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PHEV Battery Requirements – Uncertainty Based on Real World Drive Cycles and Impact on Fuel Efficiency

International Conference on Li-ion Batteries for Automotive Applications

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Ed Nam

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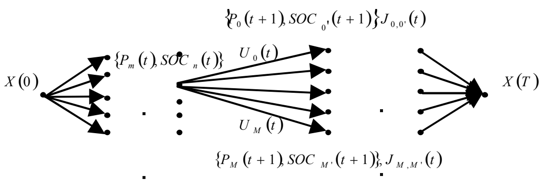
How are The Current Power and Energy Requirements Impacted by Real World Drive Cycles?

How does the Temperature Impacts Fuel Efficiency?

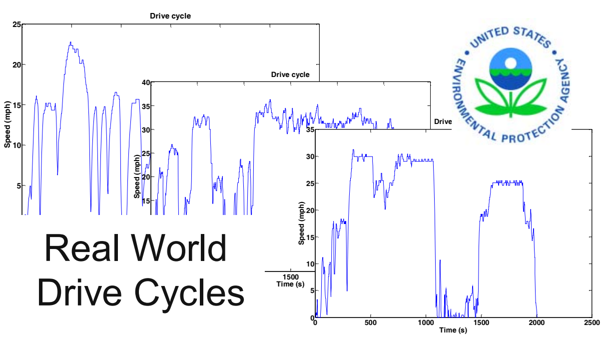
Characteristics at EOL (End of Life)		Short-Term Commercialization	Long-Term Commercialization
Commercialization Target	Year	**2012**	**2016**
Peak Pulse Discharge Power (10 sec)	kW	**45**	**38**
Peak Regen Pulse Power (10 sec)	kW	**30**	**25**
Available Energy for CD (Charge Depleting) Mode, 10 kW Rate	kWh	**3.4**	**11.6**
Available Energy for CS (Charge Sustaining) Mode	kWh	**0.5**	**0.3**
Minimum Round-trip Energy Efficiency (USABC HEV Cycle)	%	**90**	**90**
Cold cranking power at -30°C, 2 sec - 3 Pulses	kW	**7**	**7**
CD Life / Discharge Throughput	Cycles/MWh	**5,000 / 17**	**5,000 / 58**
CS HEV Cycle Life, 50 Wh Profile	Cycles	**300,000**	**300,000**
Calendar Life, 40°C	year	**15**	**15**
Maximum System Weight	kg	**60**	**120**
Maximum System Volume	Liter	**40**	**80**
Maximum Operating Voltage	Vdc	**400**	**400**
Minimum Operating Voltage	Vdc	**>0.55 x Vmax**	**>0.55 x Vmax**
Maximum Self-discharge	Wh/day	**50**	**50**
System Recharge Rate at 30°C	kW	**1.4 (120V/15A)**	**1.4 (120V/15A)**
Unassisted Operating & Charging Temperature Range	°C	**-30 to +52**	**-30 to +52**
Survival Temperature Range	°C	**-46 to +66**	**-46 to +66**
Maximum System Production Price @ 100k units/yr	$	**$1,700**	**$3,400**

Battery Requirements Evaluation Process

Vehicle Simulation



Global Optimization



Real World Drive Cycles

Battery Hardware

Emulated Vehicle

4WD Test Facility

Natural Cold Test Chamber

Energy & Power

Temperature Effects

100% Modeling

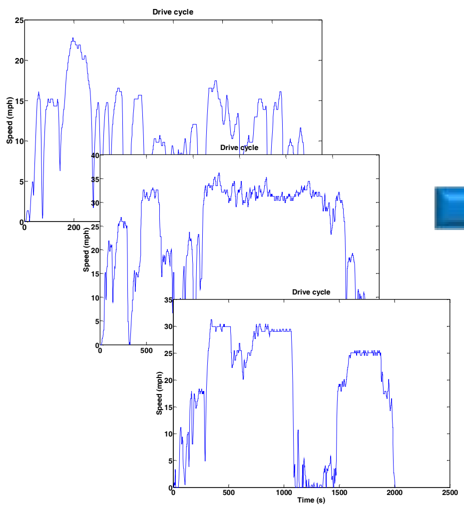
100% Hardware

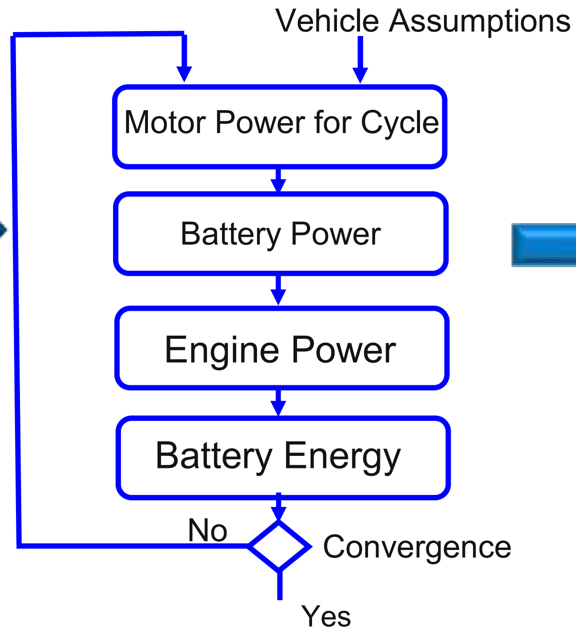
Objective: Impact of Real World Drive Cycles on Power and Energy Requirements

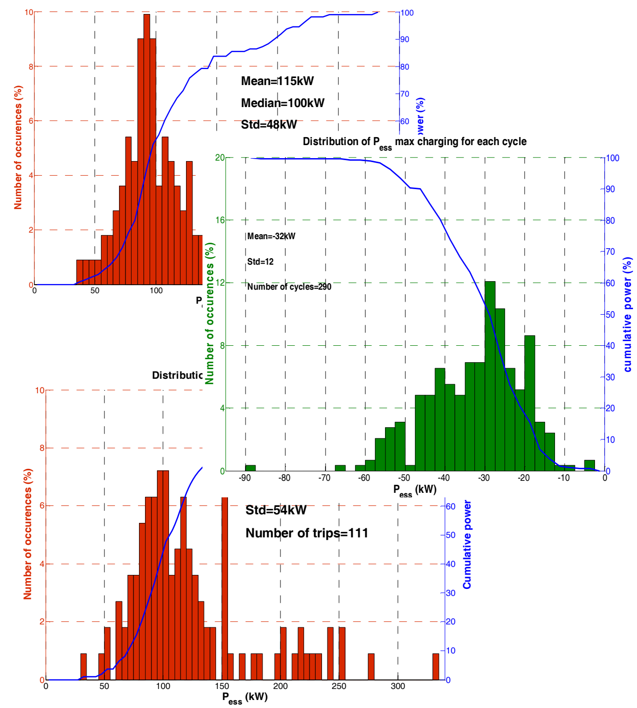
Real World Drive Cycles

Automated Sizing

Analysis (Distribution)







