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Goal Setting & Simulation Results

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U.S.DOE PHEV Stakeholder Workshop

June 13, 2007

U.S. Department of Energy

UChicago Argonne LLC

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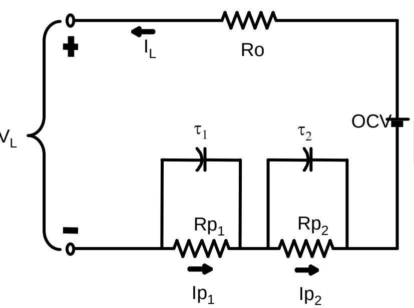
FreedomCAR & Vehicle Technologies Program

FreedomCAR & Fuel Partnership

Energy Storage Requirements Defined Using Systems-Level Approach

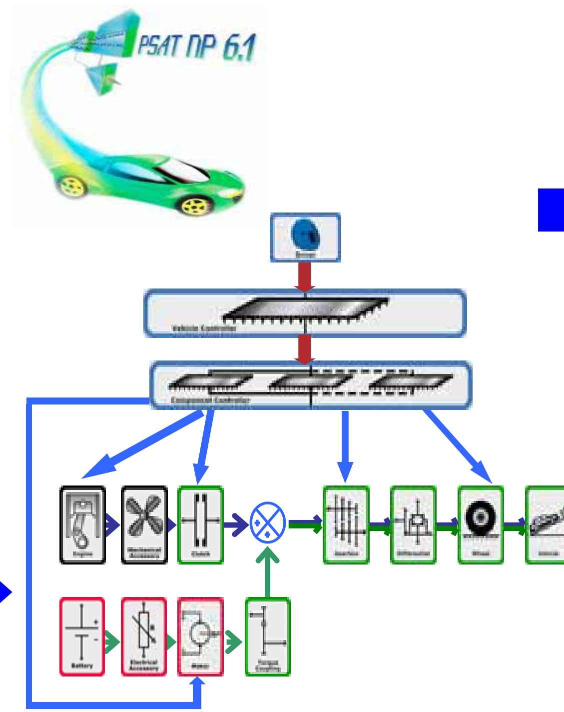
Component

Testing



Model

Vehicle Simulation

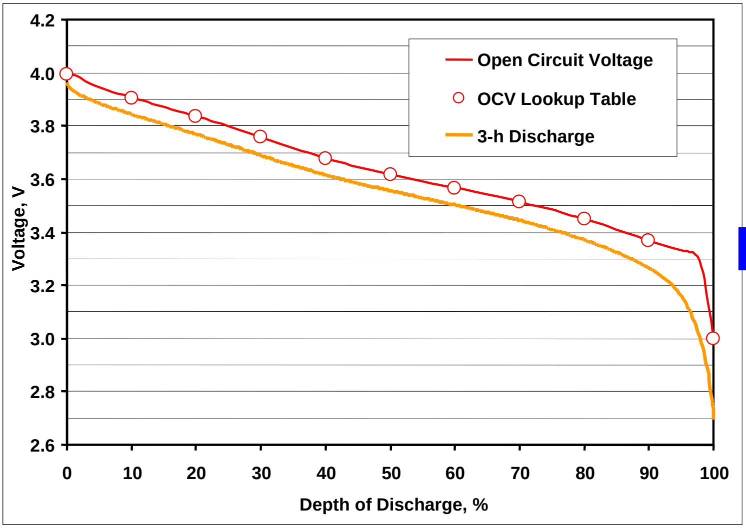


Hardware Evaluation in System Context

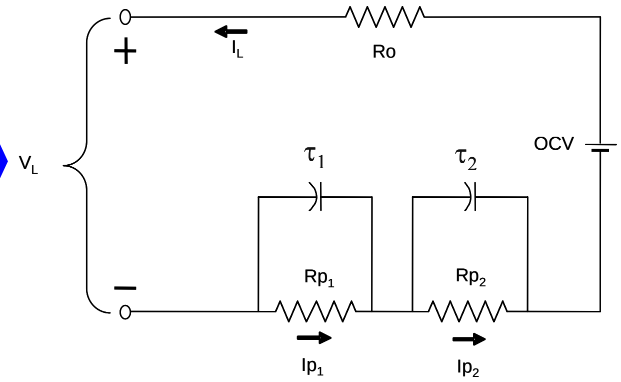
