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Research on PHEV Battery Requirements and Evaluation of Early Prototypes

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Argonne National Laboratory

Advanced Automotive Battery Conference

May 17, 2007

FreedomCAR & Vehicle Technologies Program

FreedomCAR & Fuel Partnership

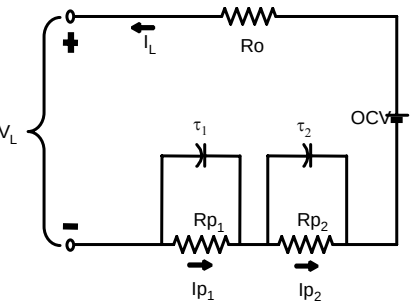
Argonne Has Leading Role in DOE PHEV Technology Development Efforts

- Vehicle Modeling and Simulation
- Vehicle Control Strategy Development
- Vehicle Benchmarking
- Vehicle Test Procedure
- Market Penetration
- Cost Analysis

Energy Storage Requirements Are Being Validated With Systems-Level Testing

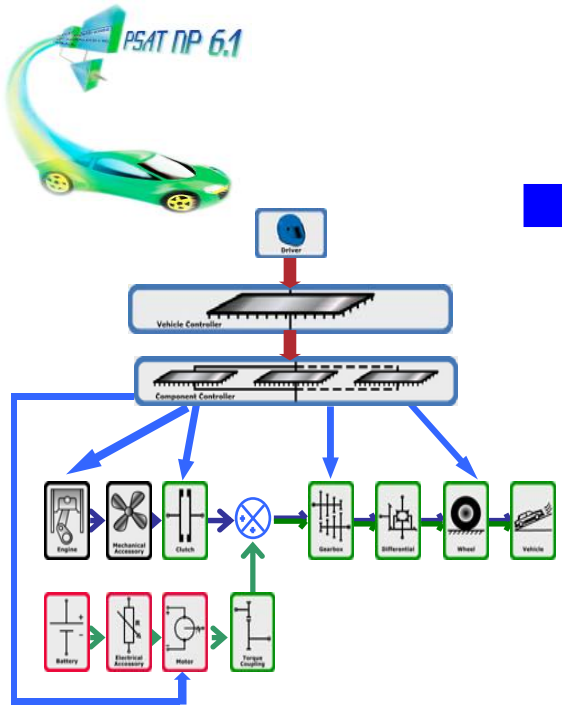
Component

Testing

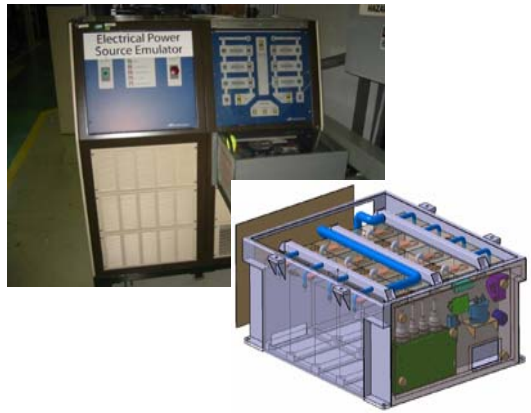


Model

Vehicle Simulation



Component in System Context

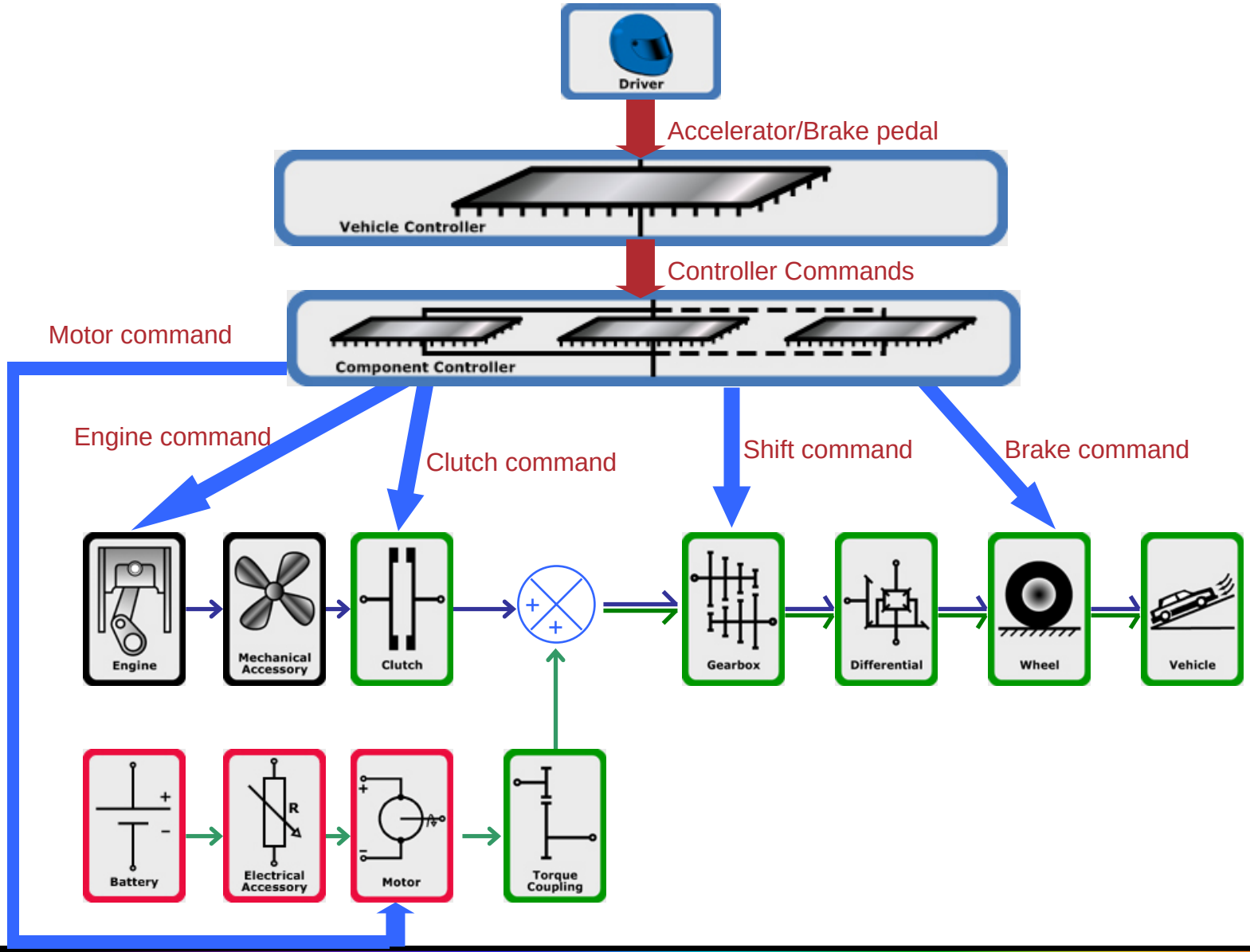


JCS VL41M

Energy Storage System Requirements Activities

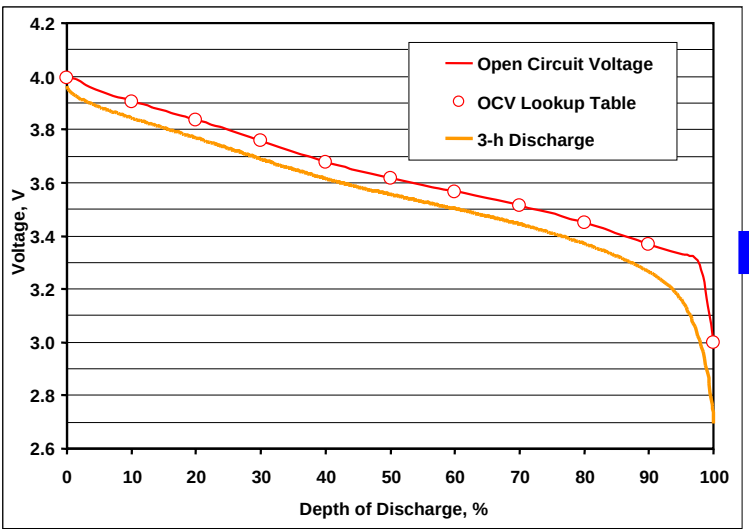
- Energy Storage Requirements Using PSAT
- Battery Requirements Validation with HIL
- PHEV Prius Vehicle Testing
- Future Activities

