NREL
NATIONAL RENEWABLE ENERGY LABORATORY

EVS 25
Sustainable Mobility Revolution
November 5-9, 2010 Shenzhen, China

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



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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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
PHEVs
Traditional EVs
Smart Grid
Location
Drive Profile
Battery Life
V2G
Vehicle Characteristics
Cost of Money
Charging Algorithms
Subsidies
Battery Specific Power & Specific Energy
Job Creation
Consumer Behavior
Battery Secondary Use
Future Cost of Gasoline

Model


Component Technology


Consumer Costs


Energy Usage


Greenhouse Gases


Government Role

Battery Ownership Model Multi-Disciplinary Team



Jeremy
Neubauer
battery secondary use, project subtask lead



Michael
Mendelsohn
economics & financing



John
Rugh
vehicle ancillary loads reduction & driving statistics



Terry
Penney
advisor on project direction



Aaron
Brooker
vehicle systems analysis, optimization & programming



Caley
Johnson
carbon markets, policy analysis & fueling stations

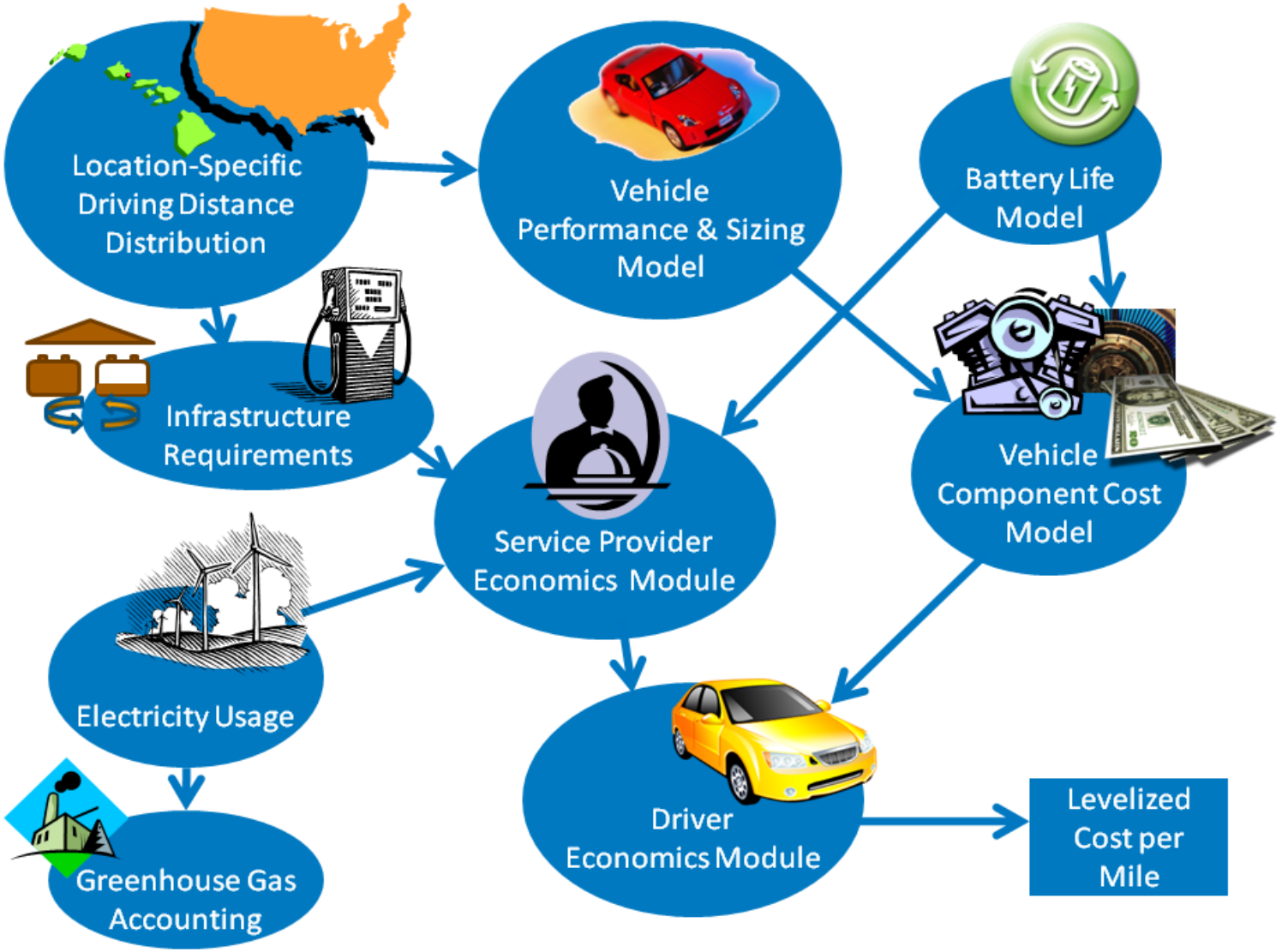


Michael
O'Keefe
power electronics, EV grid integration & programming

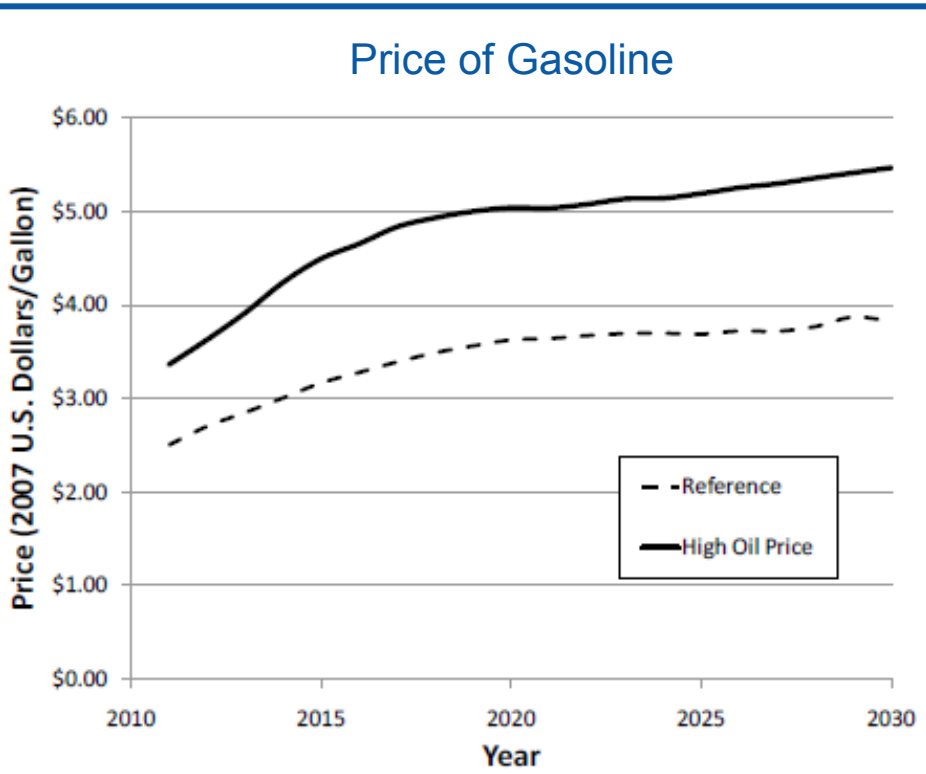


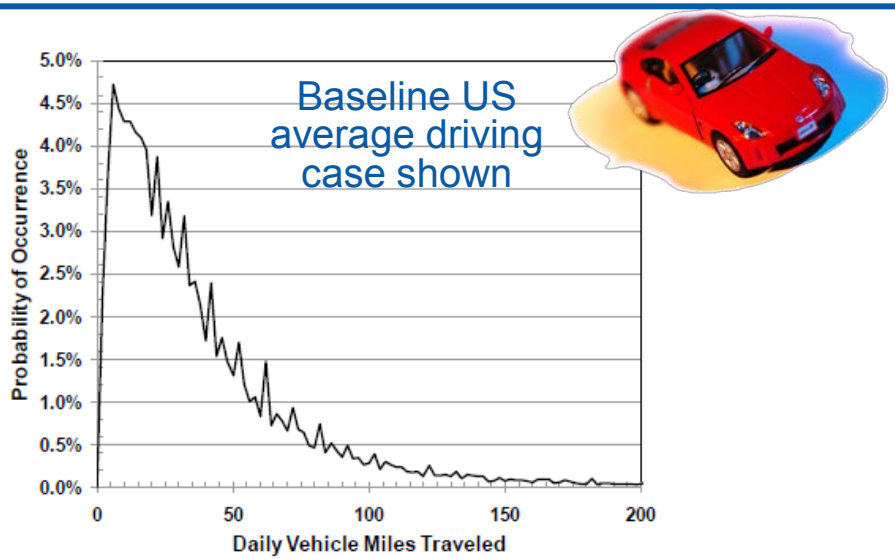
Ahmad
Pesaran
energy storage system task lead

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



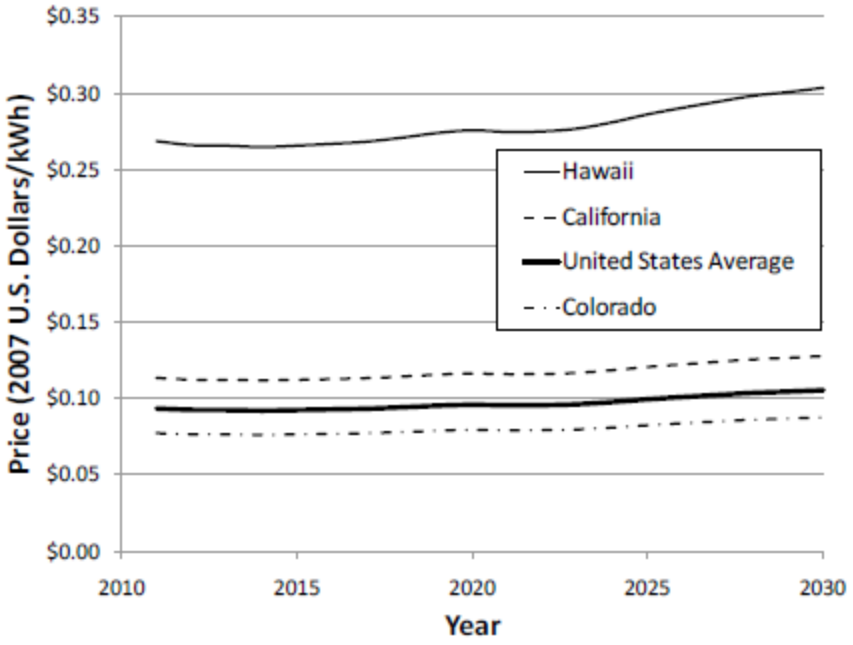
Location-Specific Driving Distance Distribution











Vehicle Performance and Sizing Model



Inputs

