PHEV Component Requirements Summary

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Argonne National Laboratory
Sponsored by Lee Slezak

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Outline

- Development of Current Requirements
- Impact of Standard Drive Cycles
- Impact of Real World Drive Cycles

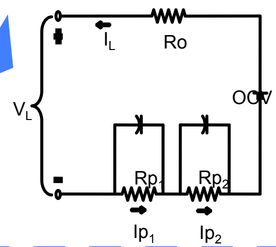
Define PHEVs Component Requirements

Component Data from R&D Teams

Battery

Testing

Model

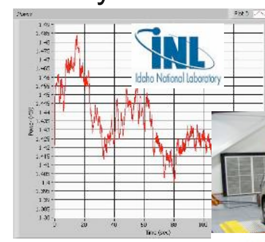


Electric Machine

2004 Prius

Accessories

Camry A/C Power



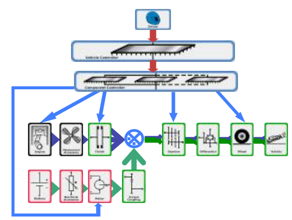
Prius A/C Power

PSAT Simulations

Vehicle Classes

Vehicle Requirements

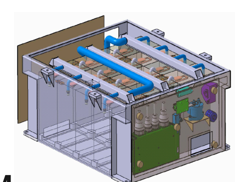
Sizing & Simulation



Results Shared with R&D Teams

Validation

Battery RCP

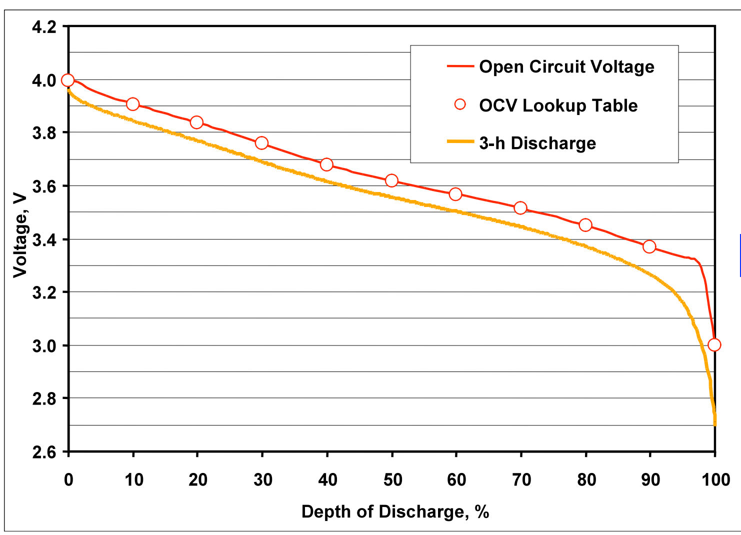


JCS VL41M

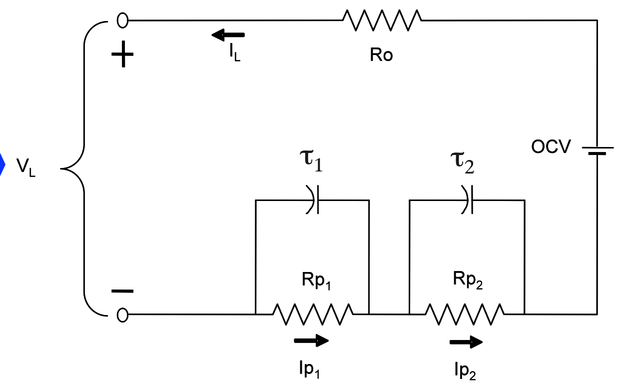
Vehicle Testing

PHEV Battery Modeling is More Complex than for Conventional HEVs

- 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

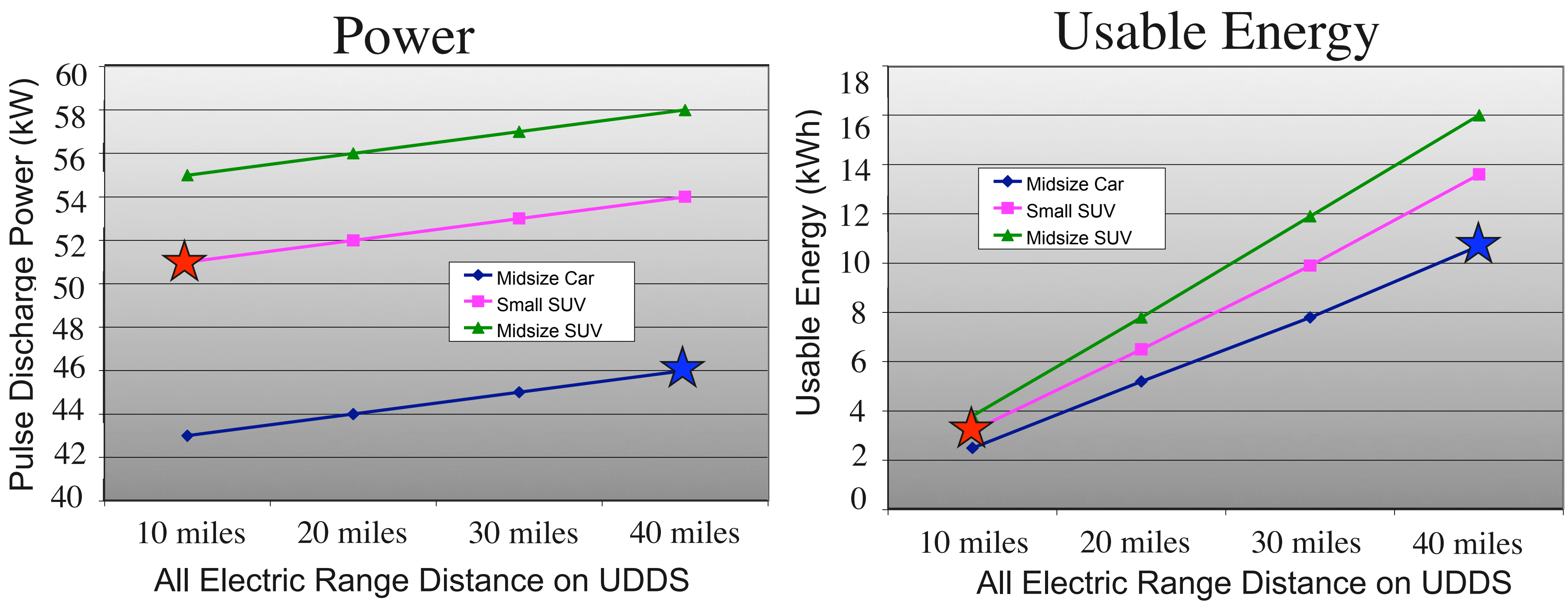


PHEV Model

Scaling Algorithm for Power & Energy

Scaling

Optimum Battery Power and Energy Defined for Several Vehicle Platforms and AER



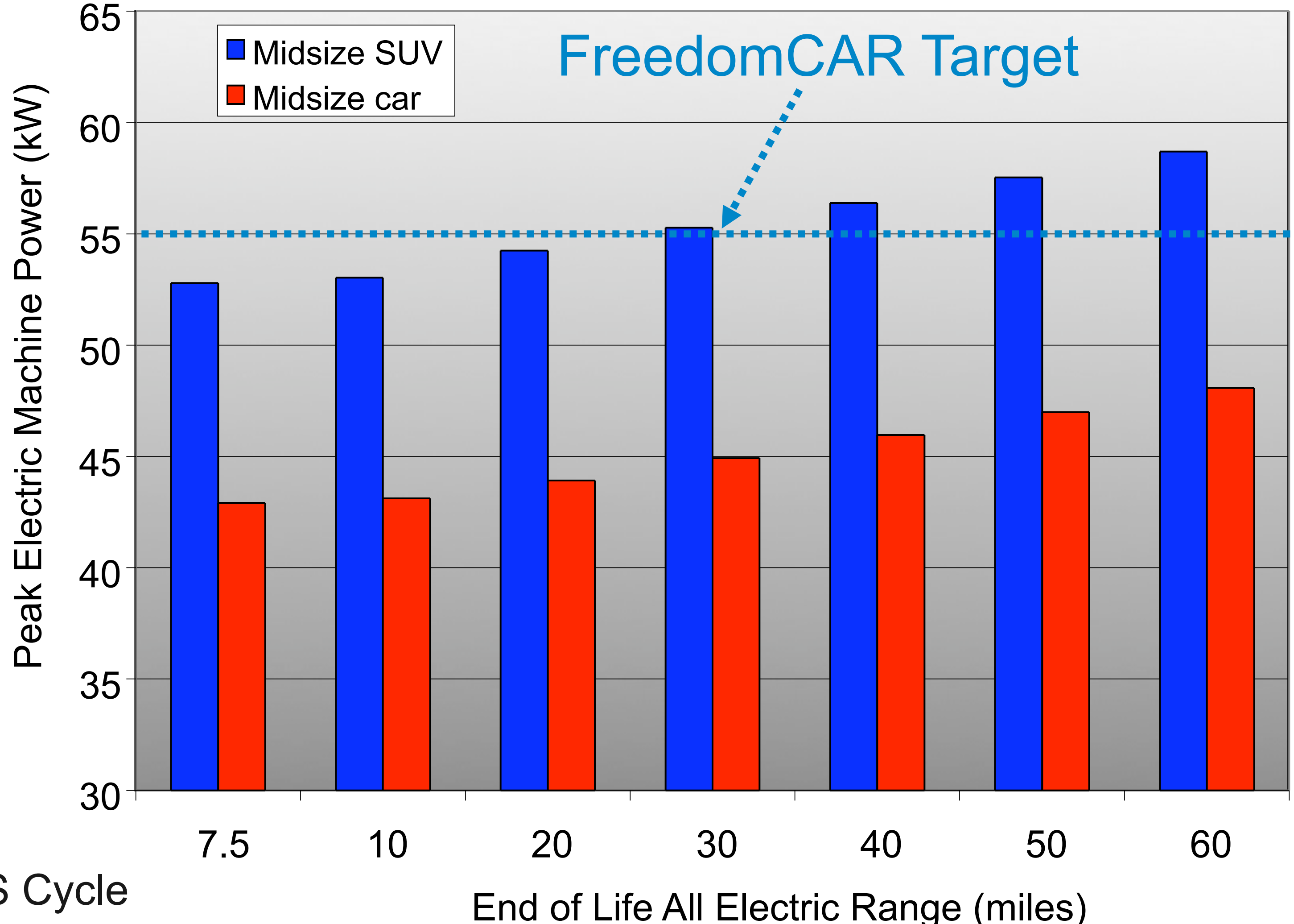
Final values selected by the ESS Tech Team

