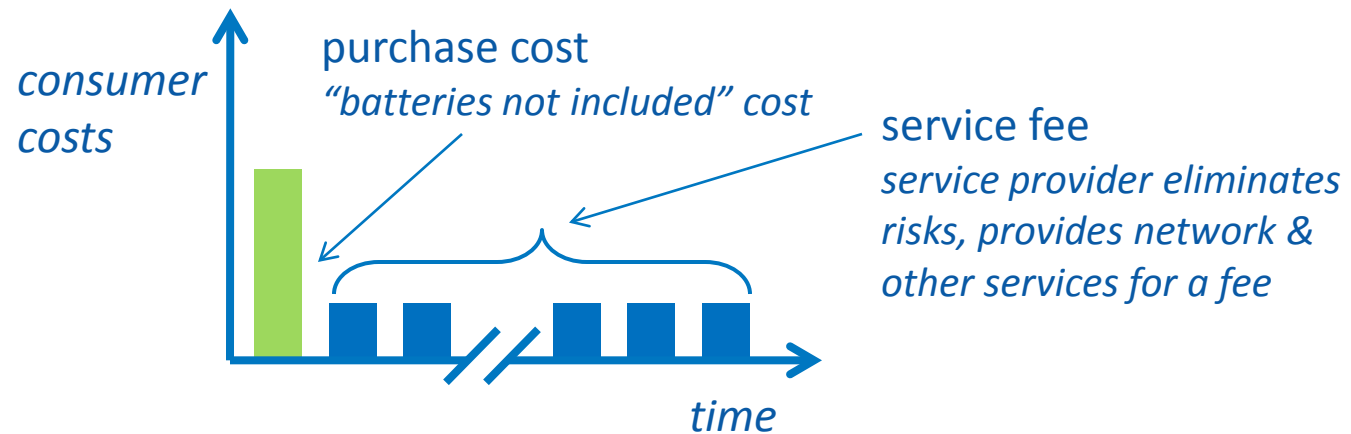


Service Provider Economics Module





Traditional EV Ownership Model:



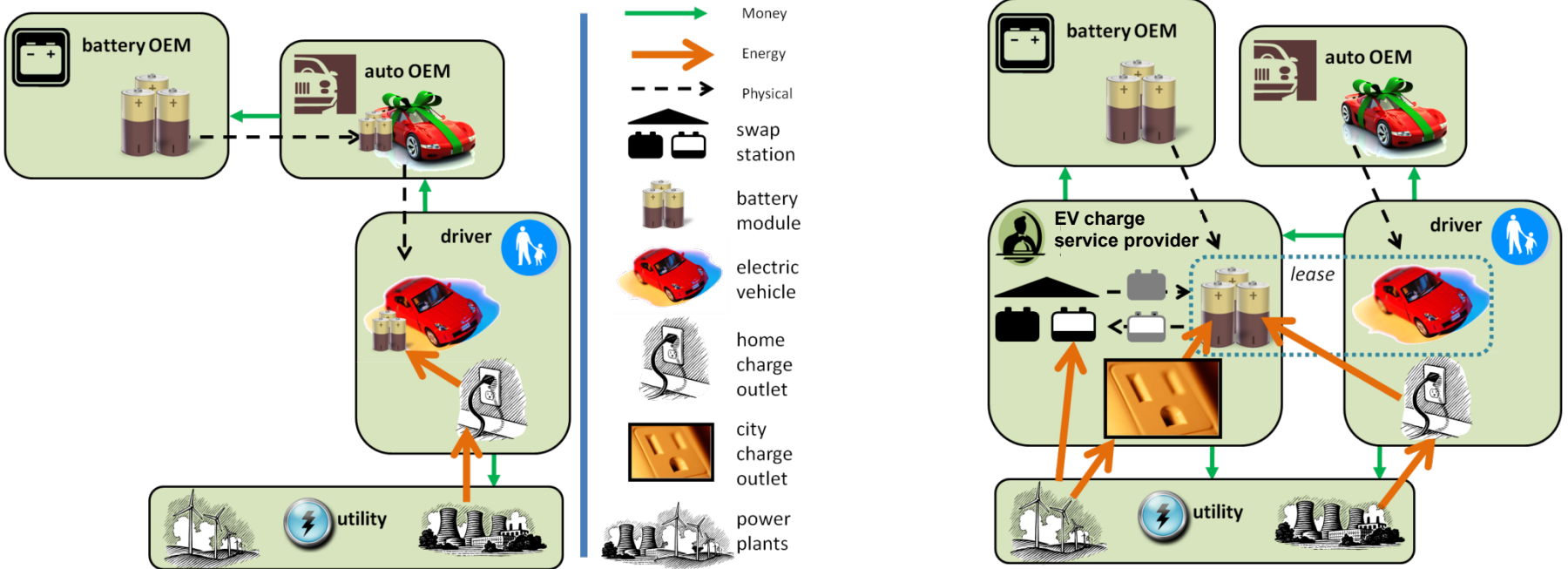
...with Service Provider



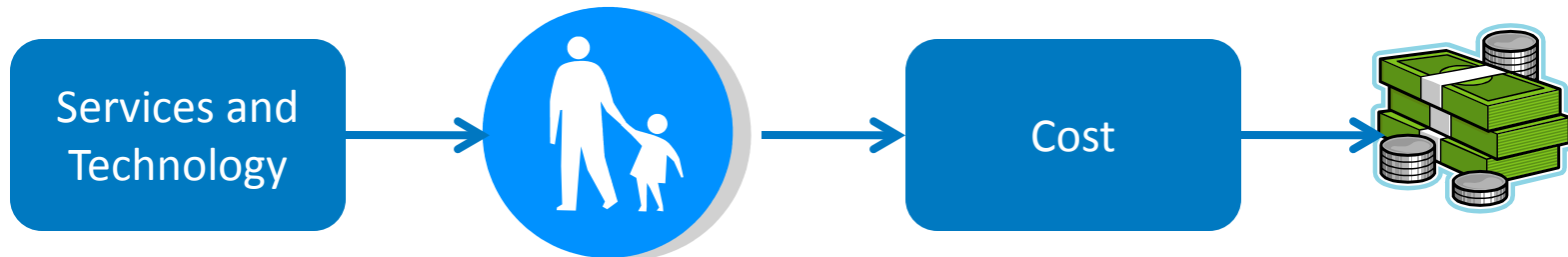
KEY

-  up-front costs
-  electricity