PSAT Primary Model for FreedomCAR Activities

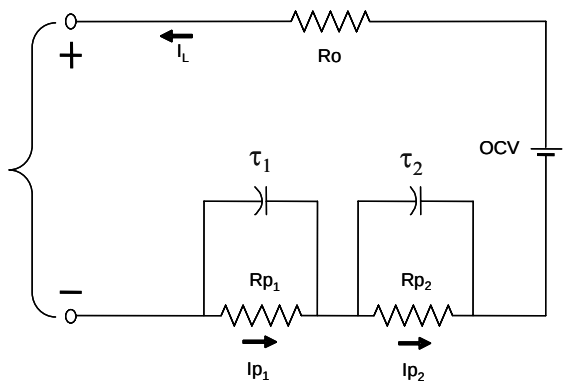


Accurate Battery Modeling Needed to Generate Requirements

- Discharge requirements for long periods resulting in considerable diffusion over-voltage.
- Available data from large capacity SAFT cells applied to SAFT VL41 M cell.
- These data were modeled and are the basis of the impedance equations used in the PHEV vehicle simulation study.



Test data

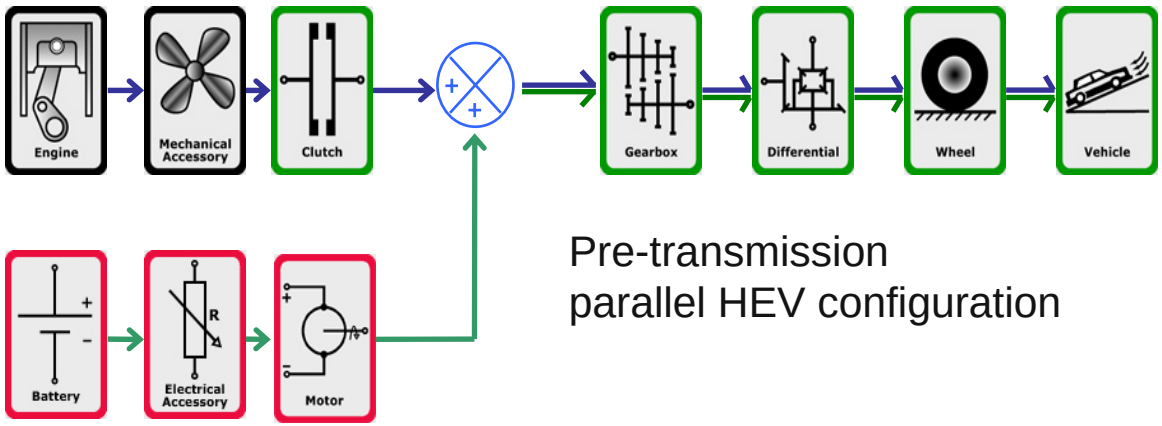


PHEV Model

Scaling Algorithm for Power & Energy

Scaling

Main Vehicle Assumptions

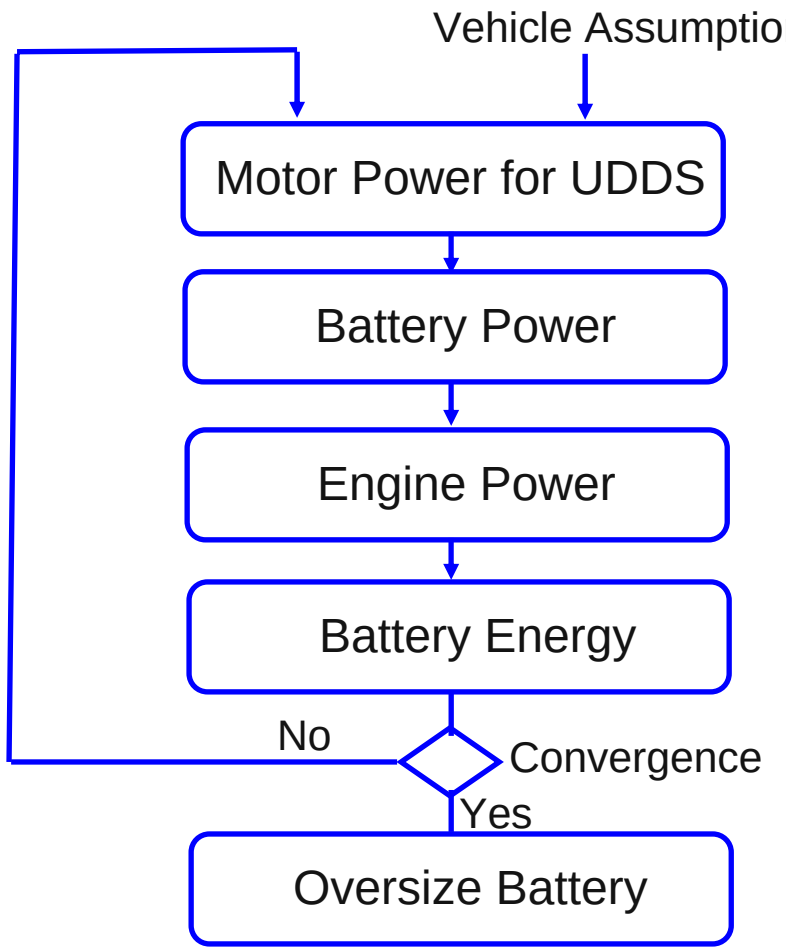


Pre-transmission parallel HEV configuration

Parameter	Unit	Value
0–60mph	s	9 +/- 0.1
0–30mph	s	3
Grade at 55 mph	%	6
Maximum Speed	mph	> 100

Parameter	Unit	Midsize Car	Crossover SUV	Midsize SUV
Vehicle				
Curb weight	kg	889	1100	1132
Vehicle Test Mass (Conventional)	kg	1629	1818	1893
Frontal Area	m^2	2.2	2.68	2.88
Drag Coefficient		0.3	0.417	0.41
Components				
Electric Machine Peak Efficiency	%	0.94	0.94	0.94
Electrical Power Accessory	W	800	1000	1200

