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Impact of Battery Characteristics on Fuel Economy

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Tampa Bay

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Sponsored by Lee Slezak, U.S. DOE

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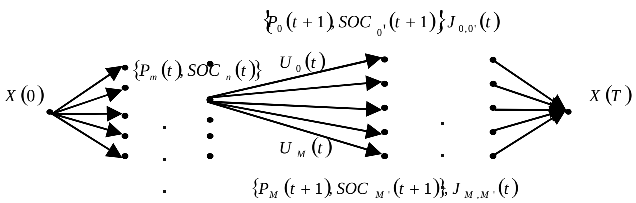
FreedomCAR & Fuel Partnership

Outline

- Process Description
- Optimum Control Strategy
- Impact of Available Energy
- Impact of Peak Power
- Impact of Temperature
  - Battery in an emulated vehicle
  - On-Road vehicle testing
- Conclusions

Battery Characteristics Evaluation Process

Vehicle Simulation



Global Optimization

Battery Hardware

Emulated Vehicle

4WD Test Facility

Natural Cold Test Chamber

Energy & Power

Temperature Effects

100% Modeling

100% Hardware

Global Optimization Allows Fair Comparison of Component Sizes and Technologies

- Knowing the drive cycle, the algorithm defines what would be the optimum component operating points to minimize fuel consumed.
- Algorithm adapts itself to all parameters influencing control:
  - Drive cycle
  - Distance
  - Component size (energy, power) and technology…

Impact of Energy

5 different AER (UDDS)
Power remains constant

Impact of Power

5 different power
Energy remains constant

PSAT Vehicle Assumptions

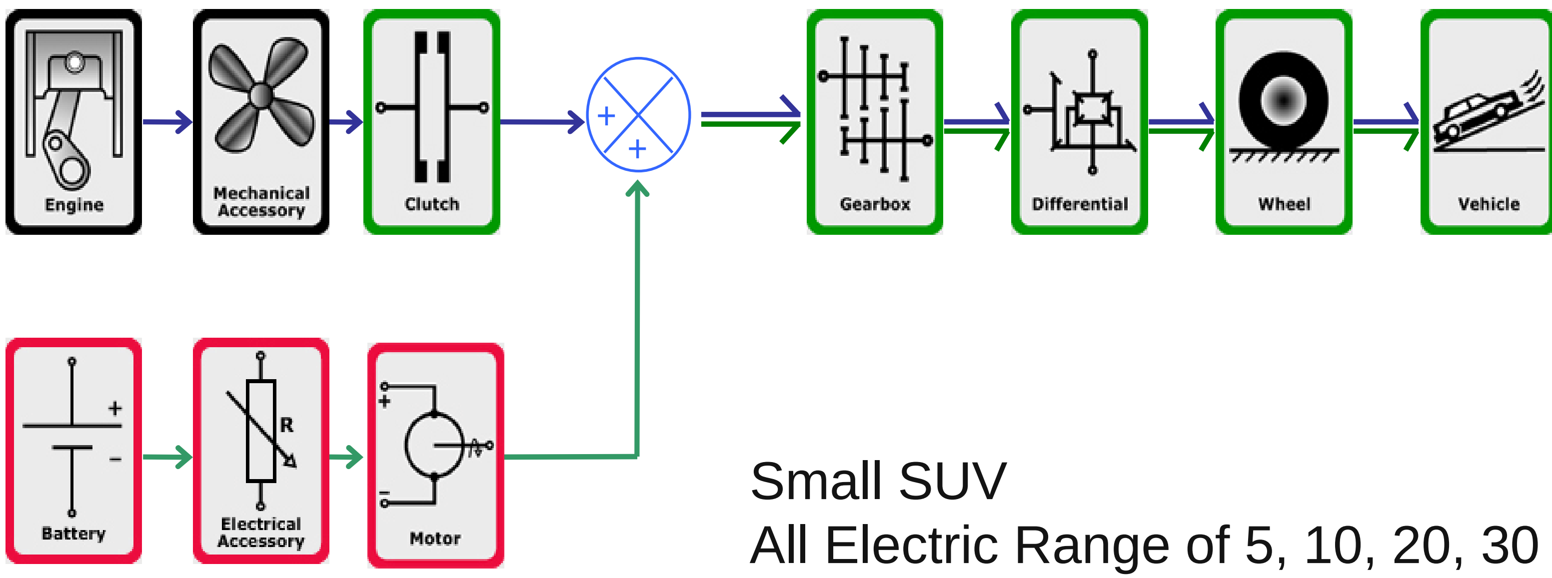
2.3L Ford
Duratec (100kW)