- Short term 10 miles AER (3.4 kWh, 50 kW) ★
- Long term 40 miles AER (11.6 kWh, 46 kW) ★

Current PHEV Battery Requirements

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**

Electric Machine Power Required within FreedomCAR Target

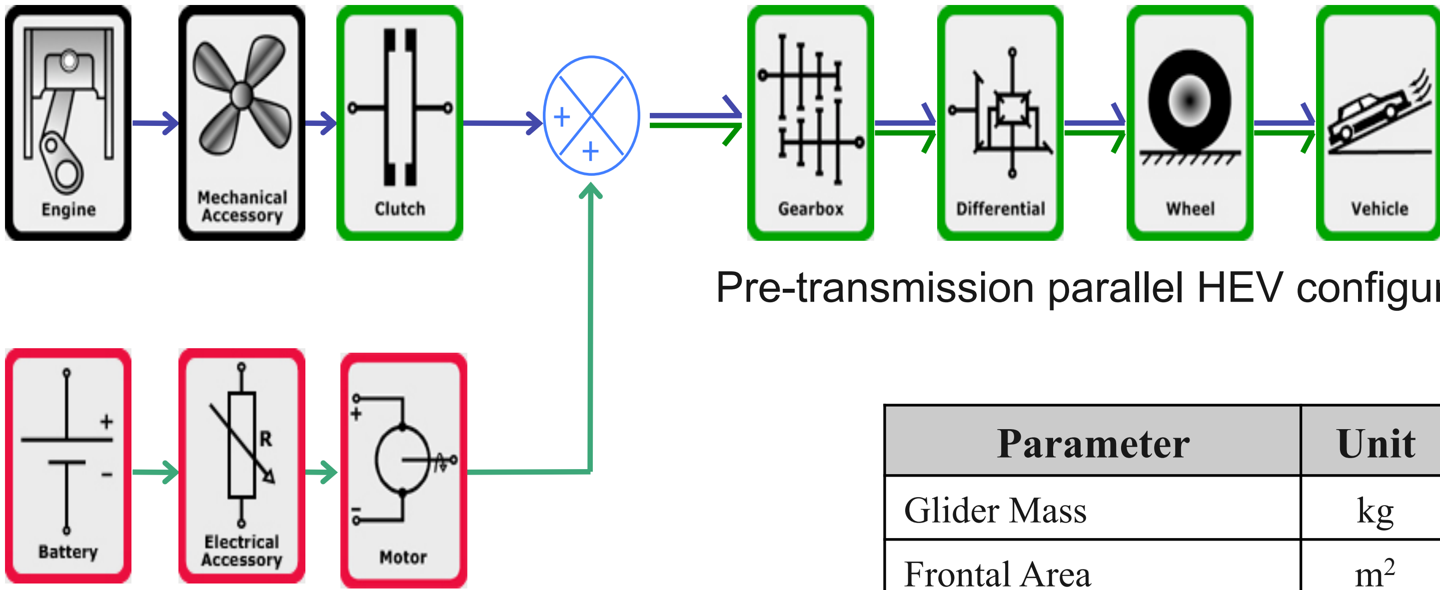


UDDS Cycle

Outline

- Development of Current Requirements
- Impact of Standard Drive Cycles
  - PHEV Sizing Based on UDDS for 10, 20 40 AER.
  - Control Strategy Options when Engine is ON
  - What is the Maximum Share of the Standard Drive Cycle than can be Run in EV?
  - What is the Share of the Standard Drive Cycle than can be Run in EV when Engine is Used at Best Efficiency?
  - PHEV Sizing Based on Various Driving Cycles.
- Impact of Real World Drive Cycles

PSAT Modeling Assumptions

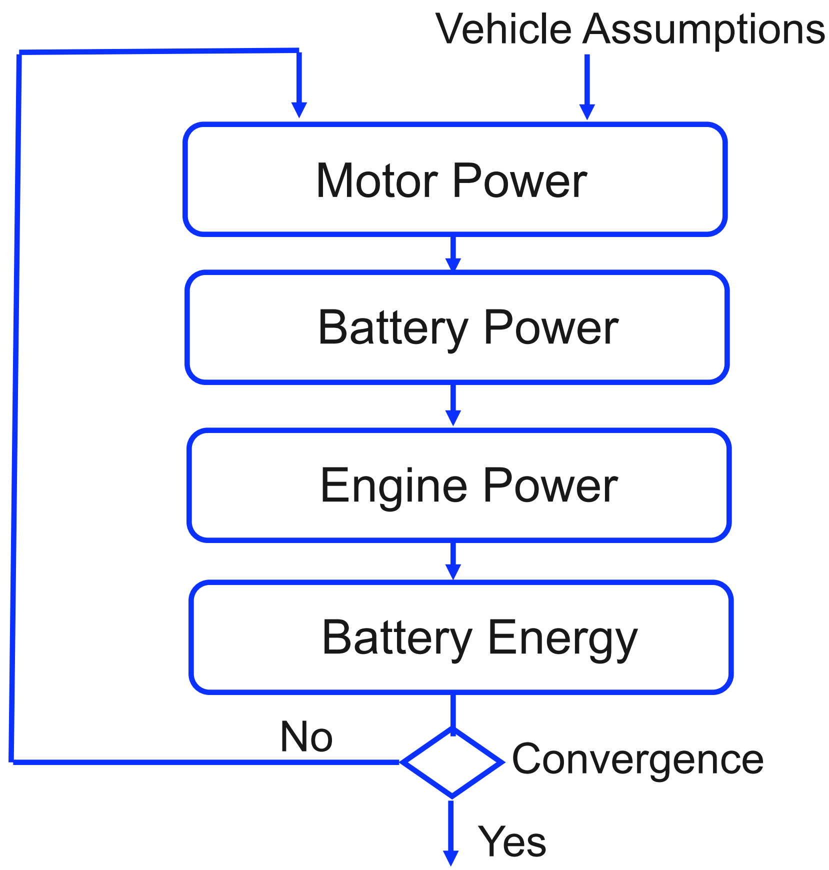


Pre-transmission parallel HEV configuration

Parameter	Unit	Midsize Car
Glider Mass	kg	990
Frontal Area	m^2	2.1
Drag Coefficient		0.31
Wheel Radius	m	0.317
Rolling Resistance		0.008