Automated Sizing Process Implemented Including Oversizing



Associated Requirements

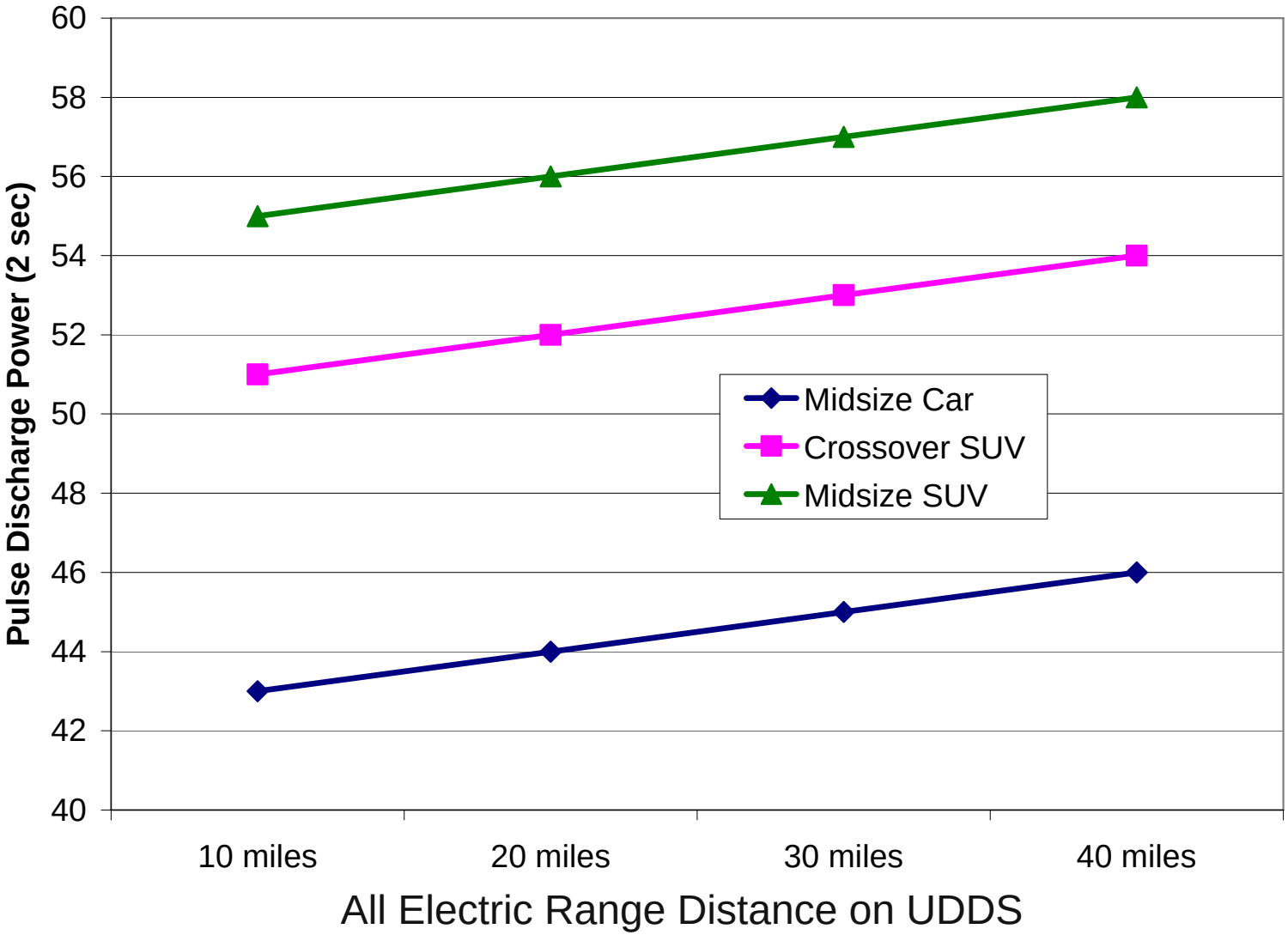
Satisfy CARB EV Range Definition

0-60 mph
Grade (Safety 1.5 for thermal)