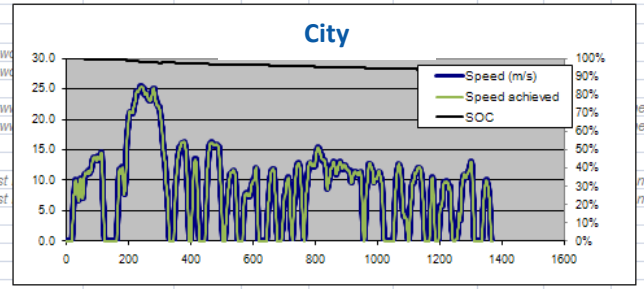
	A	B
1	**Components**	
2	Battery power (kW)	80
3	Battery energy (kWh)	24
4	Battery mass (kg/kWh)	7.8
5	Battery base mass (kg)	43.0
6	Battery round trip efficiency	90%
7	Battery life coefficient A (product)	157.29
8	Battery life coefficient B (power)	-0.6844
9	Max motor power (kW)	80
10	Motor time to full power (s)	1
11	Motor controller mass (kg/kW)	0.833
12	Motor controller base mass (kg)	21.6
13	Transmission efficiency	95%
14	Transmission mass (kg)	114
15	Drag coefficient	0.32
16	Frontal area (m^3)	2.1
17	Wheel inertia (one wheel) (kg*m^2)	0.815
18	Number of wheels	4
19	Rolling resistance coefficient	0.007
20	Wheel radius (m)	0.282
21	Wheel coefficient of friction	0.7
22	Auxiliary loads (kW)	0.7
23	Vehicle glider mass (kg)	900
24	Vehicle center of gravity height (m)	0.53
25	Drive axle weight fraction	0.55
26	Wheel base (m)	2.67
27	Regen braking percent	60%
28		
29	**Controls**	
30	Min SOC	20%
31	Percent usable SOC passing buffer	0.1
32	Max SOC	100%
33	Assist kW per percent SOC off target	0.2
34	Charge kW per percent SOC off target	0.2
35	Min SOC target speed (MPH)	50
36	Max SOC target speed (MPH)	0

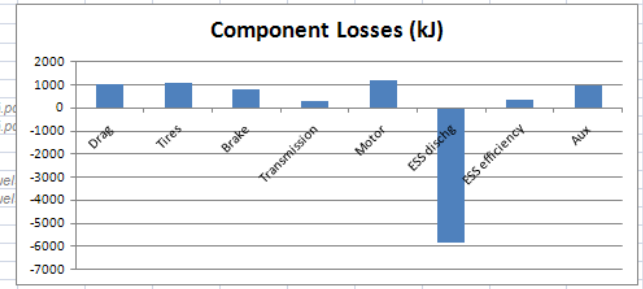
Balance SOC | Run (if calc opts.=man)

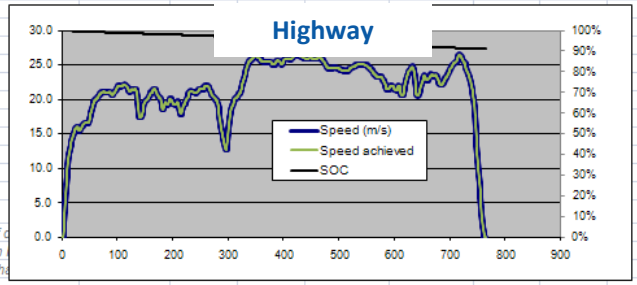
Results

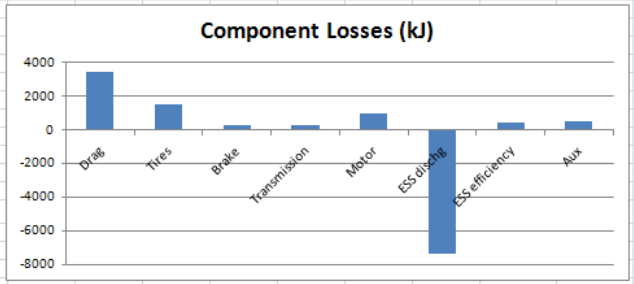
	A	B	C
43	**Results**		
44	Total mass (kg)	1331	1180 kg ~Civic, 1
45	SOC setpoint	50%	
46	Battery life (miles)	1,038,629	
47	Range (miles)	77	
48			
49		CAFÉ	Sticker
50	City (mpgge)	0.217	0.242
51	Highway (mpgge)	0.200	0.257
52	Combined	0.210	0.248