JCS VL41M

Accurate Battery Modeling Used to Generate Requirements

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



Test data

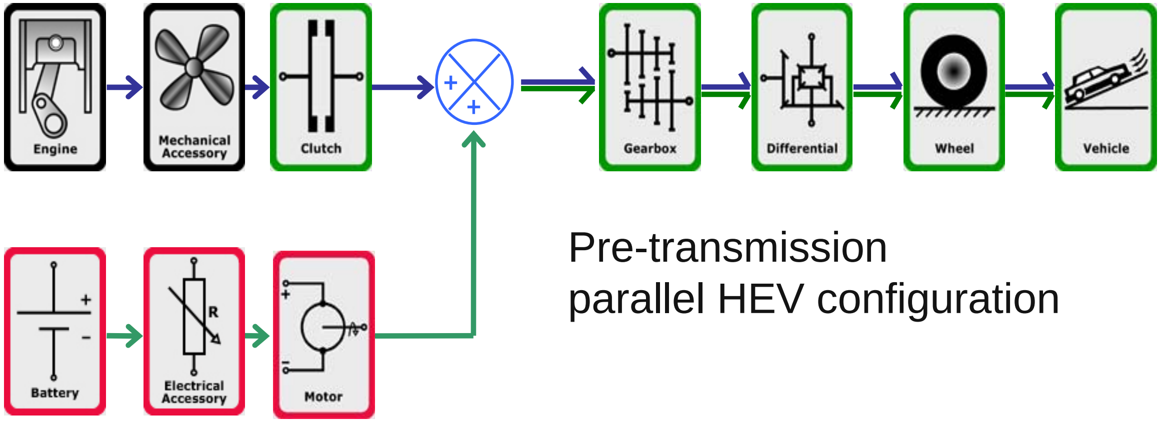


PHEV Model

Scaling Algorithm for Power & Energy

Scaling

Main Vehicle Assumptions

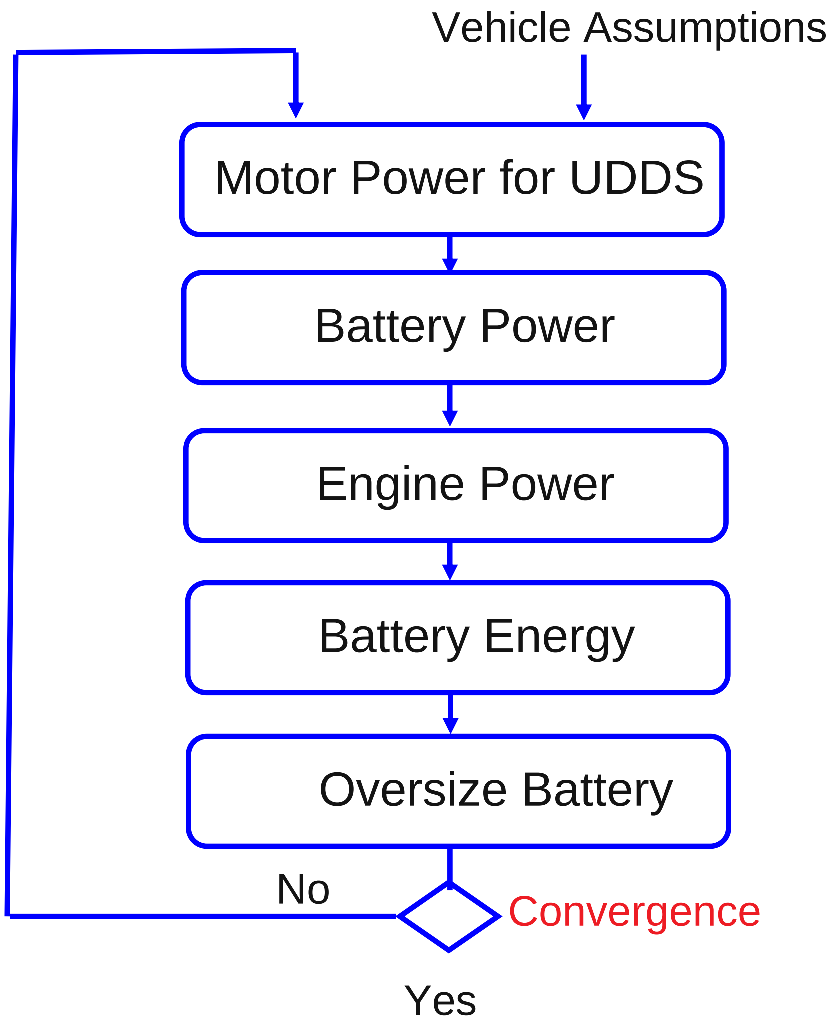


Pre-transmission
parallel HEV configuration

Parameter	Unit	Value
0–60mph	s	9 +/- 0.1
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	0.41	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



<u>Associated Requirements</u>

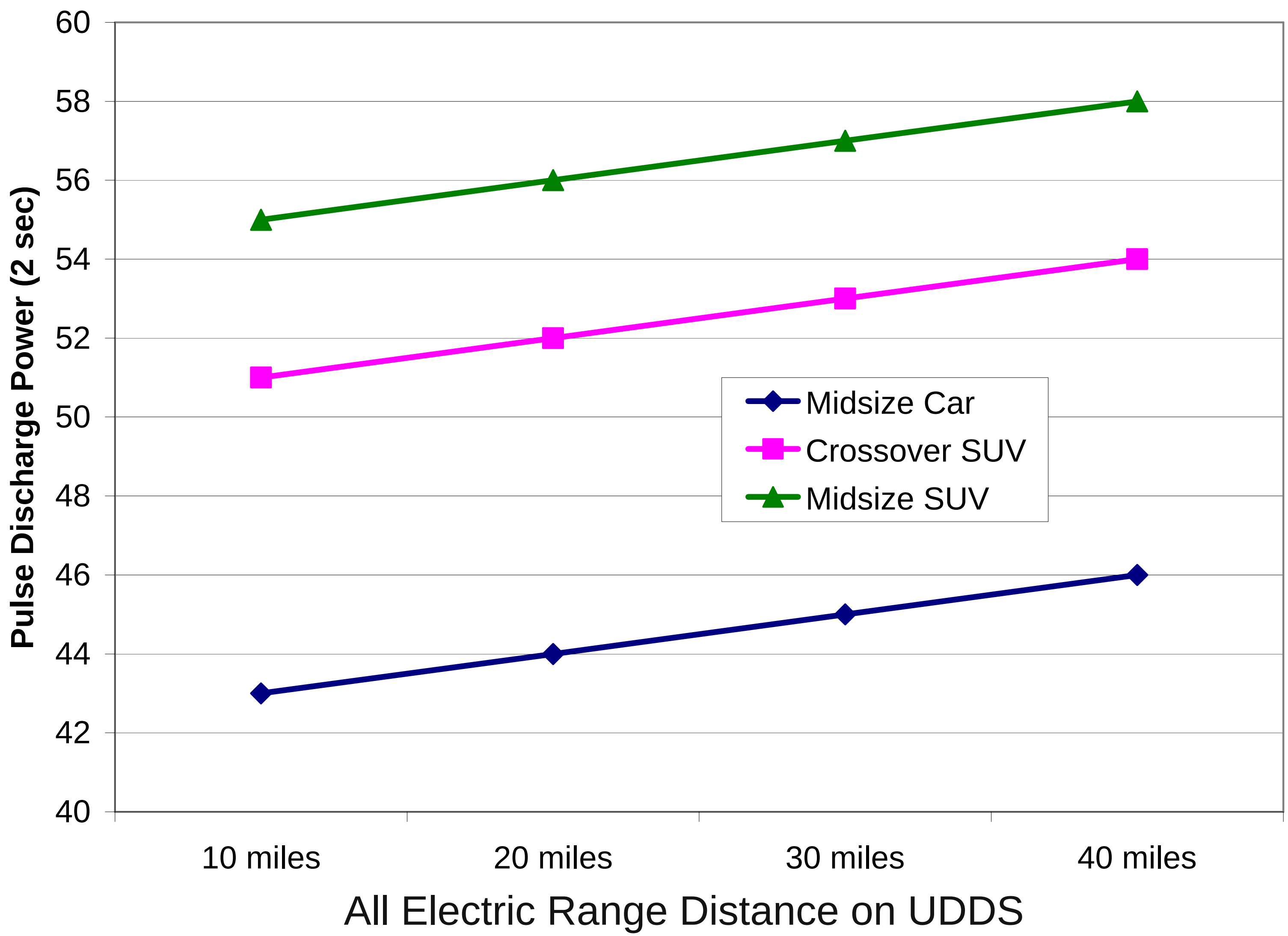
Satisfy CARB EV Range Definition

0-60 mph
Grade (Safety 1.5 for thermal)