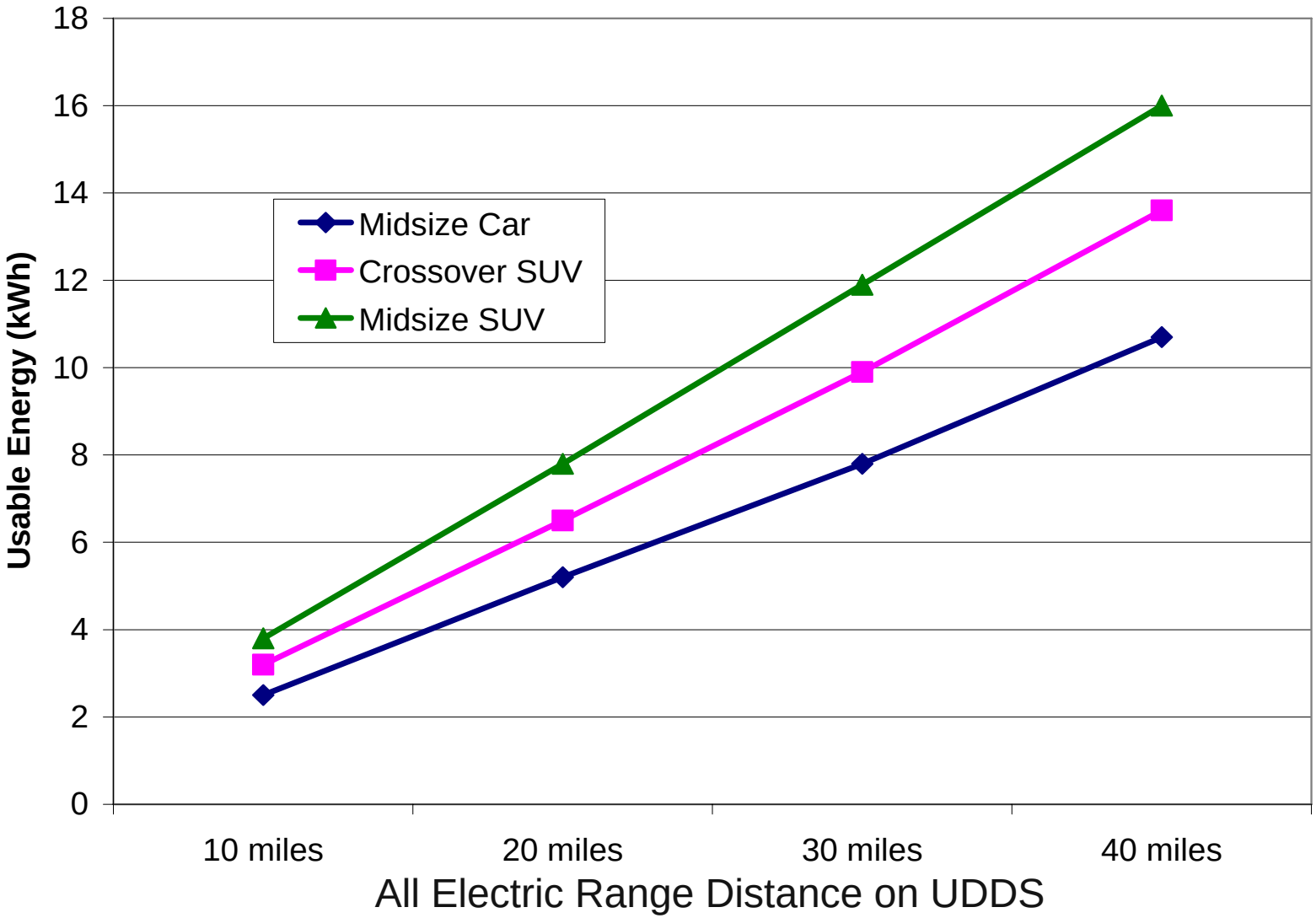
Range

30% Power, 20% Energy to have same performance at EOL

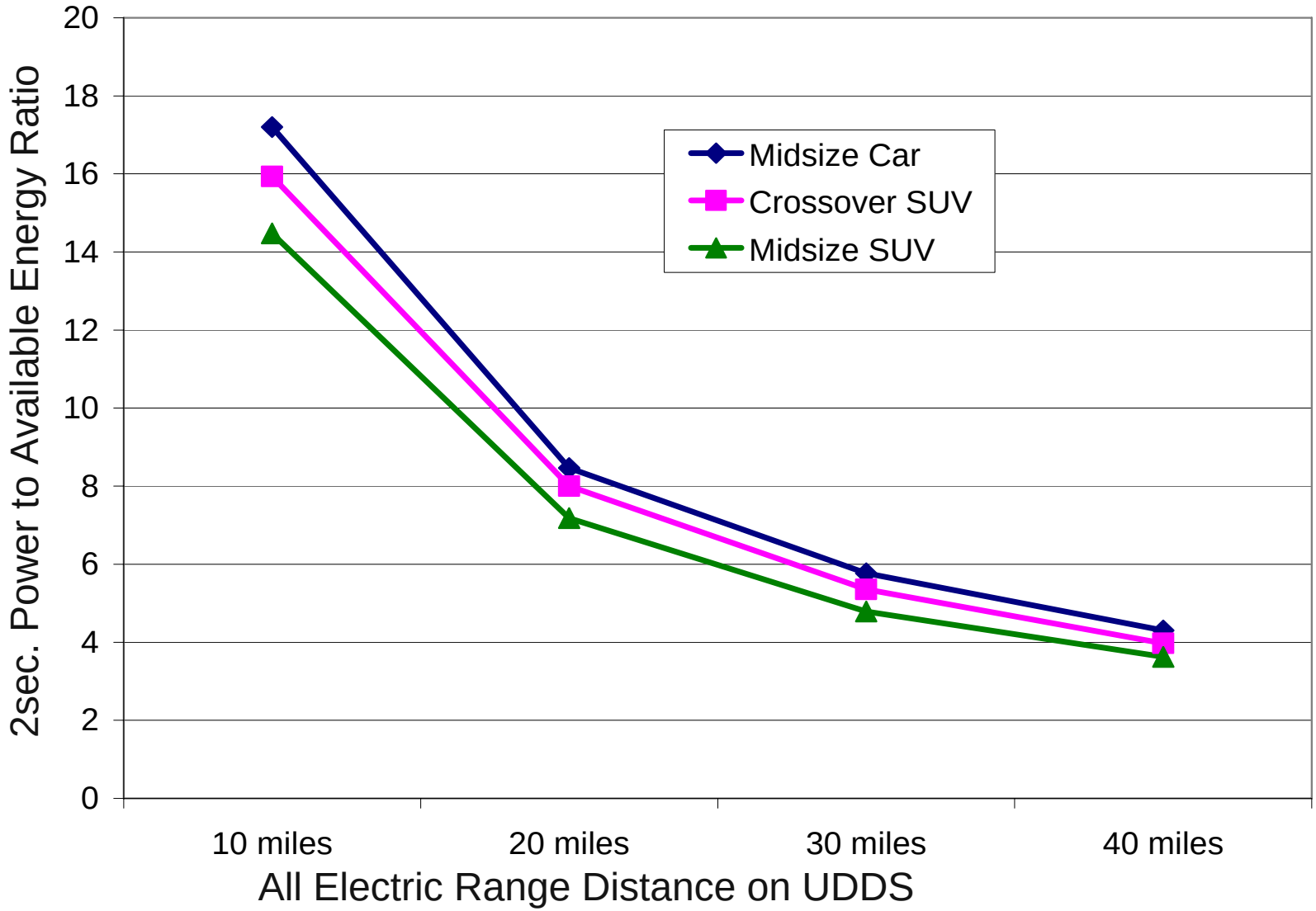
Battery Power Requirement Fairly Constant



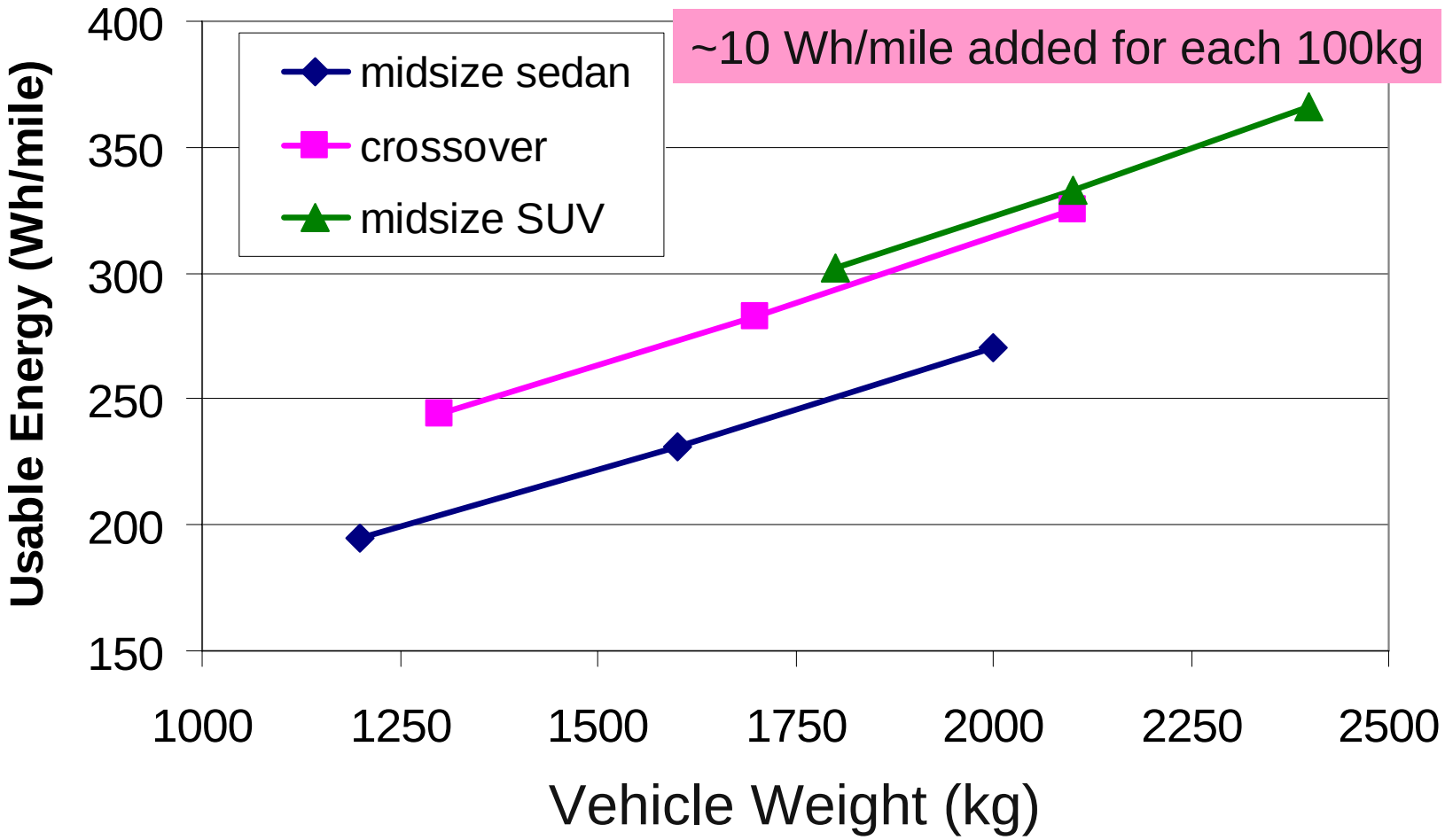
Usable Energy For Different Vehicle Platforms