-  service fees
-  battery costs

Driver Economics Module



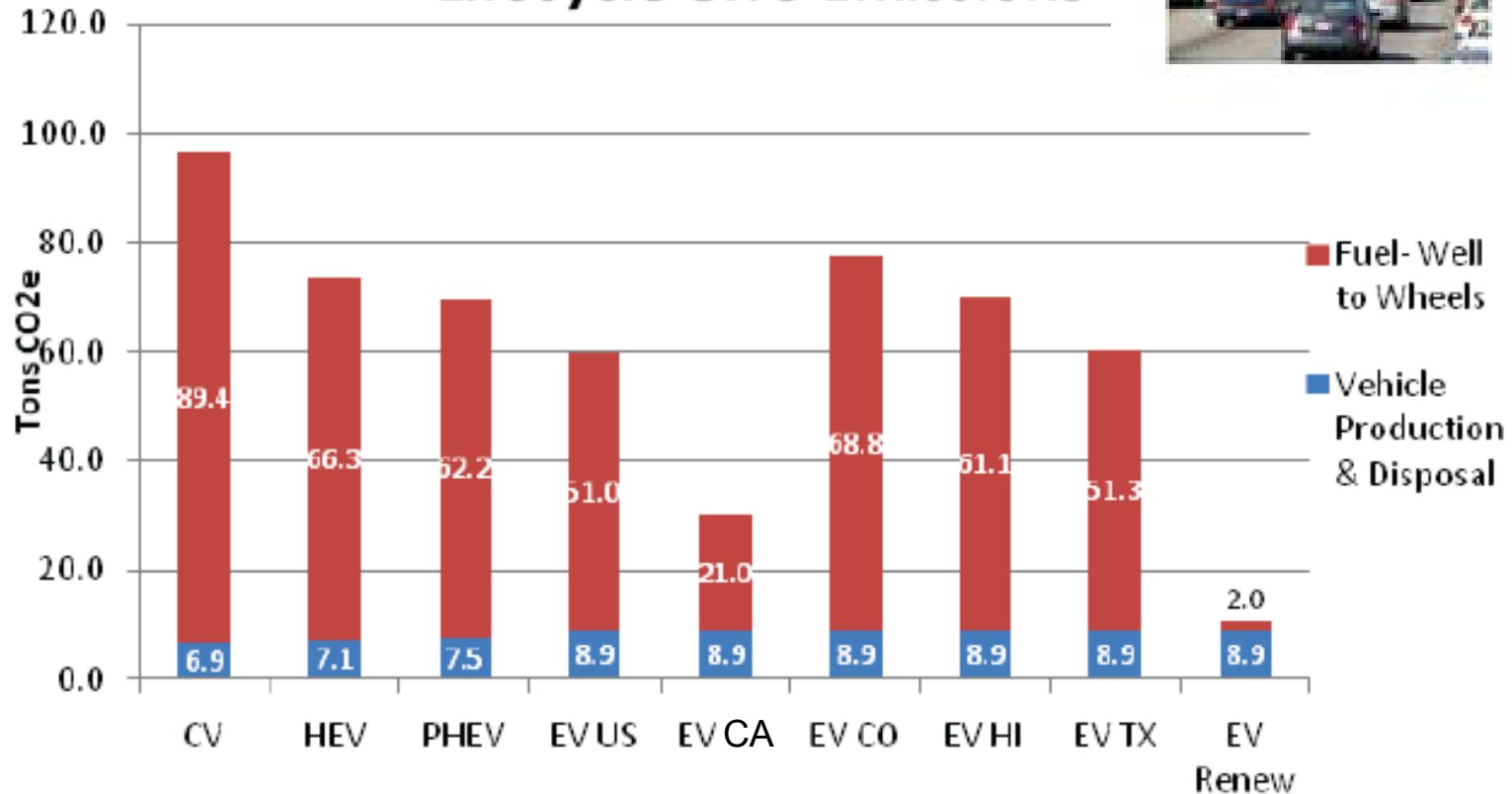
End User



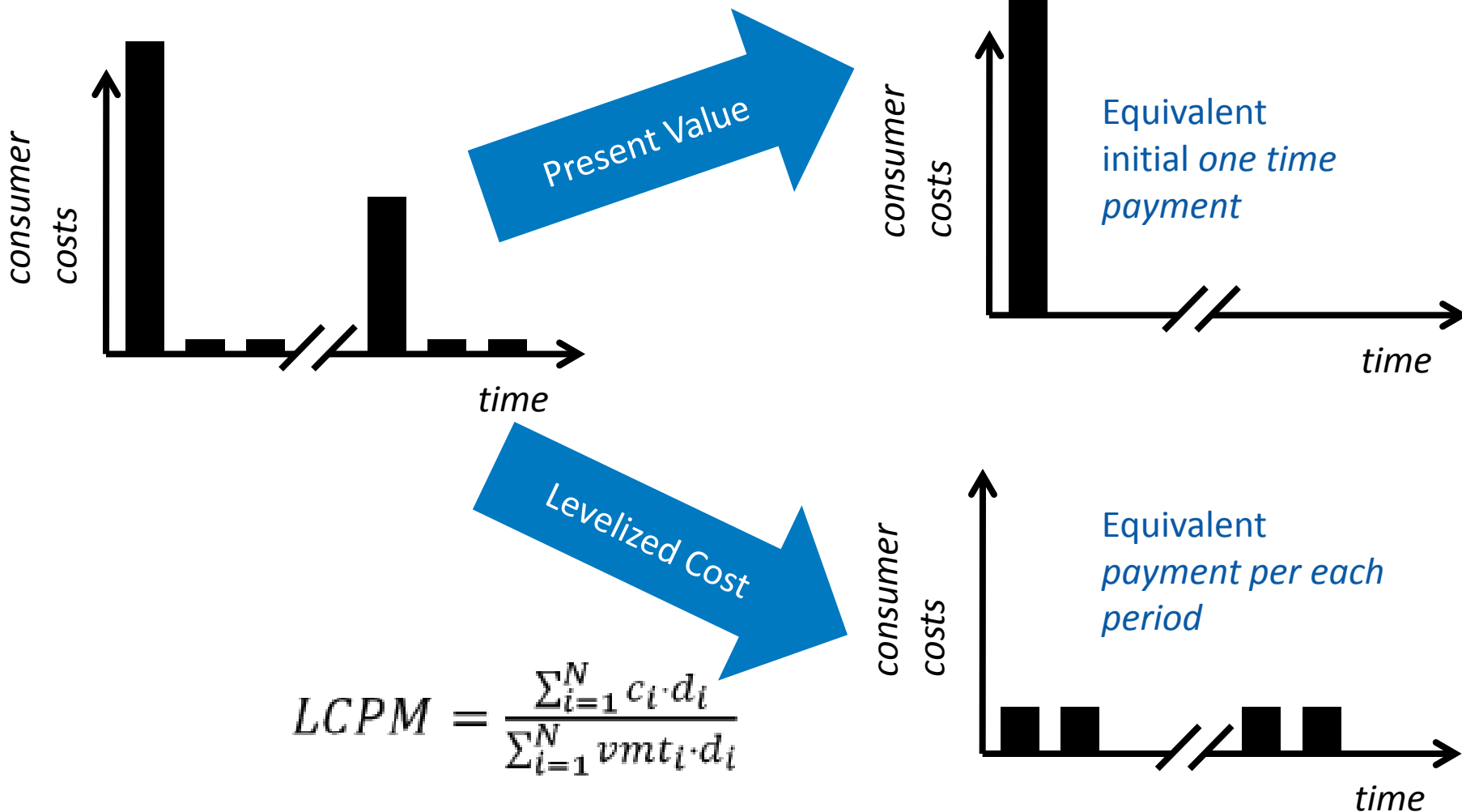