5 Spd
AMT

Ratio
3.8

P195_60_R15
Radius=0.317

Cd = 0.315
FA = 2.244 m^2



Li-ion
JCS
41 Ah
72 cells
61 kW (10s)
6.4 kWh usable

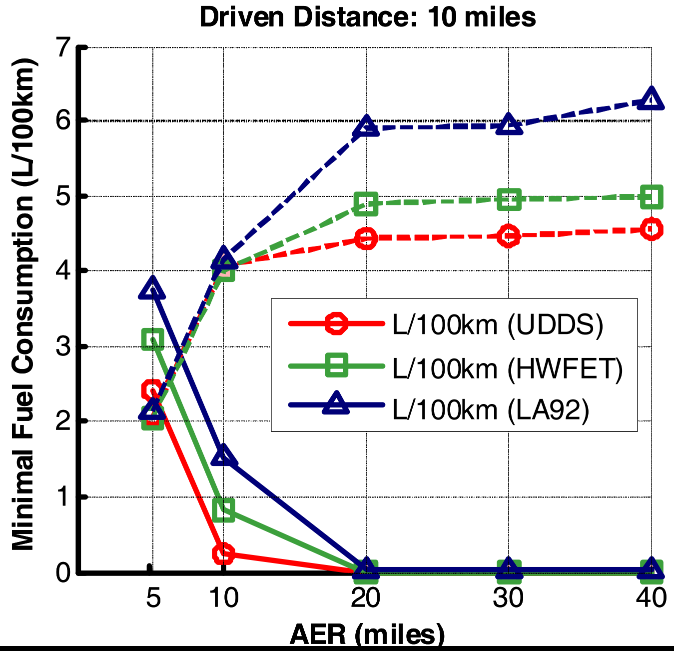
800W

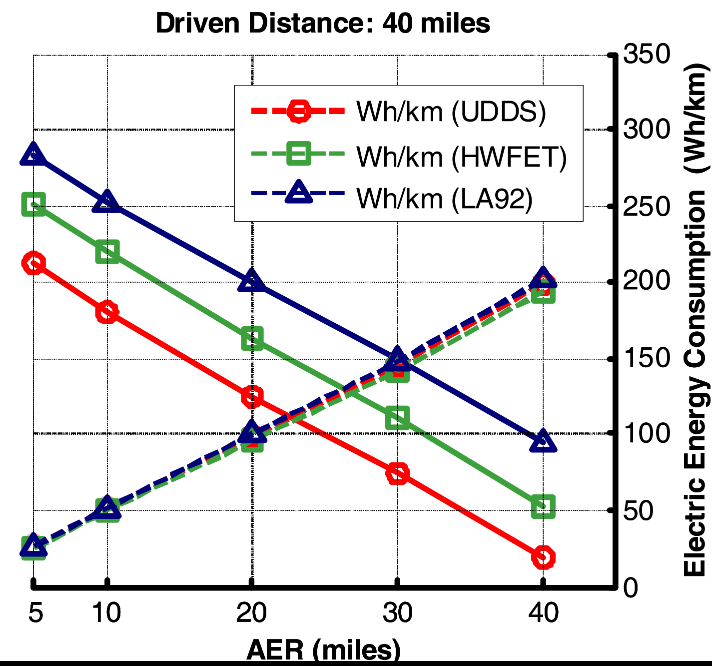
UQM
75kW
Peak

Small SUV
All Electric Range of 5, 10, 20, 30 and 40 miles on UDDS

Energy Sizing Impacts Fuel Displacement when Distance Traveled > AER

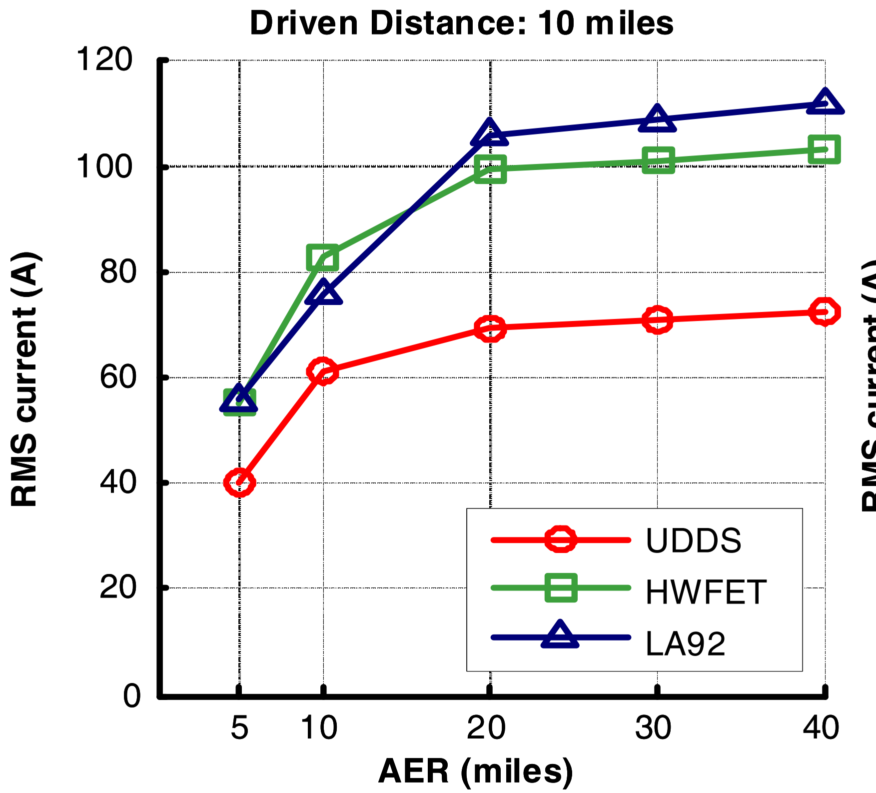
- Distance Traveled < AER
  - On a given cycle, little sensitivity to energy sizing
  - LA92 leads to a 34% increase in electric Wh/km compared to UDDS
- Distance Traveled > AER
  - Decrease in fuel consumption is proportional to increase in AER
  - 1.5 L/100 km difference between UDDS and LA92