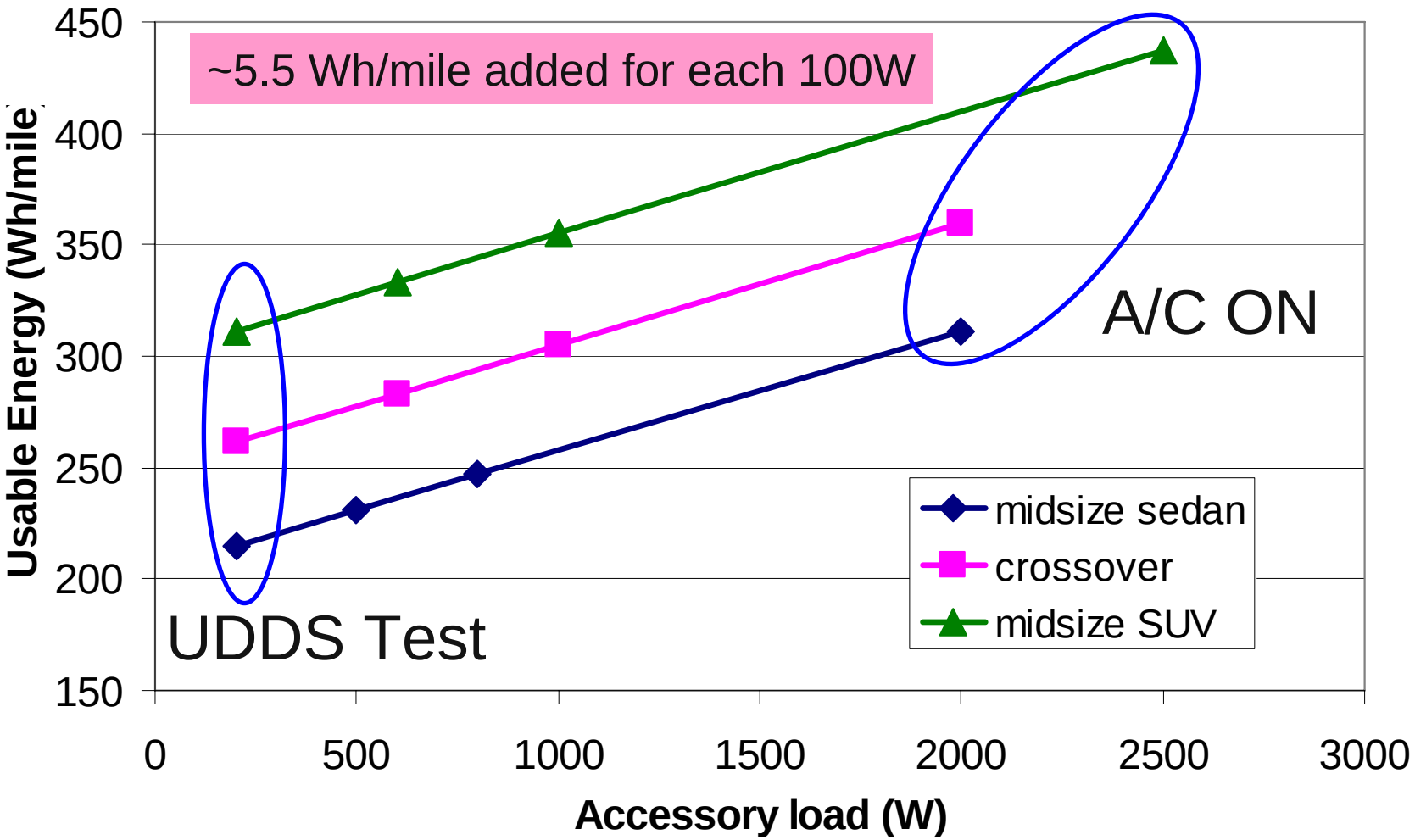
Power/Energy Ratio Decreases with AER



Vehicle Mass Impact on Usable Energy



Electrical Accessory Impact on Usable Energy



Energy Storage Requirements Summary

	Midsize Car	Crossover SUV	Midsize SUV
Reference Value for the Uncertainty	230	280	330
Vehicle Mass Uncertainty(1)	195>X>270	245>X>325	300>X>365
FA and Cd Uncertainty(1)	220>X>240	270>X>300	320>X>345
Electrical Acc. Uncertainty(1)	215>X>310	262>X>360	310>X>435
Representative Average Selected	250	320	380

Energy Storage System Requirements Activities

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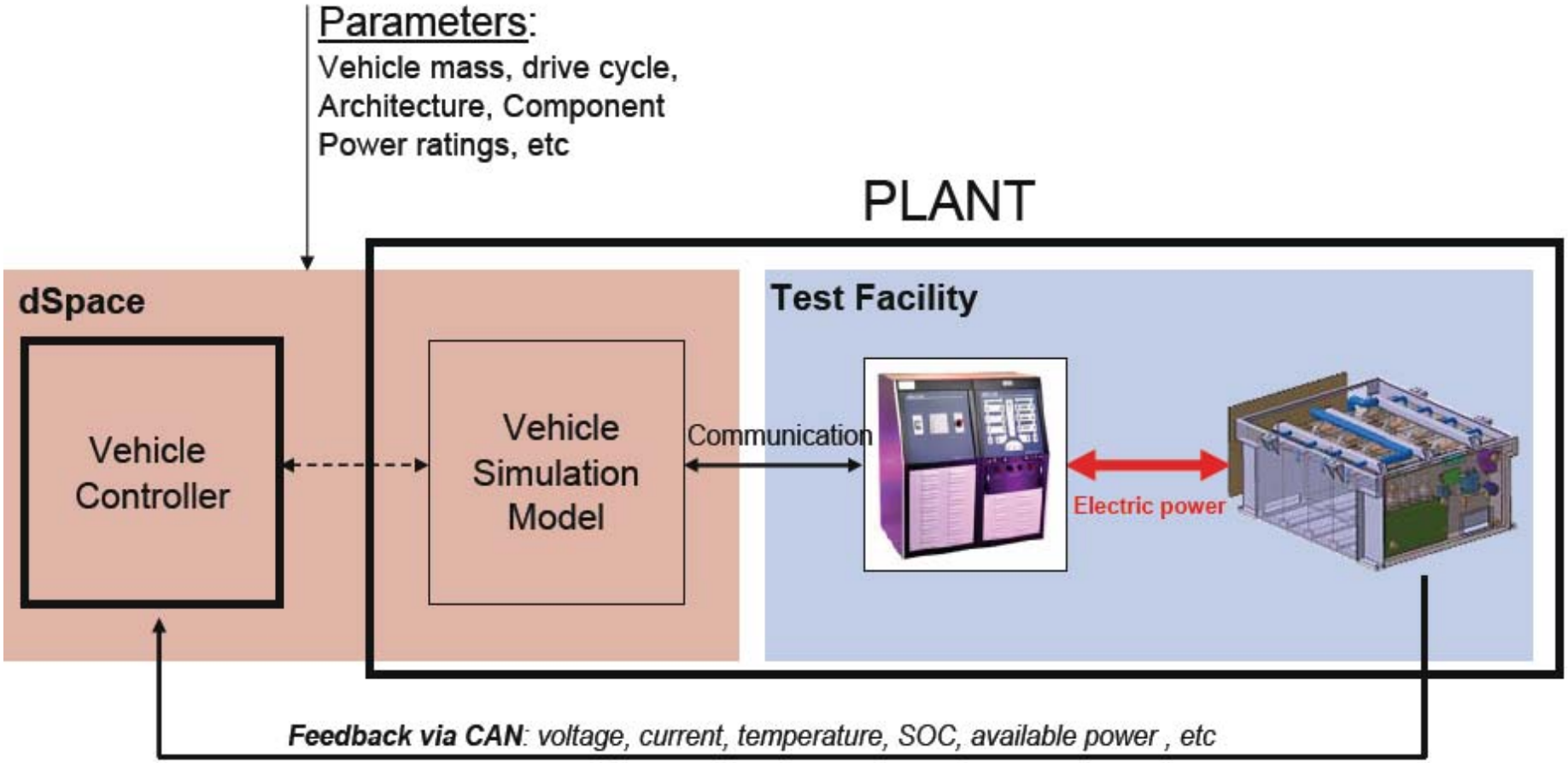
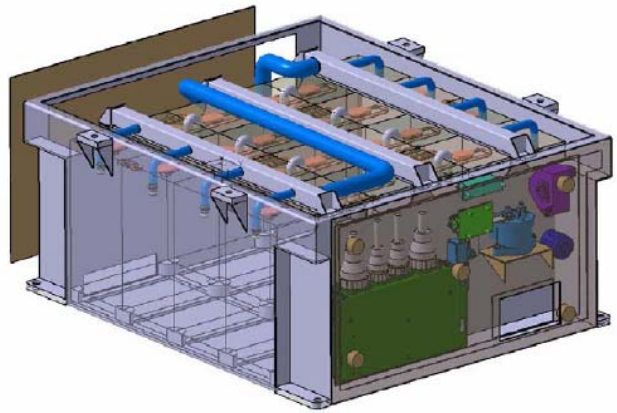
Battery HIL Allows Hardware Characterization in a Virtual Vehicle Environment



