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Impact of Real World Drive Cycles on PHEV Fuel Efficiency and Cost for Different Powertrain and Battery Characteristics

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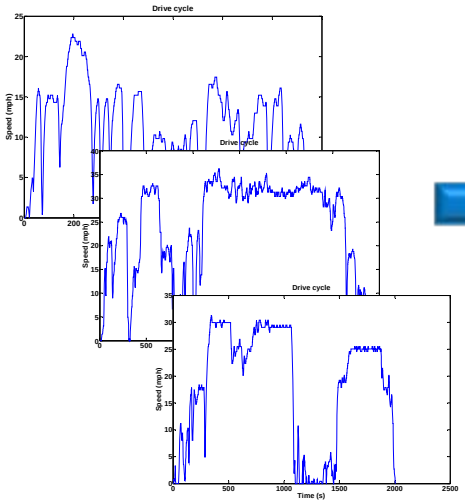
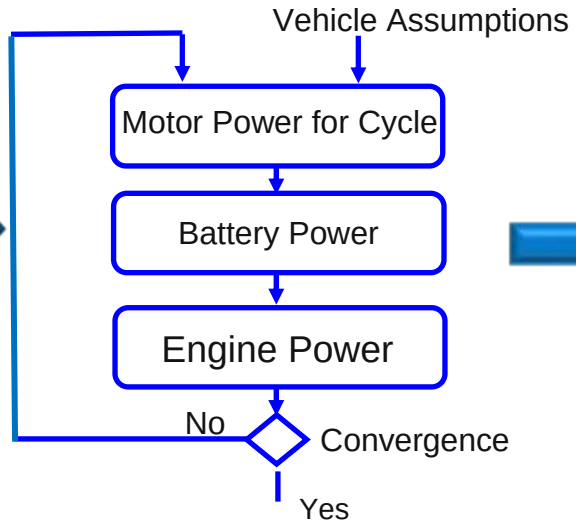
Objective: PHEV Fuel Efficiency and Cost on RWDC

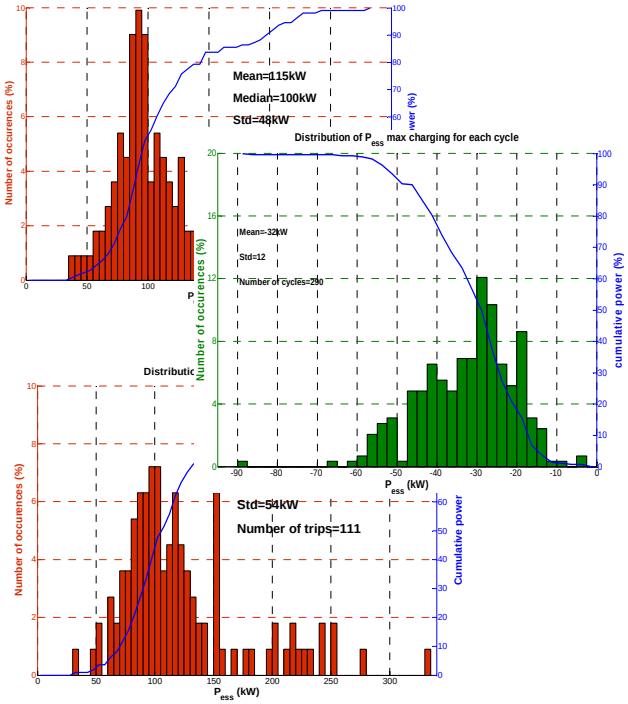
Real World Drive Cycles

Automated Sizing

Analysis (Distribution)







>110 Trips
One day in
Kansas City

Power Split
Midsize Vehicle

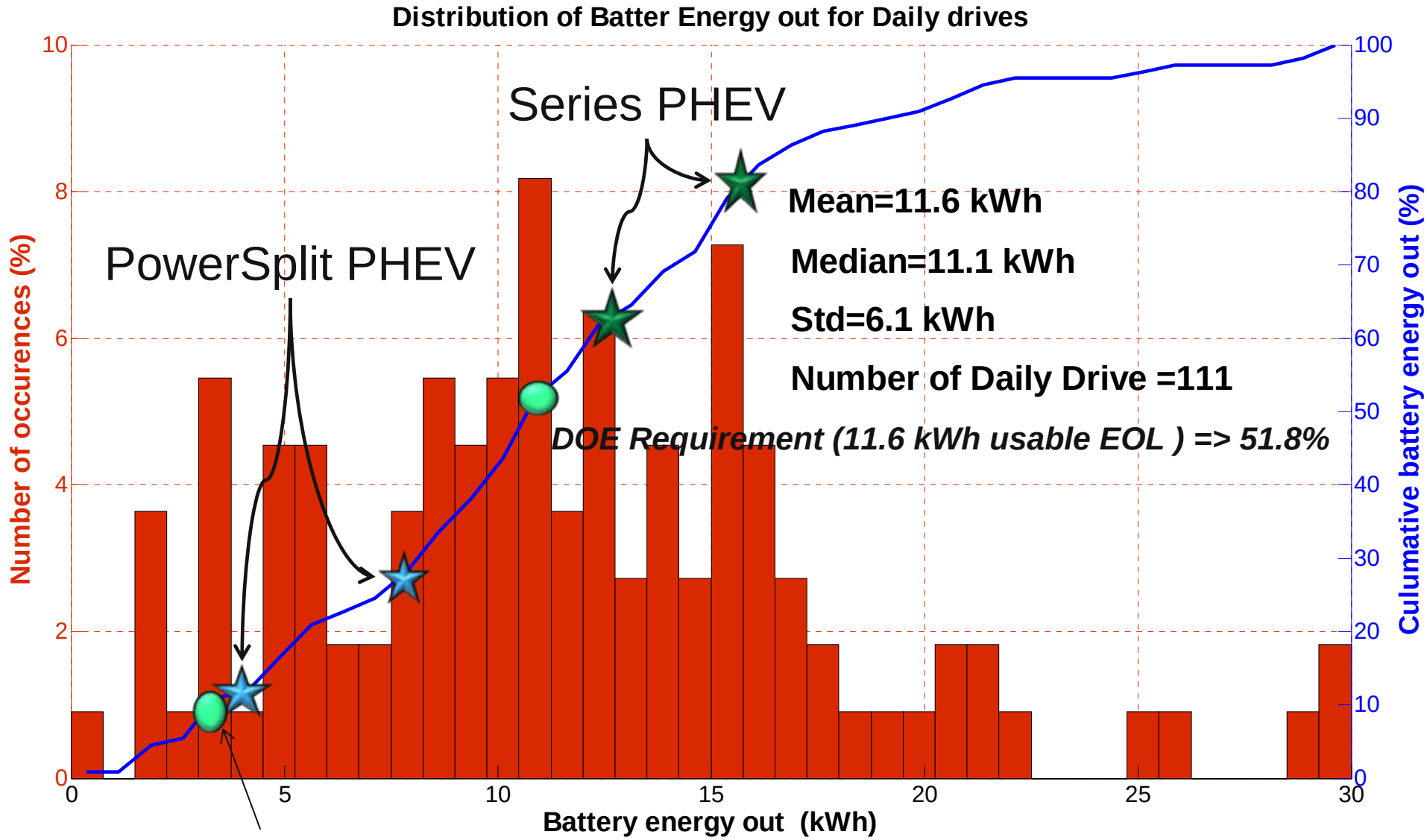
Only Hot Conditions Assumed, no Grade!