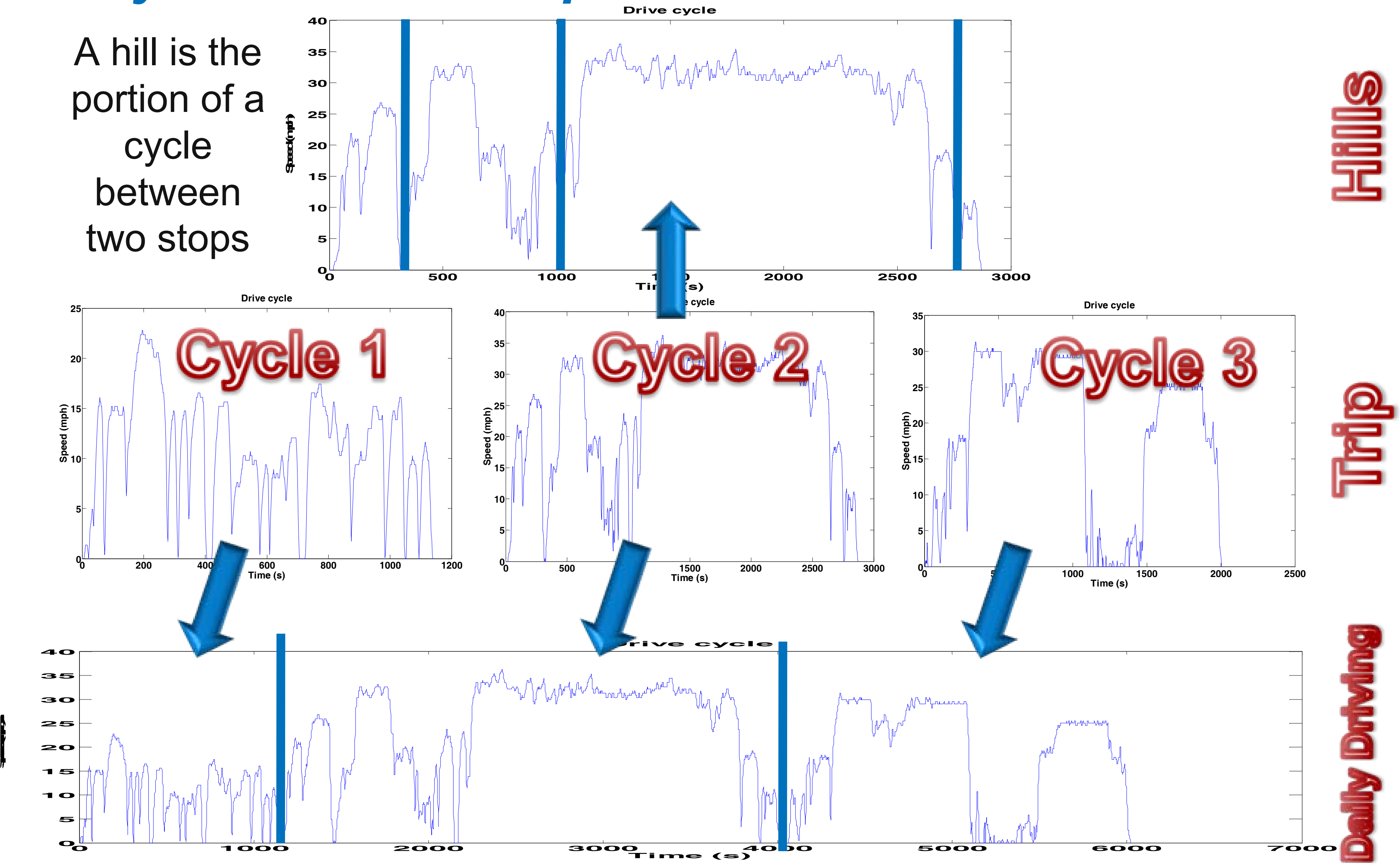
>110 Trips
One day in
Kansas City

Power Split
Midsize Vehicle

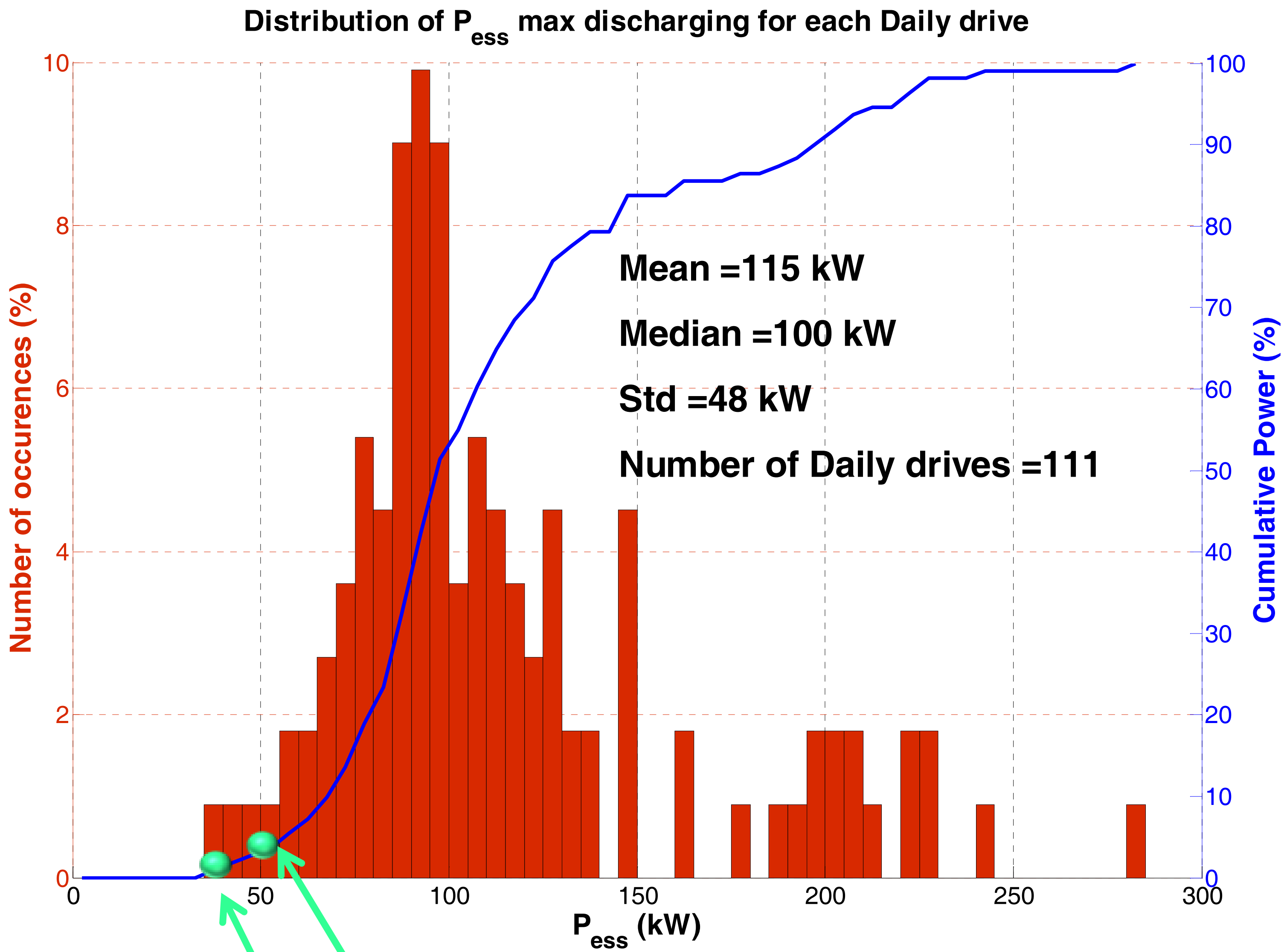
Only Hot Conditions Assumed!