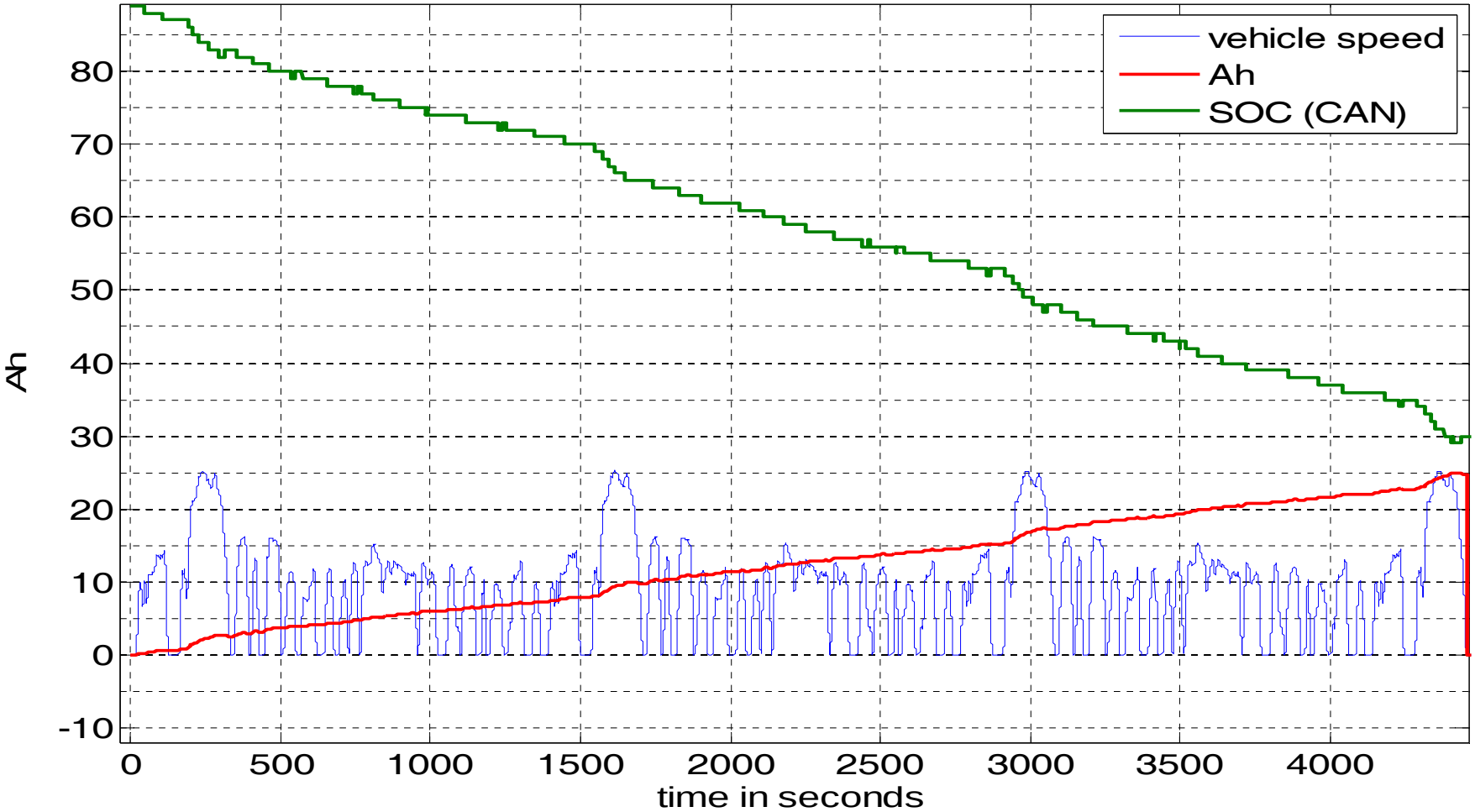
Johnson-Control-Saft VL41M

- Main Li-ion VL41M Specifications
  - 41Ah @ C/3
  - 72 cells (194.4 – 288 V)
  - 61 kW for 30 sec. at 50% SOC
  - 10 kWh total
  - Water-cooled



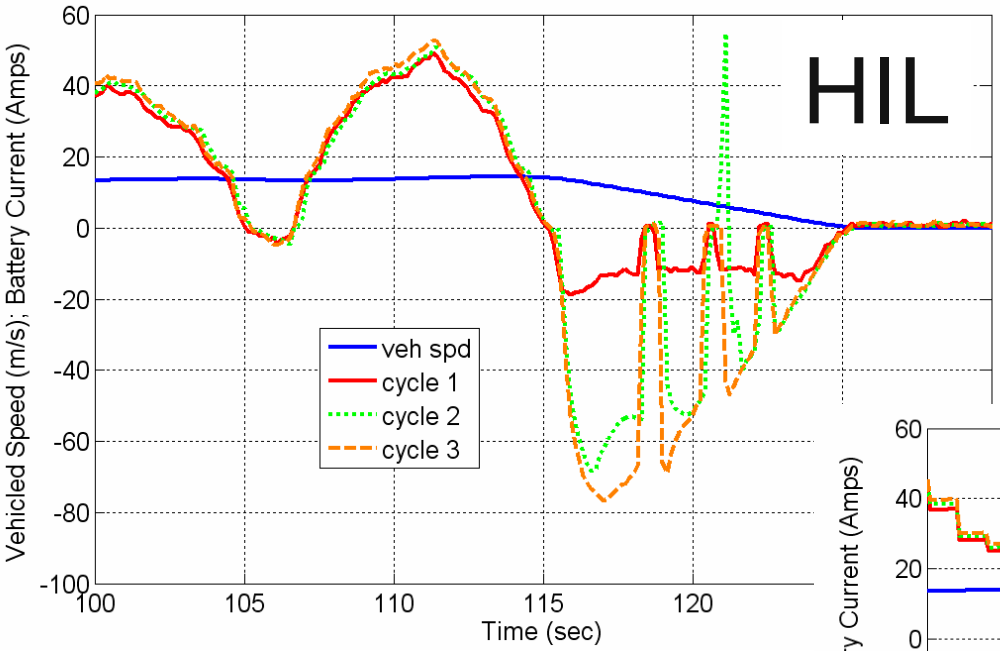
- During testing, several key parameters were characterized
  - Voltage
  - Temperature
  - State of Charge
  - Available battery power
  - Other vehicle data