Different PHEV Powertrains and Battery Sizes

Powertrain Configuration	Battery Size	PHEV Class
Power Split PHEV	4 kWh*	Low Energy PHEV
	8 kWh*	
Series PHEV	12 kWh*	High Energy PHEV
	16 kWh*	

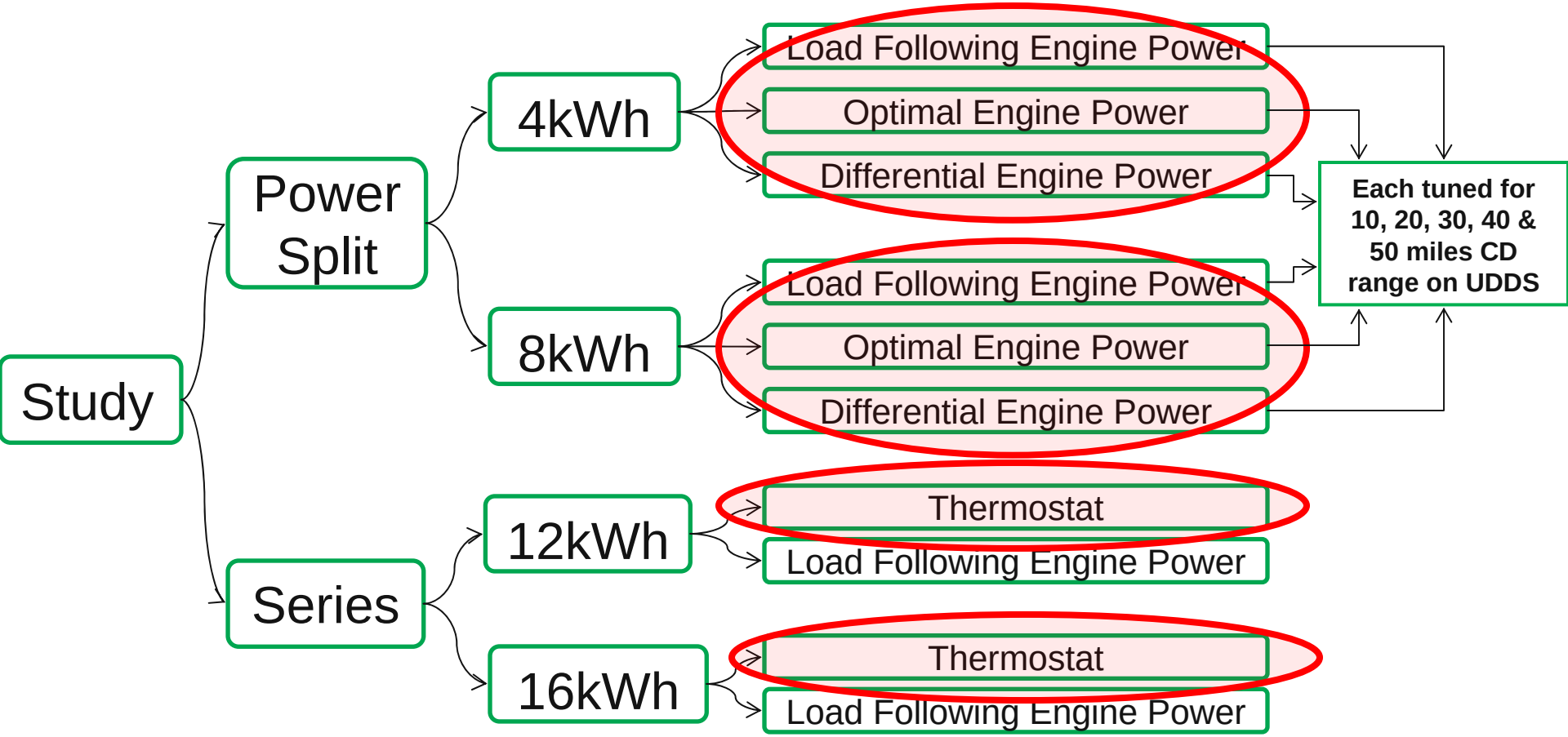
(*) Total battery energies - BOL – 60% used