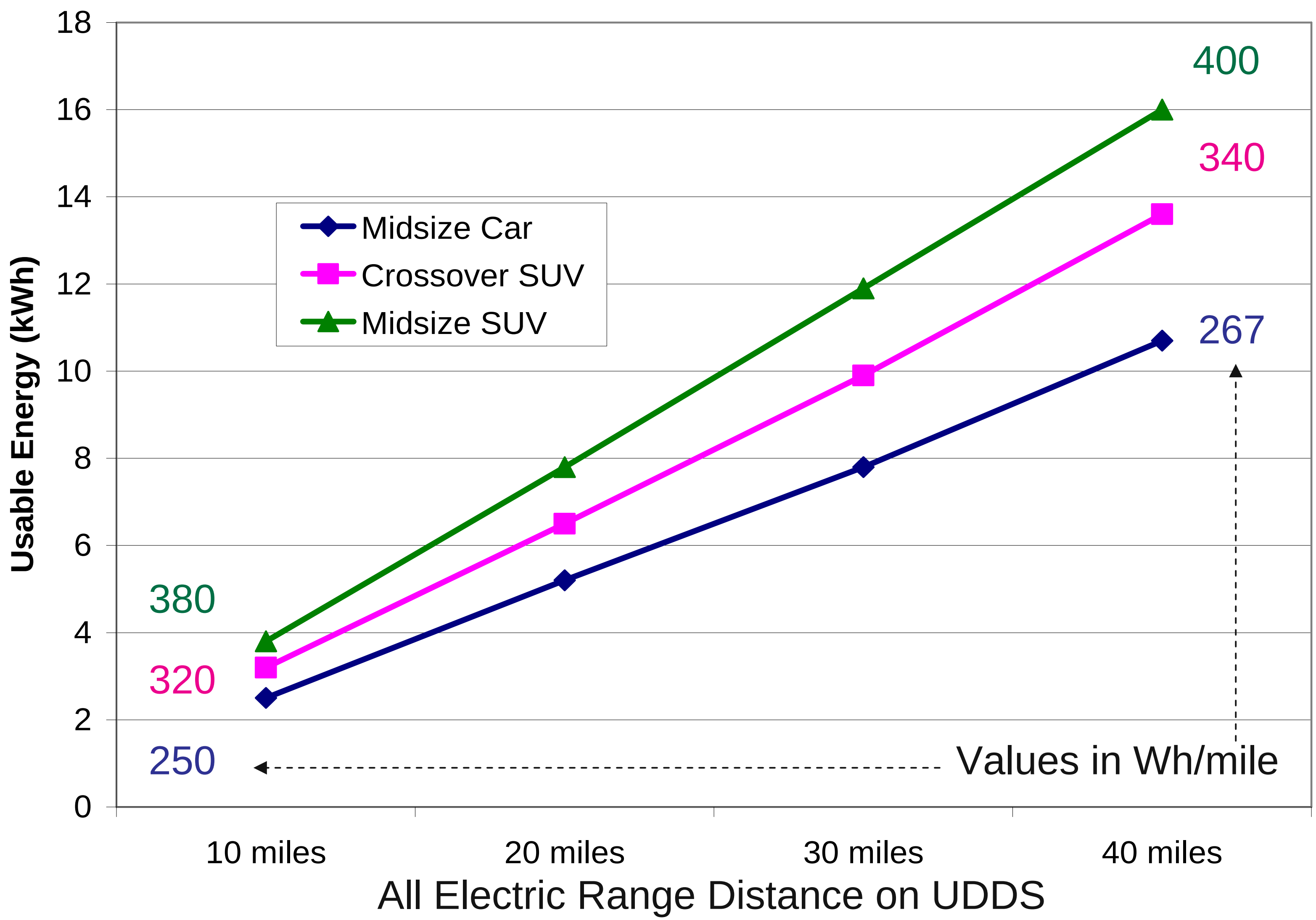
Range

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

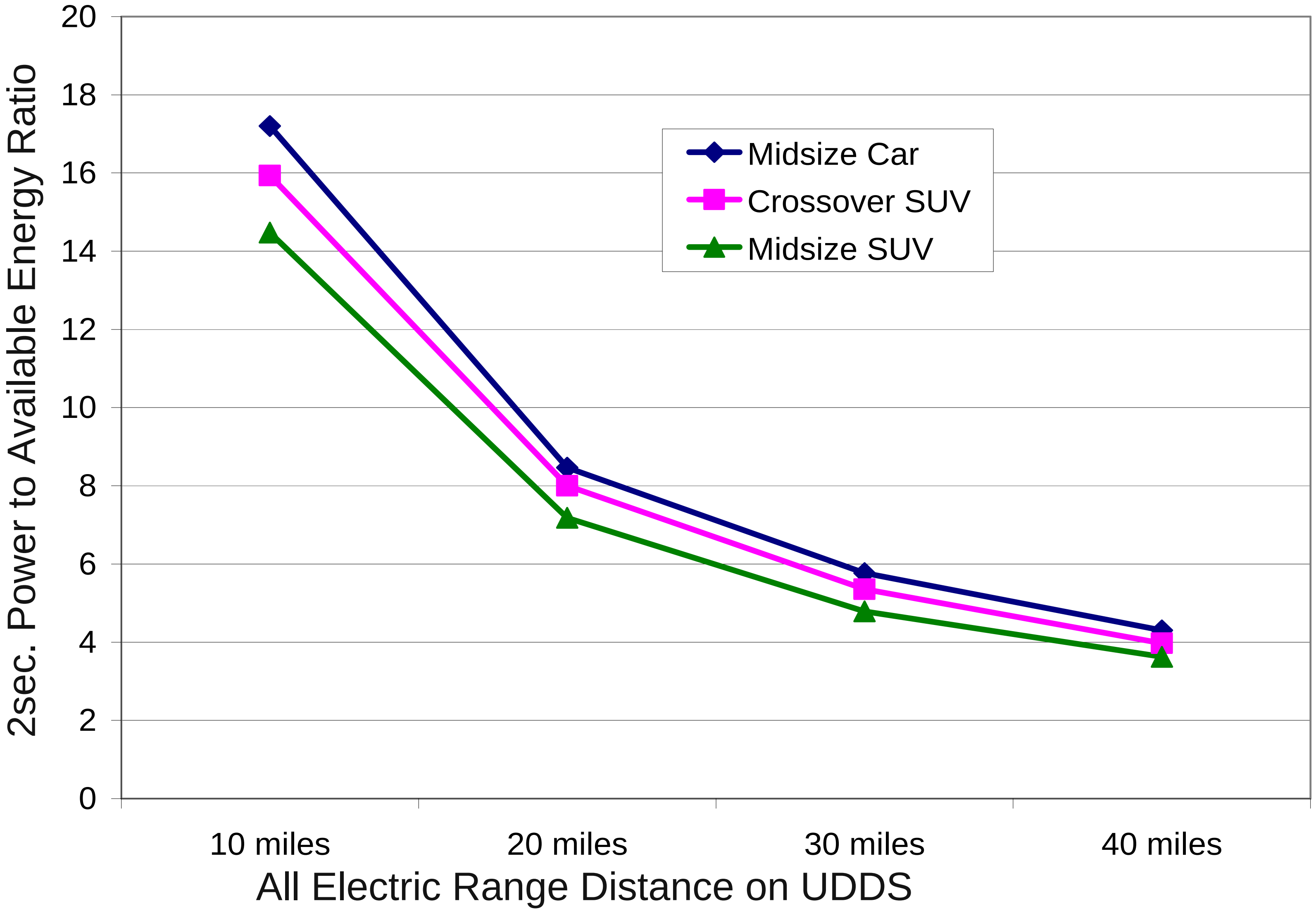