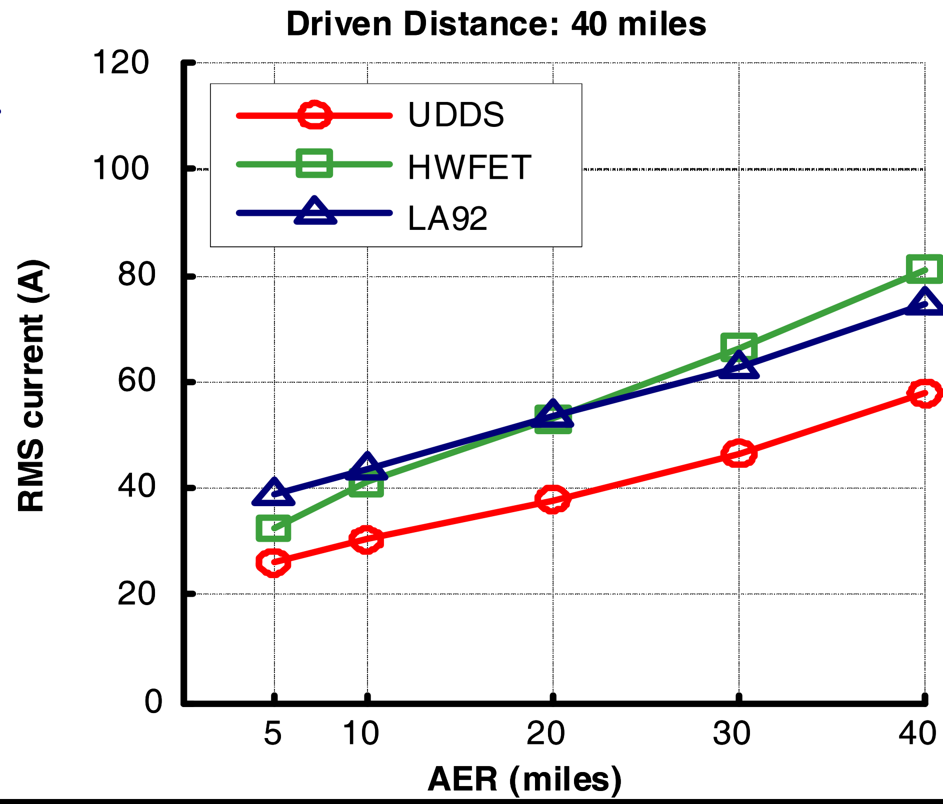




Energy Impact on Battery use depends on Trip Distance

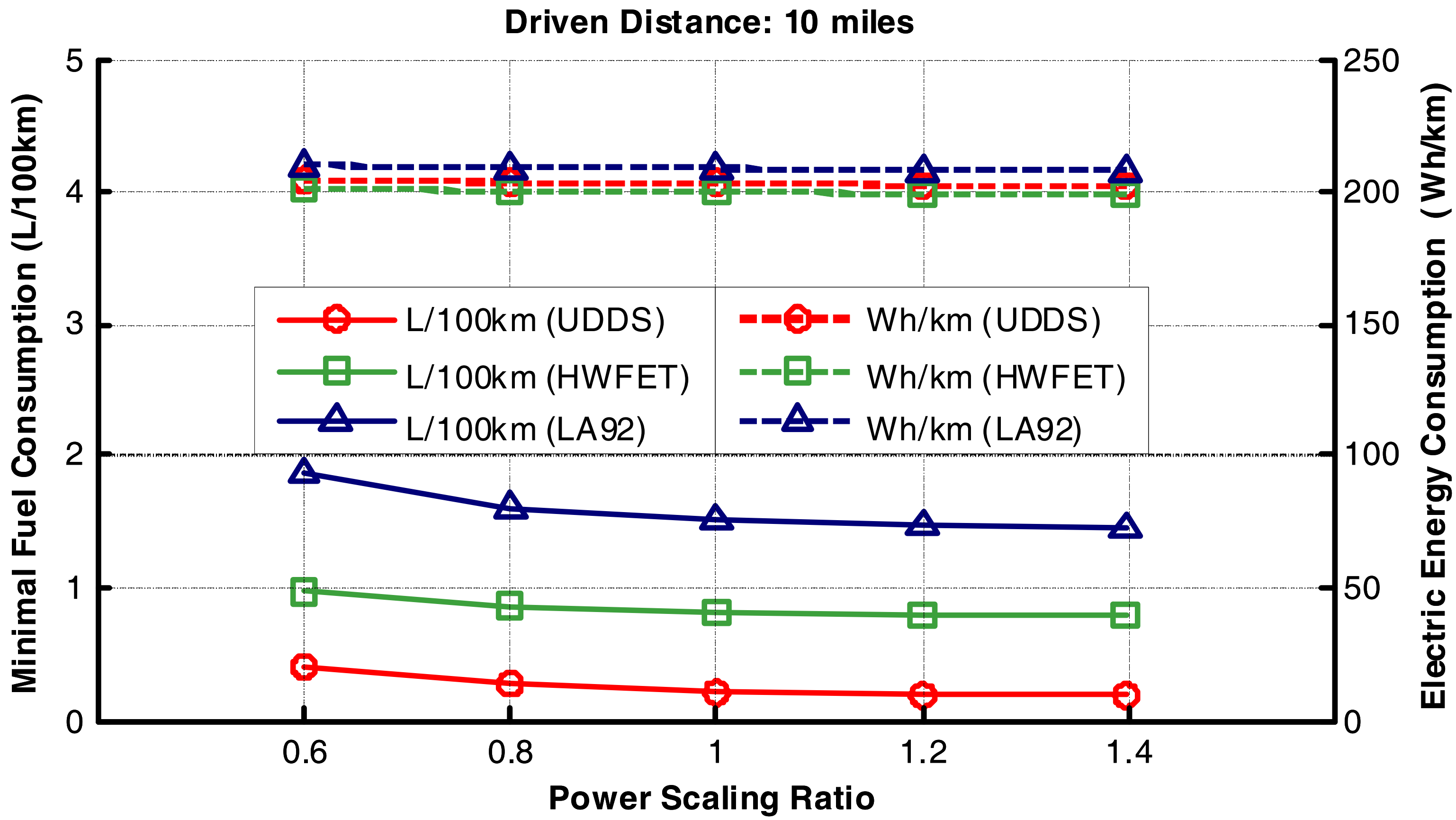
- Distance Traveled < AER,
  - ➡ EV or EV-predominant mode,
  - ➡ Similar RMS current
- Distance Traveled > AER,
  - ➡ Blended mode,
  - ➡ Lower RMS current