Battery Energy Selection Based on RWDC



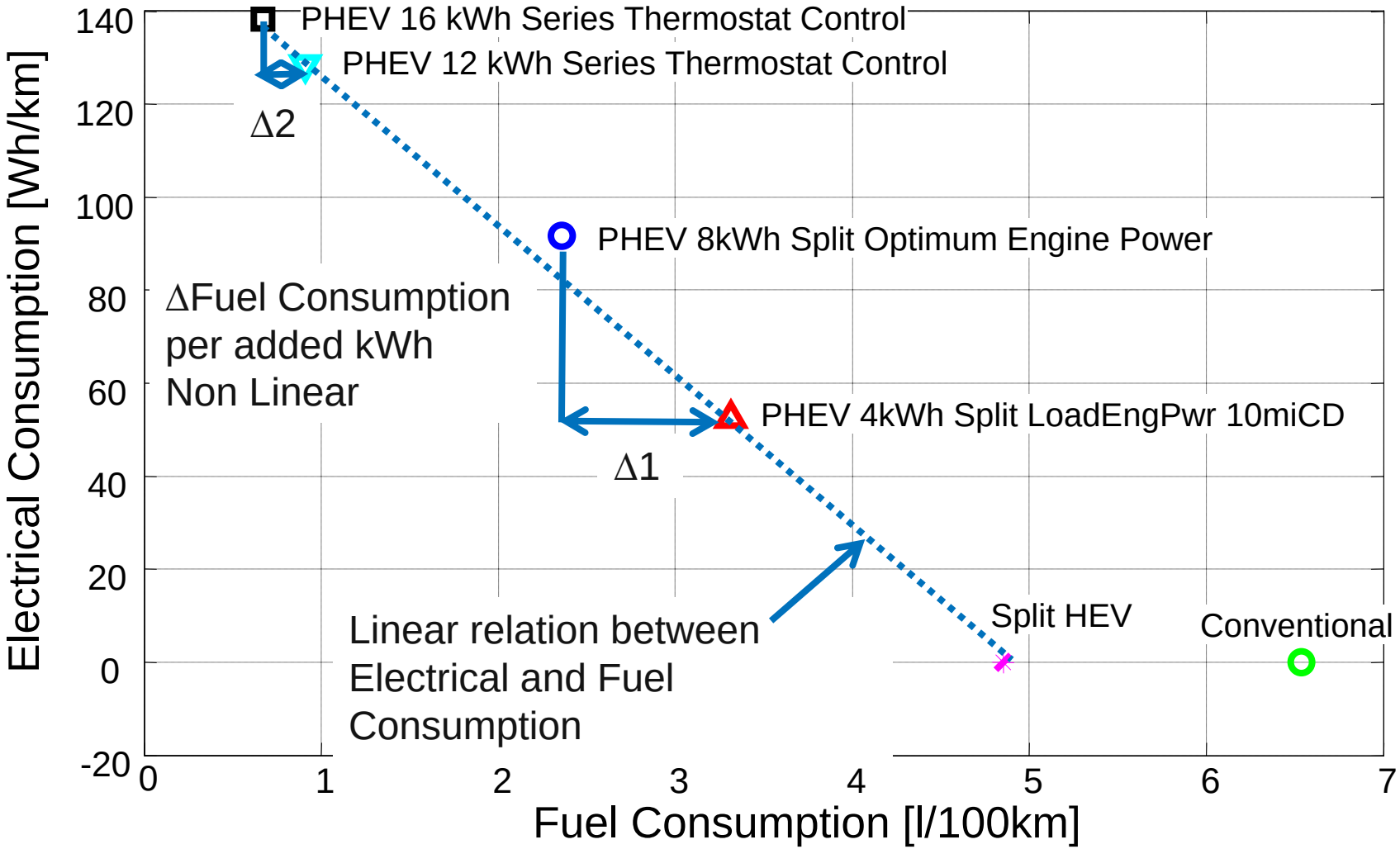
DOE Requirement (3.4 kWh usable EOL) => 10%