Analysis of Vehicle Speed Traces at Different Levels

A hill is the portion of a cycle between two stops



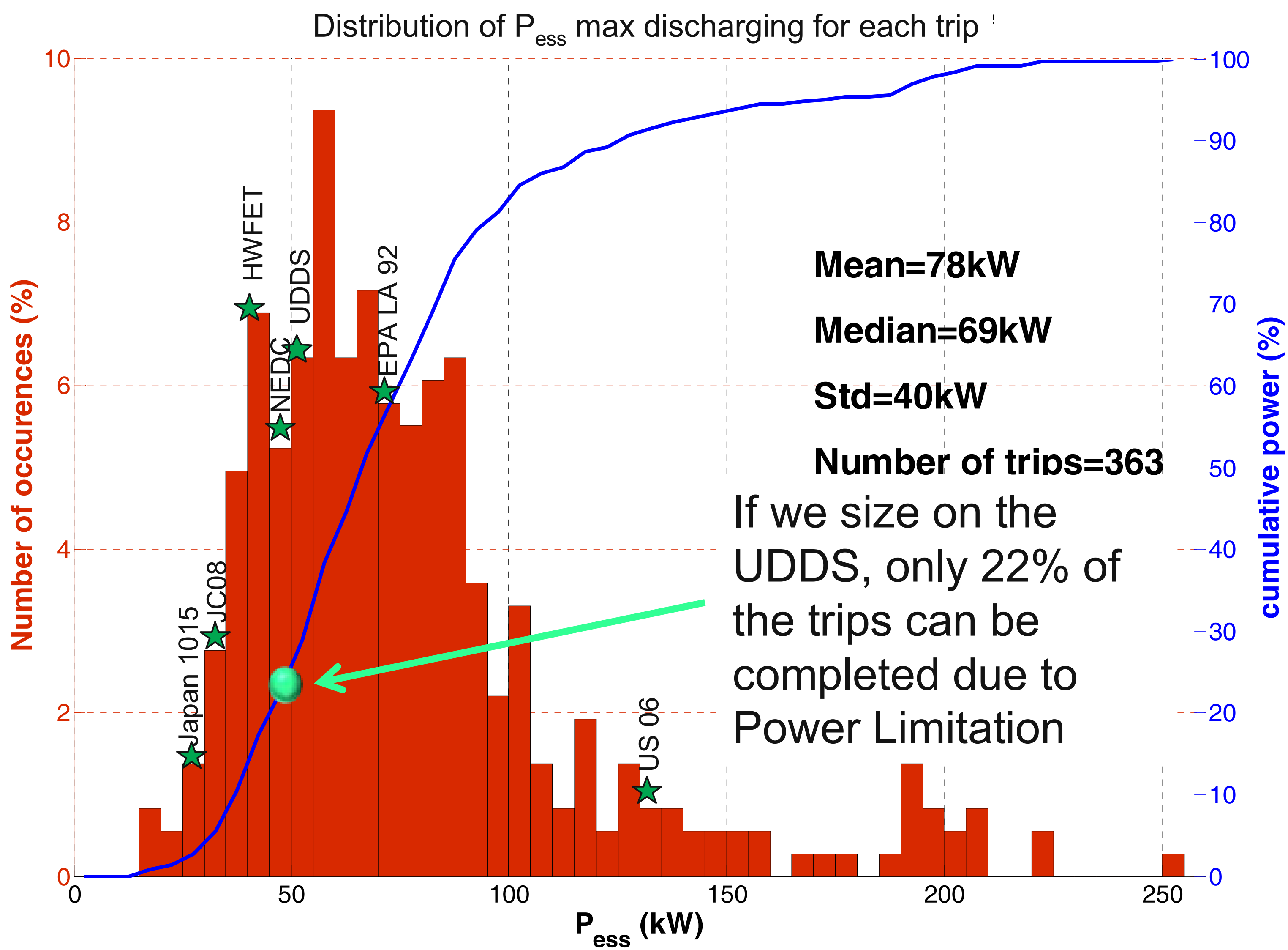
50% of the Daily Trips Require >100 kW



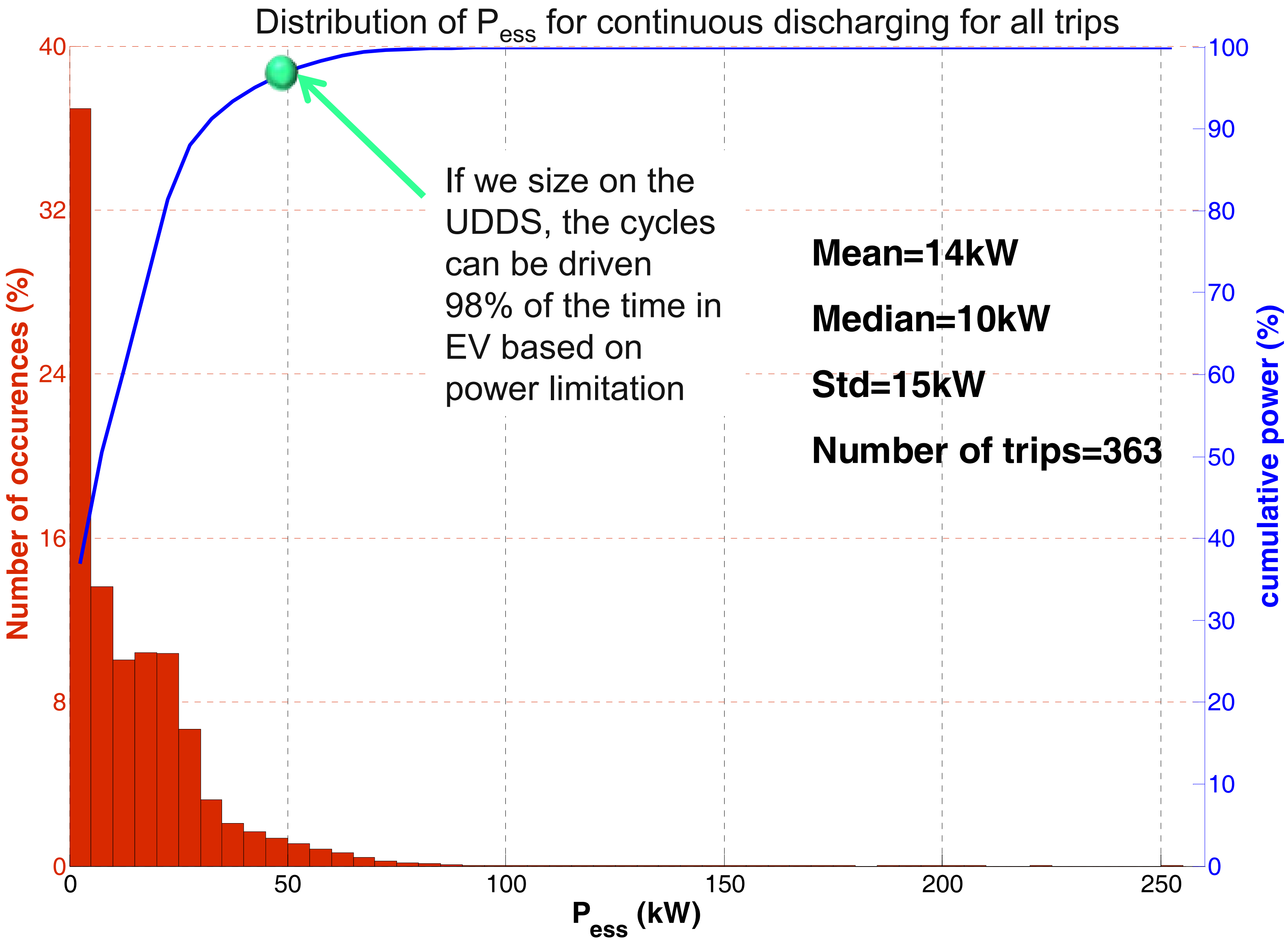
DOE Requirement (50 kW) => 3.5%

DOE Requirement (46 kW) => 2.9%

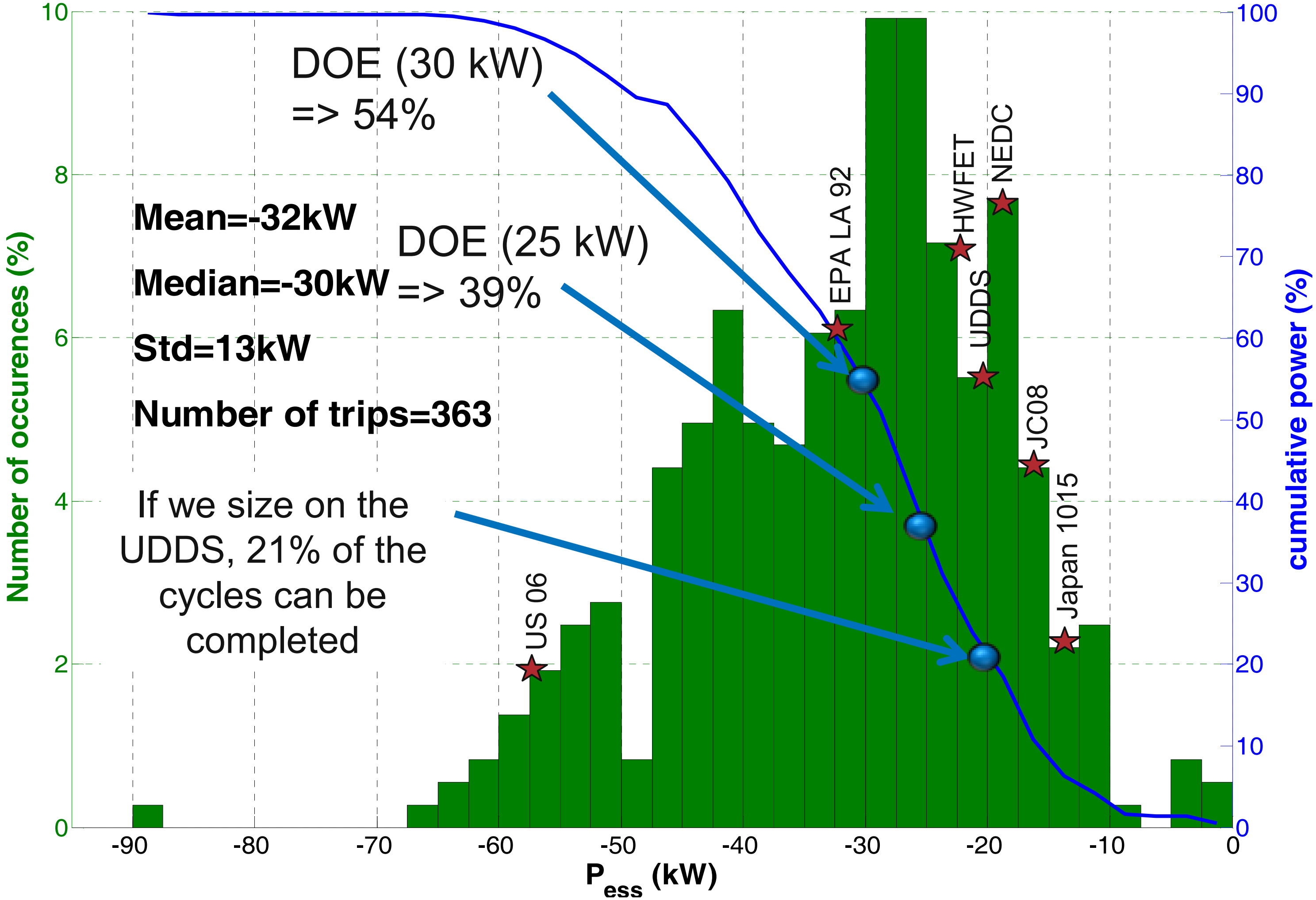
Distribution of Discharging Peak Power Per Trip