Battery Power Fairly Constant With AER



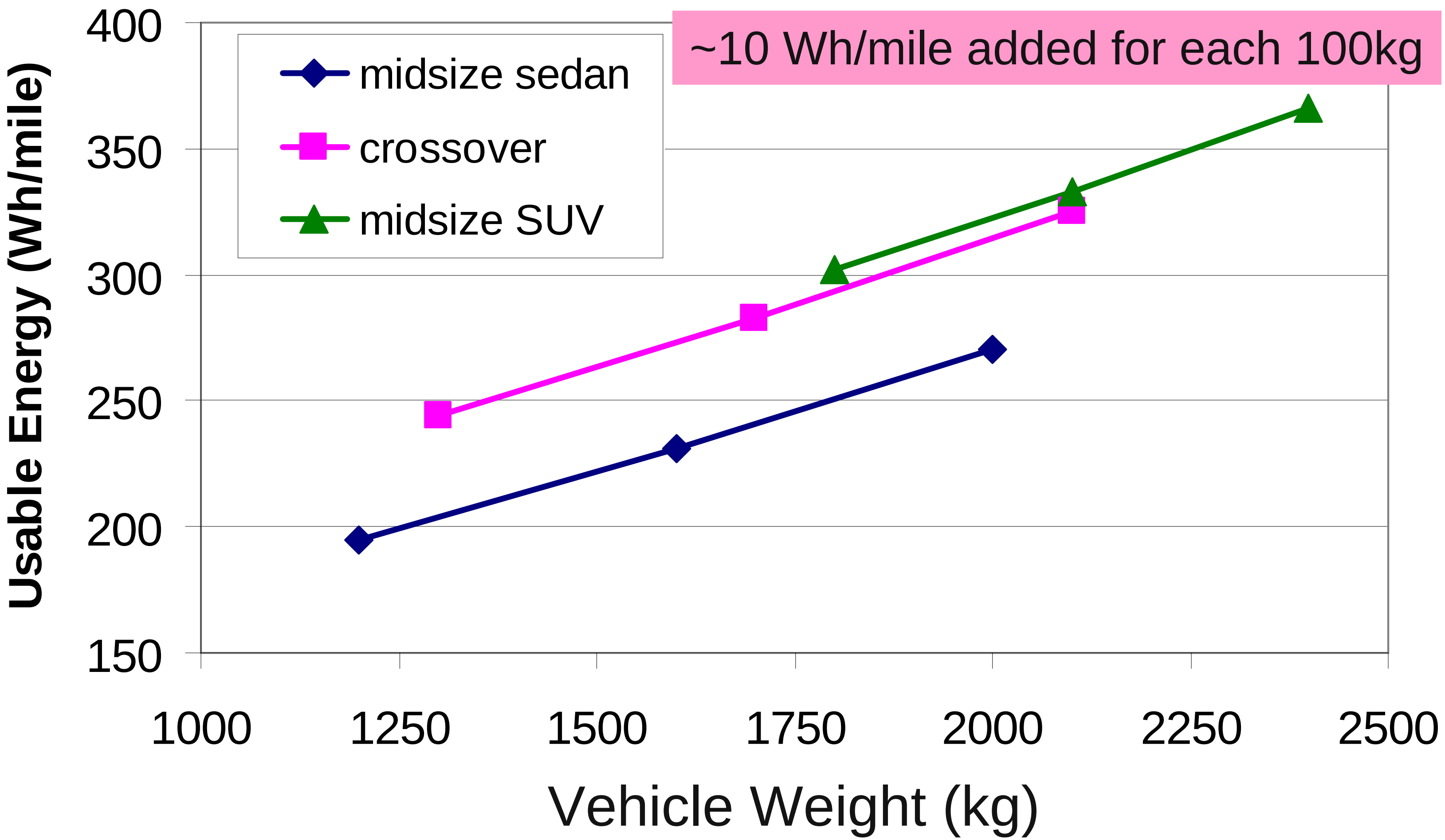
Usable Energy Linearly Increase with AER