Several Vehicle Control Strategies Were Analyzed

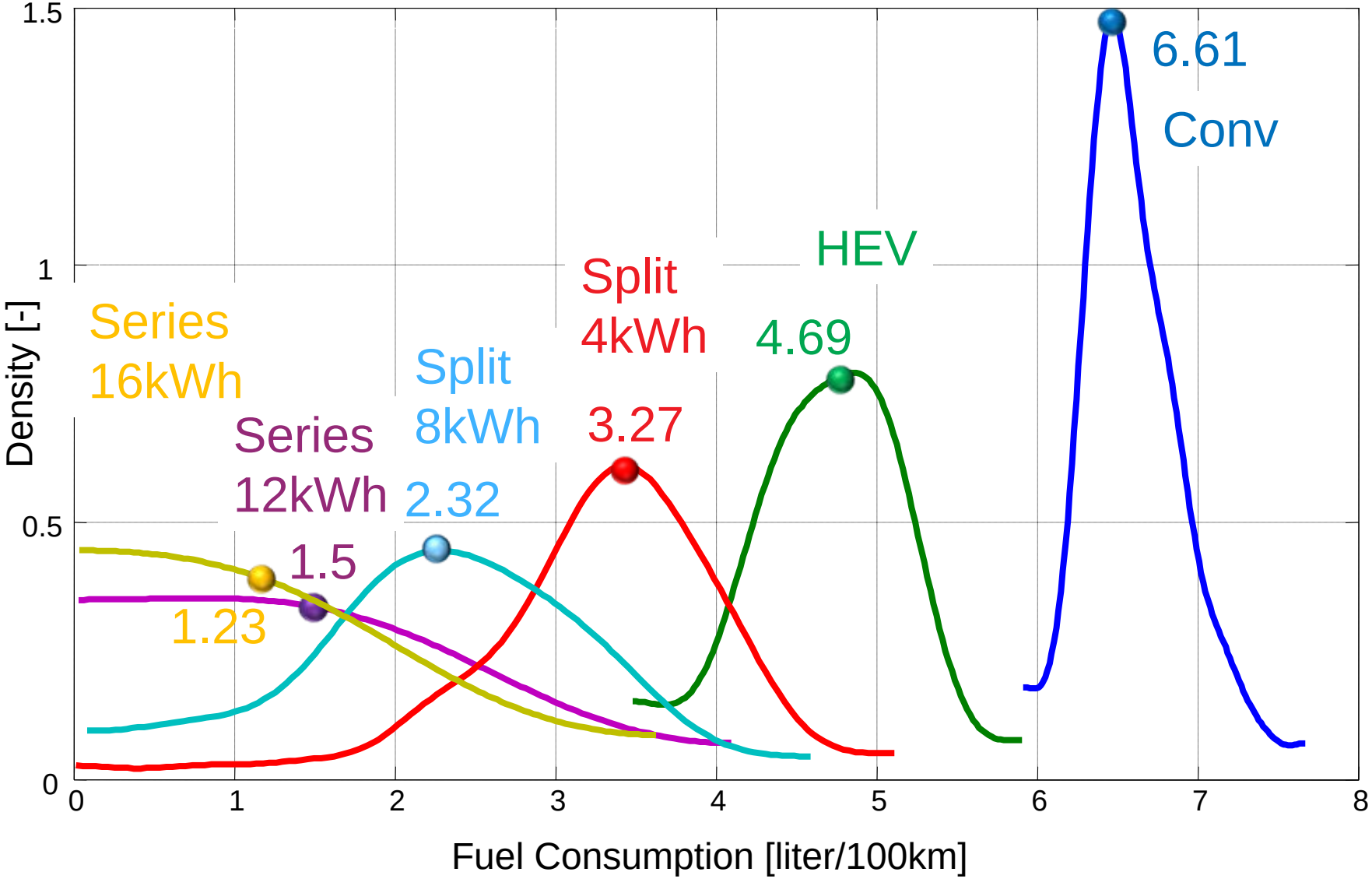


A single control was selected in this presentation based on fuel efficiency, engine ON/OFF and Irms

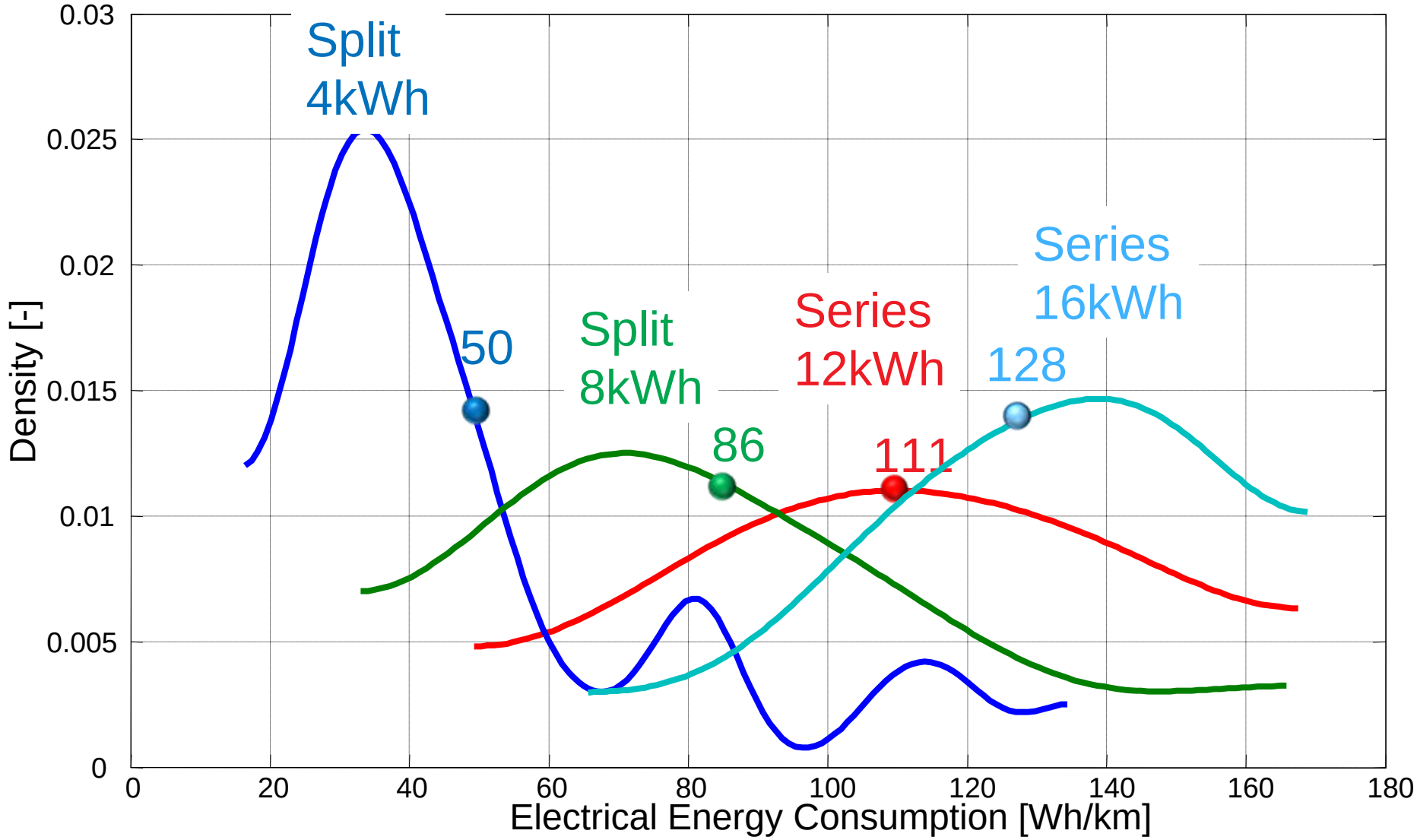
Mean Values for the Configurations Considered