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

Vehicle Sized to Meet Requirements



<u>Associated Requirements</u>

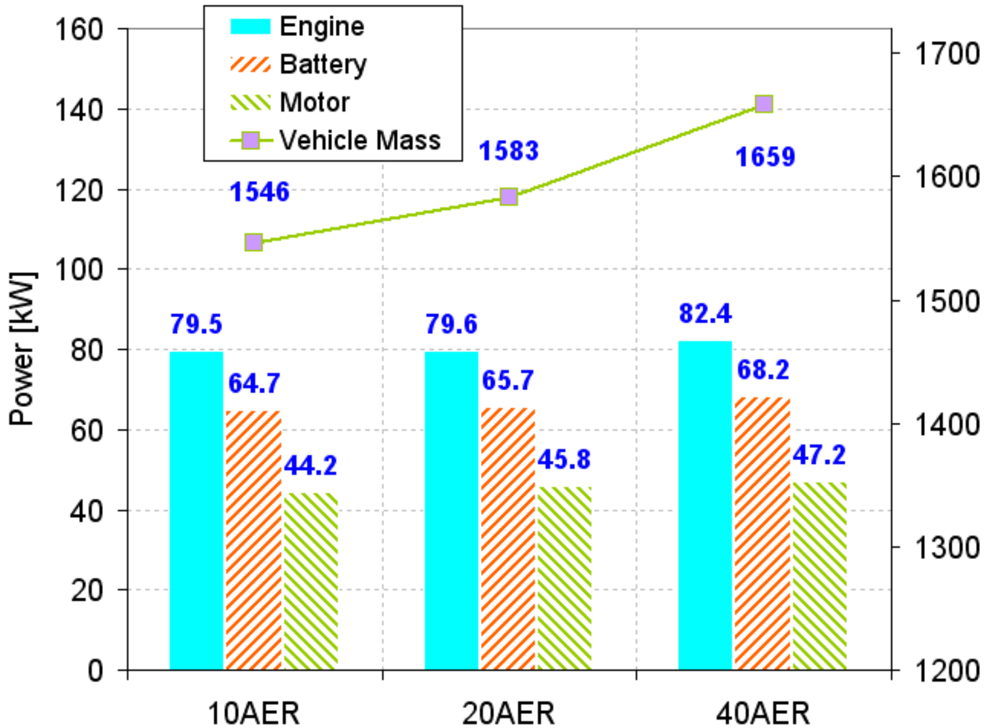
Drive Cycle in EV Mode

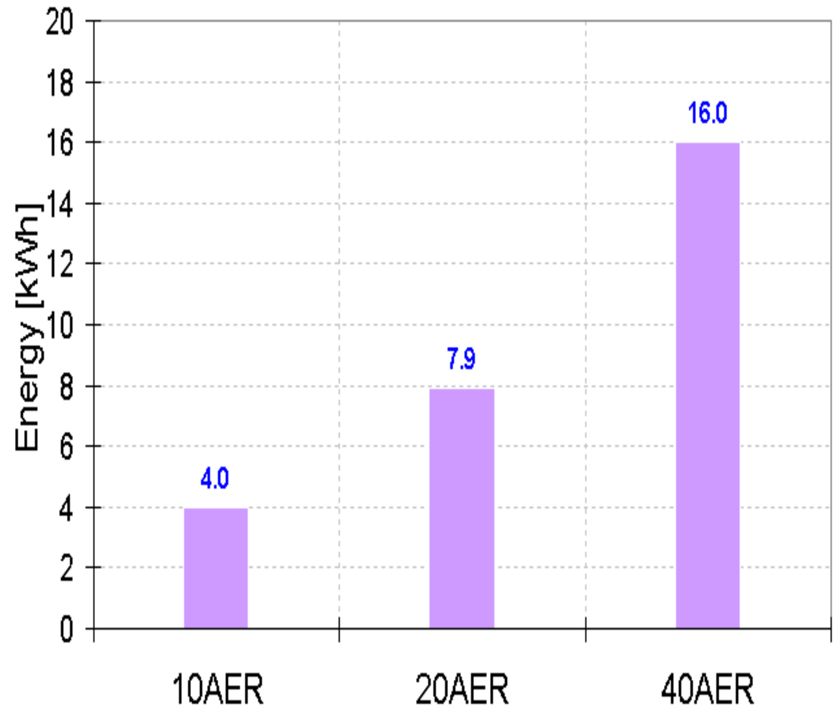
<u>Perfo:</u>
IVM-60 mph

<u>Grade:</u>
60 mph 6% grade

Range

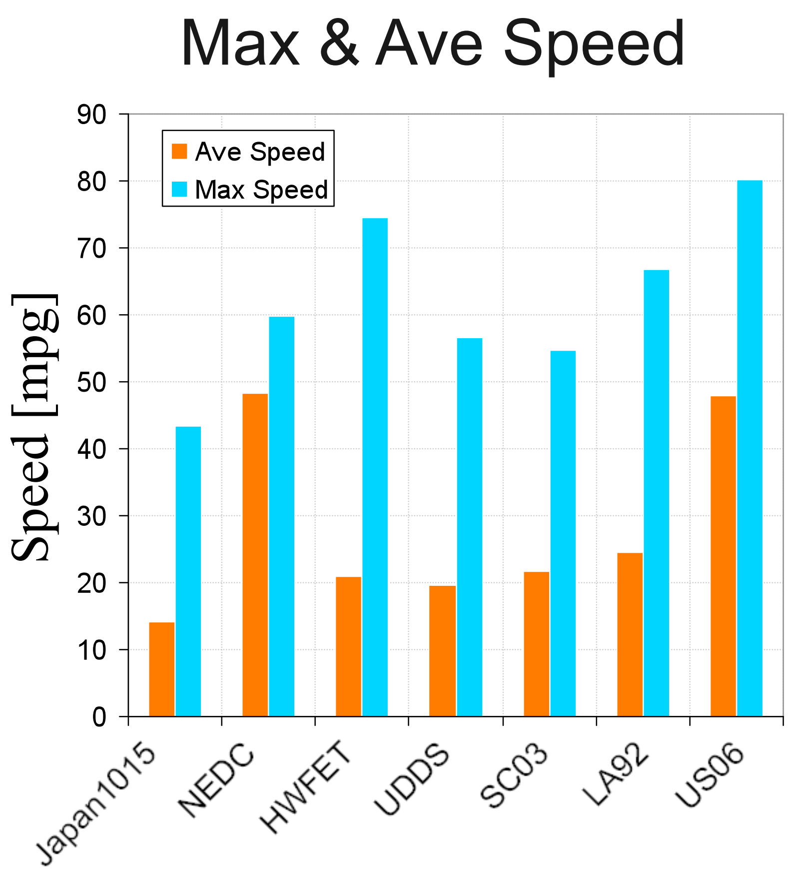
Component Sizing on UDDS

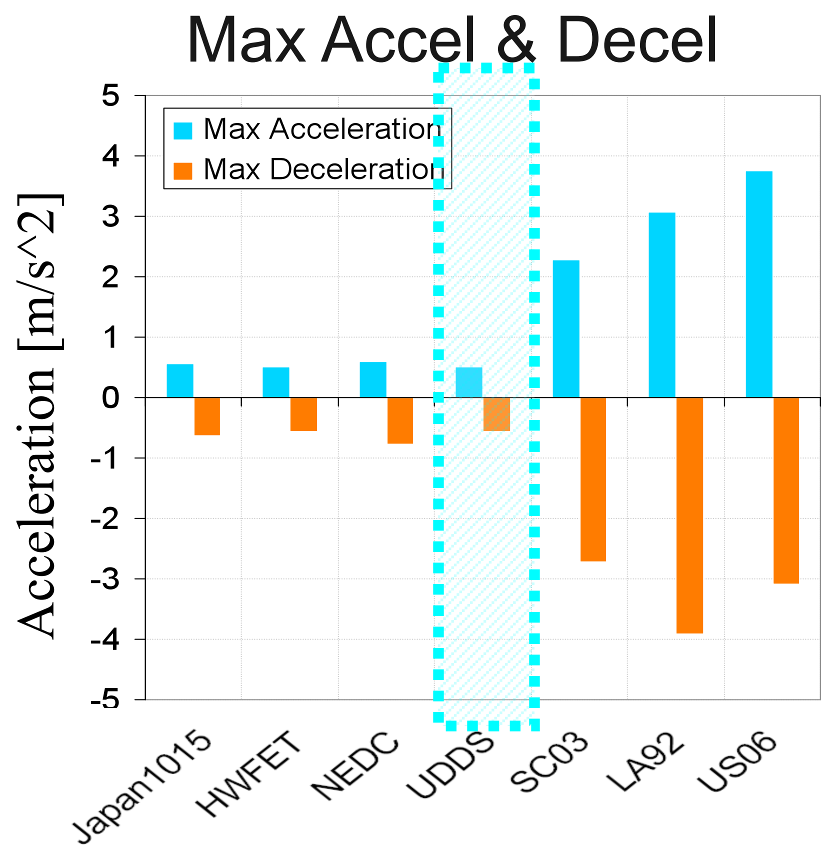




- Battery power slightly increases due to vehicle mass
- Battery capacity changed to maintain acceptable battery pack voltage (~200V)

Cycle Characteristics : SC03, LA92 and US06 are More Aggressive





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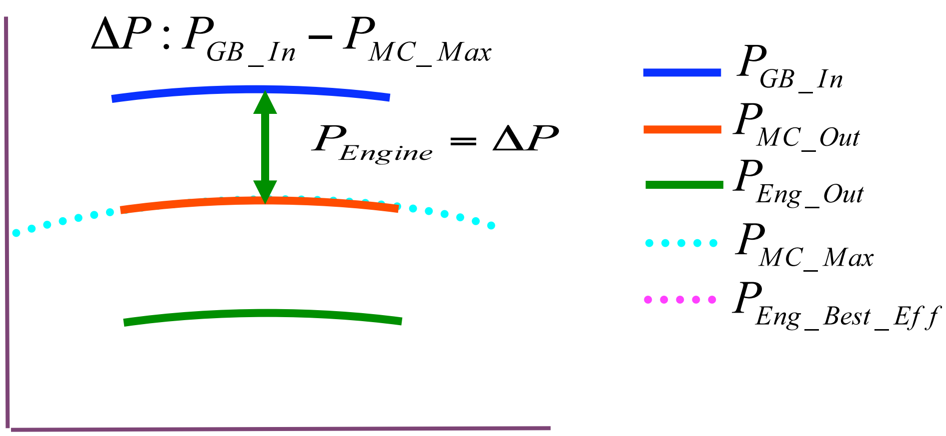
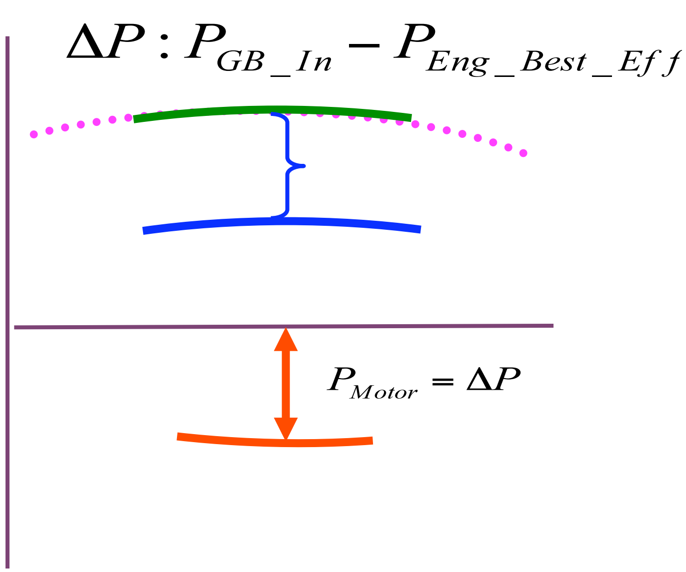
Two PHEV Controls Were Considered



- Engine Minimum Assist :

  Engine is turned on when Motor torque reaches its maximum power curve. Engine provides the delta power between required power at the gearbox input and maximum motor power



- Engine Assist at Best Efficiency :
  Engine is turned on when Motor power reaches its maximum power curve. The engine operates at the best efficiency region. The surplus power from the engine is used to charge the battery.