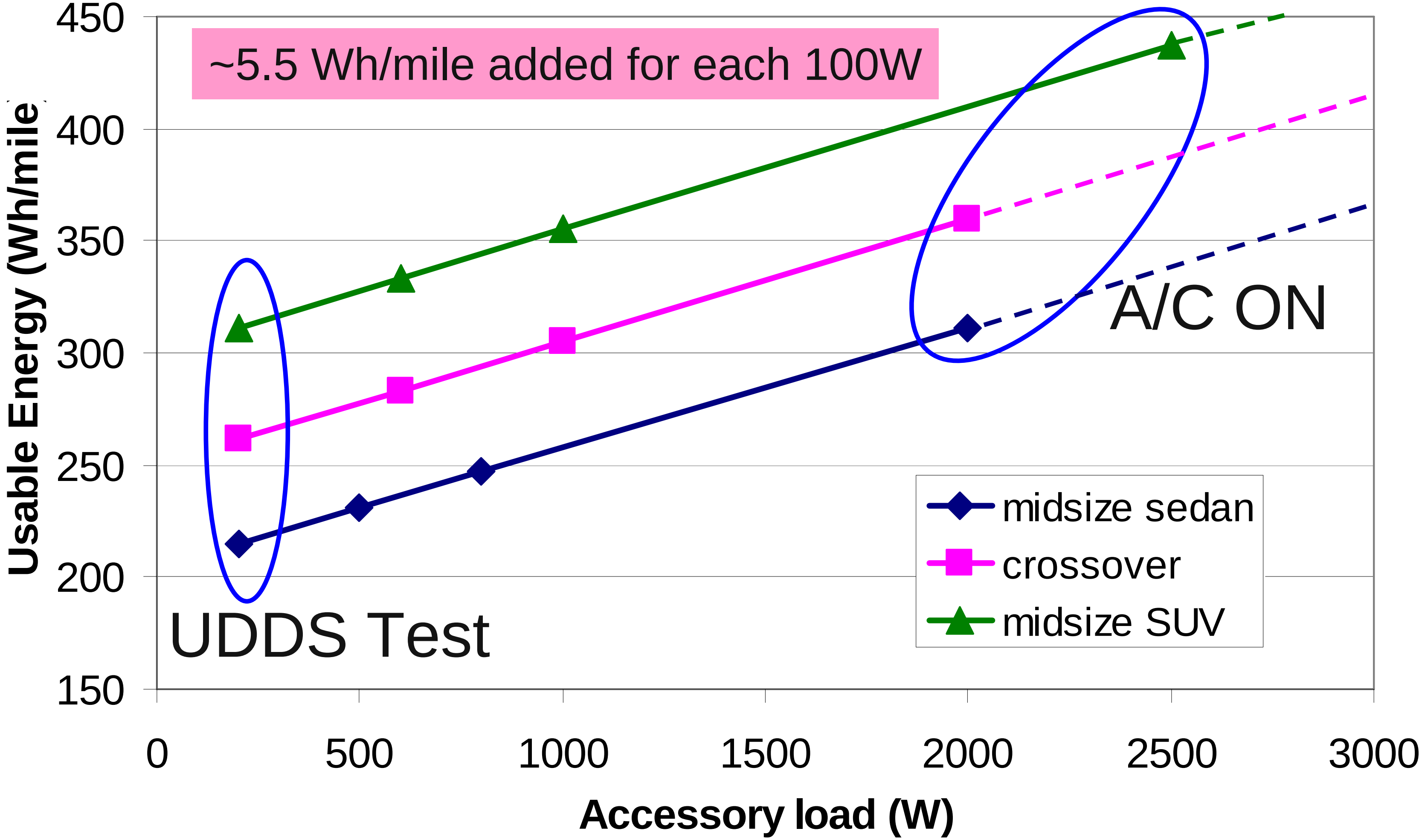
Power/Energy Ratio Decreases with AER



Vehicle Mass Has Little Impact on Usable Energy



Electrical Accessory Could Have Major Impact on Usable Energy

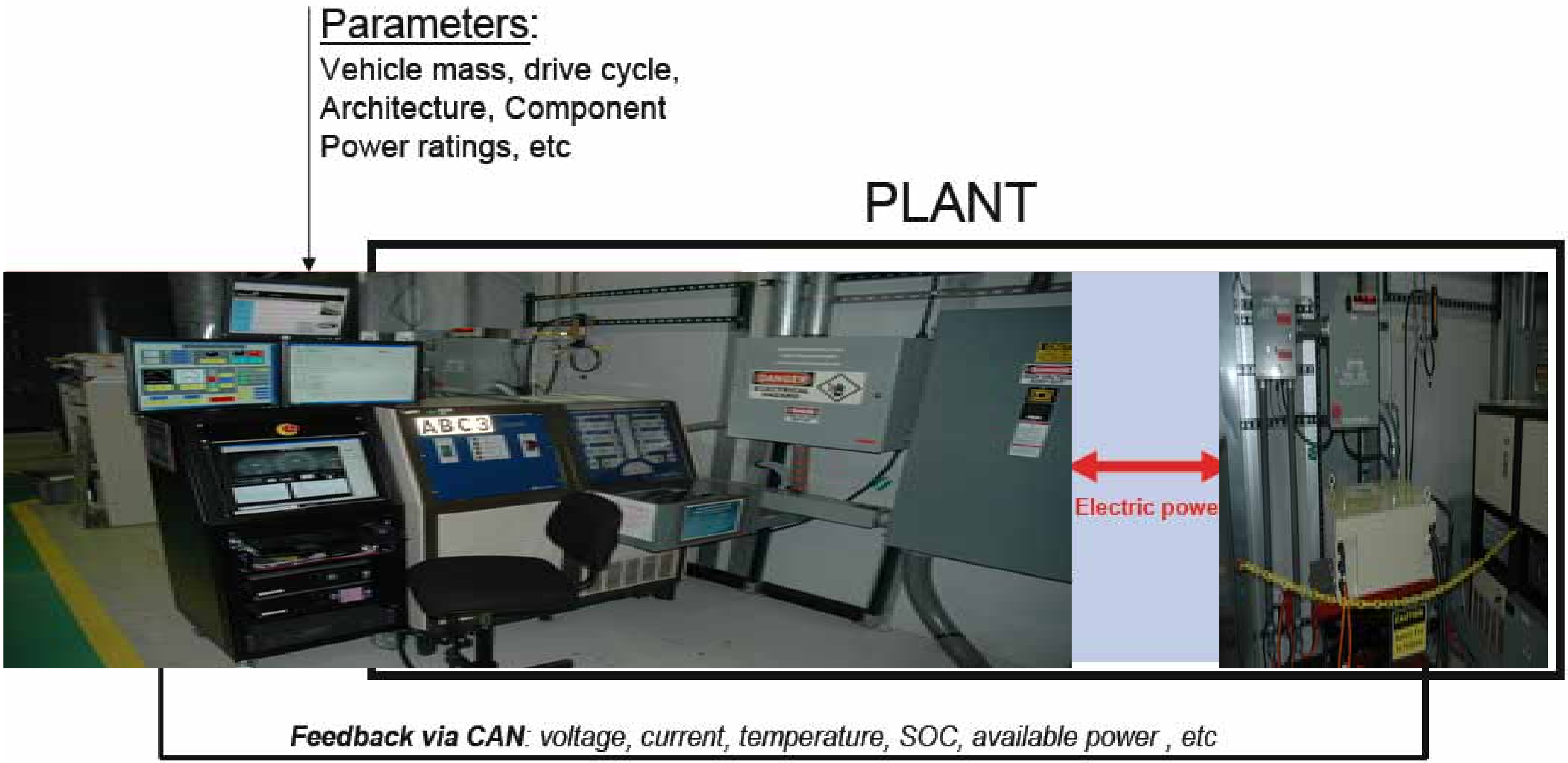


Energy Storage Requirements Summary

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

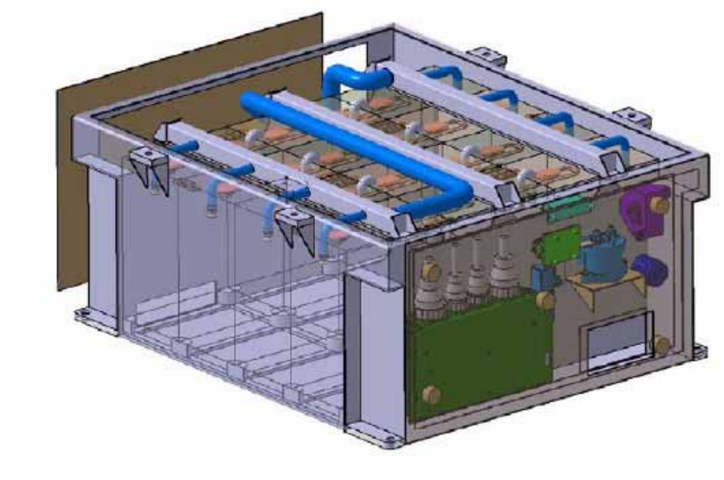
Values in Wh/mile

PSAT Results Validated Through Hardware Characterization in a Virtual Vehicle Environment