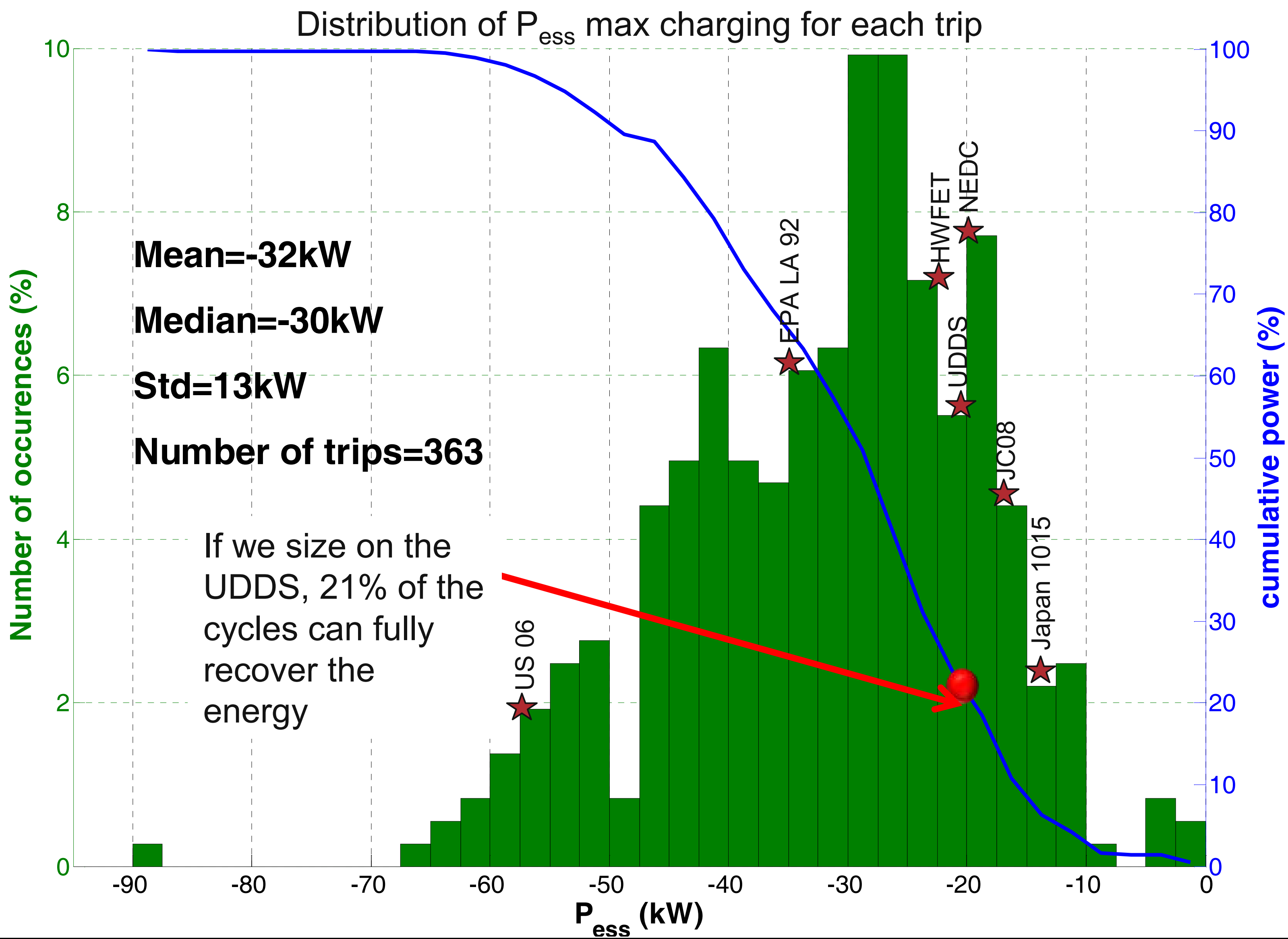
Distribution of Discharging Power (All Points)



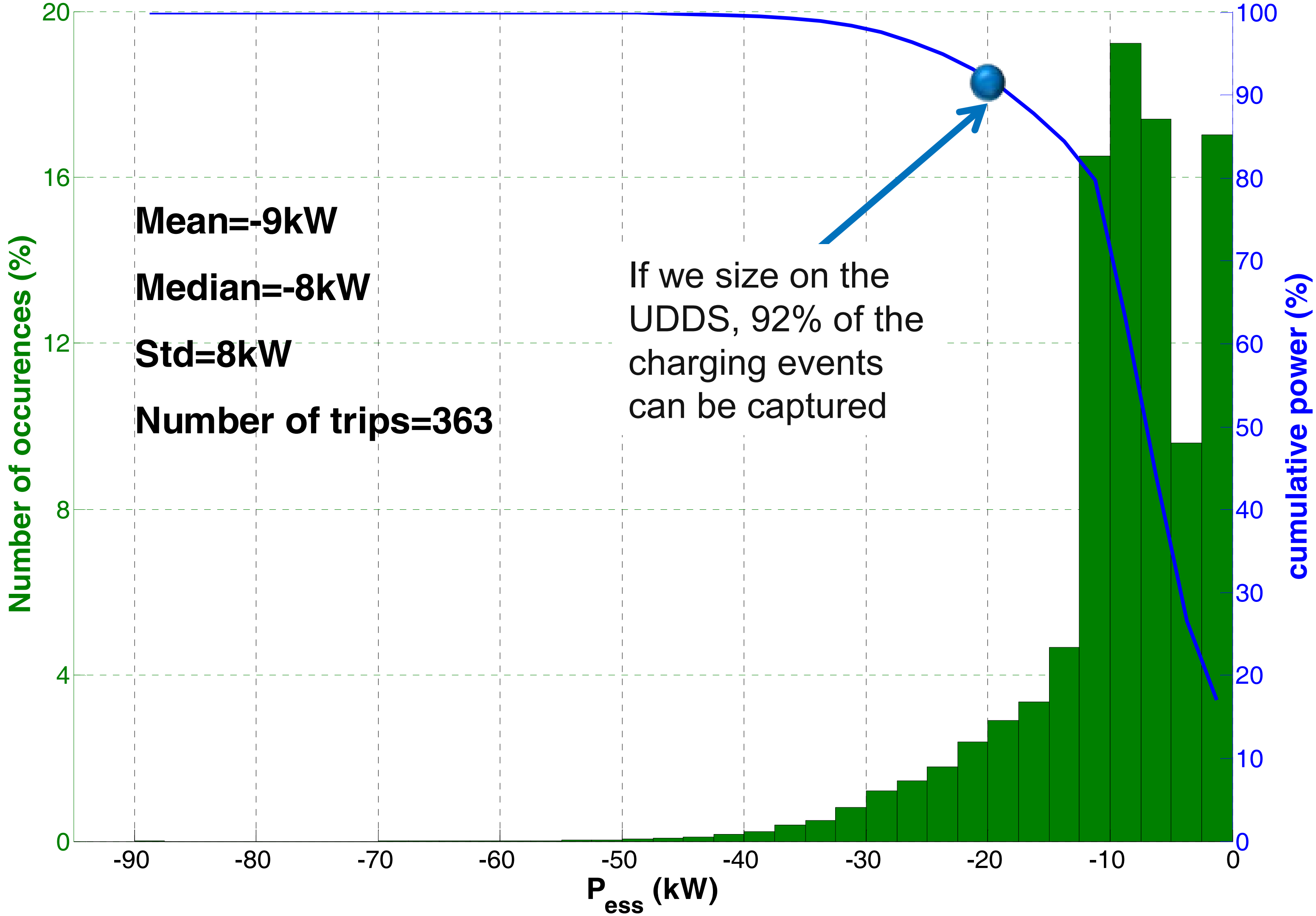
Distribution of Charging Peak Power Per Daily Driving