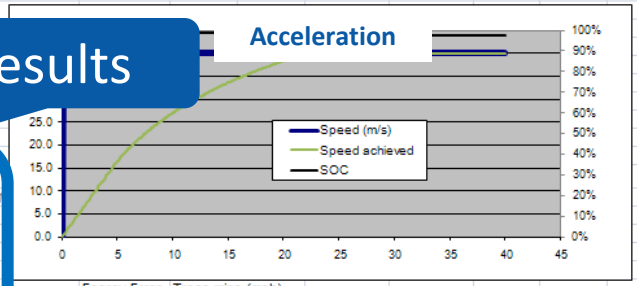
Energy Error	Trace miss (mph)
0.000%	0
0.000%	0

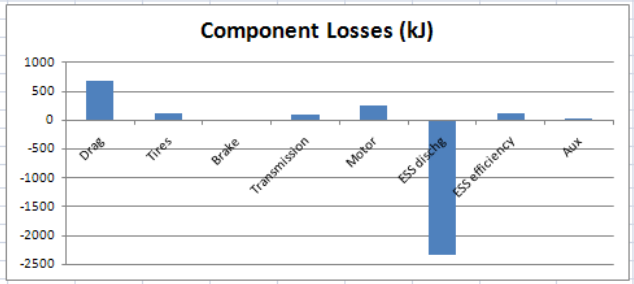












IO | Main | NPC | ESS Life | Vehicle | UDDS | HWY | Accel | Motor | ESS Chars | ESS Recharge Wear | trip Data | Validation

Vehicle Component Cost Model

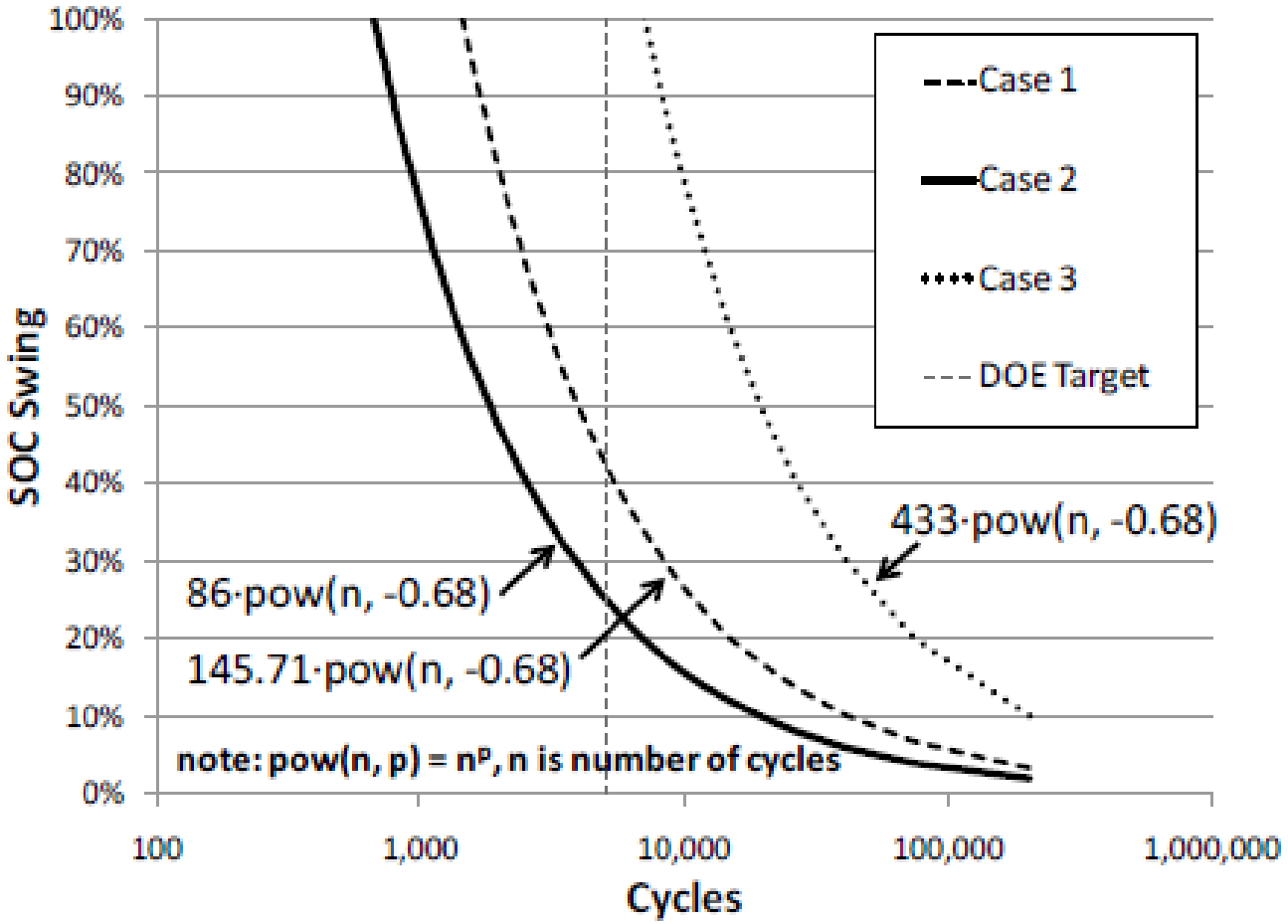
Baseline technology costs have been calibrated against currently available vehicles