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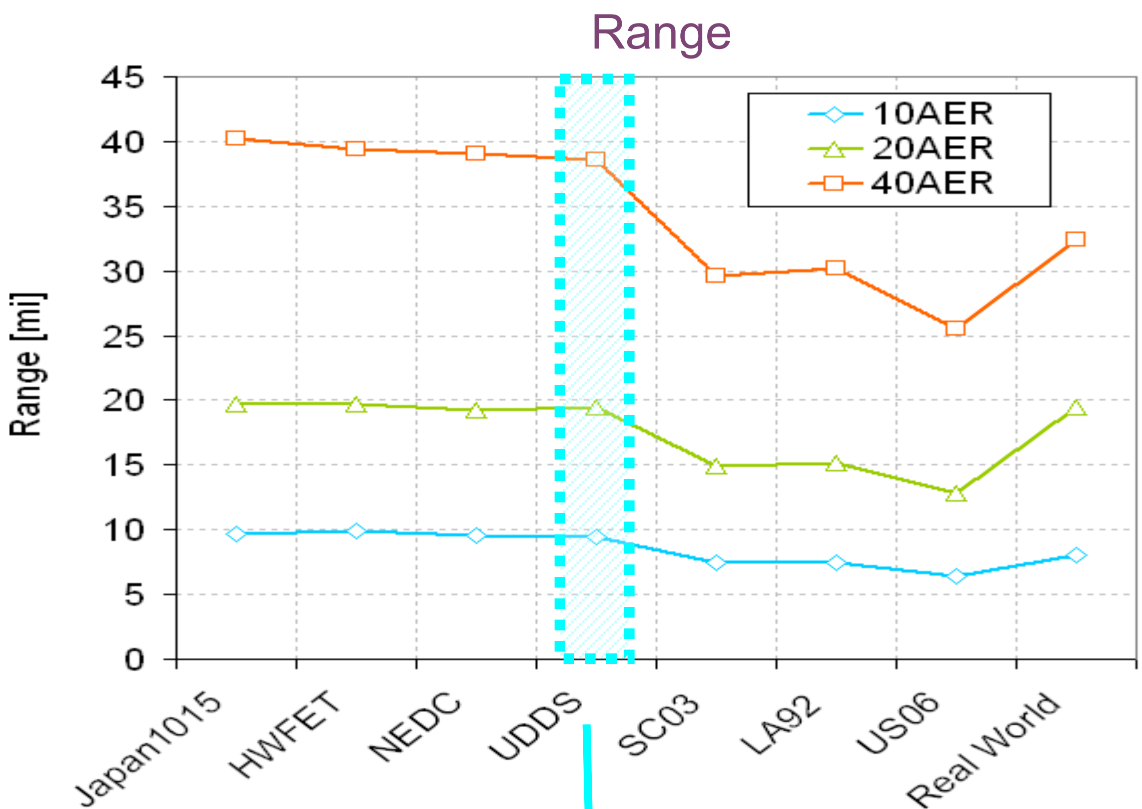
Charge Depleting (CD) Capability Decreases as Drive Cycle Aggressiveness Increases



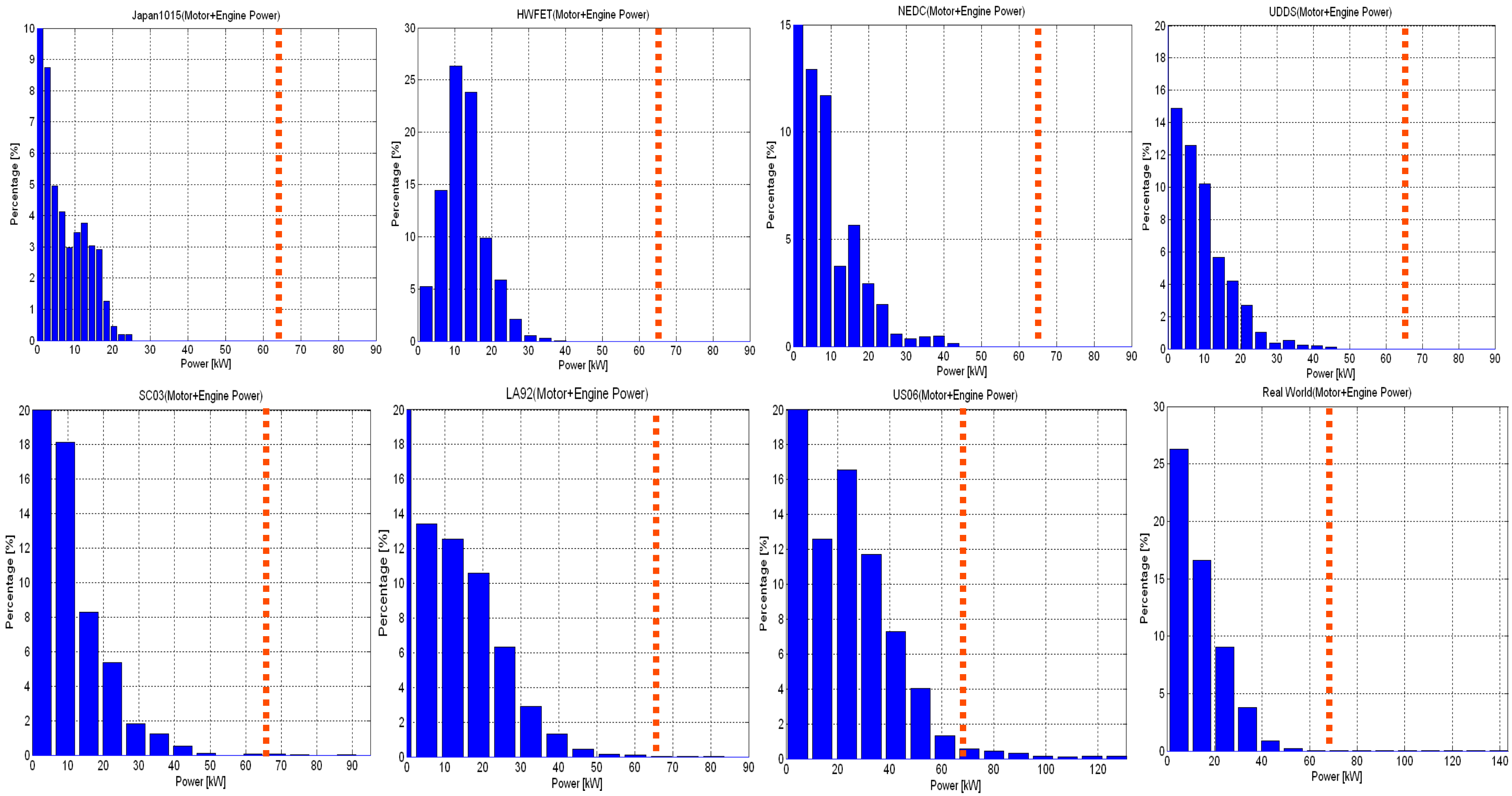
Aggressiveness Decreases ← → **Aggressiveness Increases**

CD Increases ← → **CD Decreases**

Engine Minimum Assist

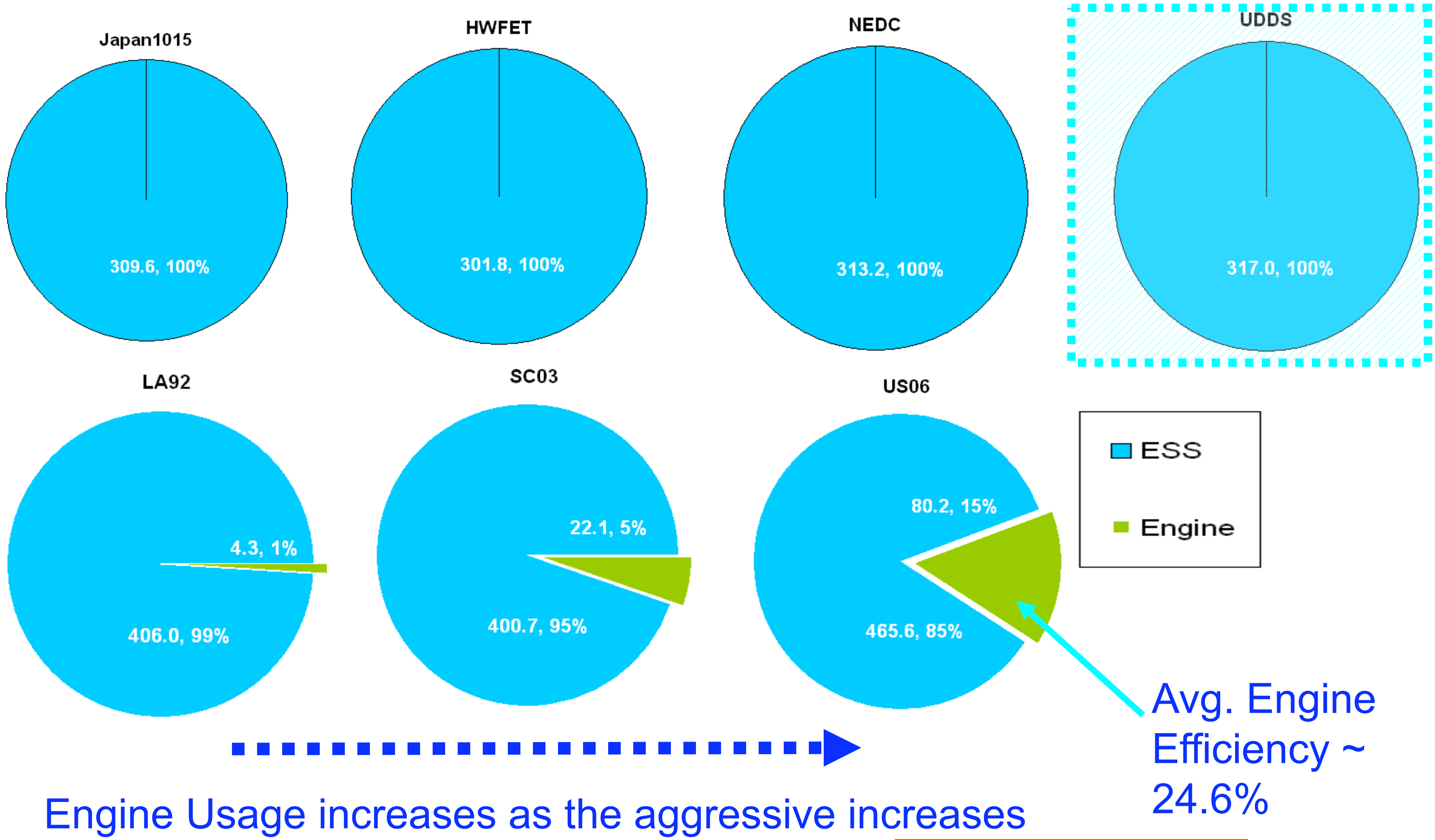
Engine Used Only When Electric Machine Reaches its Limit