Peak Battery Power Has Little Influence on Fuel Consumption

- Lower fuel consumption for lower power levels due to decrease in regenerative braking energy



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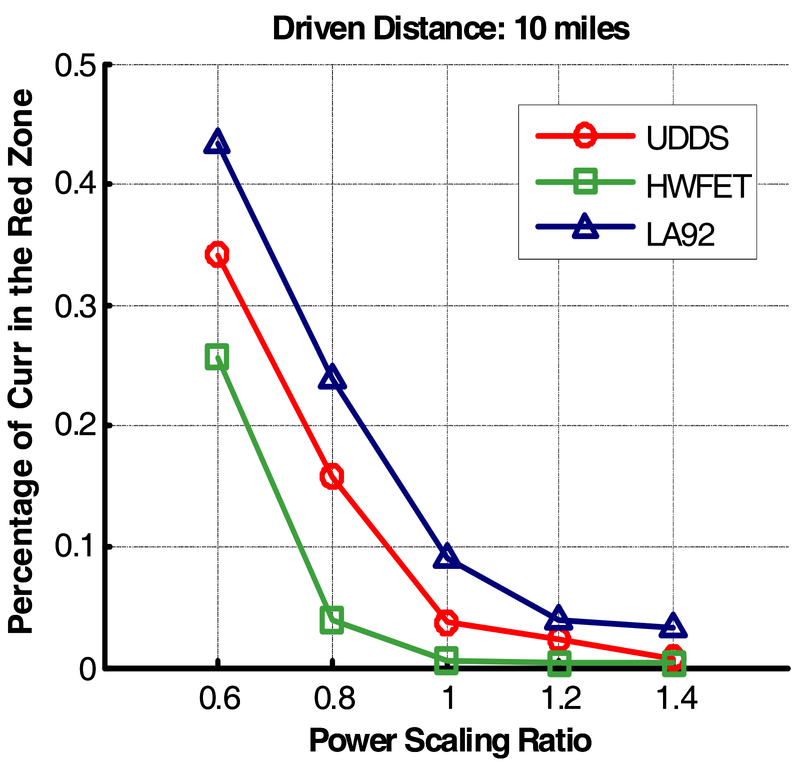
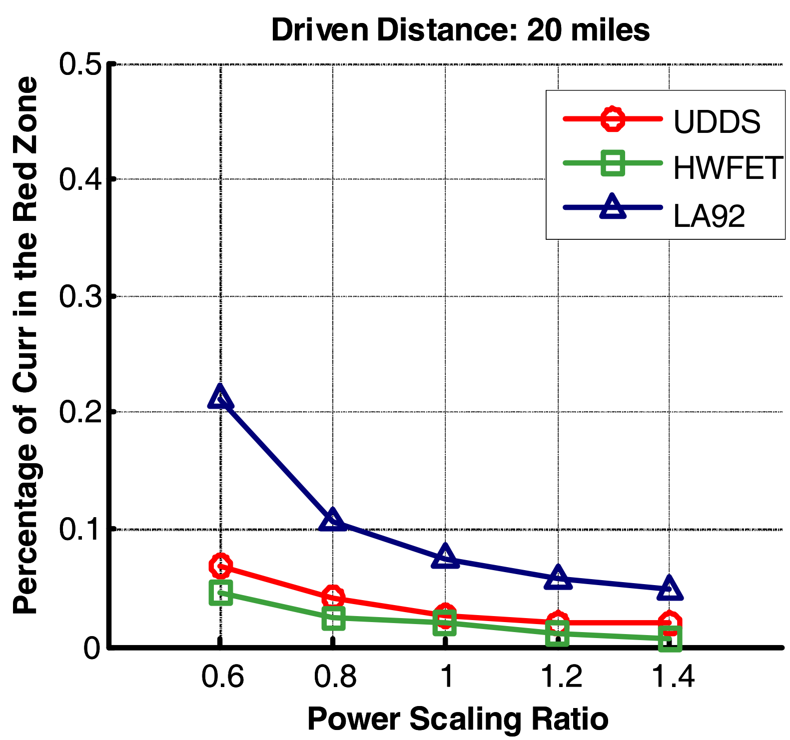
Lower Power Leads to Higher Time Spent at High Currents