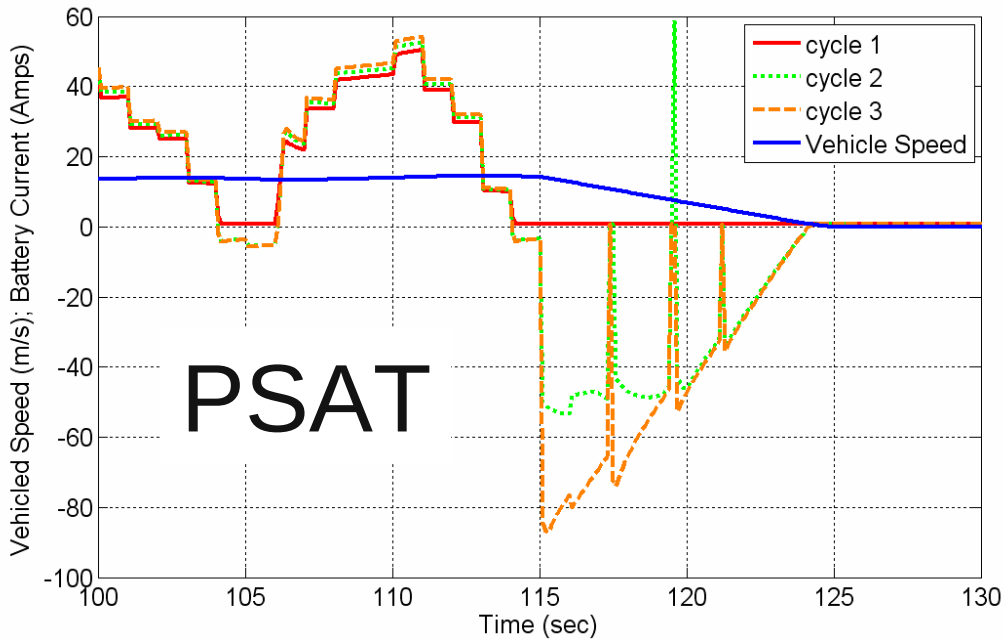
Midsize Vehicle Emulated on EV Mode on UDDS



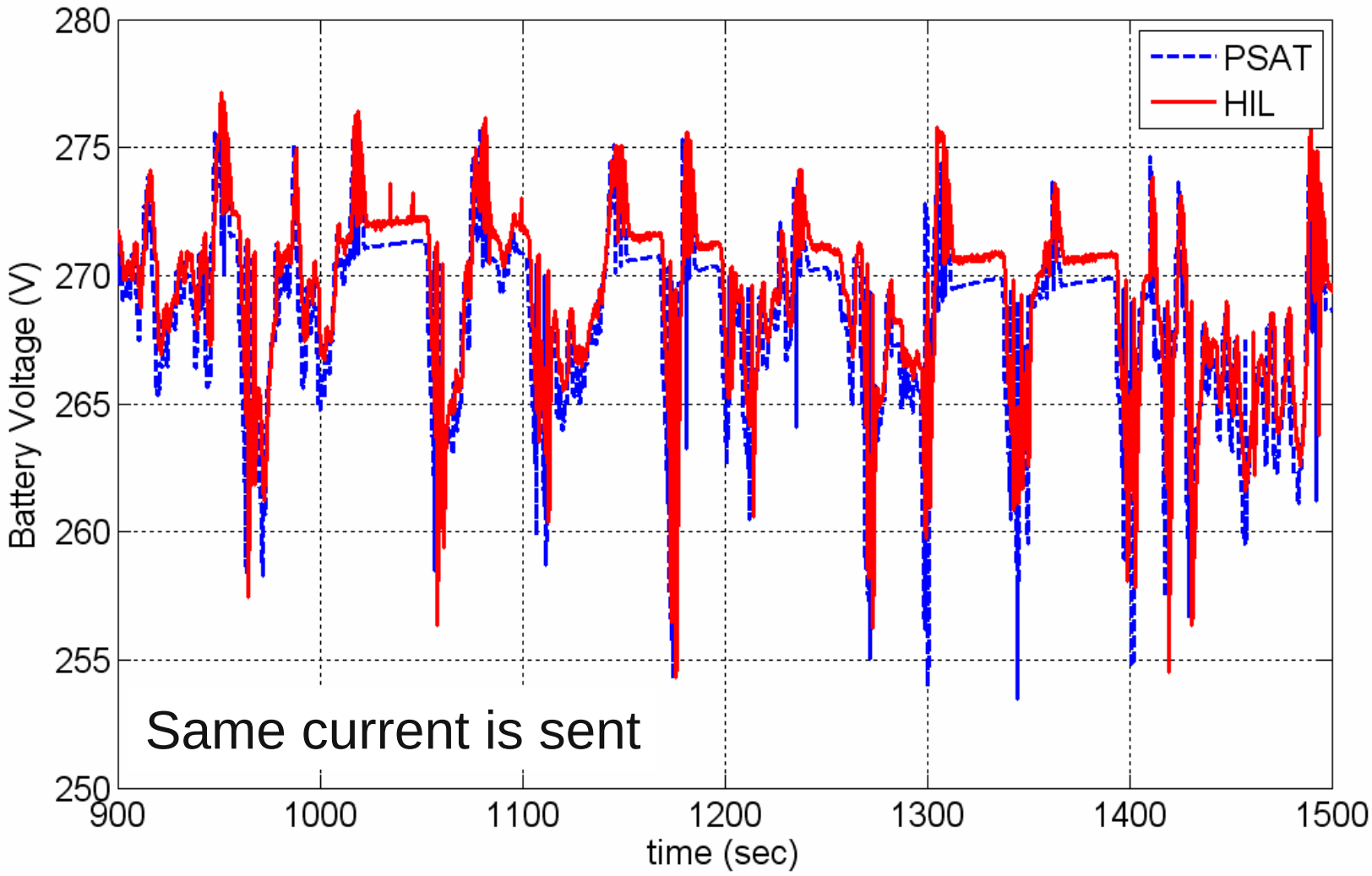
Pre-transmission Parallel HEV Configuration

Comparison with Model Shows Discrepancy in Charging During First Cycle





Hardware Displays Higher Pack Voltage



PSAT Battery Model Validated Within <5% for Energy Requirements

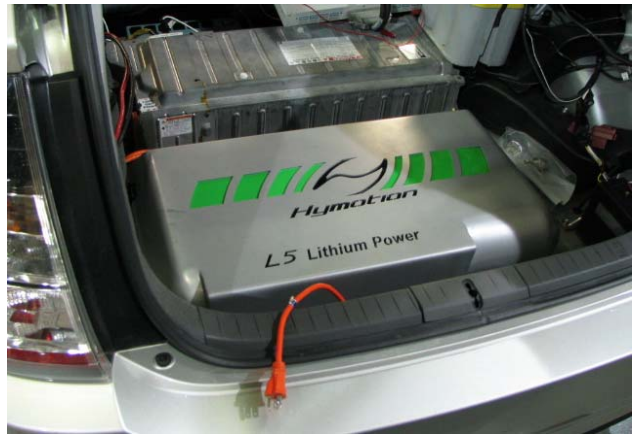
	Units	HIL	PSAT
AER from 0.9 to 0.3 SOC	mi	24.79	26
Battery Ah Depleted	Ah	25	24.7
Battery Electrical Energy	kWh	6.29	6.57
Energy Consumption	Wh/mi	253.7	241

Energy Storage System Requirements Activities

- Energy Storage Requirements Using PSAT
- Battery Requirements Validation with HIL
- PHEV Prius Vehicle Testing
- Future Activities