Maximum Power Required at Gearbox Input for UDDS (~67.4kW)



Engine Minimum Assist

Energy Consumption of Engine Increases as the Aggressiveness of Cycle Increases



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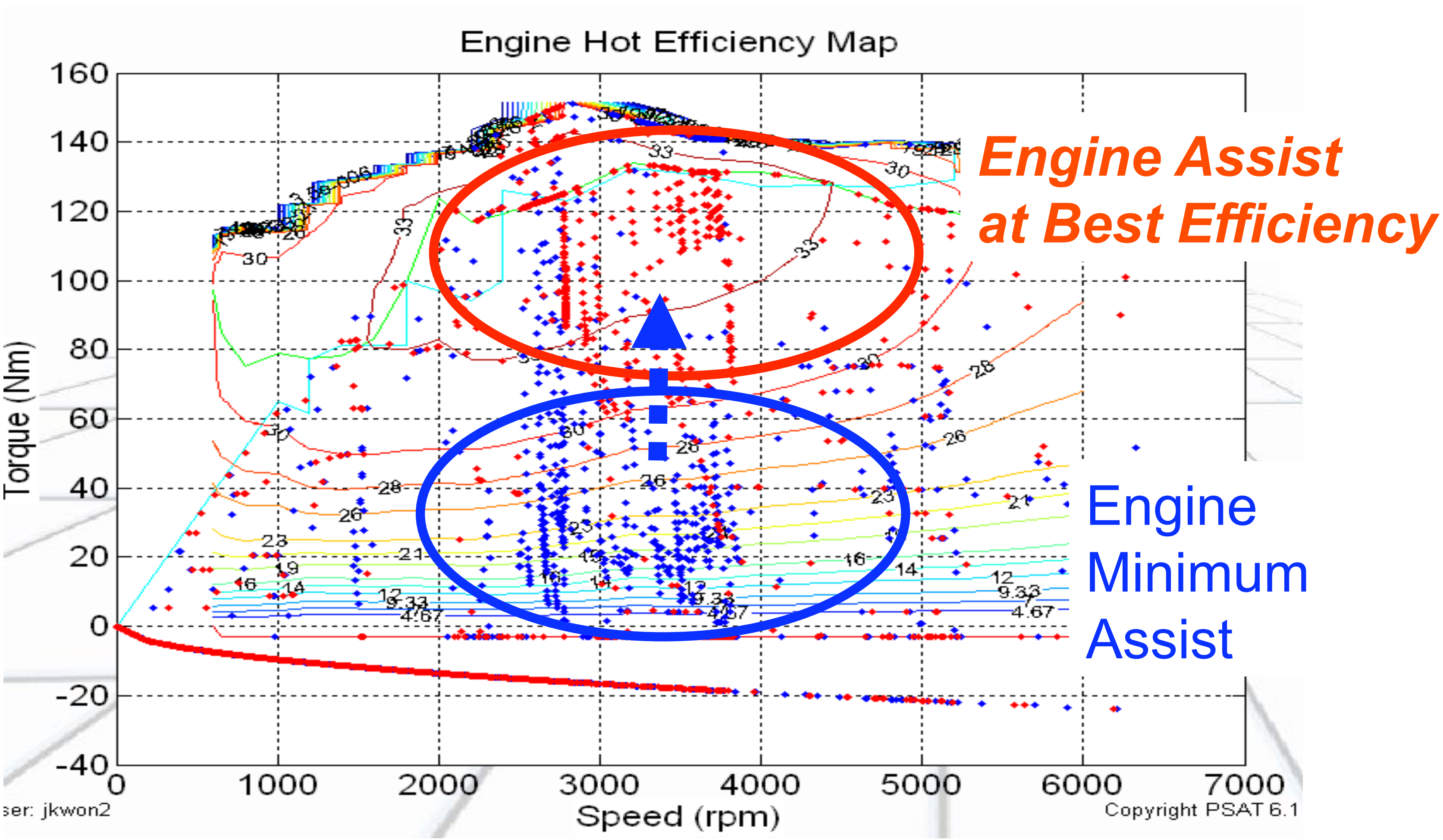
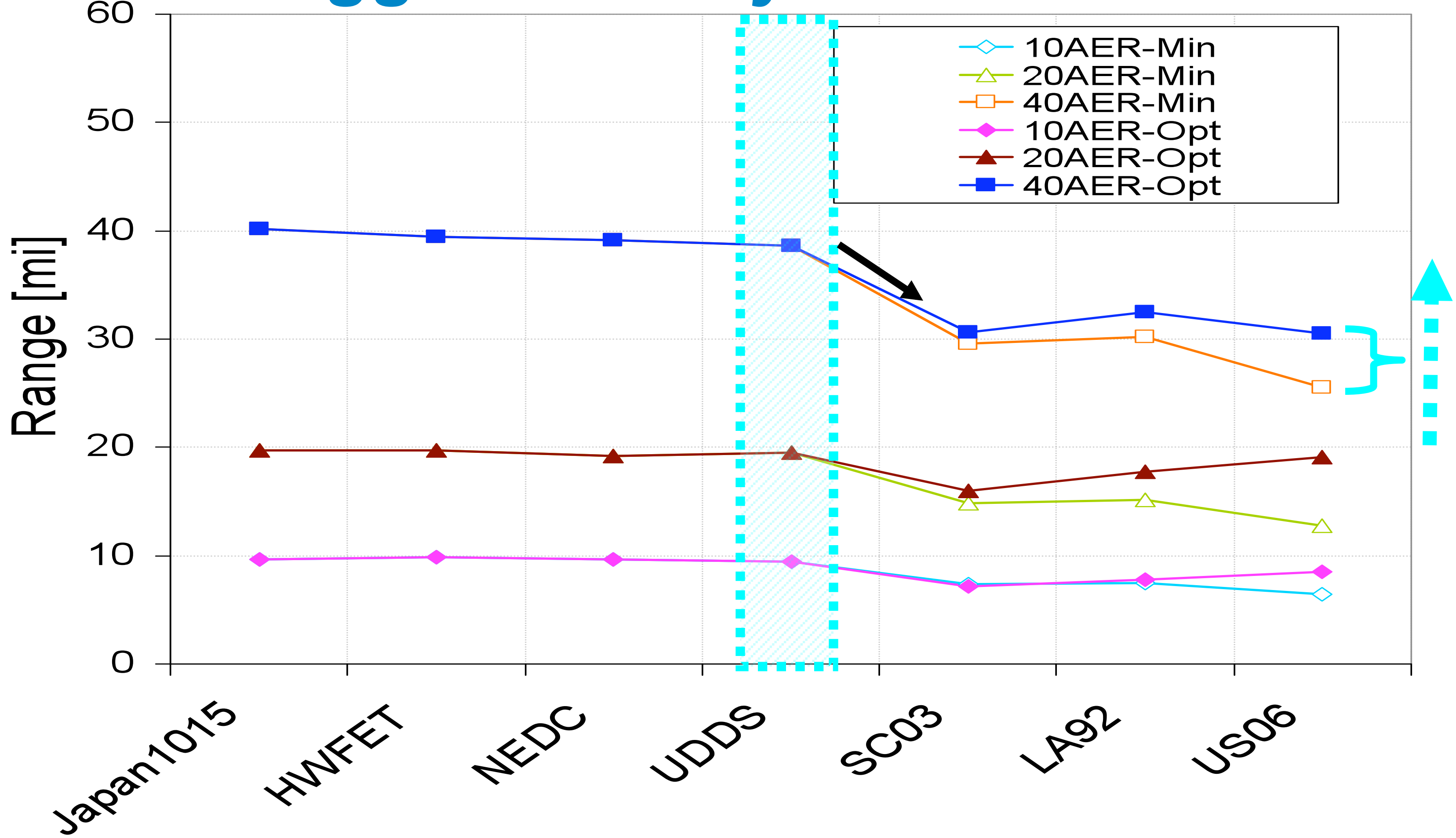
How does Engine Assist at Best Efficiency Control Strategy Affects Energy Consumption?