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



Generation

Efficiency

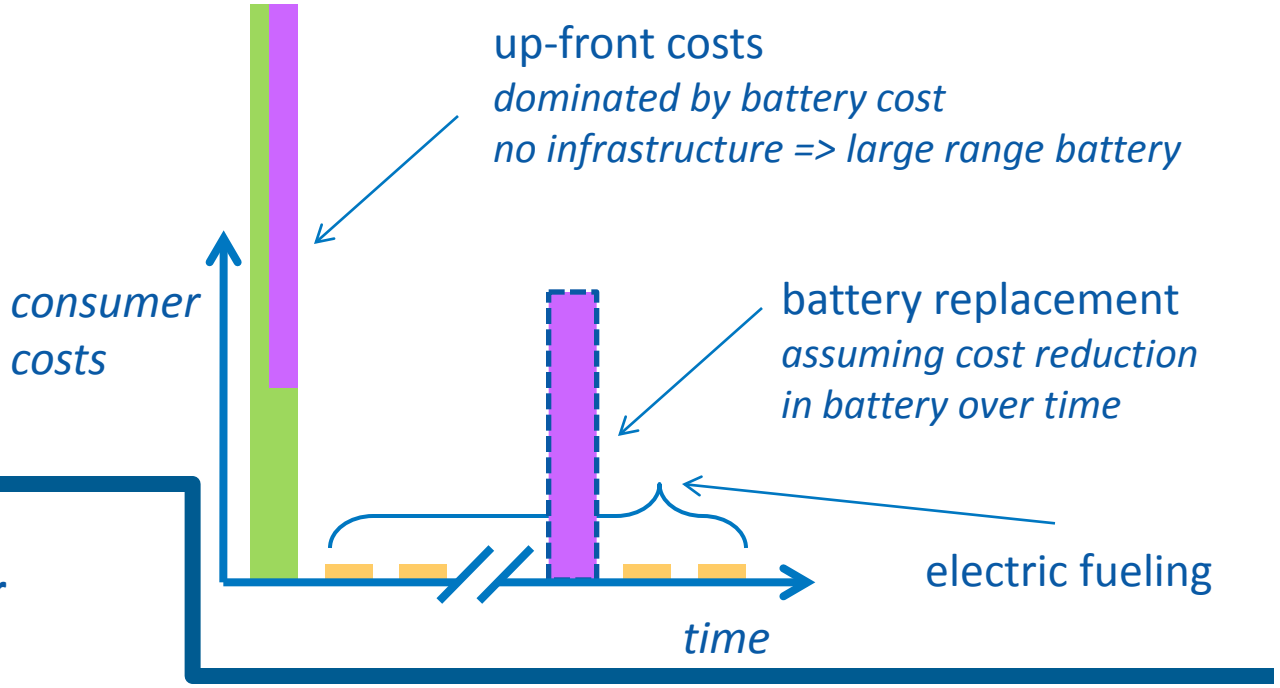
kWh of Electricity Used



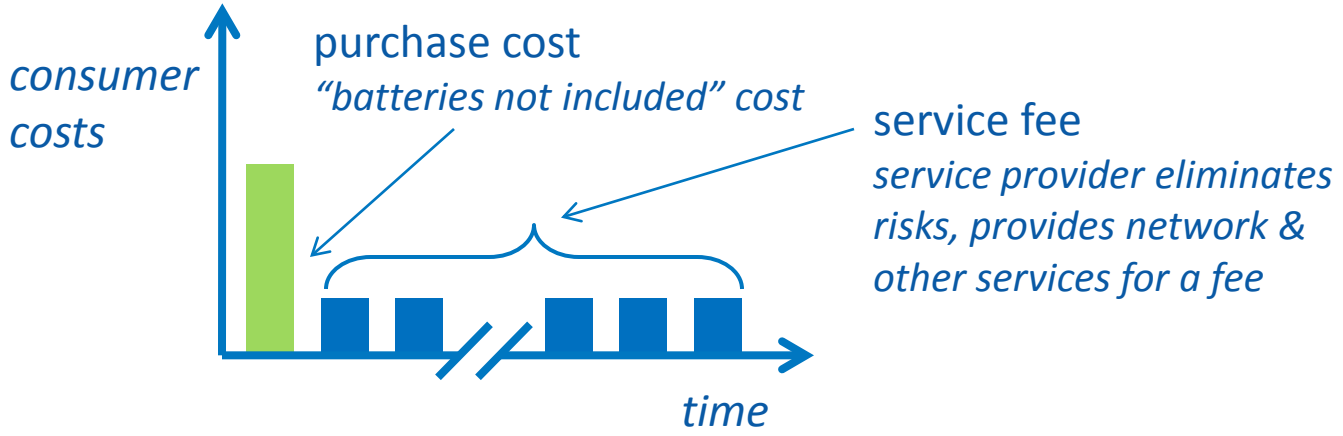
Demand

Service Provider Economics Module

Traditional EV Ownership Model:



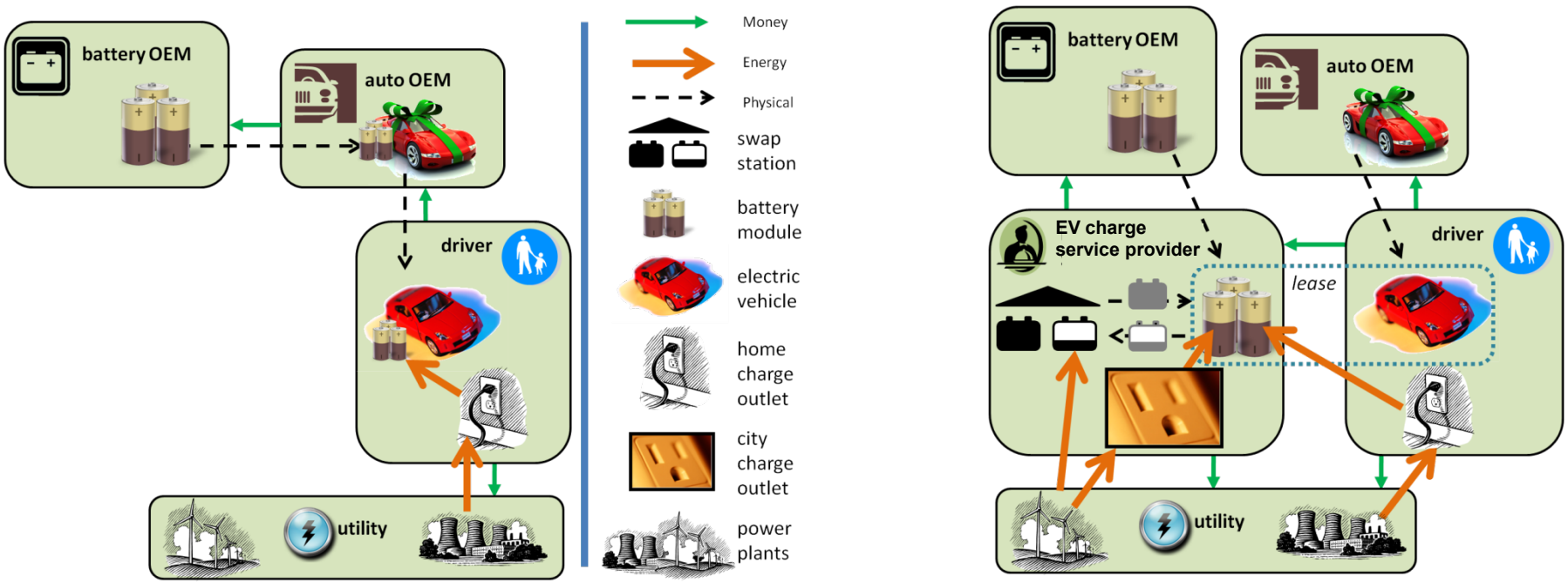
…with Service Provider



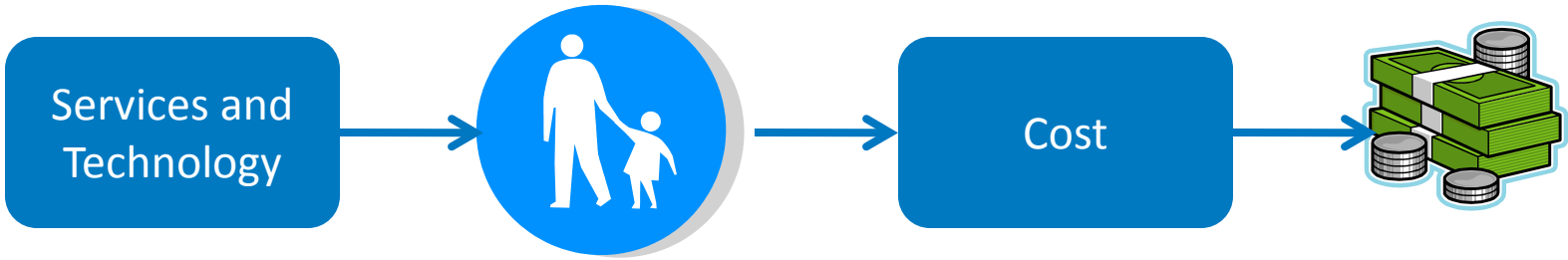
KEY

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

Driver Economics Module

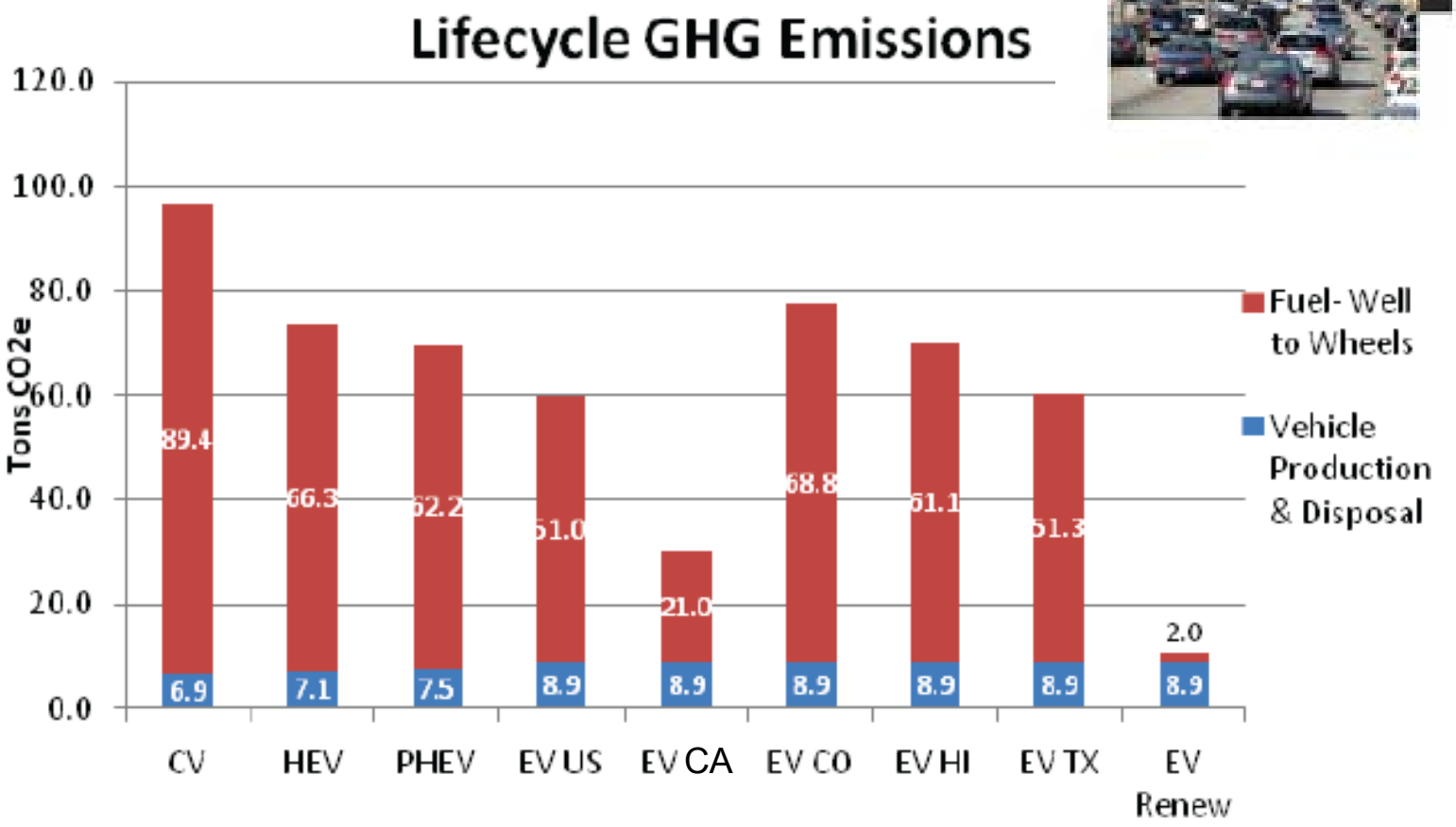


End User

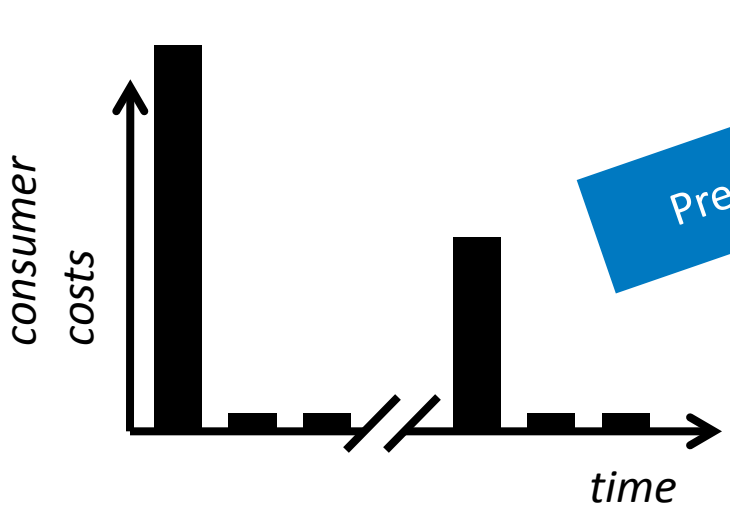


Greenhouse Gas Accounting

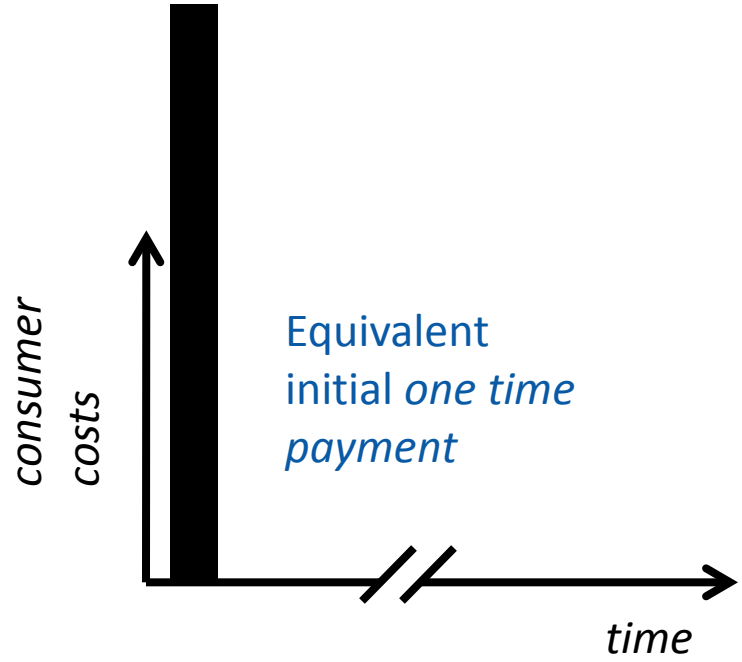




Levelized Cost per Mile (LCPM)