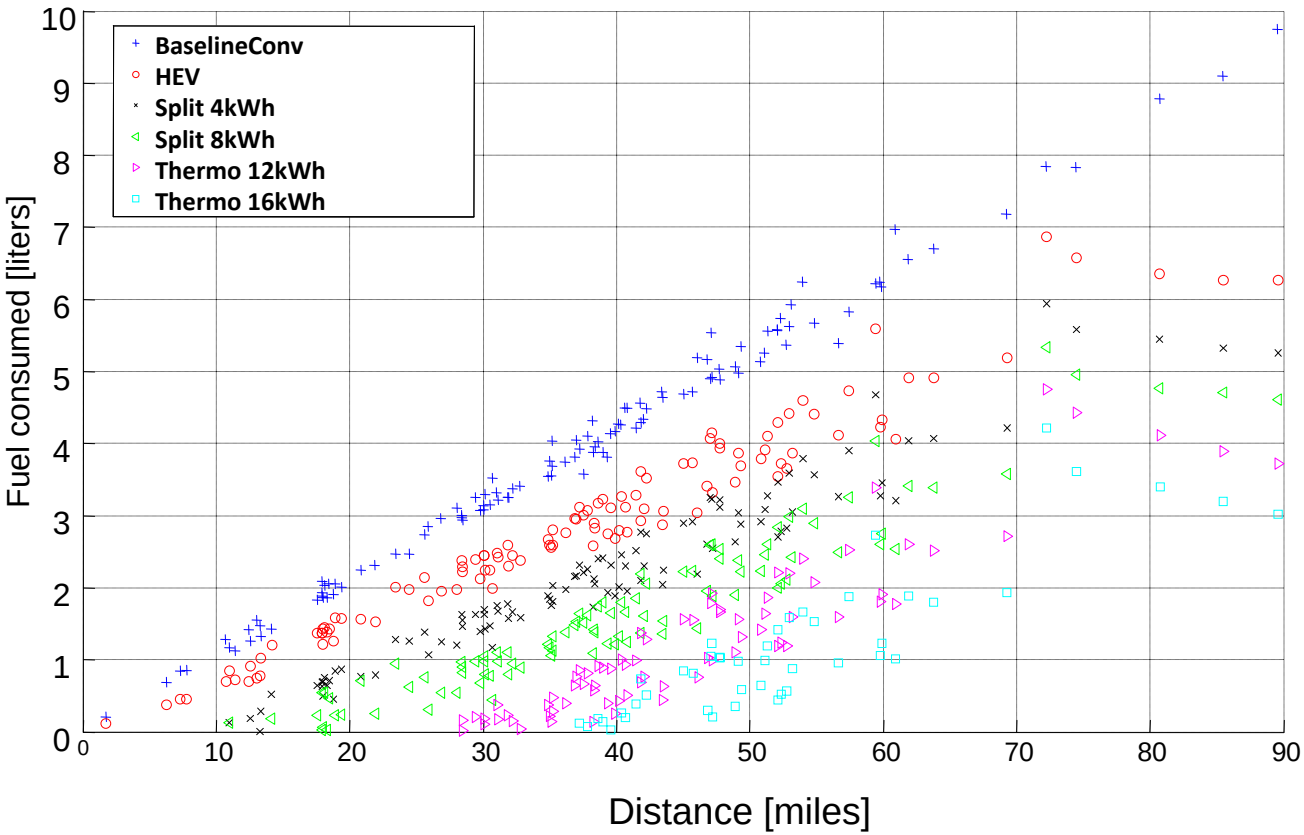
Impact of Battery Energy on Fuel Consumption