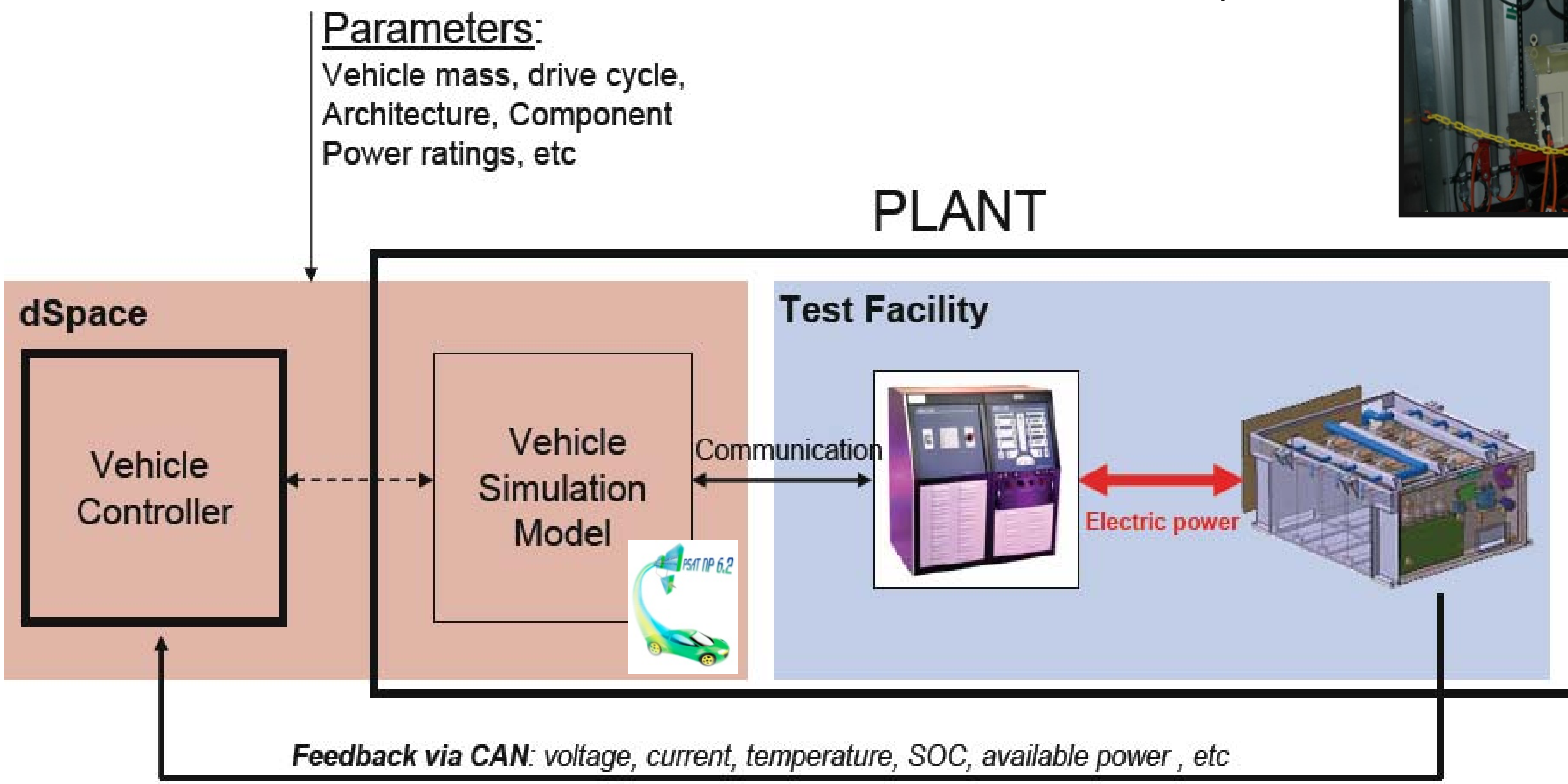




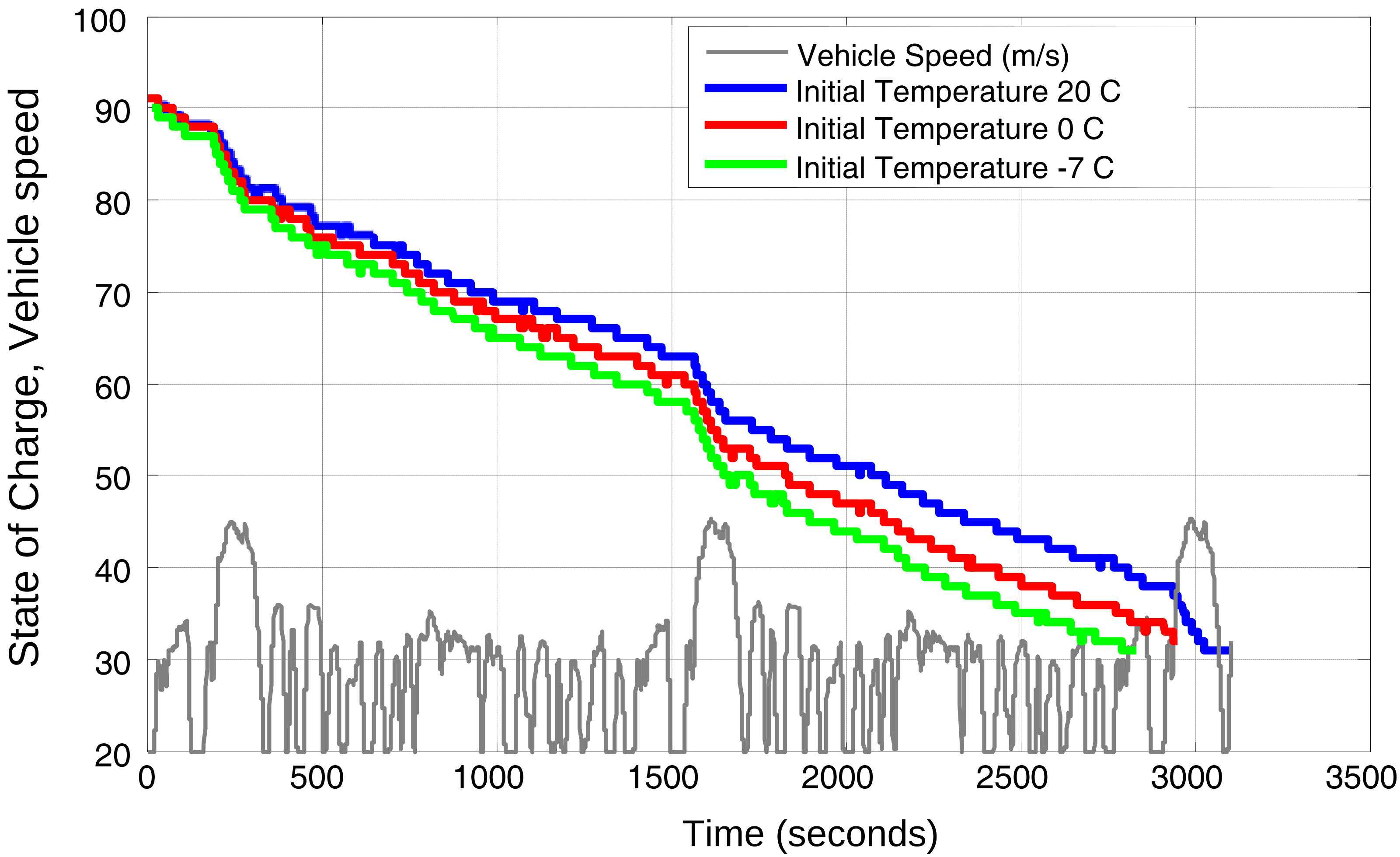
Battery current is considered in the "red zone" when it exceeds the continuous maximum value (>150 Amps for reference)