Greenhouse Gas Accounting



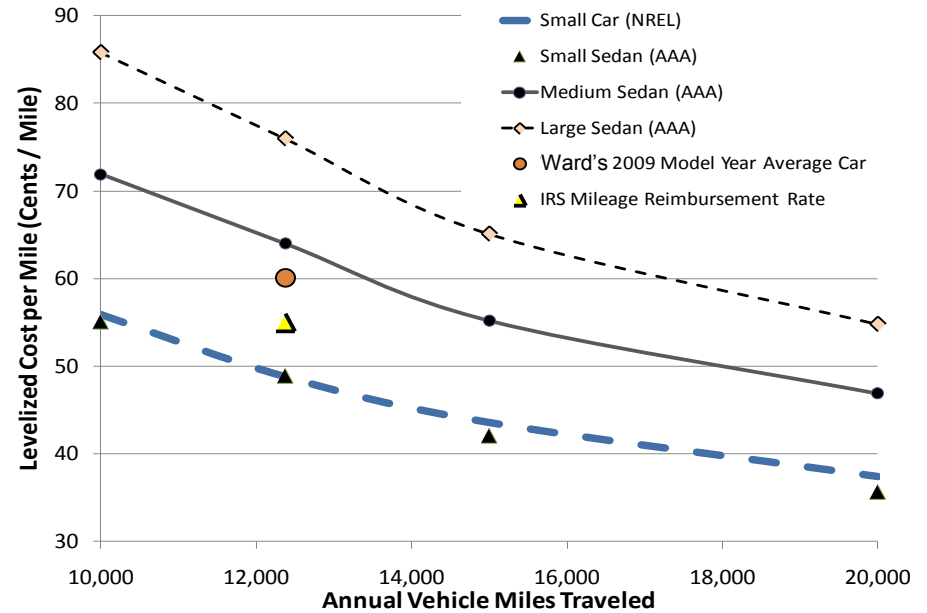
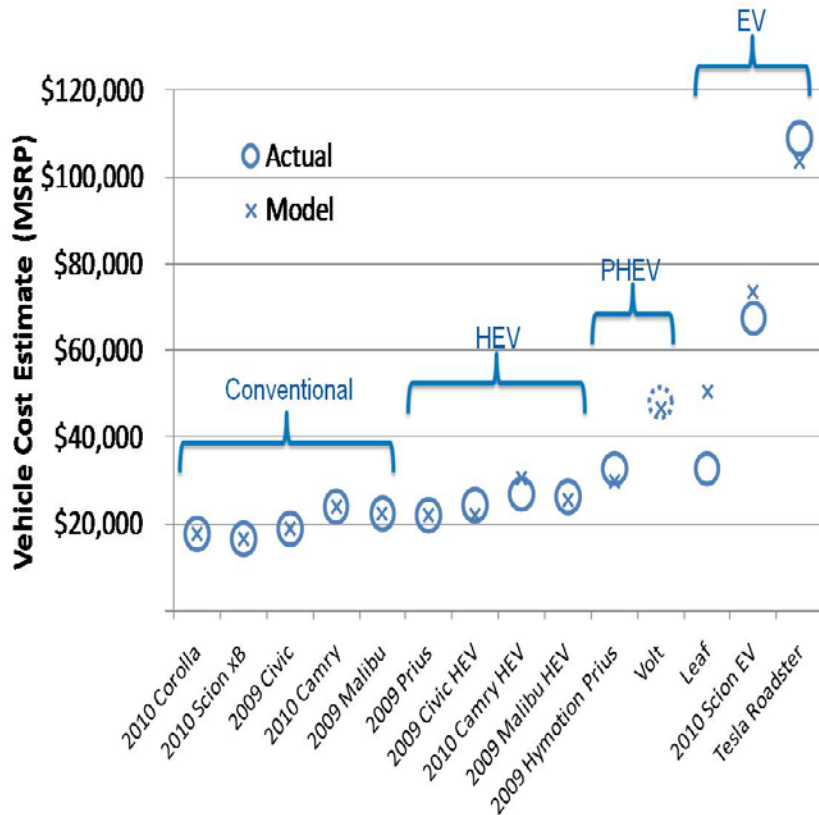
Lifecycle GHG Emissions