Engine Assist at Best Efficiency Increases AER for Aggressive Cycles



Engine Assist at Best Efficiency

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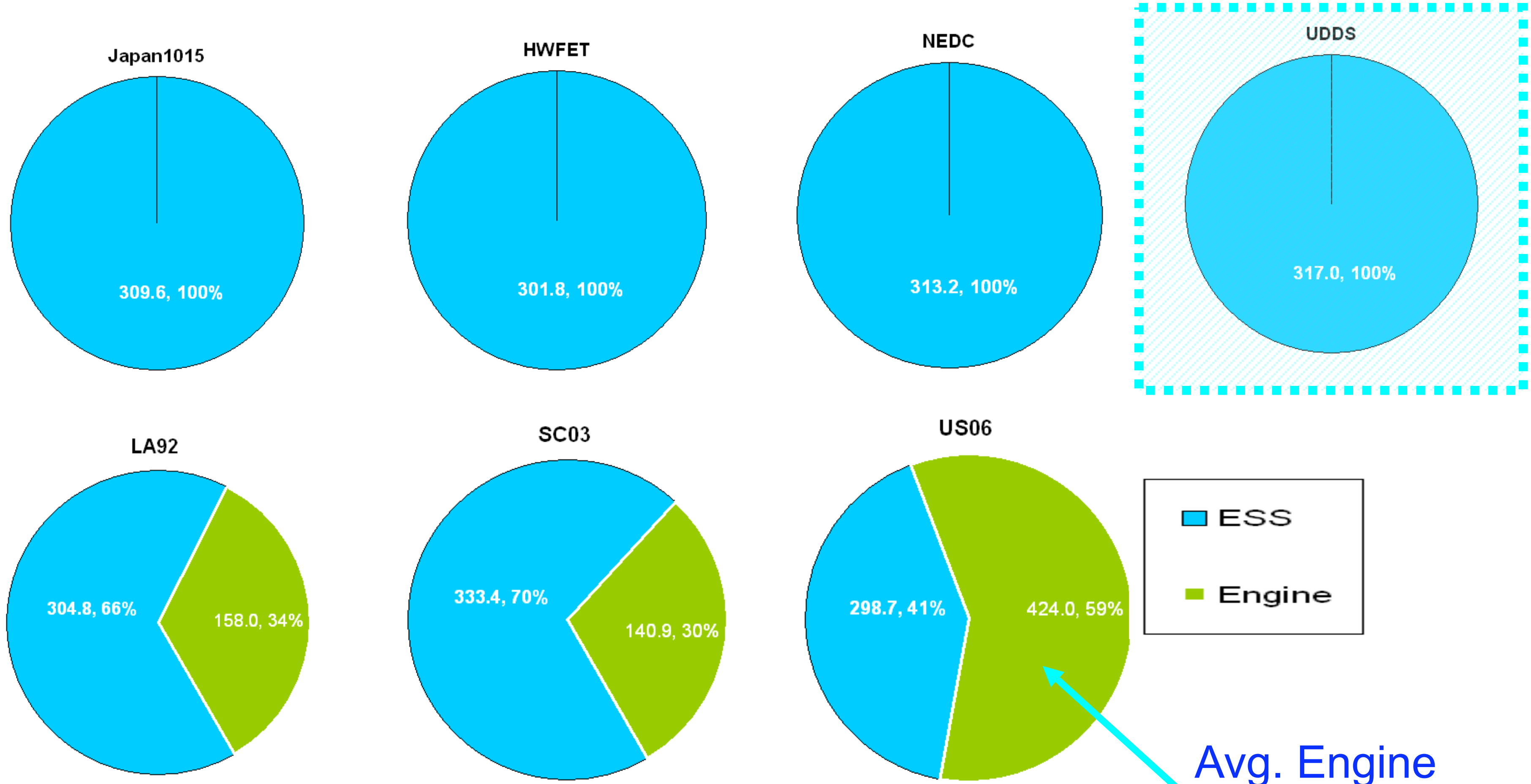

Avg. Engine Efficiency ~ 29.0%

Engine Usage increases as the aggressive increases

Engine Assist at Best Efficiency

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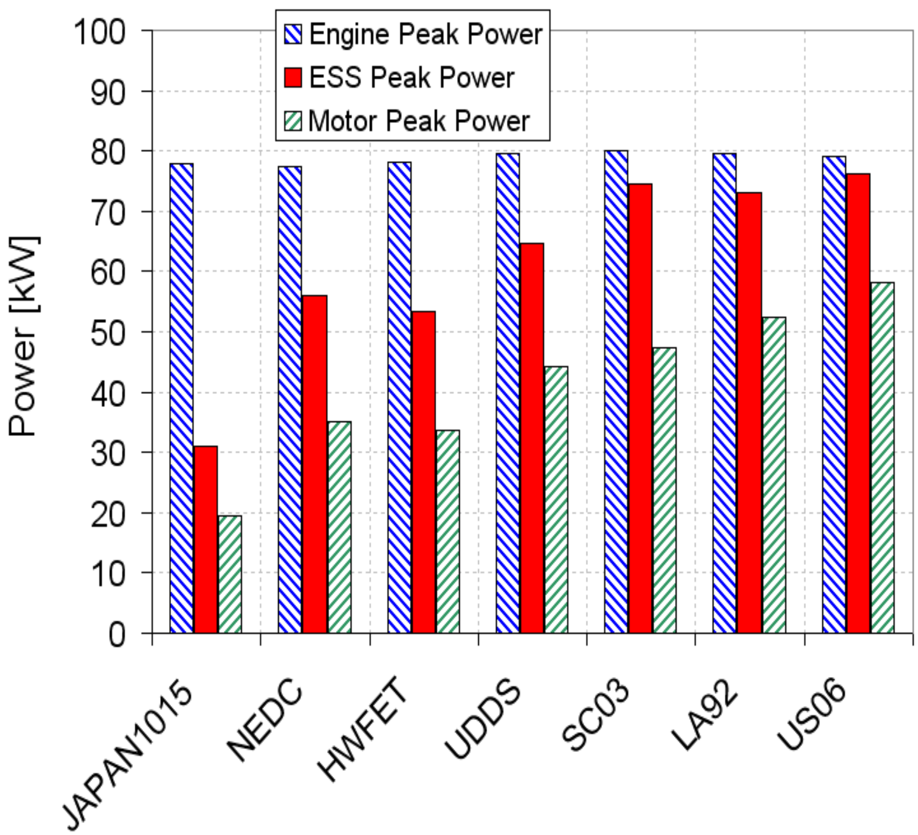
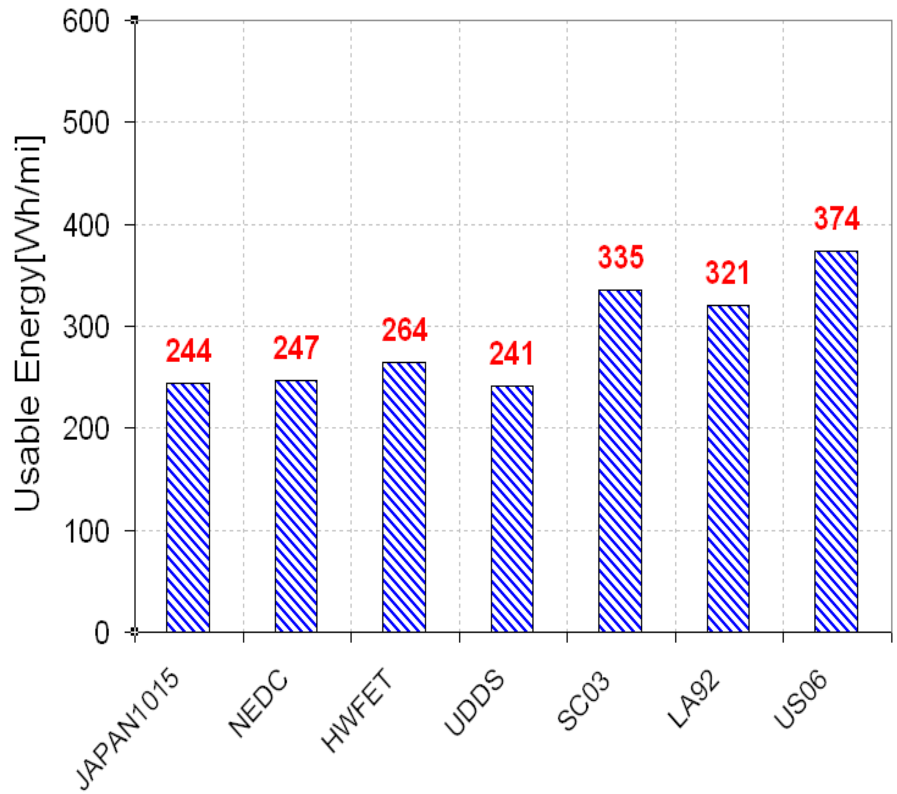
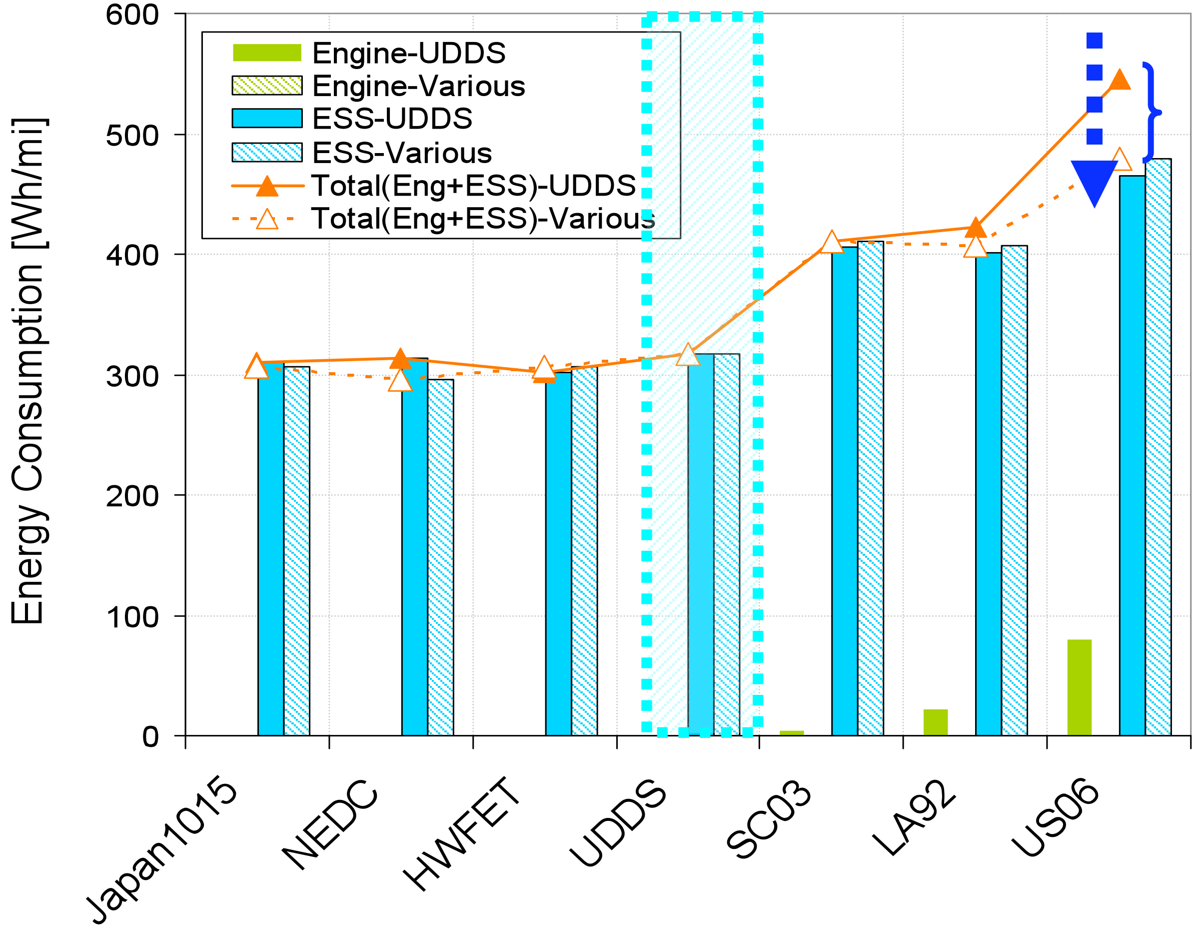
When Battery Sized for Each Cycle, its Power Increases With Cycle Aggressiveness