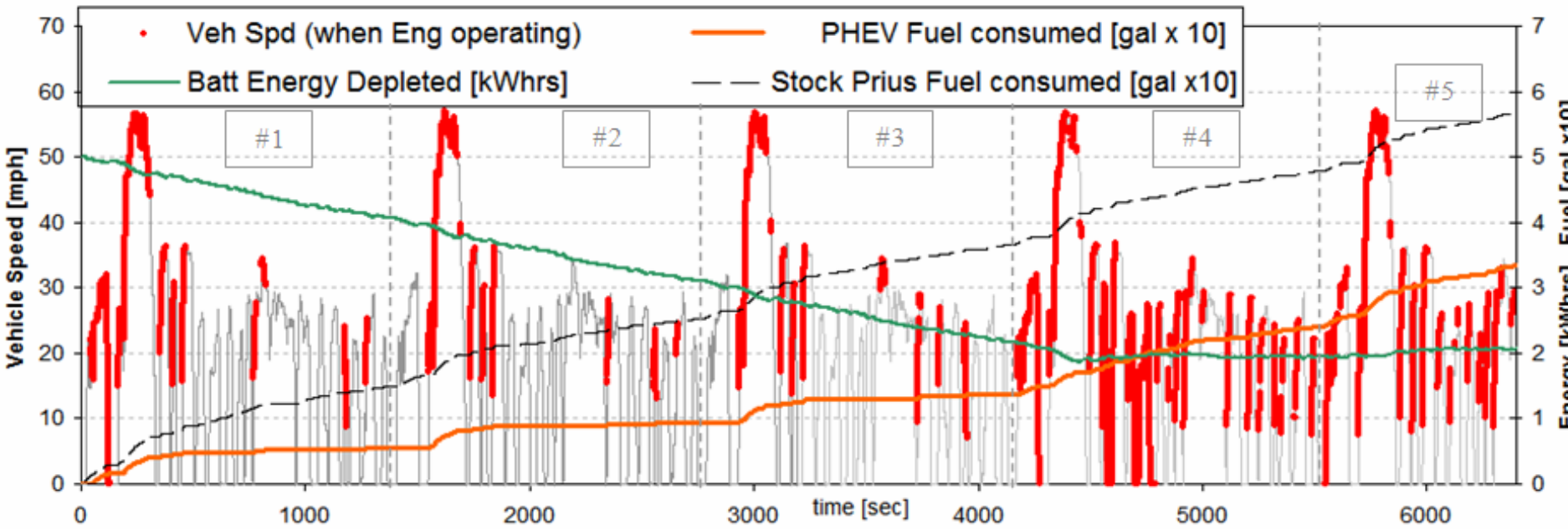
Vehicle Test Setup

5kWh Li-ion Hymotion implemented in ANL's highly instrumented 2004 Prius

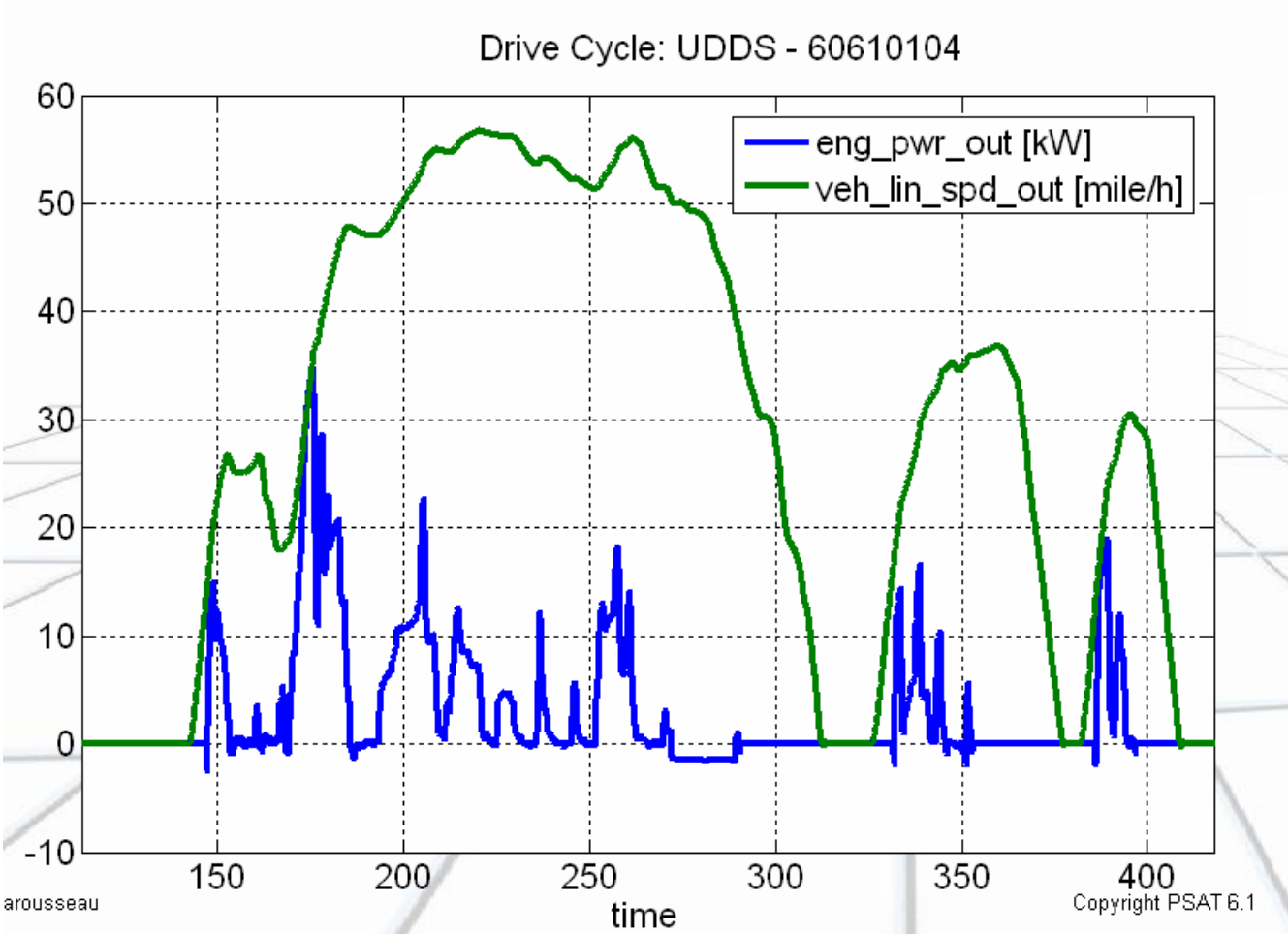


Electrical and Fuel Energy During UDDS Cycles

UDDS	#1	#2	#3	#4	#5
Miles Driven (mi)	7.48	7.48	7.48	7.48	7.47
Fuel Used (gal)	0.051	0.037	0.040	0.101	0.113
Electrical Energy Consumed (DC kWh)	0.93	0.96	0.94	0.23	-0.12
Fuel Economy (mpg)	148	200	187	74.3	66.4
Electrical Consumption (DC Wh/mi)	123	128	125	30.6	15.9
Operating Cost ($/mi)	0.035	0.031	0.032	0.041	0.039



Hymotion Prius Uses Engine at Low Power



Validated Prius Model Used to Evaluate Battery Requirements for Power Split Configuration

	Electrical Consumption (Wh/mi)	Fuel Economy (mpg)
HyMotionTest – Third UDDS	125	187
PSAT – Improved Engine Operating Conditions	72	160
PSAT – Improved Engine Operating Conditions and Increased Accessory Loads (800 W)	103	160

Energy Storage System Requirements Activities

- Energy Storage Requirements Using PSAT
- Battery Requirements Validation with HIL
- PHEV Prius Vehicle Testing
- Future Activities

Energy Storage System Requirements Summary

- PSAT used to define battery requirements for several vehicle classes and AER.
- For pre-transmission parallel HEVs:
  - Power requirement fairly independent of AER
  - Usable Energy is linear function of AER
- Electrical accessory loads should be carefully considered when selecting the usable energy.
- Battery HIL demonstrated a 5% validation of the battery model for energy requirements.
- Vehicle testing demonstrated that, when implementing high capacity batteries in power split HEVs, the energy requirements could be lowered by as much as 40%.

ESS Requirements Future Activities

- Evaluate the impact of additional drivetrain configurations including series, other parallel and power splits.
- Size the battery for different applications (not just for UDDS).
- Use battery HIL to define the thermal limitations of the VL41M and their implications on the requirements.
- Continue to evaluate PHEVs as they become available for testing and understand the control strategy changes from one generation to another based on emission control.