Evaluation of Battery In An Emulated Vehicle System

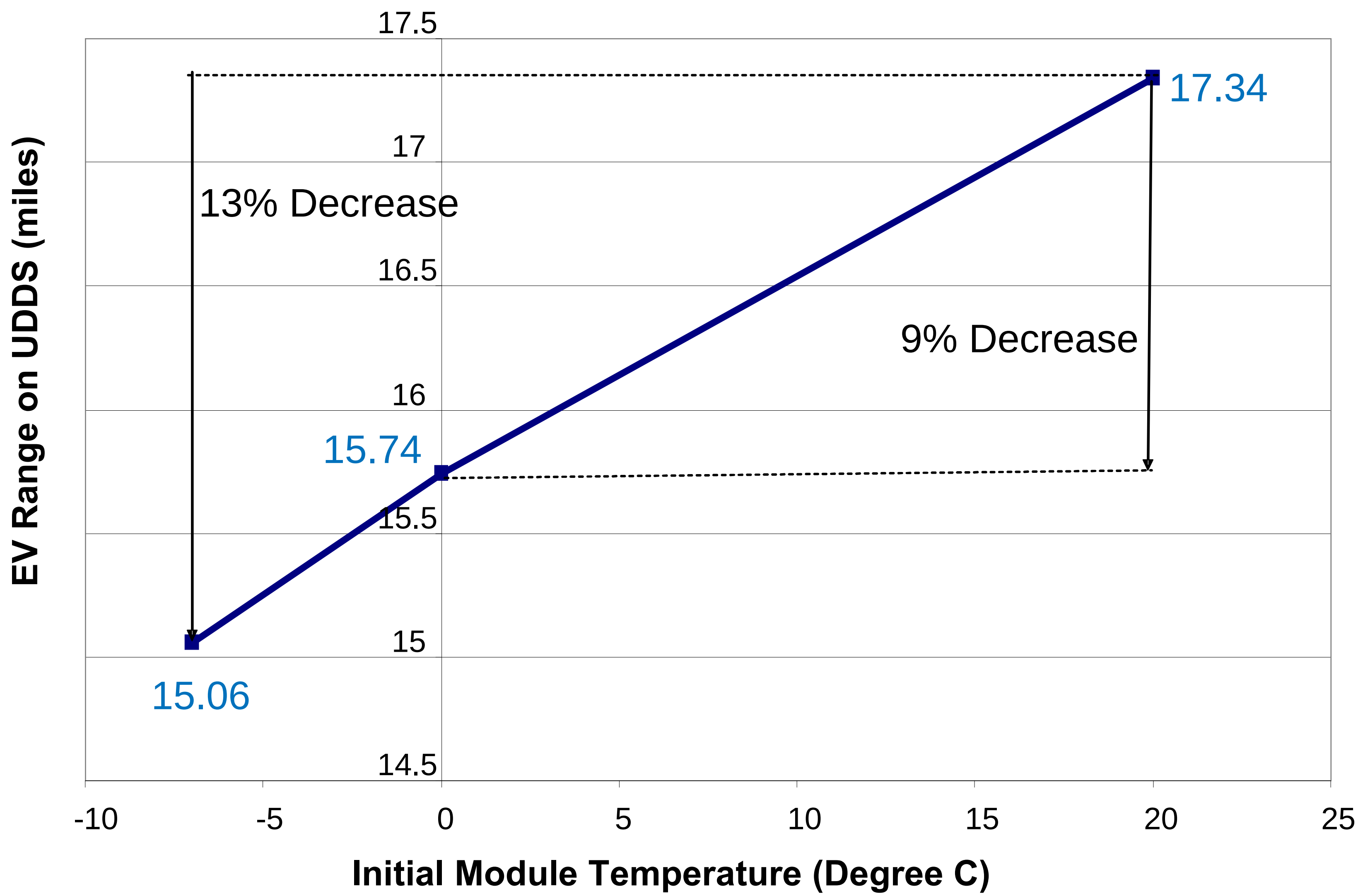
JCS VL41M
260V, 41Ah



AER Decreases with Temperature



AER Drops by 13% at -7C



AER Decrease Mostly Due to Regen Energy and Other Losses than Internal Resistance

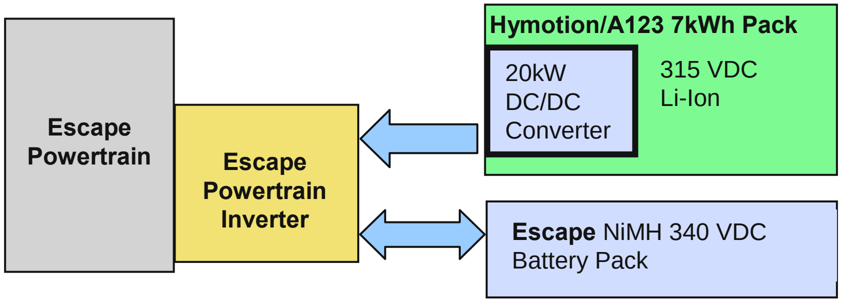
Battery Losses at Lower Temperature

Initial Temperature	Battery kWh	ΔkWh
20	6.2	0
0	5.6	0.53
–7	5.5	0.73

Source

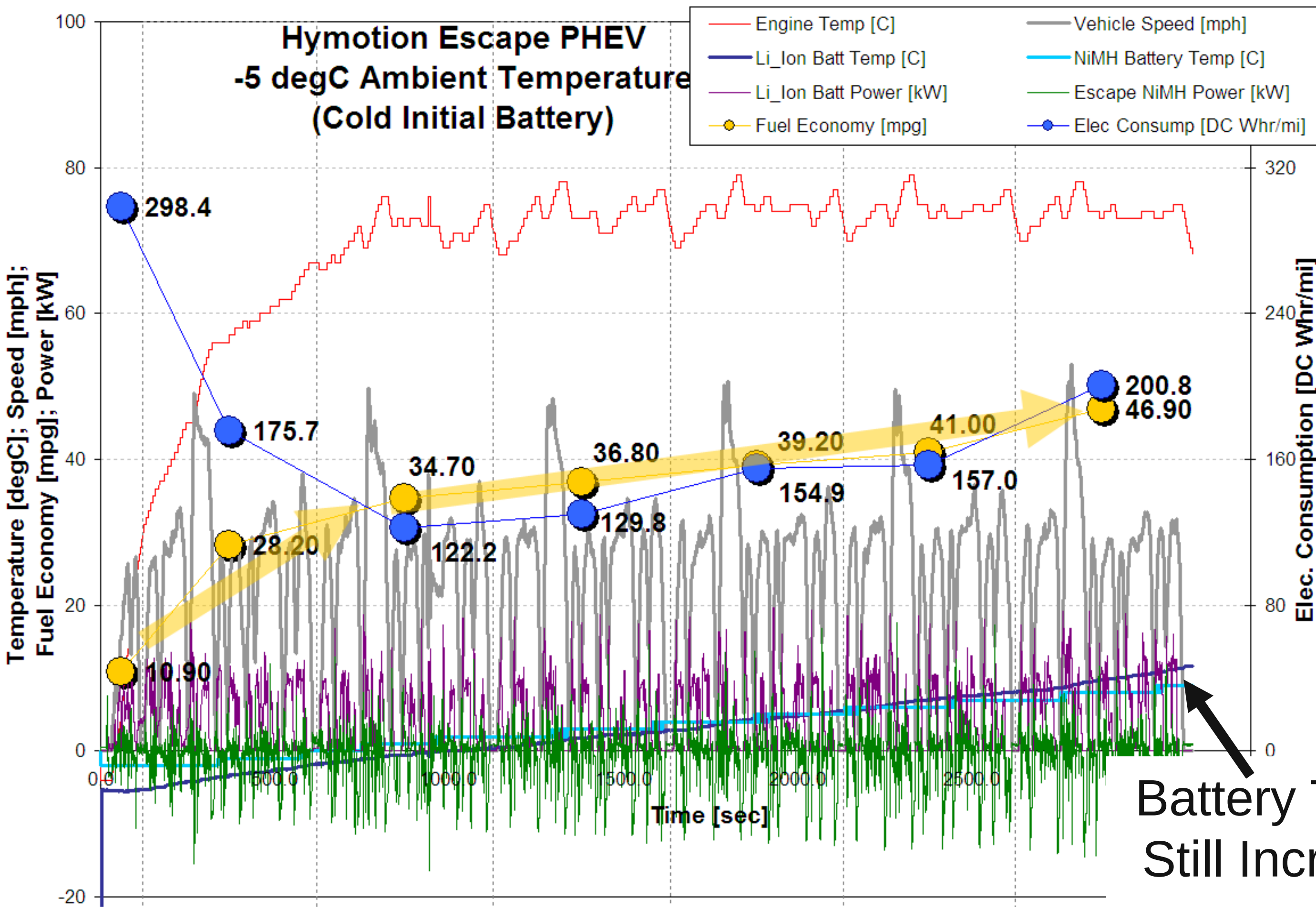
Initial Temperature	ΔWh compared to Wh delivered at 20°C	Δ *Regen Energy* as % of ΔWh	ΔI^2Rt as % of ΔWh	Δ *Other Losses* as % of ΔW
0C	530	34%	8%	58%
–7C	730	34%	12%	54%

Battery Temperature Impact During On-Road Testing



Hymotion Escape PHEV
7 kWh Li-ion (A123)