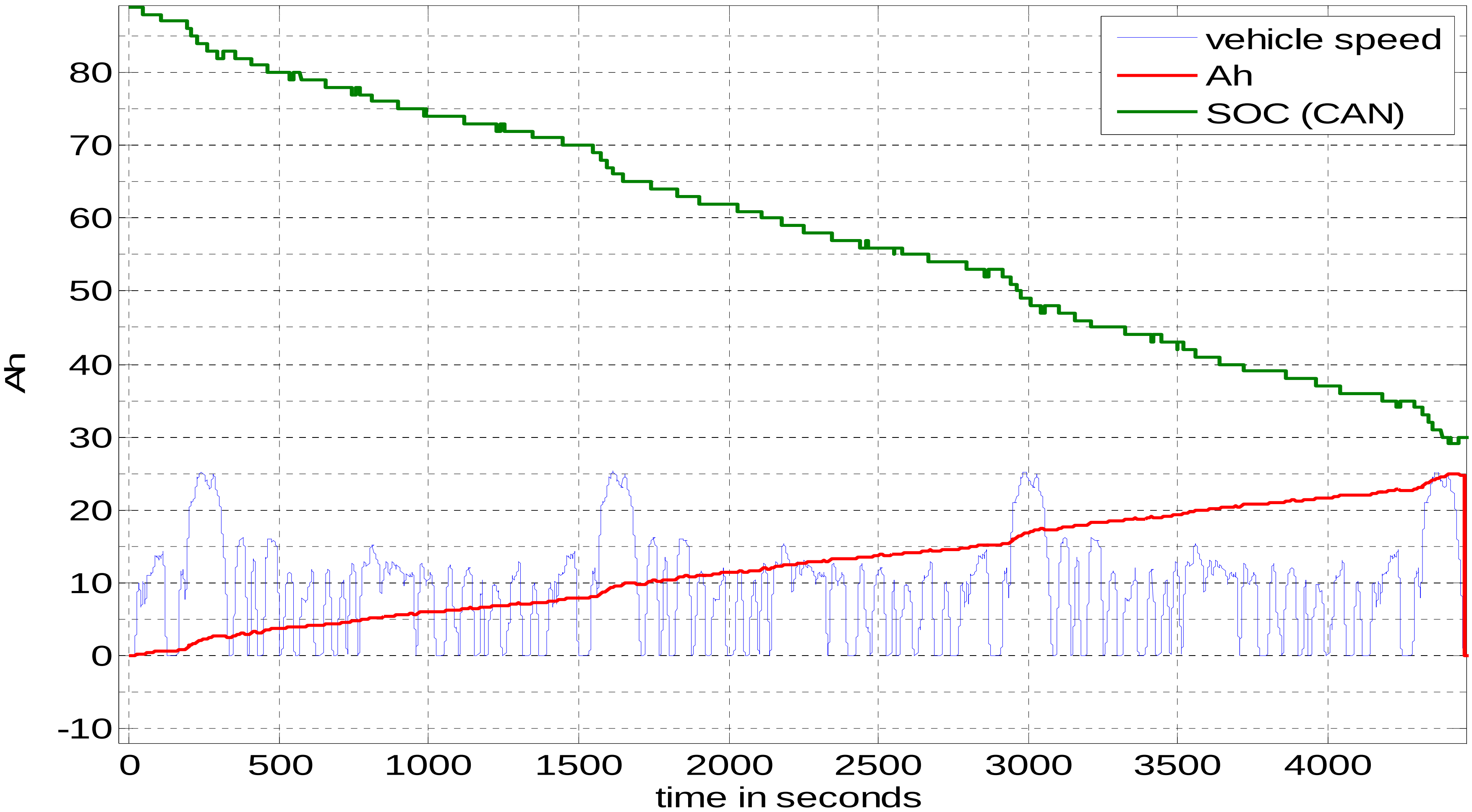
Johnson-Control-Saft VL41M

- 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



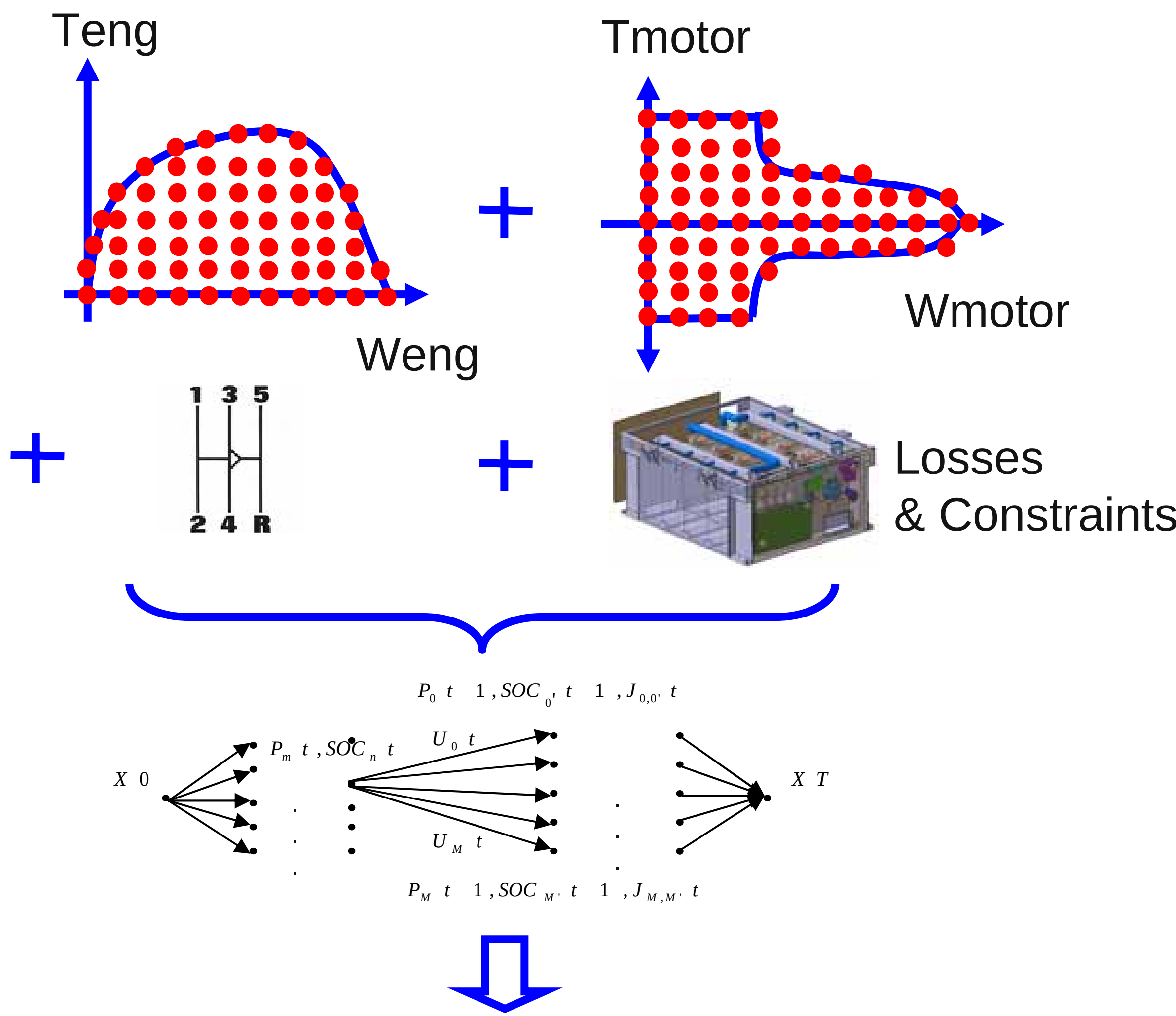
Pre-transmission Parallel HEV Configuration

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

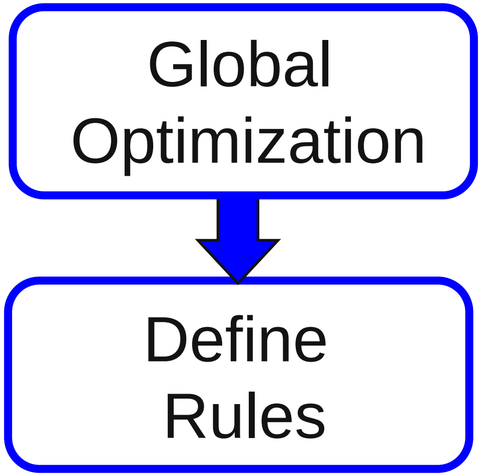
Control Strategy Evaluation - Methodology

Global Optimization



Engine Torque, Motor Torque, SOC, Gear Ratio

Control Strategy Evaluation - Methodology



When do we start/turn off the engine?
How do we split the torque?
How do we manage SOC?