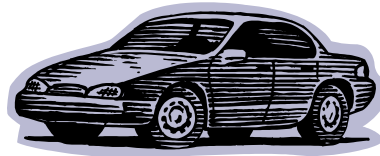
Levelized Cost per Mile (LCPM)



Validation: The model does well at estimating the cost of vehicle technologies



We compared the LCPM of the following vehicles:



CV
Conventional Vehicle
(gasoline)

Hybrid Electric Vehicle
HEV (gasoline)



Plug-in Hybrid Electric Vehicle [40 mile]
(electricity / gasoline)

PHEV40

Electric Vehicle [100 mile]
(electricity)

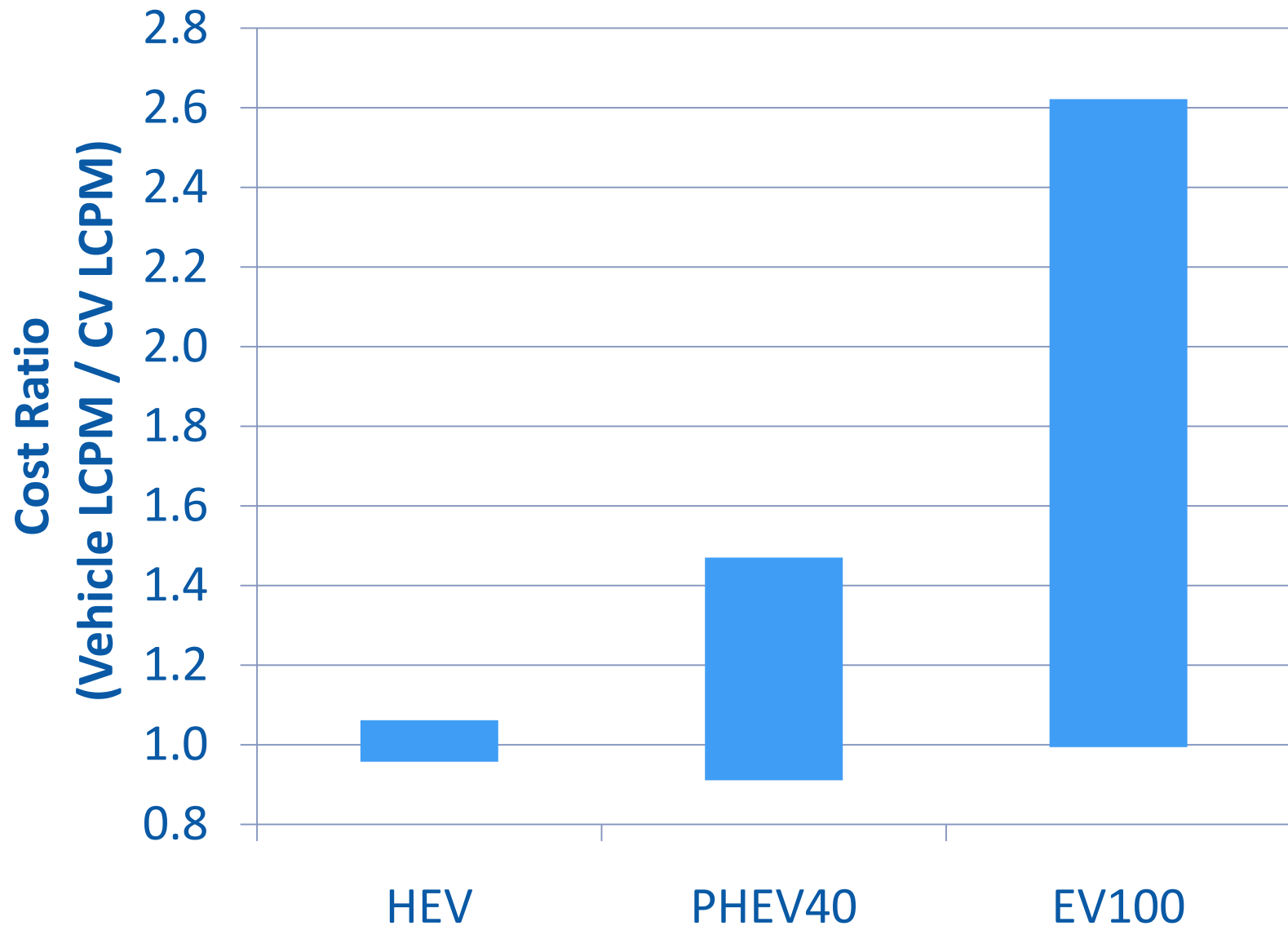
EV100



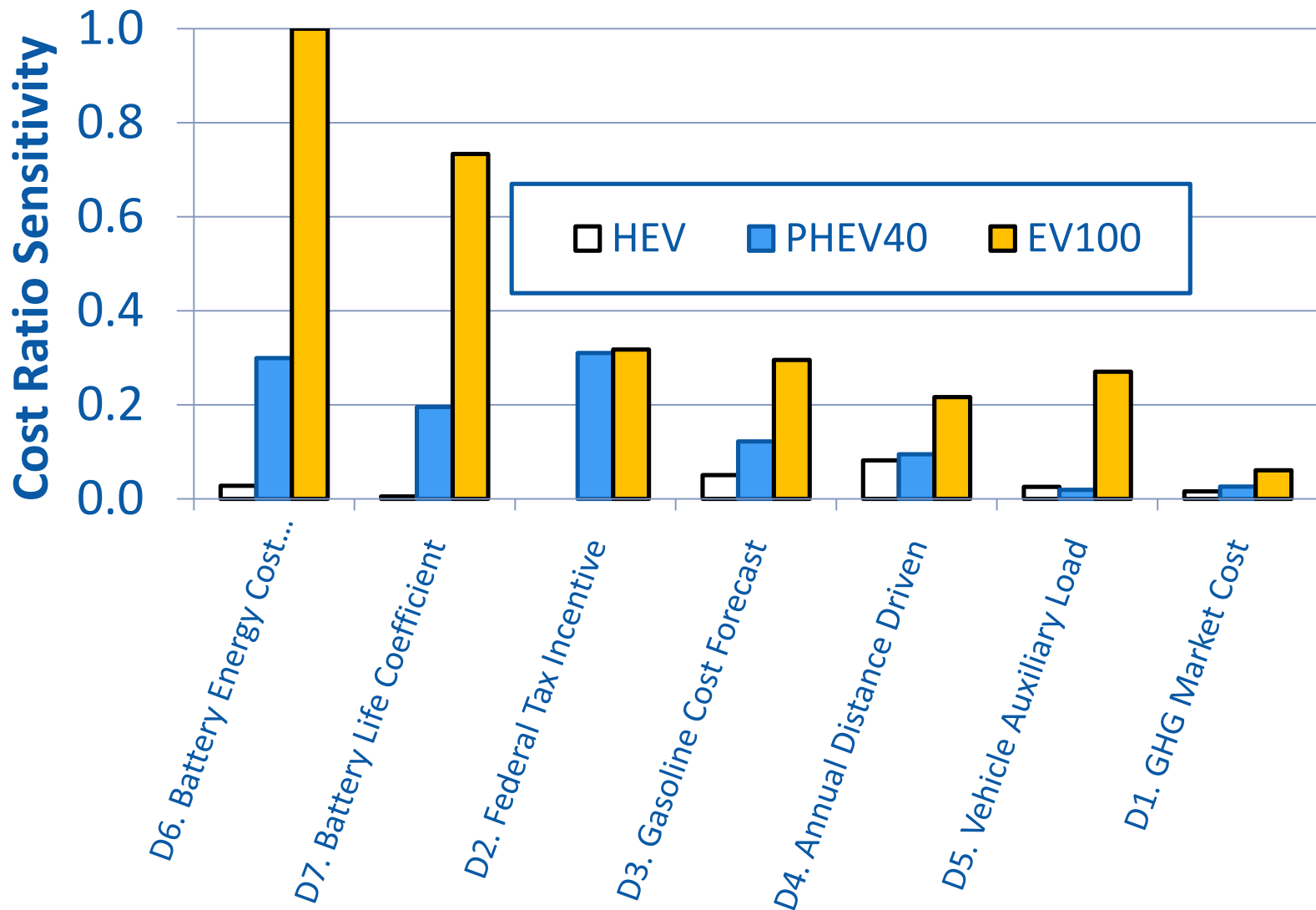
...considering the following variable inputs...