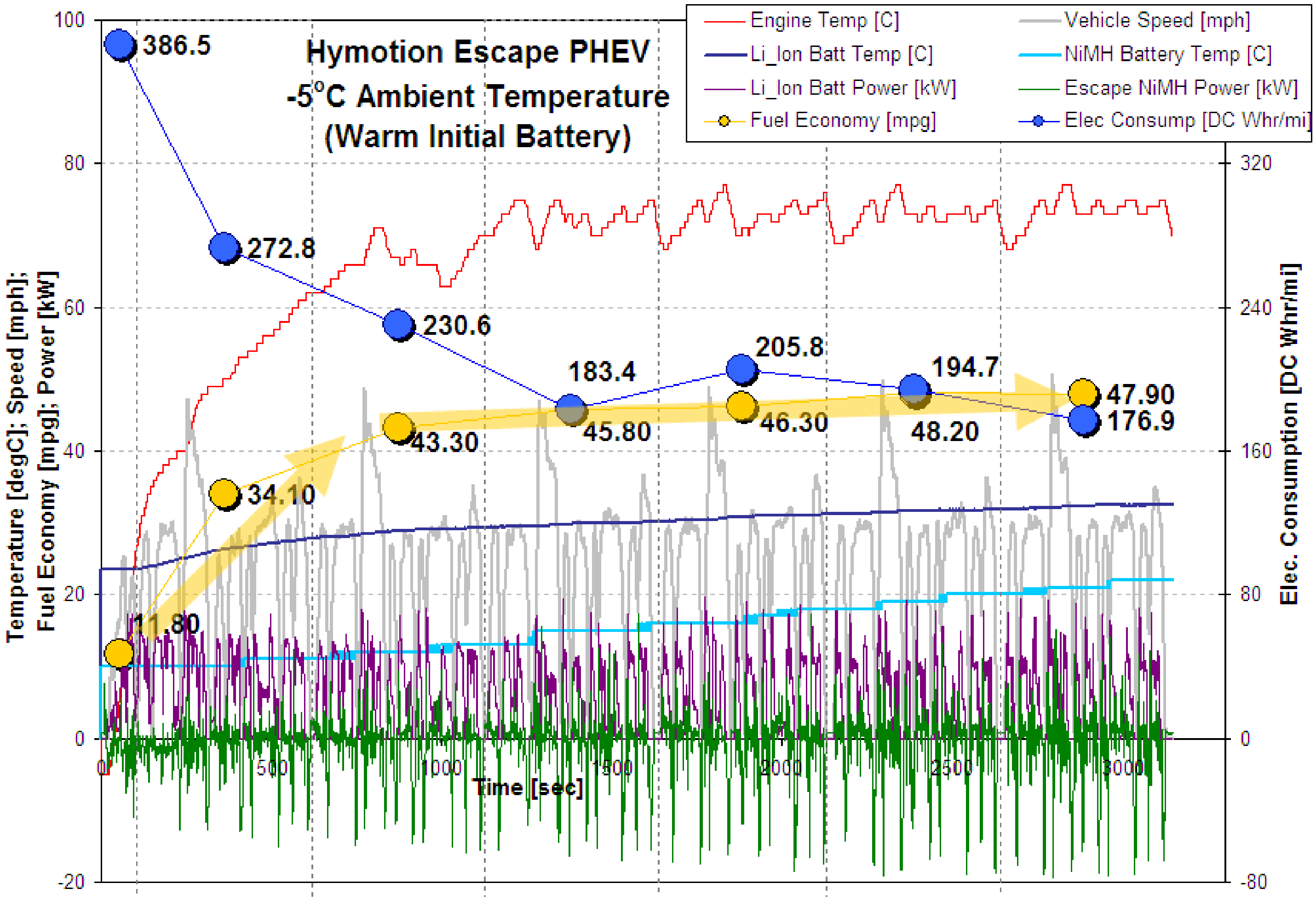
Fuel Economy Still Increases After 20 miles!



Battery Temperature Still Increasing After 60 minutes!