Impact of Battery Energy on Electrical Consumption



4kWh Battery Energy Provides 50% of the Gains Achieved with 16 kWh Battery



$$\sum_{conv} = 454.02\ liters$$

$$\sum_{HEV} = 328.61\ liters\ (-27.6\%)$$

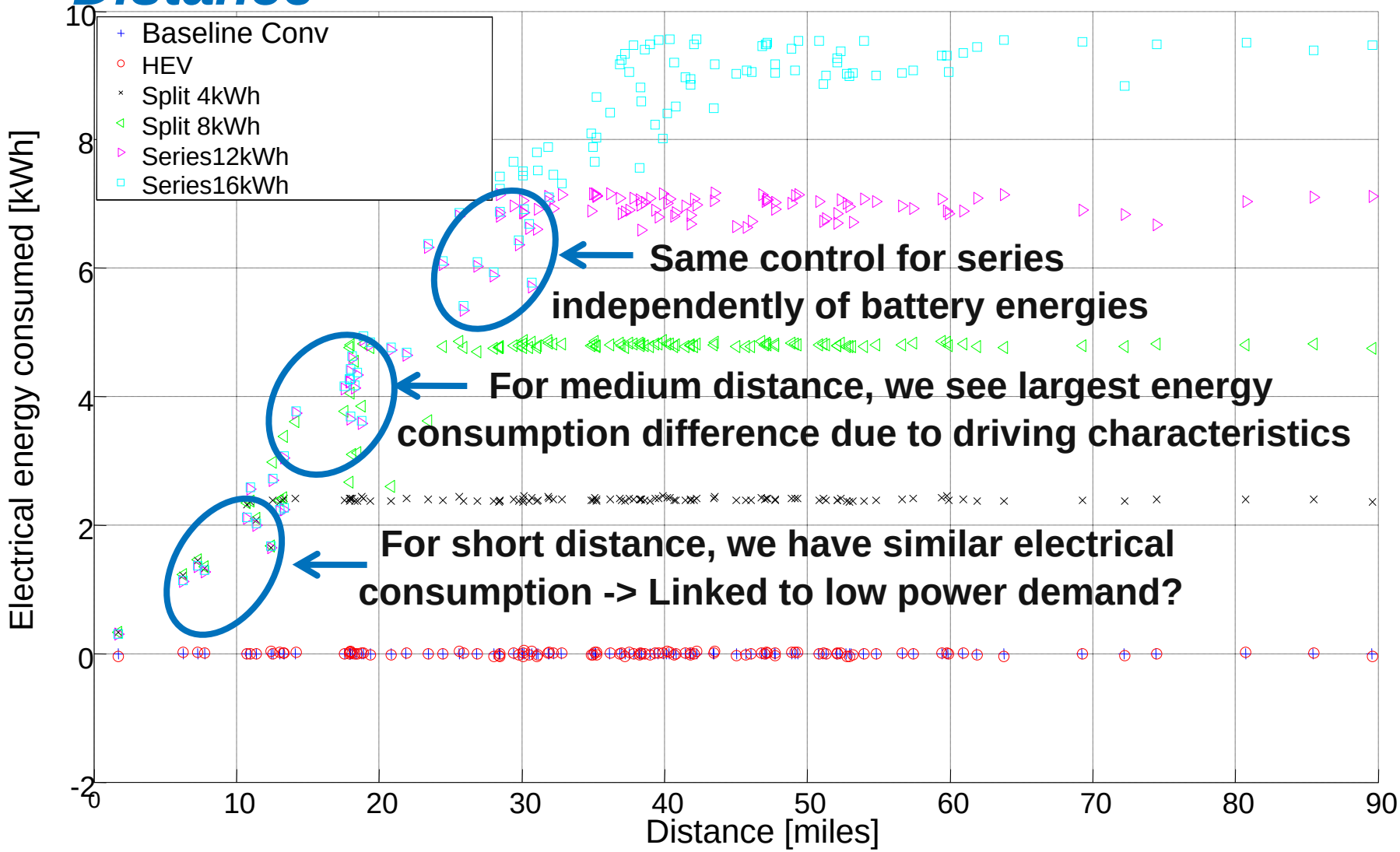
$$\sum_{Split4kwh} = 238.55\ liters\ (-47.5\%)$$