Variable	Min	Max
D1: GHG Market Cost (2007 U.S. Dollars/Ton CO2e-Year)	0.00	28.53
D2: Federal Tax Incentive (2007 U.S. Dollars)	0	7,500
D3: Gasoline Cost Forecast	EIA Reference	EIA High Oil Price
D4: Annual Distance Driven (Miles/Year)	9,059	15,691
D5: Vehicle Auxiliary Load (W)	700	2,200
D6: Battery Energy Cost Coefficient (2007 U.S. Dollars / kWh)	350	700
D7: Battery Life Coefficient	86 (low cycle life)	433 (high cycle life)

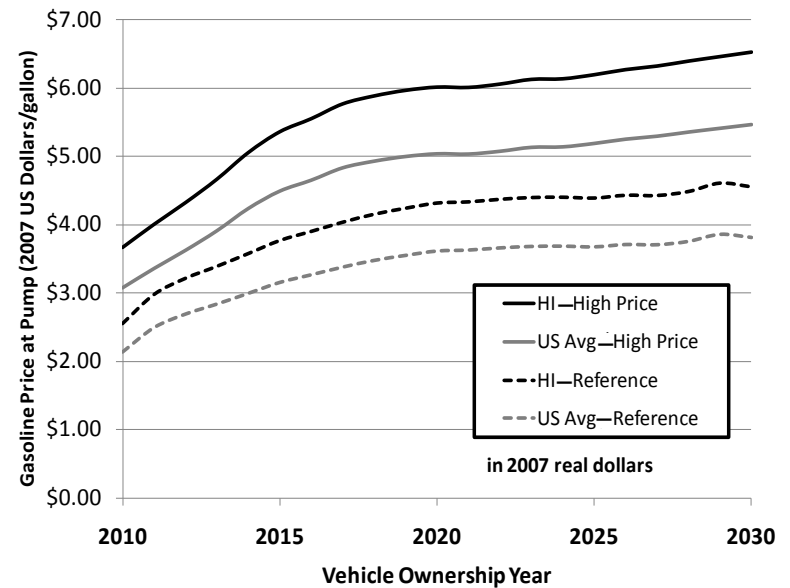
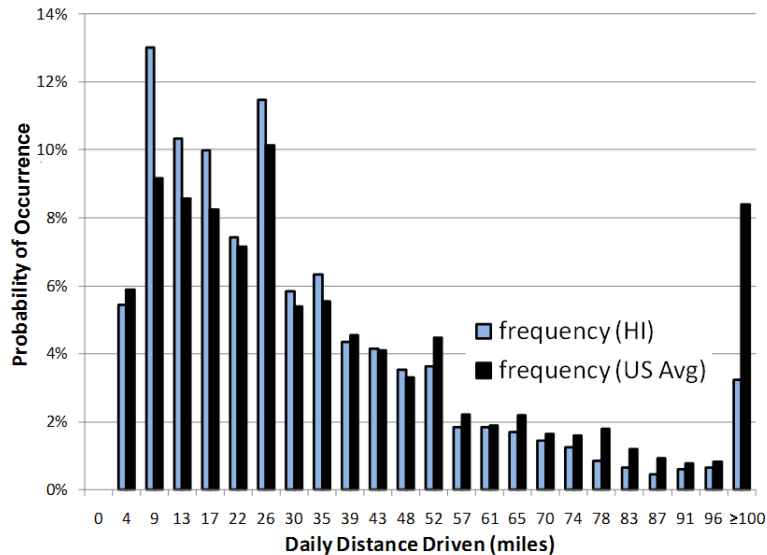
...and found the EV can be cost competitive, but is quite sensitive to changes in assumptions