Sizing based on Each Driving Cycle Decreases Energy Consumption for Aggressive Cycles



The greater impacts are shown on more aggressive cycles, such as SC03, LA92, and US06

10 AER

Conclusion

- The choice of driving cycles influences PHEV design decisions.
- All standard drive cycles considered are less aggressive than real-world driving conditions.
- All electric operation can be achieved on aggressive drive cycles with small additional battery power (10 to 15 kW) compared to the UDDS. However, considering Li-ion technology, available power might not be an issue.
- Should the batteries be designed on UDDS to satisfy CARB requirements when it is not representative of real-world driving conditions?

Outline

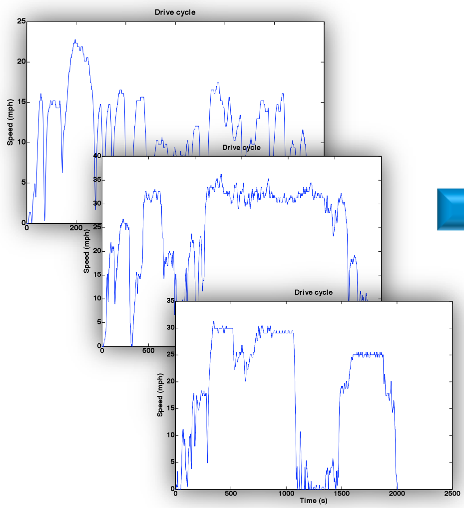
- Development of Current Requirements
- Impact of Standard Drive Cycles
- Impact of Real World Drive Cycles

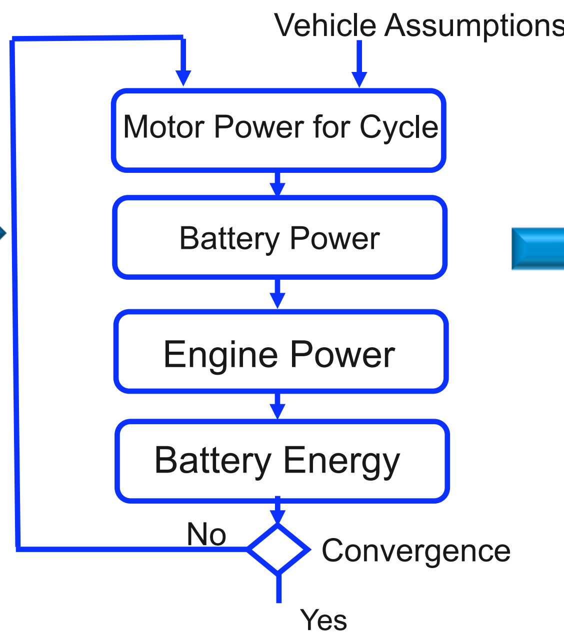
Objective: Impact of Real World Drive Cycles on Power and Energy Requirements

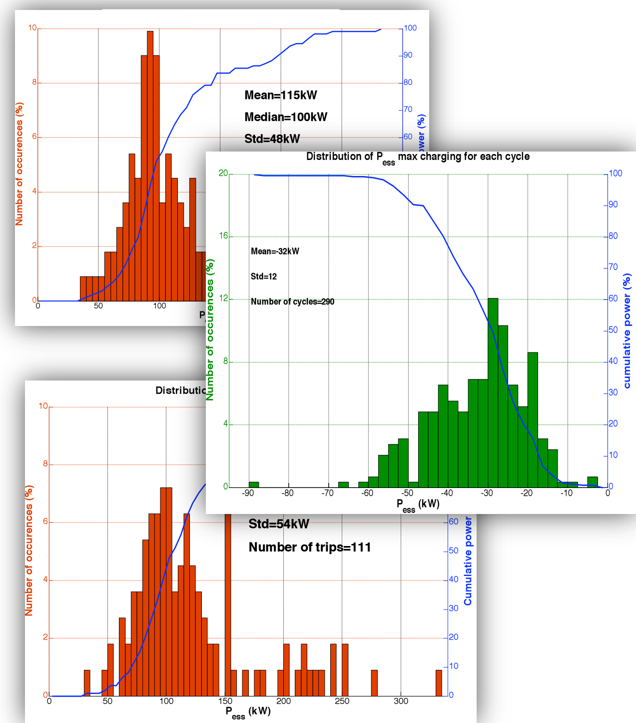
Real World Drive Cycles

Automated Sizing

Analysis (Distribution)