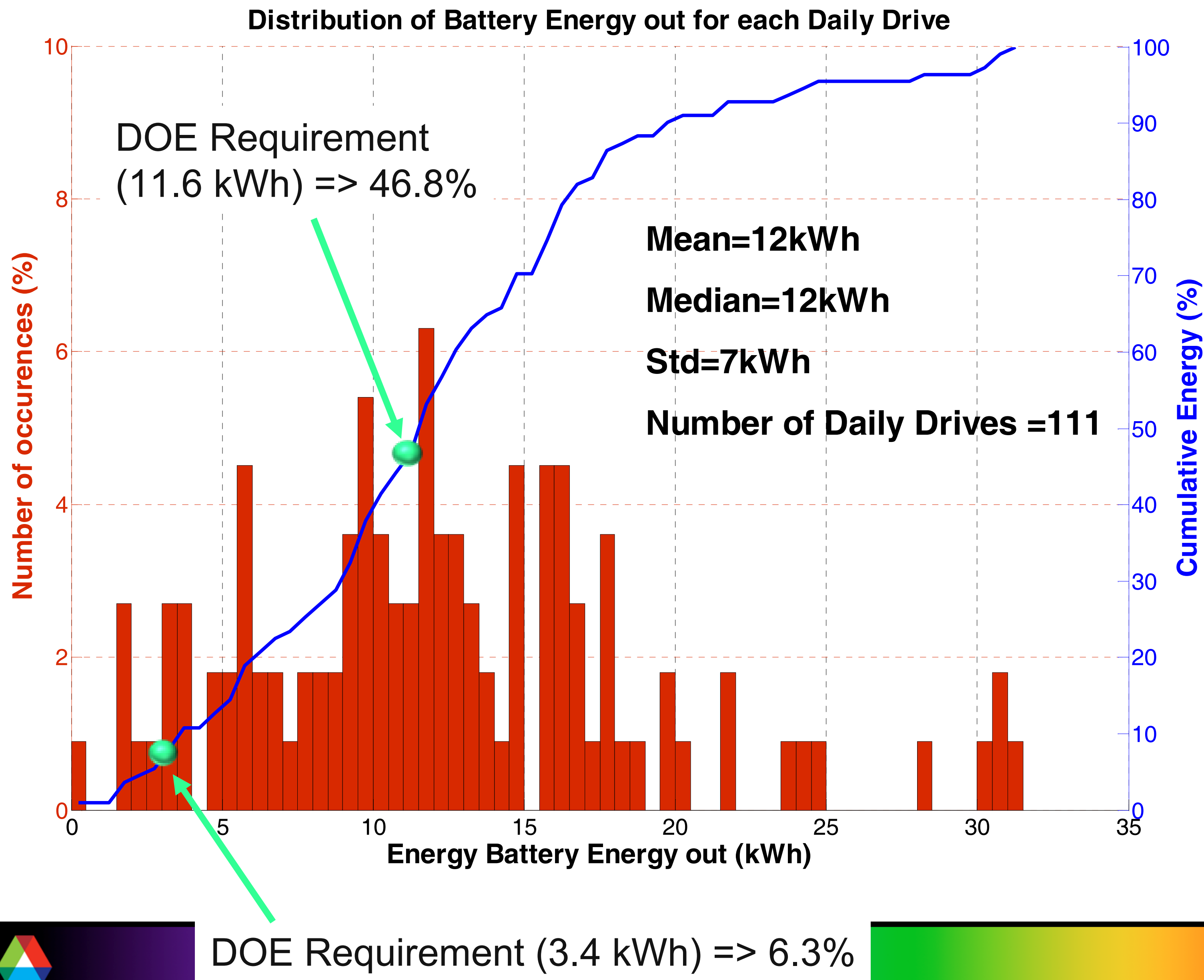
Distribution of Charging Peak Power Per Trip



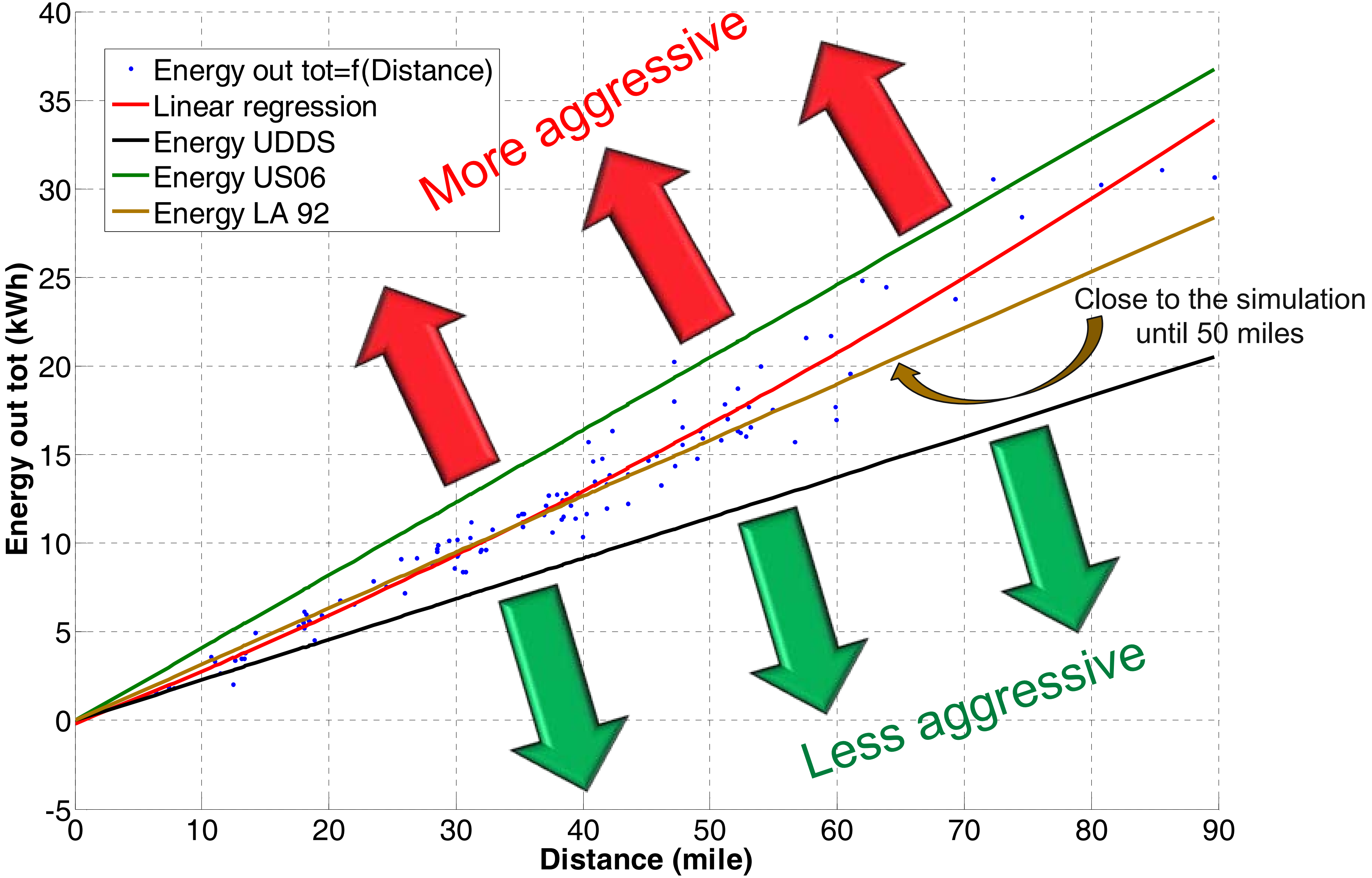
Distribution of Charging Power (All Points)



12 kWh Usable is Required to Complete 50% of the Daily Drives



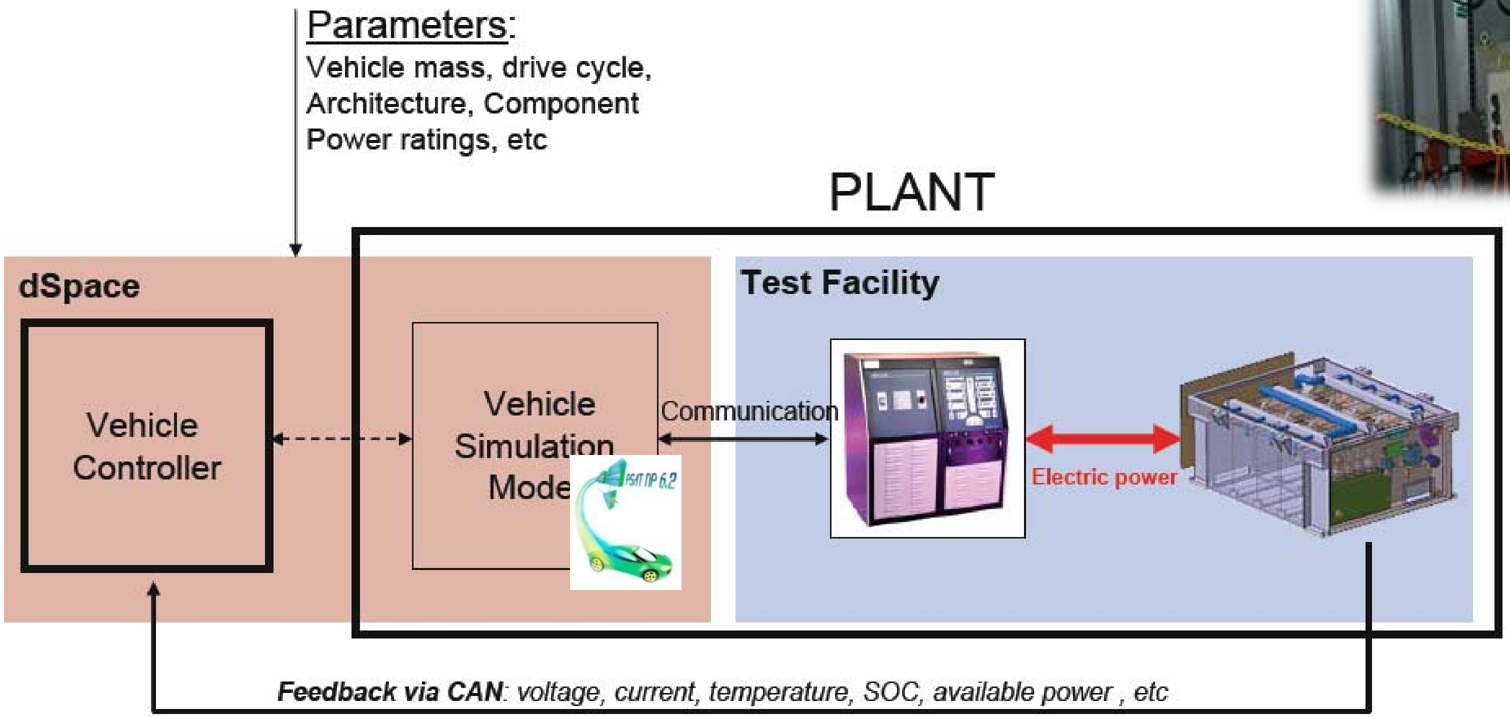
Evolution of Available Energy as a Function of Distance