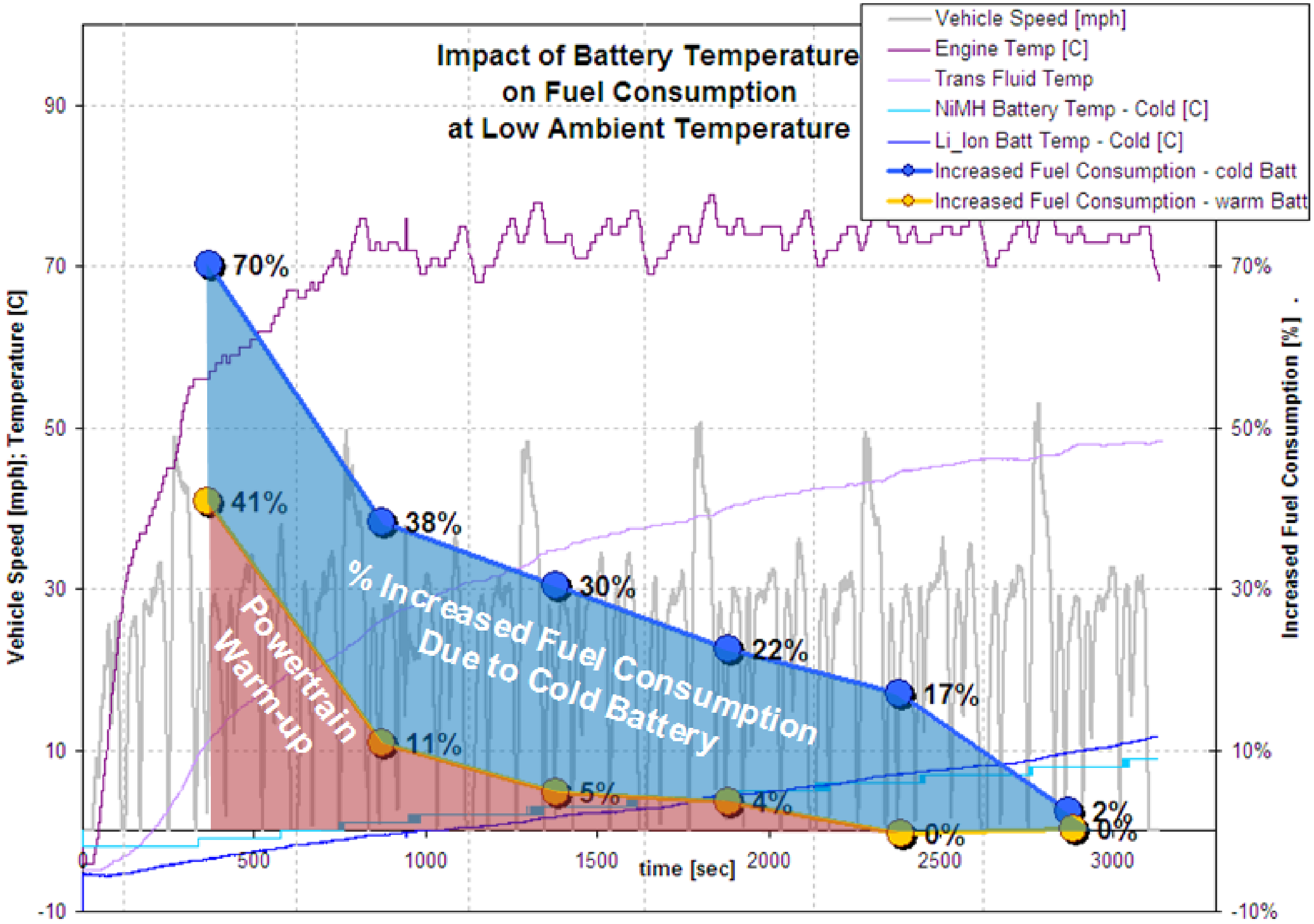
Entire Vehicle Was Cold

Higher Li-ion Temperature Leads to Increased Battery Usage and Lower Fuel Consumption



Both Batteries Warmed – Cold Vehicle

Most of the Fuel Consumption Increase Due to Cold Battery



Percent increase in fuel consumption over steady-state fuel consumption –5°C

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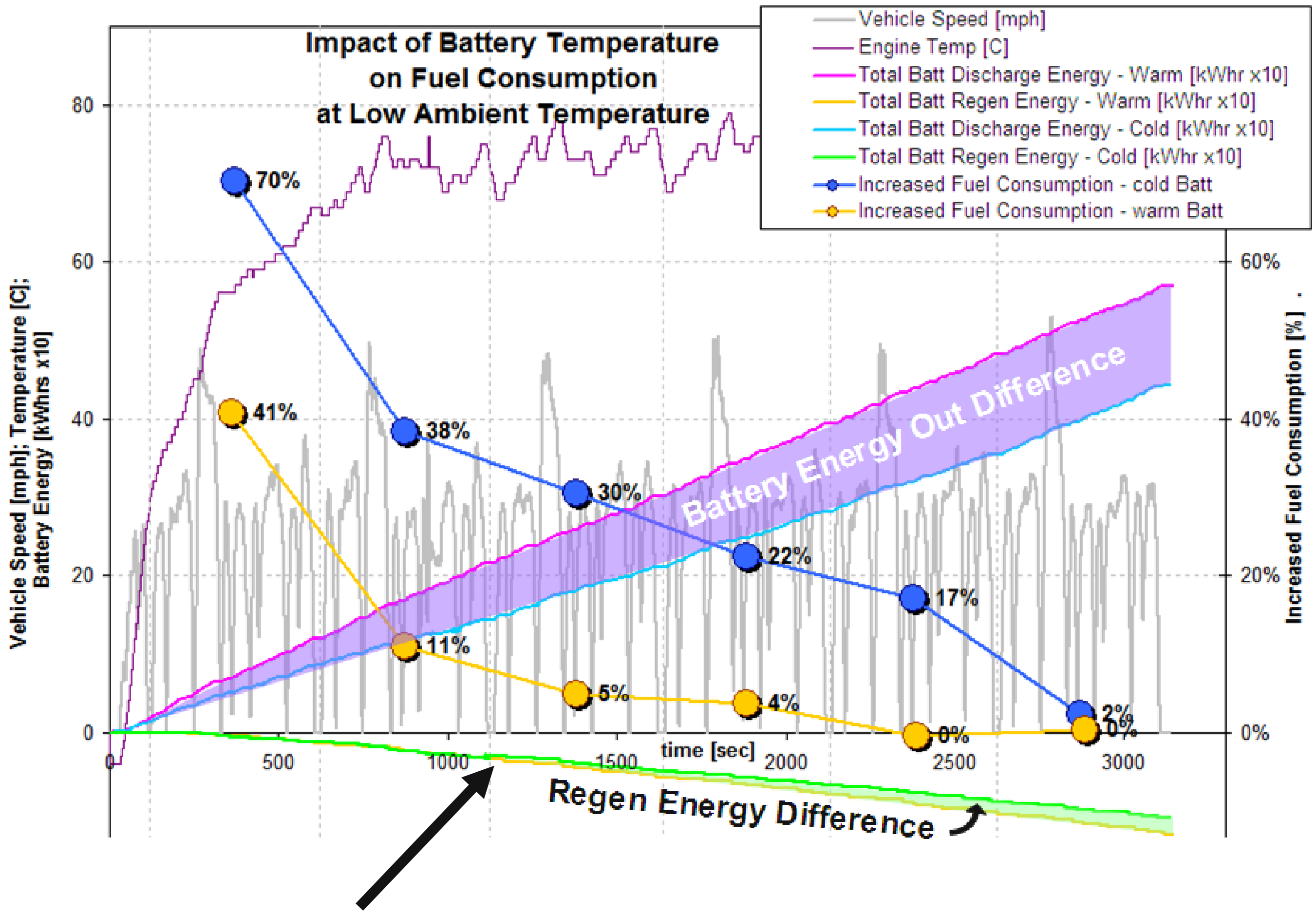
Impact of Cold Battery Mostly Due to Discharge Energy



Regenerative Braking Difference only Due to NiMH

Conclusion

- When the distance driven is higher than the AER, the optimal control is blended. As the engine is operated at high power, the battery RMS current is lowered.
- The available battery energy has significant impact on fuel consumption.
- The peak battery power affects fuel consumption mostly with regard to regenerative braking energy.
- The RMS battery current is influenced by several factors:
  - Blended control lowers Irms
  - Irms increases with electrical consumption
- Lower power batteries operate more often above their continuous current limits

Conclusion (cont'd)

- Testing a battery in an emulated vehicle, the AER decreases by 9% at 0°C and by 13% at -7°C, as compared with 20°C conditions. Decreases in regenerative braking energy combined with "other losses" explain the changes.
- For the PHEV conversion tested, the on-road test results demonstrated that:
  - The powertrain warm-up causes most of the losses during the early stage of the drive cycle (10 minutes)
  - The battery pack then accounts for most of the changes in fuel consumption
- At cold temperatures, control limitations, especially discharging energy, are the main reason for lower fuel economy.