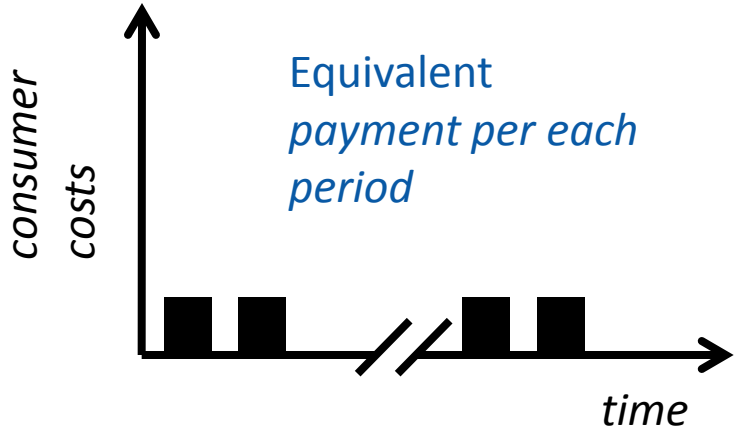
Present Value



Equivalent initial *one time payment*

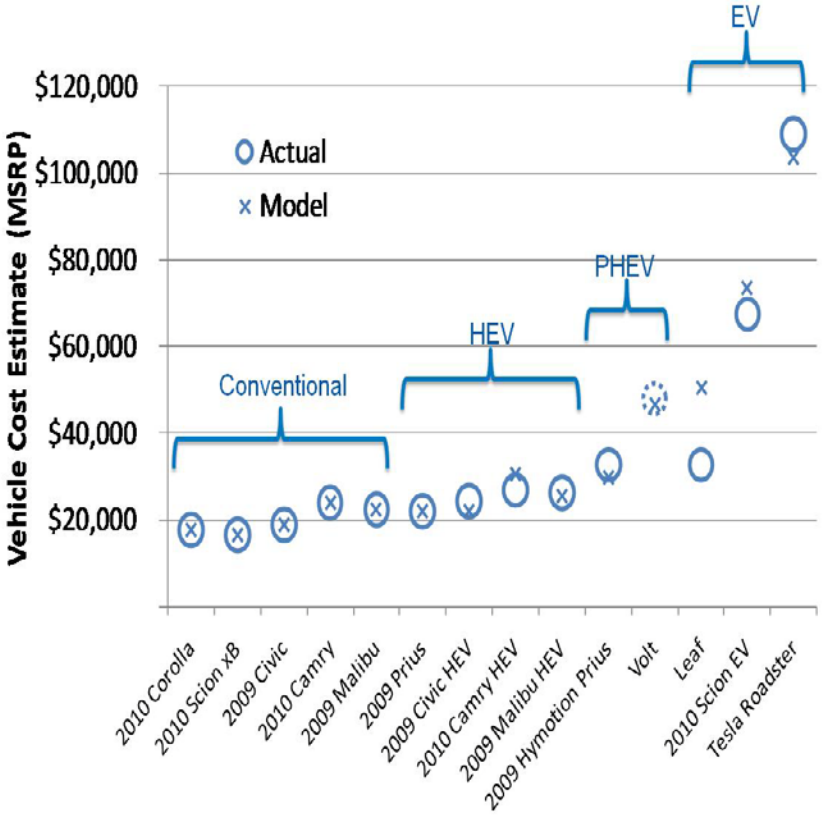
Levelized Cost

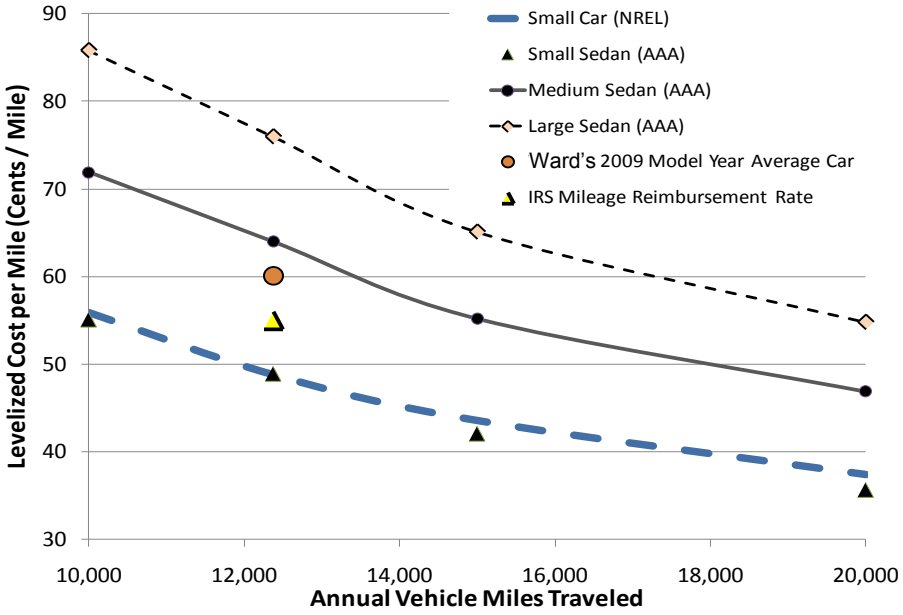
$$LCPM = \frac{\sum_{i=1}^{N} c_i \cdot d_i}{\sum_{i=1}^{N} vmt_i \cdot d_i}$$