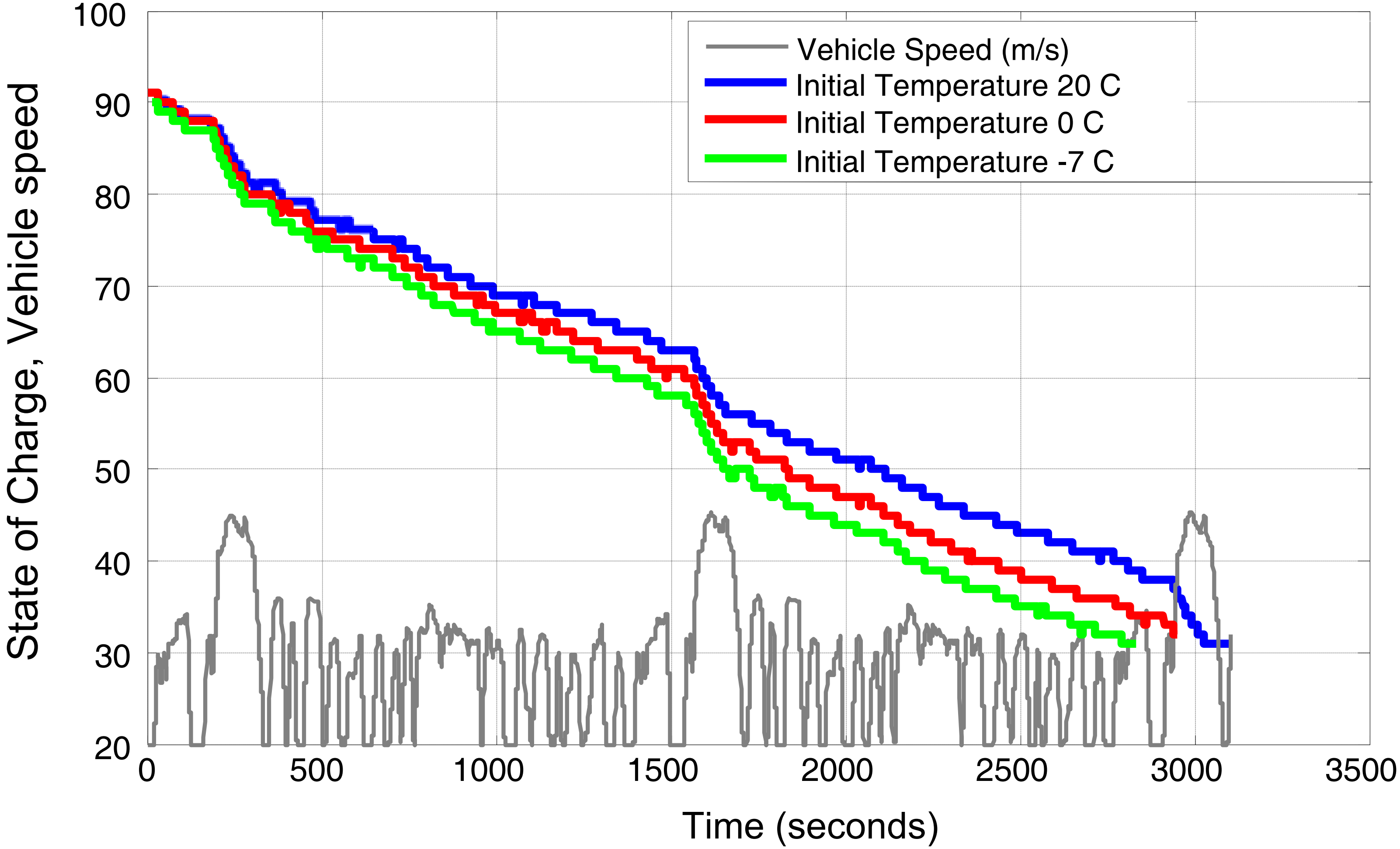
Objective: Impact of Temperature on Efficiency (Powertrain Unchanged)

Evaluation of Battery In An Emulated Vehicle System

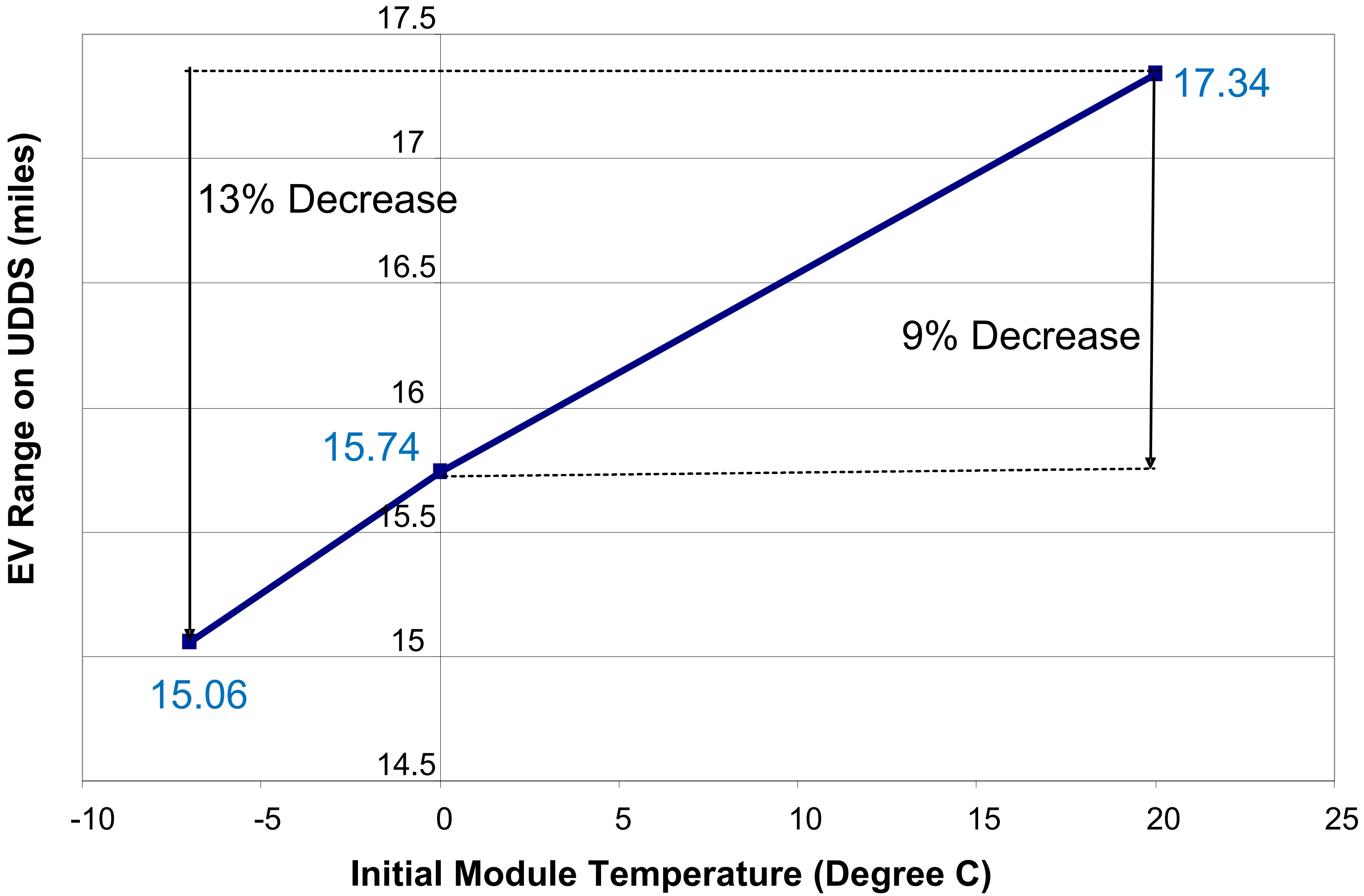
JCS VL41M
260V, 41Ah



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

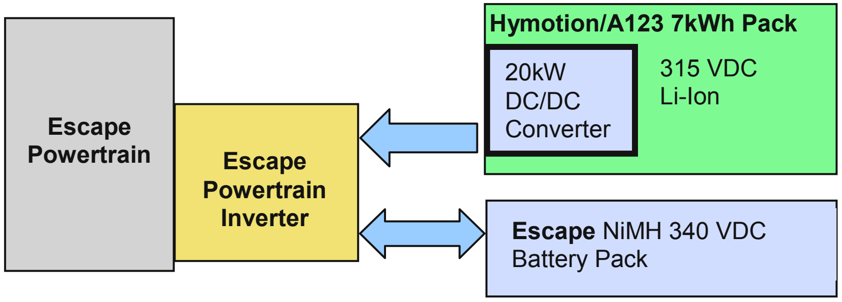
Initial Temperature	Battery kWh	Δ*kWh*
20	6.2	0
0	5.6	0.53
–7	5.5	0.73