$$\sum_{Split8kwh} = 172.7\ liters\ (-62\%)$$

$$\sum_{Serie12kWh} = 98.8\ liters\ (-78.2\%)$$

$$\sum_{Serie16kWh} = 54.3\ liters\ (-88\%)$$

Used Battery Energy as a Function of Driving Distance

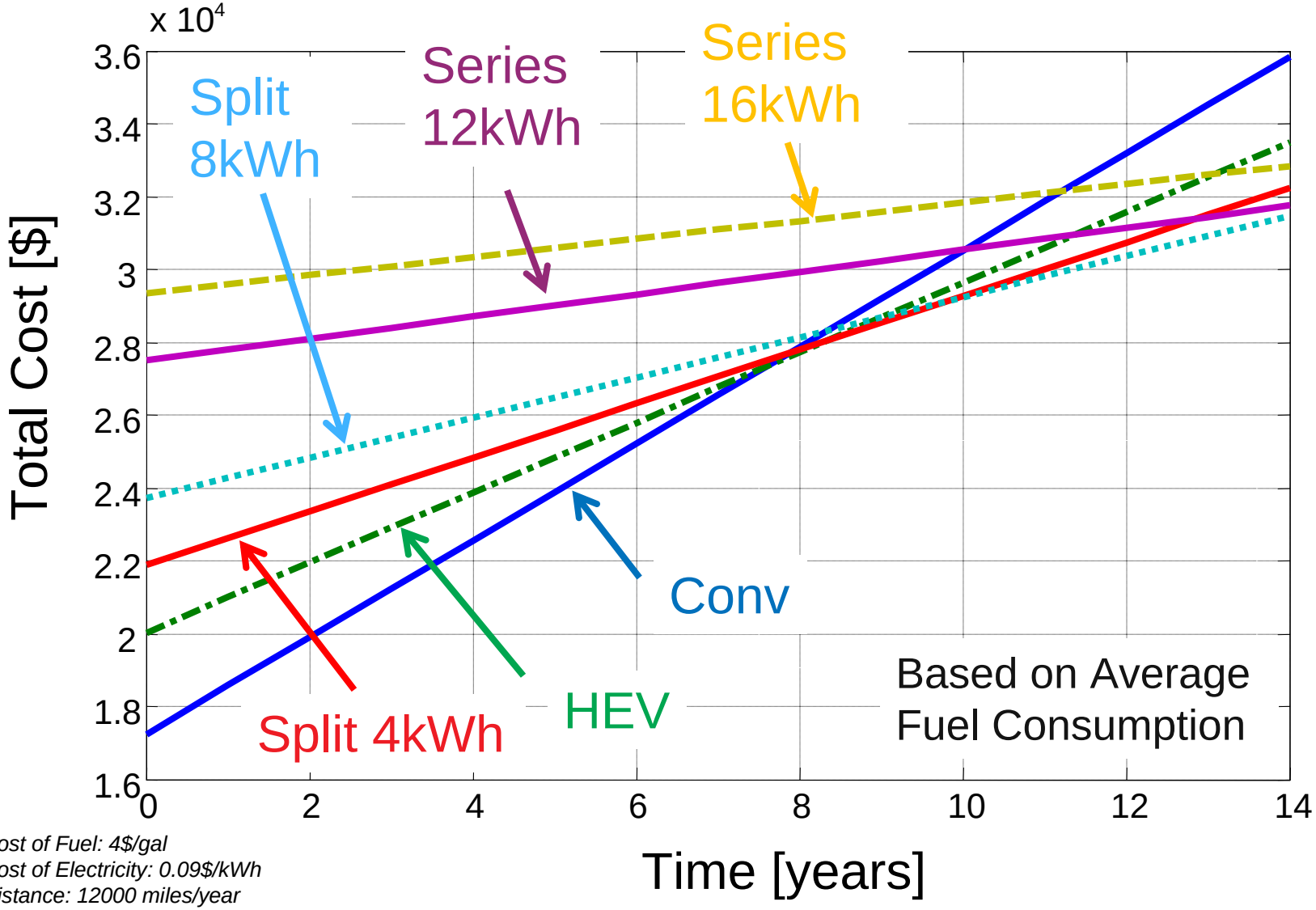


Input Parameters and Assumptions for Cost Analysis

Parameter	Value
Engine	300+3*Power+275*Number_cylinder
HEV Battery	40 $/kW
PHEV Battery	380*Total_Energy + 25*Peak_Power
Electric Machine (EM)	7 $/kW
EM Controller	9 $/kW
Battery Charger	$800

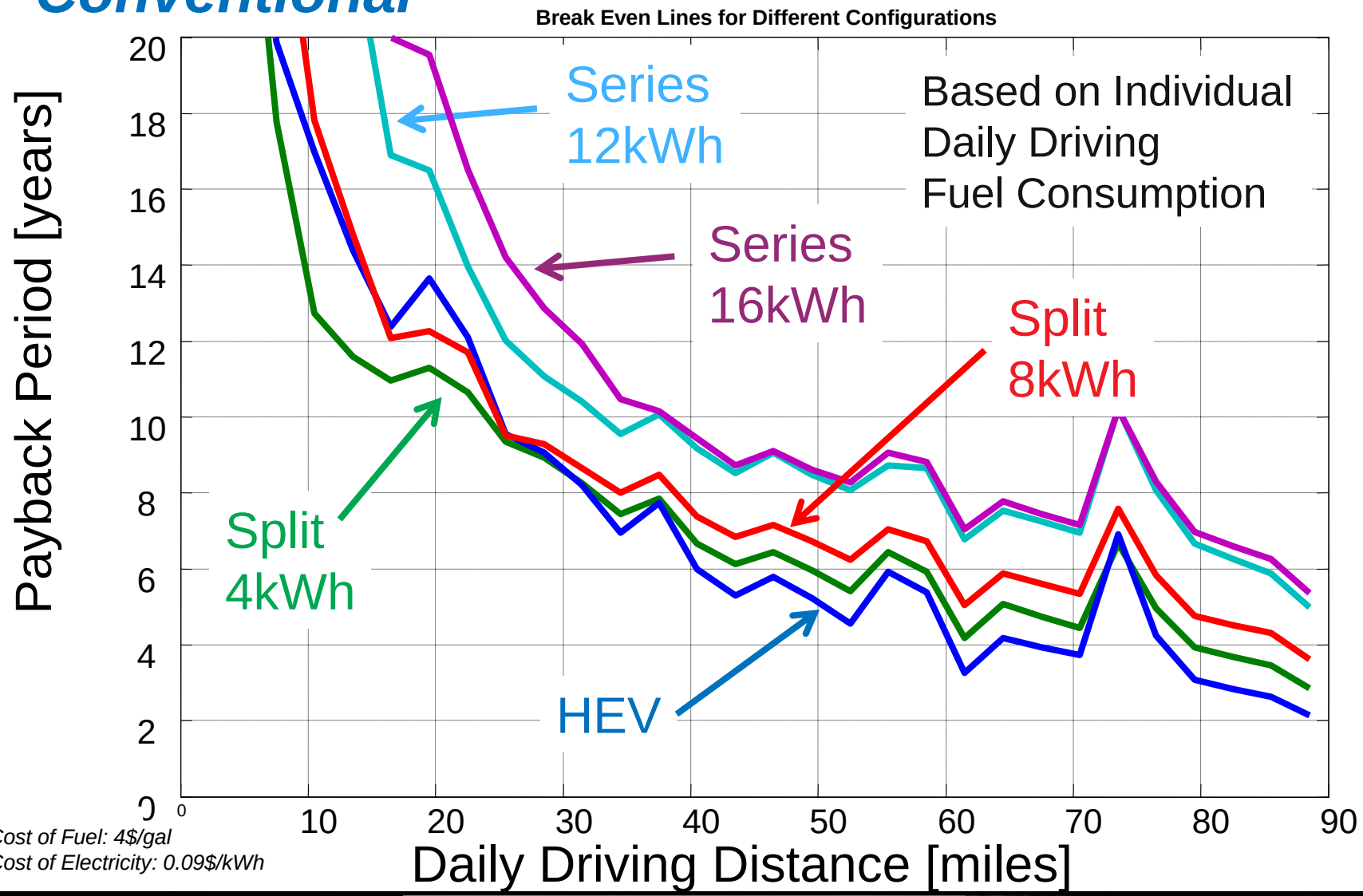
Parameter	Vehicle Cost ($)
Conventional	17245
HEV	20029
PHEV 4kWh	21881
PHEV 8kWh	23709
PHEV 12kWh	27487
PHEV 12kWh	29338