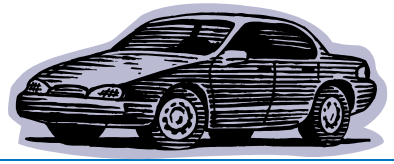
Equivalent *payment per each period*

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 (gasoline)
HEV





Plug-in Hybrid Electric Vehicle [40 mile] (electricity / gasoline)
PHEV40

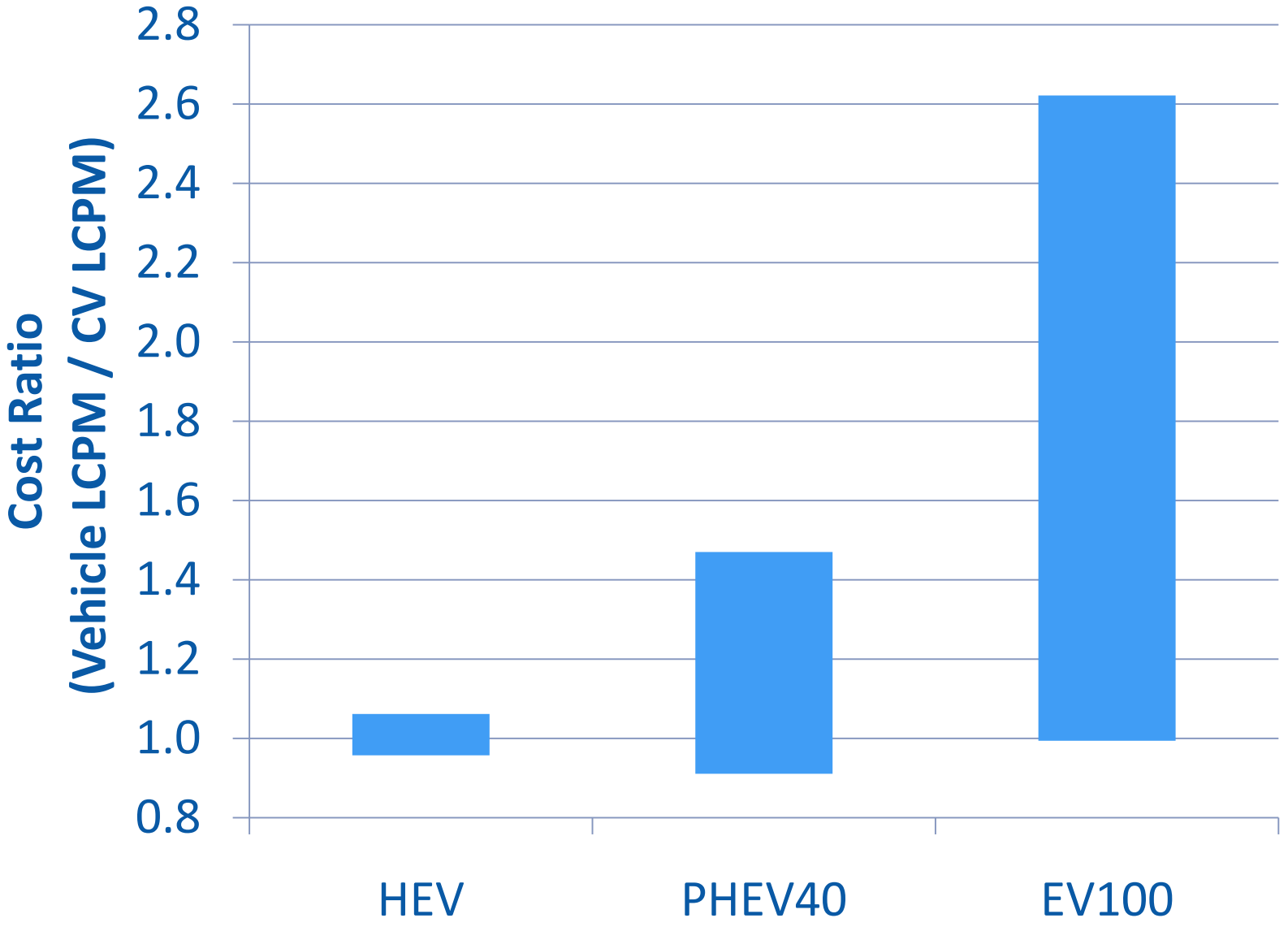
Electric Vehicle [100 mile] (electricity)
EV100



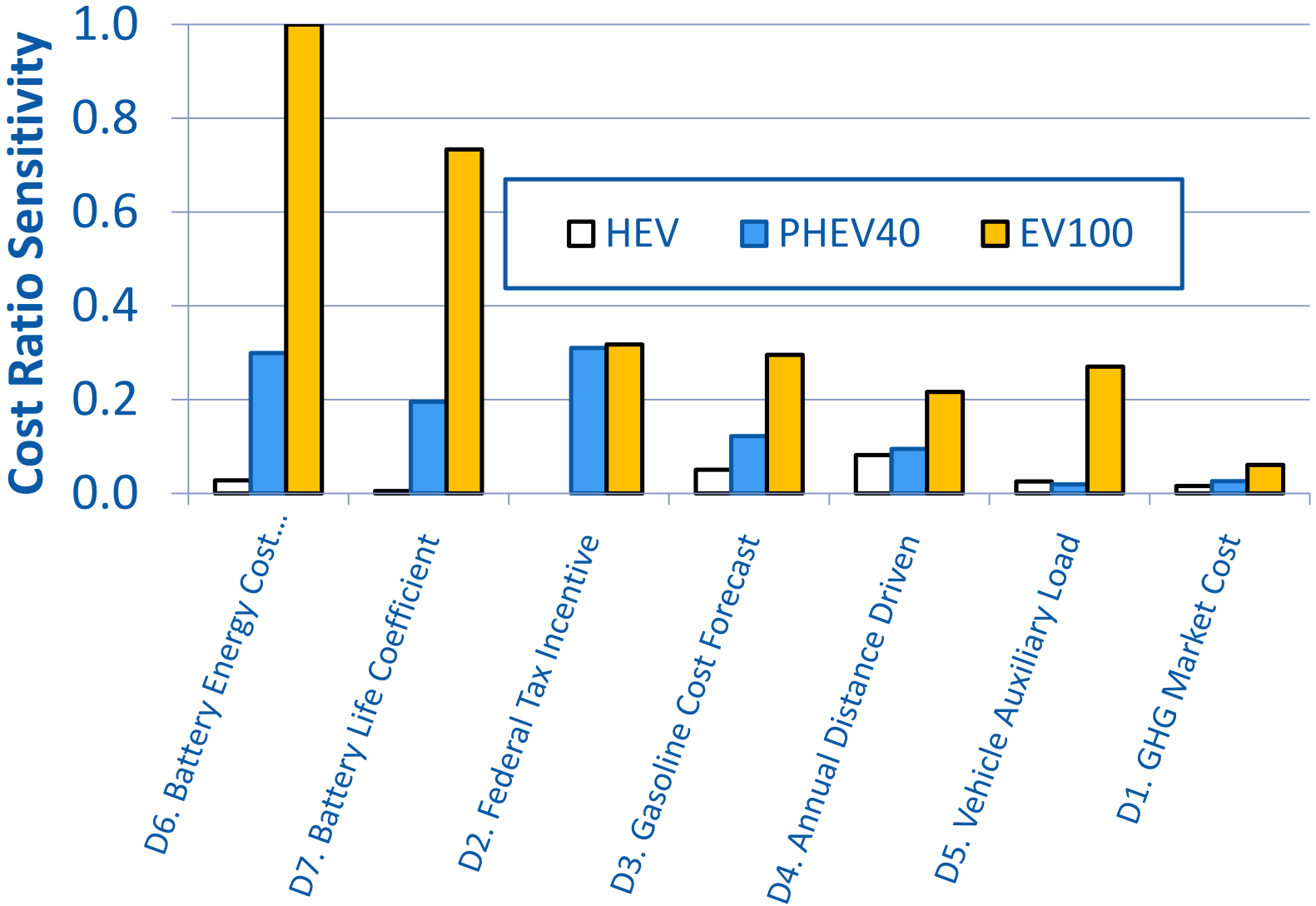
…considering the following variable inputs…

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)