Source

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

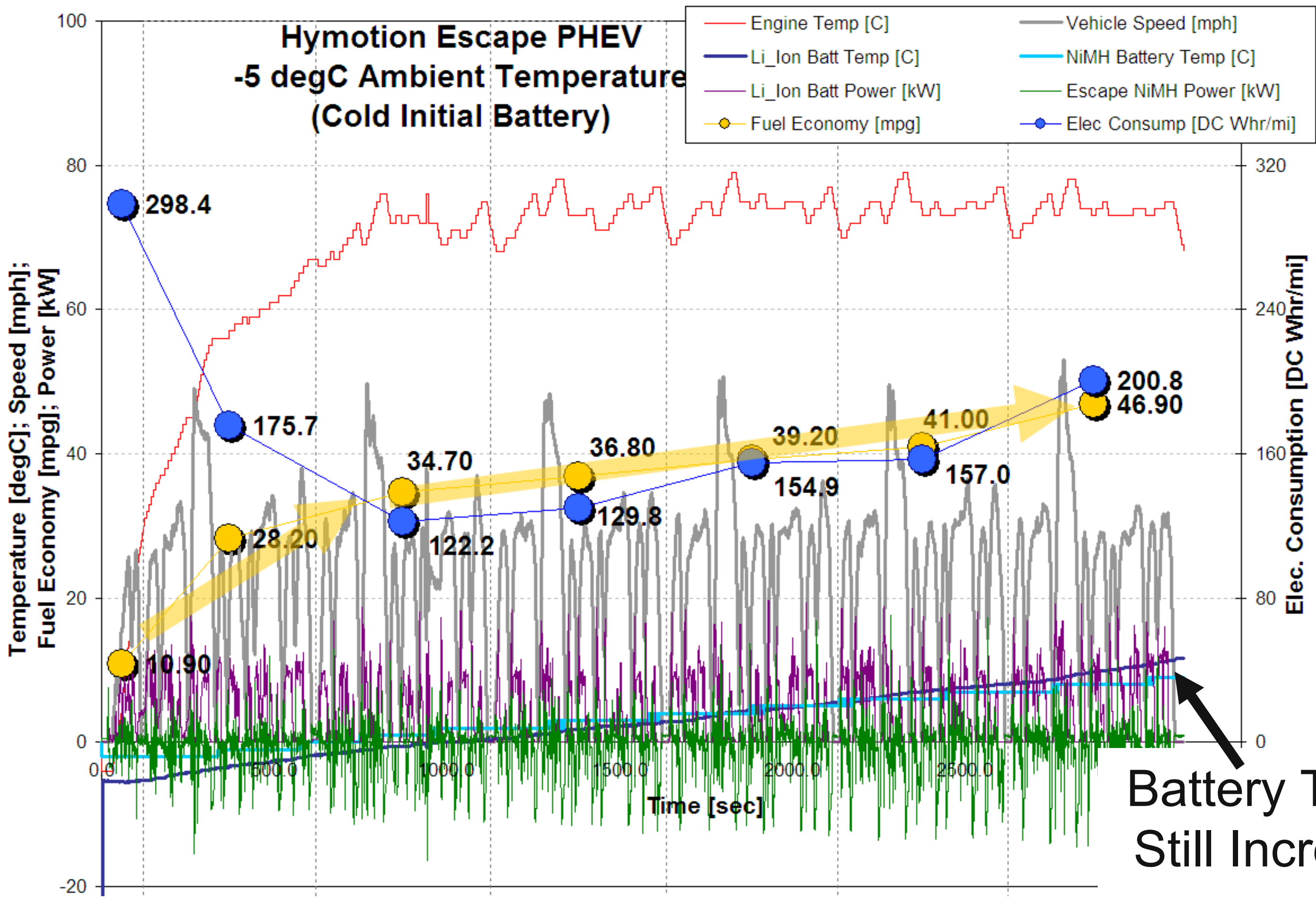
Objective: Impact of Temperature on Vehicle Efficiency

Battery Temperature Impact During On-Road Testing



Hymotion Escape PHEV
7 kWh Li-ion (A123)

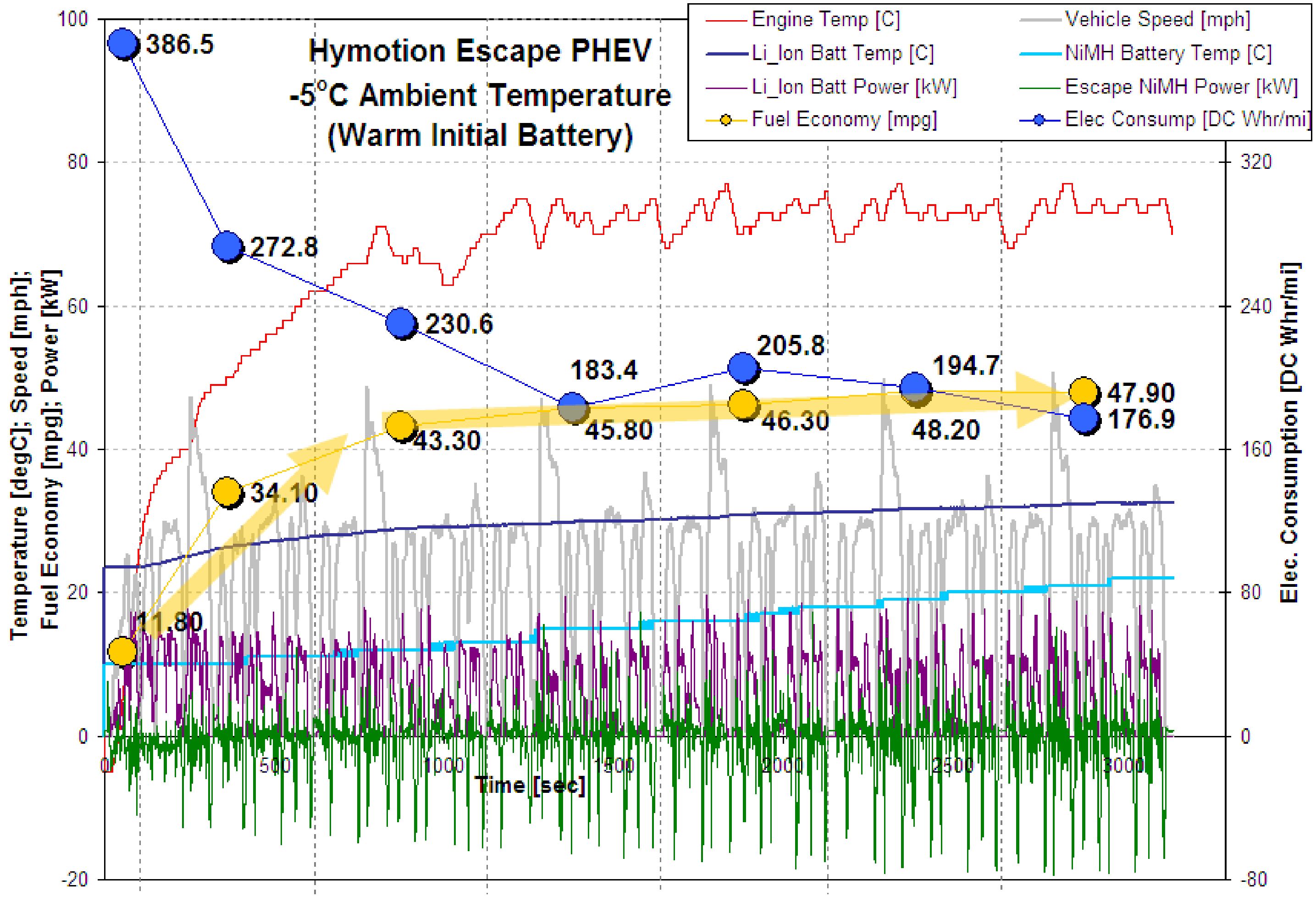
Fuel Economy Still Increases After 20 miles!