Breakeven Lines Vs. Conventional



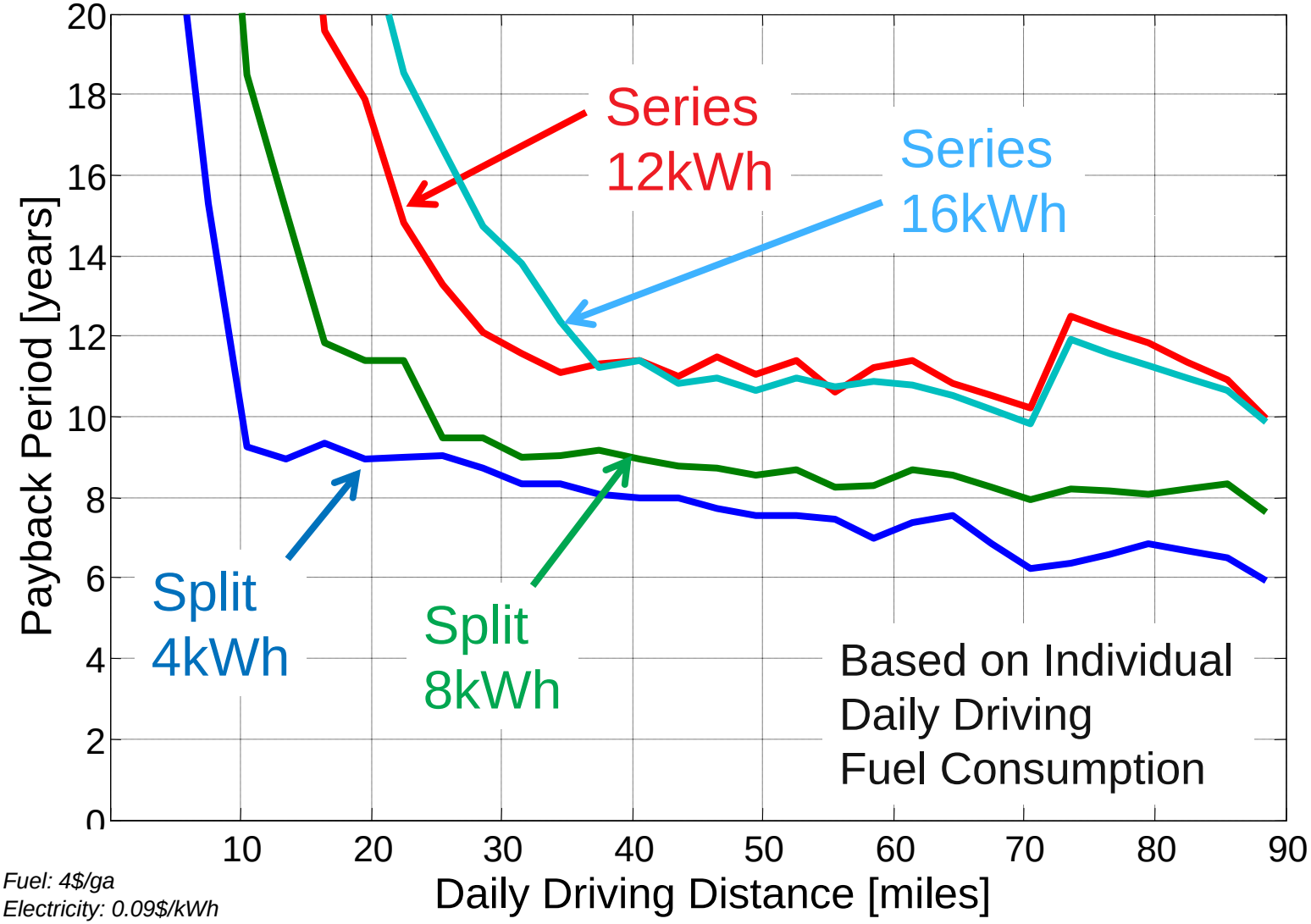
Cost of Fuel: 4$/gal
Cost of Electricity: 0.09$/kWh
Distance: 12000 miles/year

Payback as a Function of Distance Vs. Conventional



Cost of Fuel: 4$/gal
Cost of Electricity: 0.09$/kWh

Payback as a Function of Distance Vs. HEV



Cost of Fuel: 4$/ga
Cost of Electricity: 0.09$/kWh

Conclusions

- Different powertrain configurations, including conventional, HEVs and several PHEVs were simulated on more than 110 real world daily drive cycles.
- The power split configuration was selected for the HEV and PHEV 4 and 8kWh cases, while the series option was used for the largest battery energies (12 and 16 kWh).
- Significant fuel economy gains were demonstrated both with HEVs and PHEVs with fuel displacement increasing linearly with available electrical energy.
- Benefits of adding 4kWh of battery energy seems to decrease from 12 to 16 kWh due to the distribution of the daily driving distances.

Conclusions (Cont'd)

- Benefits of each vehicle configuration depend on how far the vehicle is driven.
- While the electrical consumption is similar for small and long driving distance, the main differences occur during medium trips.
- Based on the assumptions considered (mid-term), the cost of PHEVs remains high, requiring further research and development for batteries and electric machines.
- Higher fuel prices would help too ;)