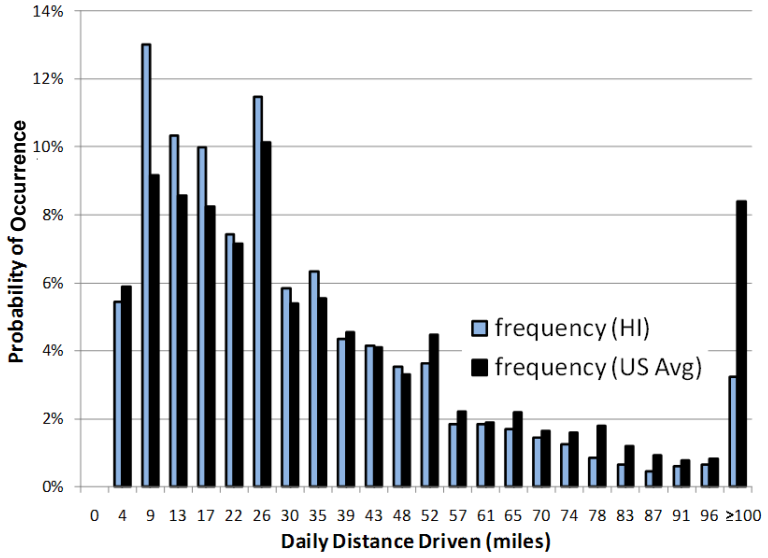
…and found the EV can be cost competitive, but is quite sensitive to changes in assumptions

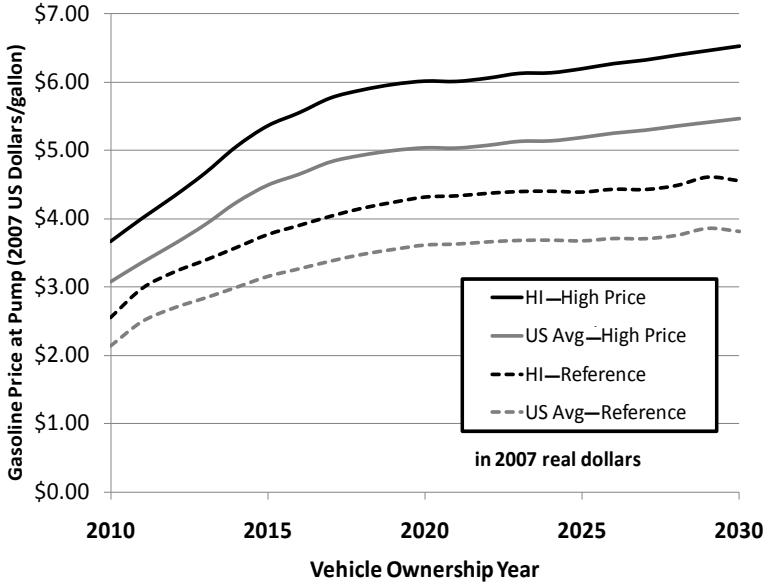


Battery Cost And Life Are The Strongest Factors



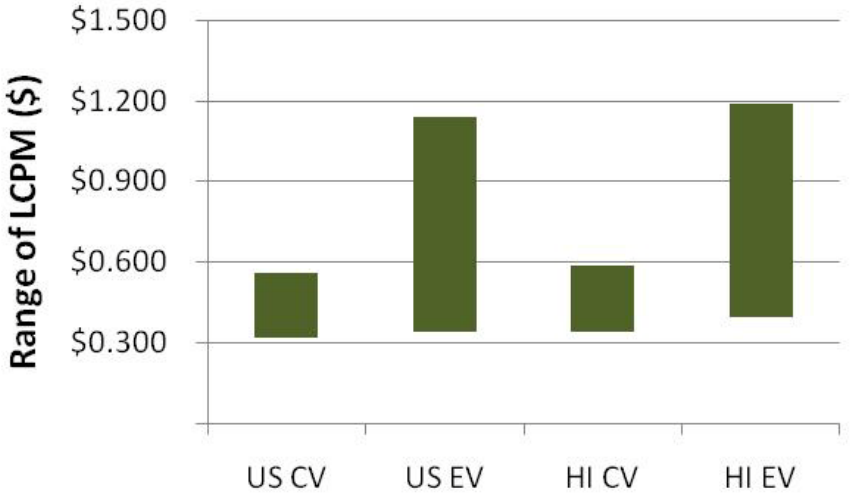
Niche Markets



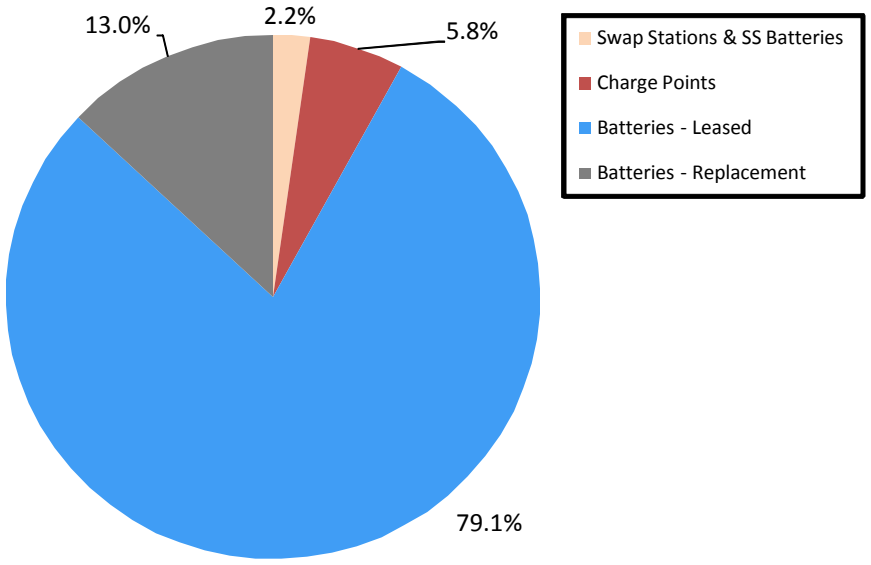


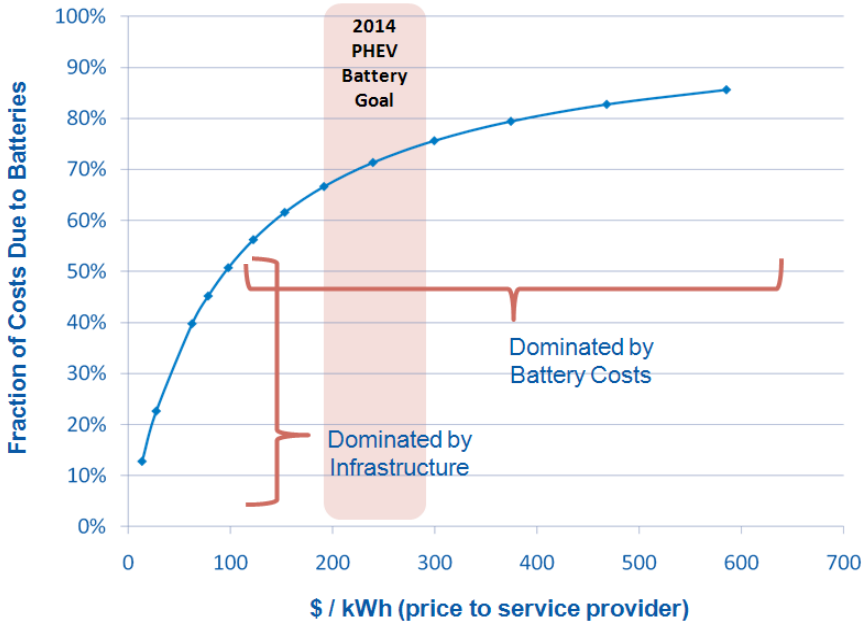
Hawaii: more battery-friendly driving distribution & higher gas prices…

…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

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