Battery Temperature Still Increasing After 60 minutes!

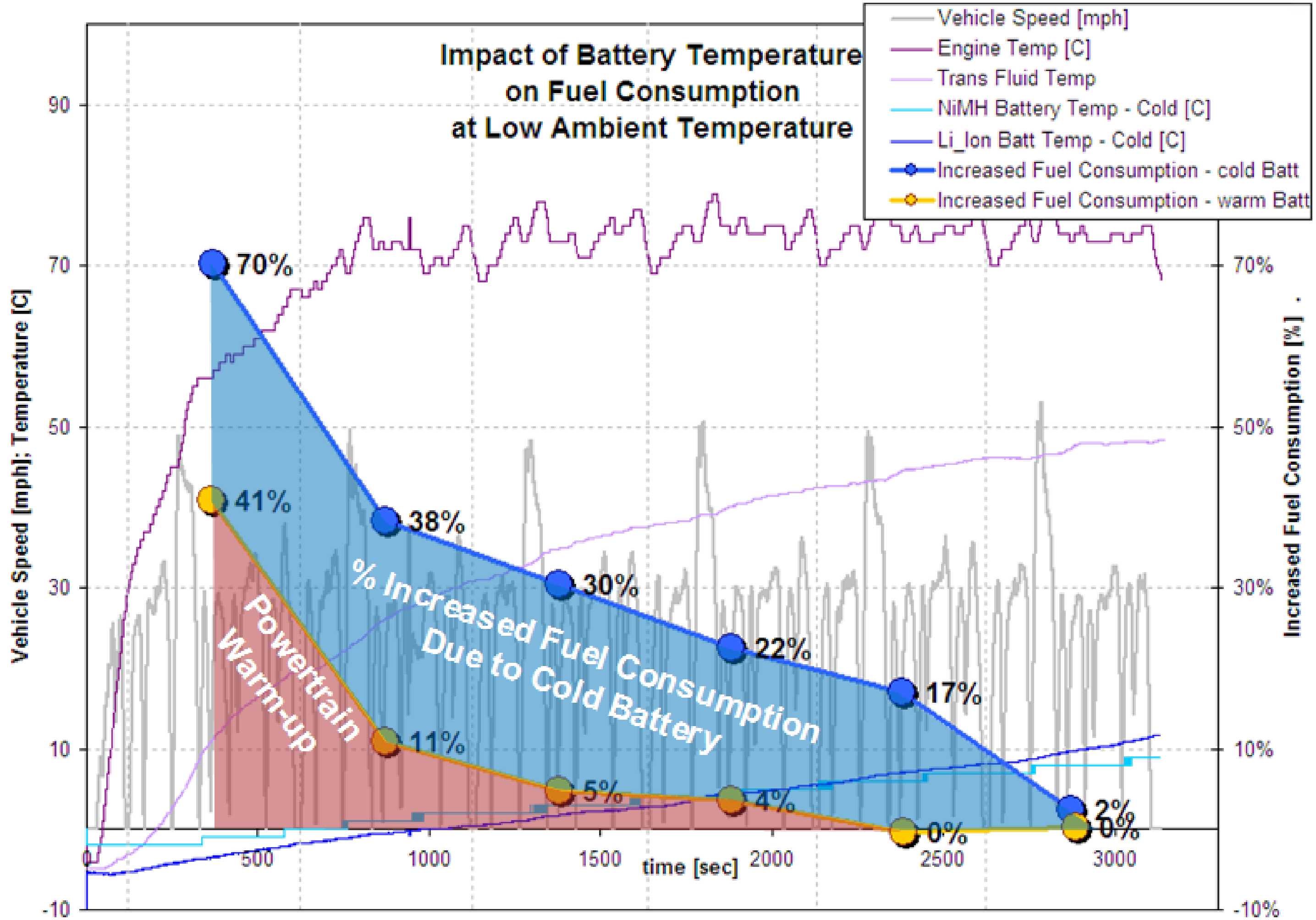
Entire Vehicle Was Cold

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



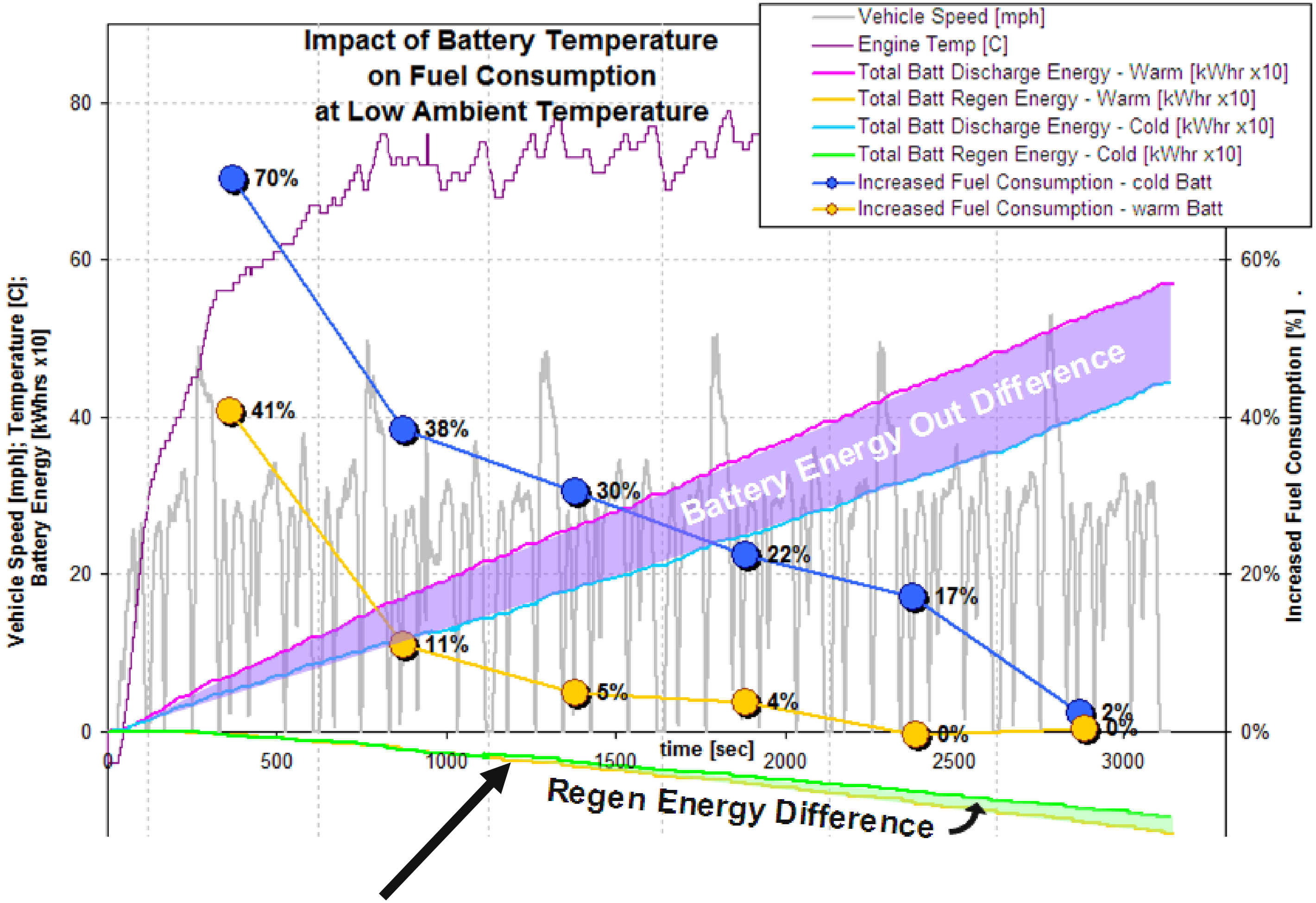
Both Batteries Warmed – Cold Vehicle

Most of the Fuel Consumption Increase Due to Cold Battery



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

Impact of Cold Battery Mostly Due to Discharge Energy



Regenerative Braking Difference only Due to NiMH

Conclusion

- The PHEV requirements analysis is only valid for the set of drive cycles considered and should not be generalized to the US market.
- Aggressive driving will put limits on all EV range, which in turn favors a blended mode operational strategy.
- When the battery is sized for the UDDS,
  - 3% of the daily driving and 20% of the trips can be completed in EV due to power limitation. However, the power requirements are sufficient 97% of the time.
  - 1.5% (short term goal) and 50% (long term goal) of the daily driving can be completed in EV due to energy limitation
- The real world drive cycles are more aggressive than the UDDS, resulting in larger energy requirements to drive the same distance.
- LA92 better represents current drive cycle aggressiveness.

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.

Contact Information

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