Control Strategy Evaluation - Methodology

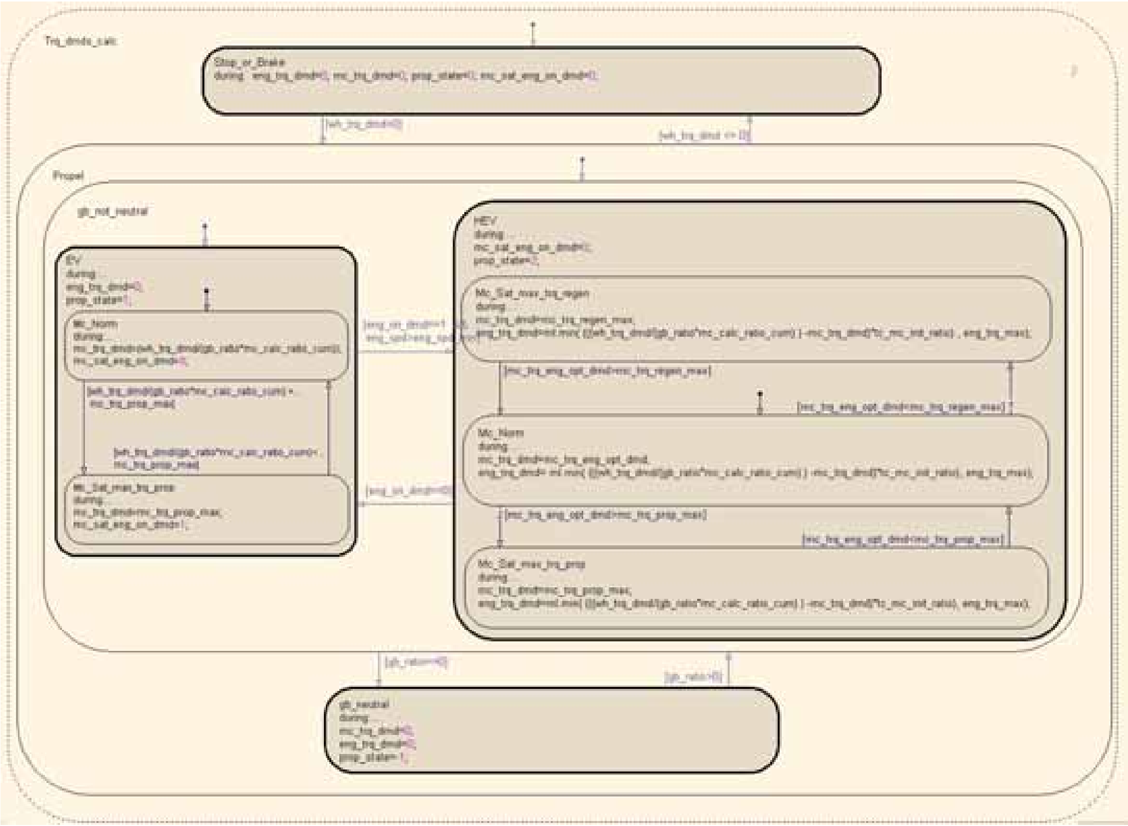
Global Optimization

↓

Define Rules

↓

Develop Control



Control Strategy Evaluation - Methodology

Global Optimization

↓

Define Rules

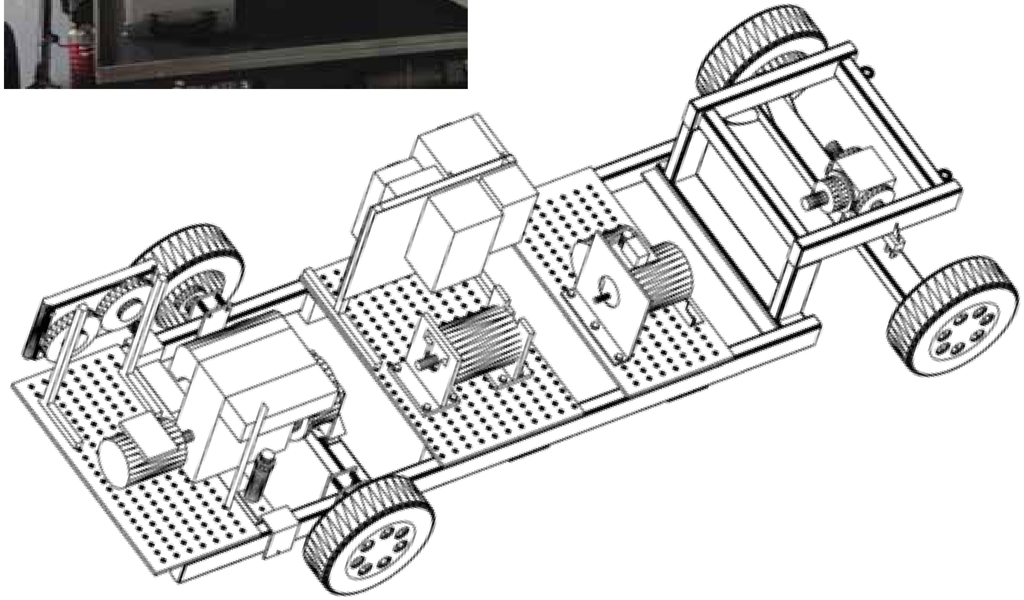
↓

Develop Control

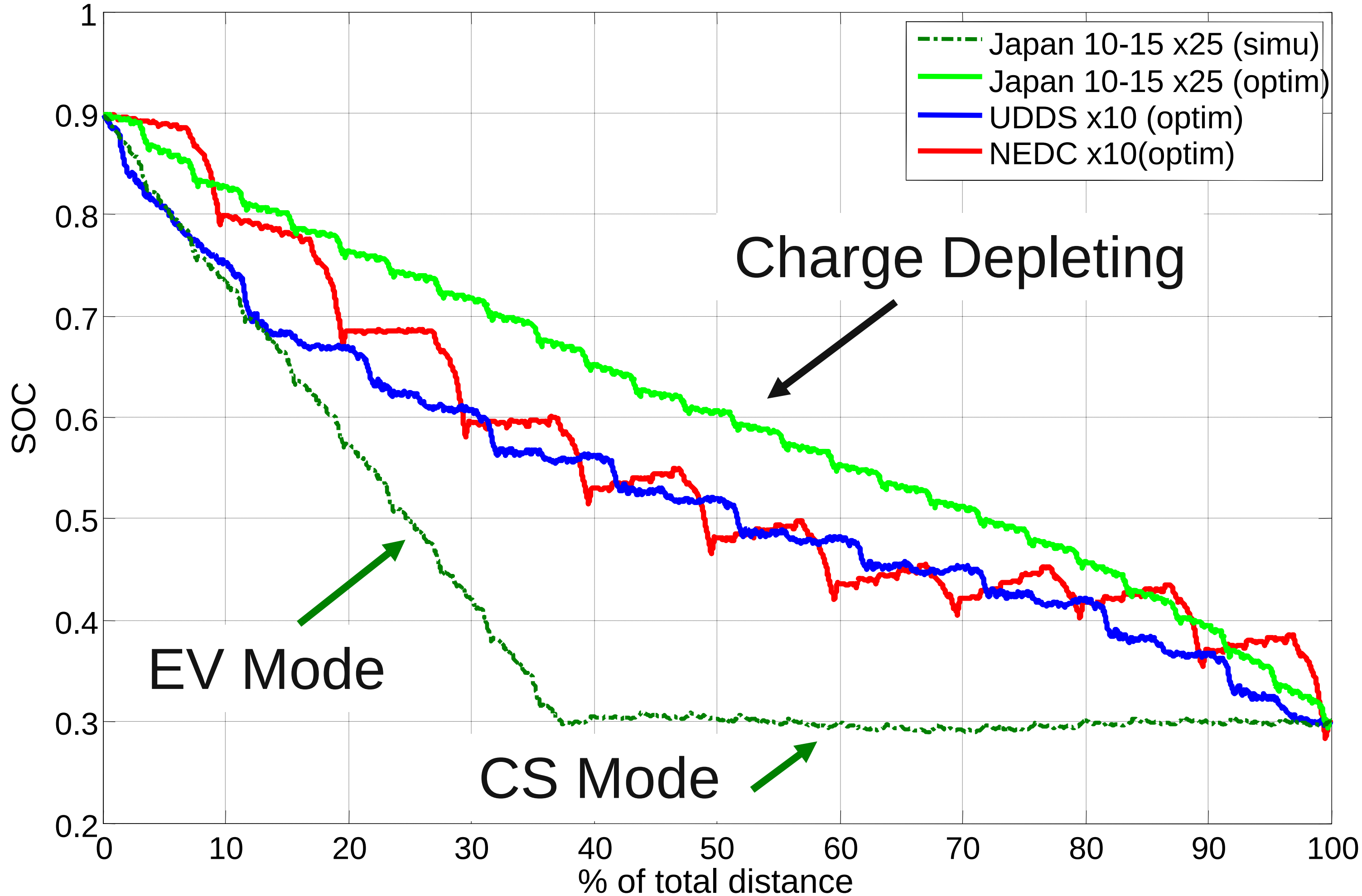
↓

Implement Control

MATT:
Mobile
Advanced
Technology
Test bed

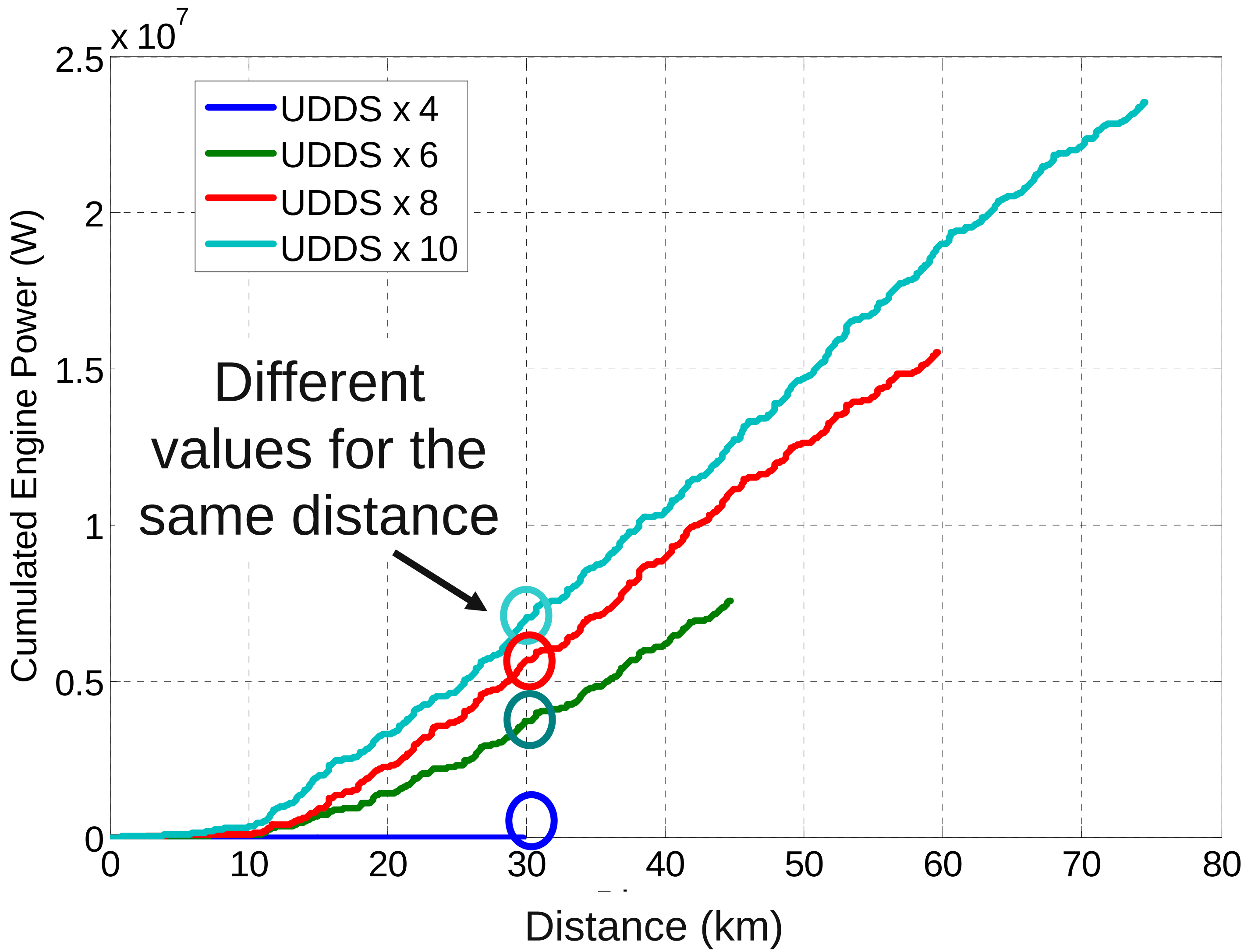


Engine Should be Used Throughout the Trip When Distance > AER



Global optimization – Pre-transmission parallel midsize HEV

Optimum Control Depends on Distance



Global optimization – Pre-transmission parallel midsize HEV

Simulation Studies Main Results

- PSAT used to define battery requirements for several vehicle classes and AER.
- For pre-transmission parallel HEVs:
  - Power requirement fairly independent of AER
  - Usable battery 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%.

PSAT Current/Future Activities

- Goal setting
  - 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 requirements.
- Control strategy evaluation
  - Global optimization
  - Real-time control development
  - Control parameters tuning using heuristic optimization (DIRECT, Genetic Algorithm…)
- Use MATT to define emission impact of control strategies

PSAT Current/Future Activities

- Impact of Component Technologies on Fuel Economy
  - Battery technology
  - Engine technology and fuel (gasoline, diesel, hydrogen, ethanol…)
- PHEV Fuel Economy Potential for Different Powertrain Configurations
  - Existing configurations
    - *Power splits: Prius, Lexus RX400h, Ford Escape, GM 2 mode*
    - *Pre-transmission parallel (Sprinter PHEV)*
    - *Series engine (GM Volt)*
  - Specific configurations (wheel motor, post-transmission…)
- Perform trade-off studies as ways to achieve some level of performance while easing requirements on one area or another.