Battery Cost And Life Are The Strongest Factors

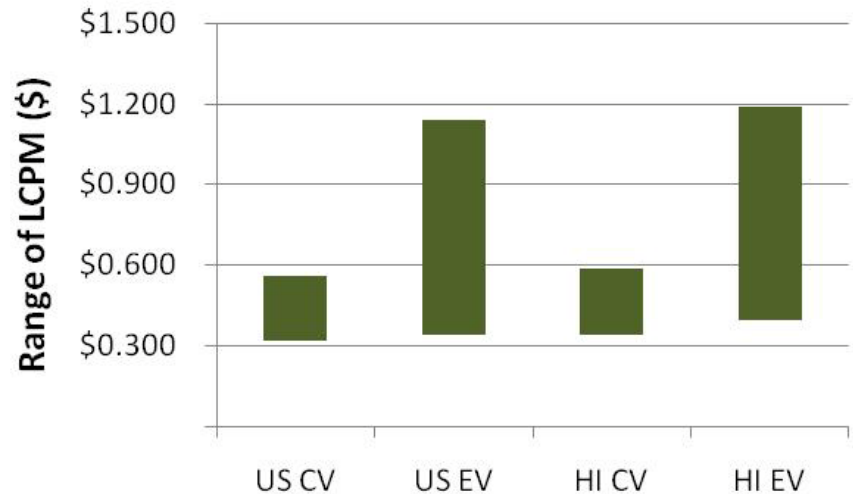


Niche Markets

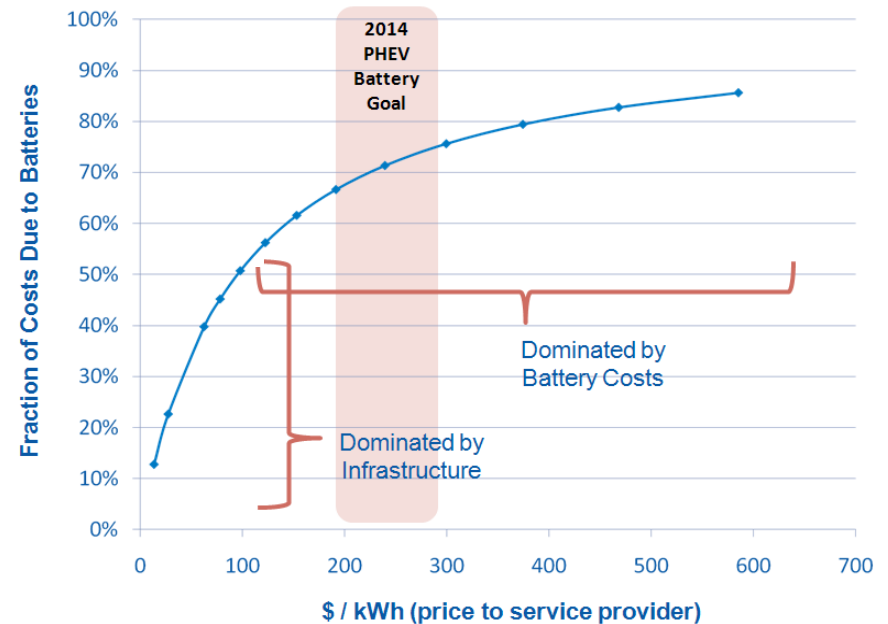
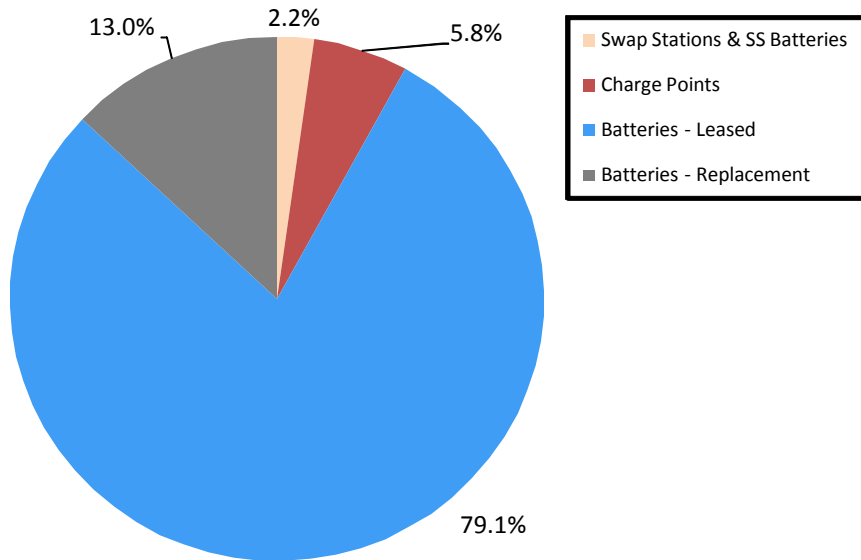


Hawaii: more battery-friendly driving distribution & higher gas prices...

...but higher electricity prices and no effect on dominant battery prices



Service Providers



Service provider costs are dominated by batteries (up to ~92%), allowing charge points and swap stations to be provided at minimal marginal cost

Summary

- This presentation is meant to give you a quick preview of the “Battery Ownership Model” and its capabilities
- The purpose of the model is to assist the U.S. Department of Energy in understanding how various business plans for EVs compare to other technologies
- The preliminary results presented herein show:
 - EV costs are most sensitive to battery cost and life assumptions within the scope of other parameters considered herein
 - Service provider costs are dominated by battery rather than infrastructure cost; thus one may be able to provide significant added value at minimal additional cost
- Additional application and development of the tool will continue in FY11

Acknowledgements

We would like to thank our sponsor, Dave Howell, Energy Storage R&D, Vehicle Technology Program, U.S. Department of Energy.

Thanks to the U.S. Department of Energy's Hawaii Clean Energy Initiative and its Transportation Working Group for their interest in the tool and feedback.