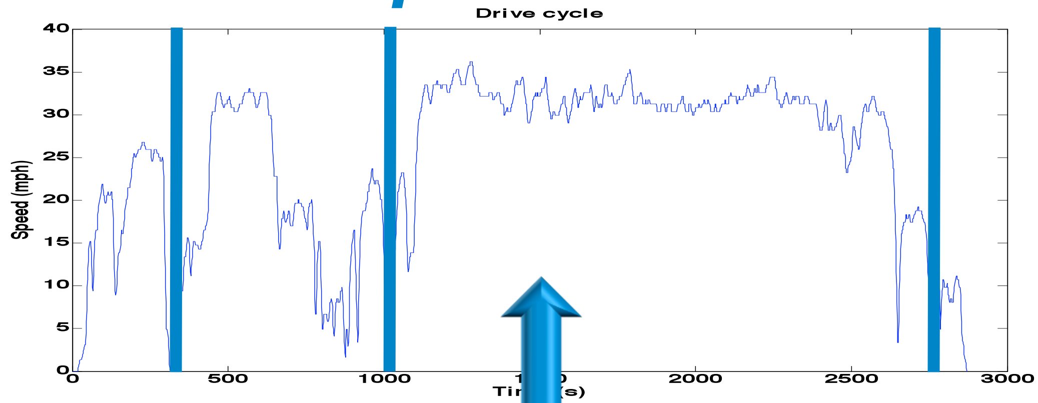
>110 Trips
One day in
Kansas City

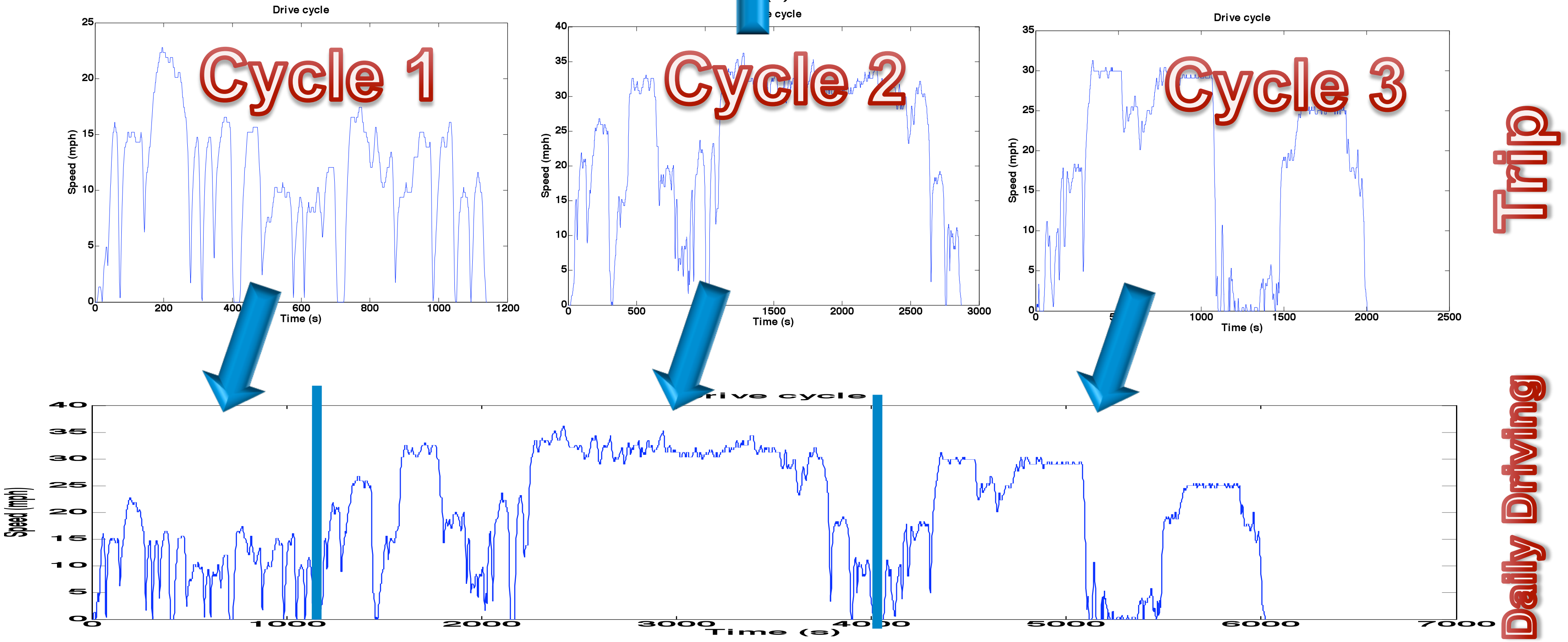
Power Split
Midsize Vehicle

Only Hot Conditions Assumed!

Analysis of Vehicle Speed Traces at Different Levels

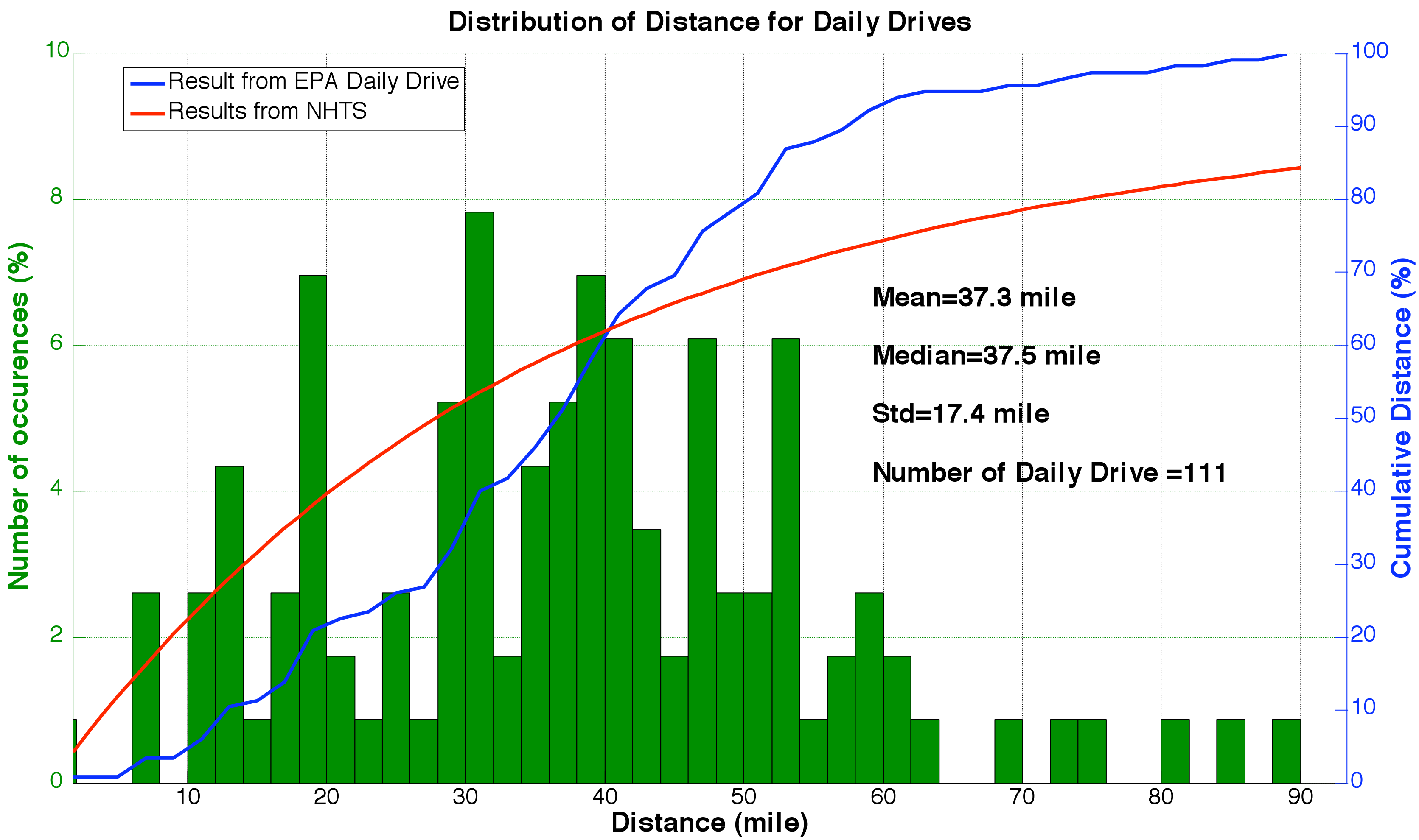
A hill is the portion of a cycle between two stops





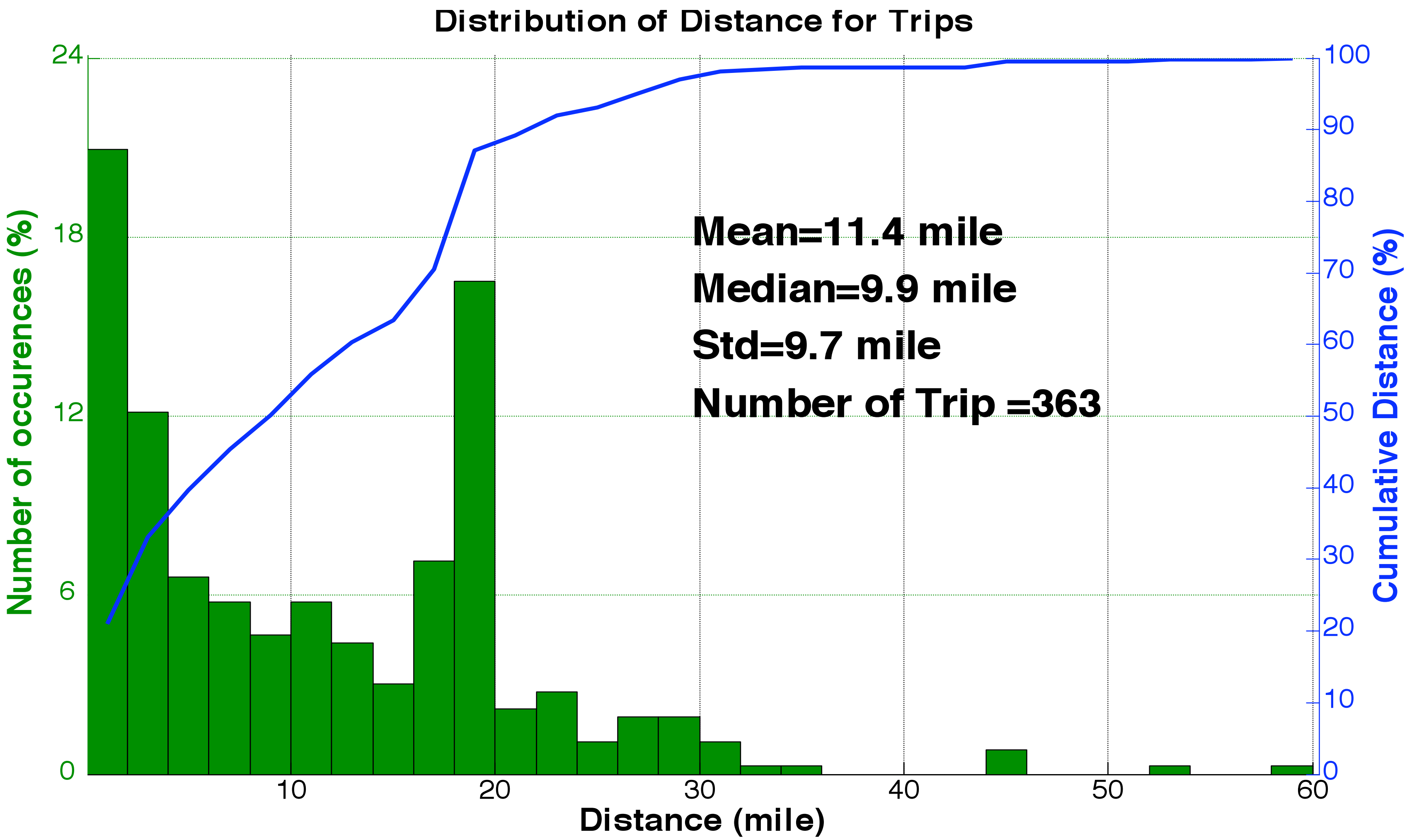
Daily Driving Characteristics

- 111 different drivers – All based on Conventional Vehicles

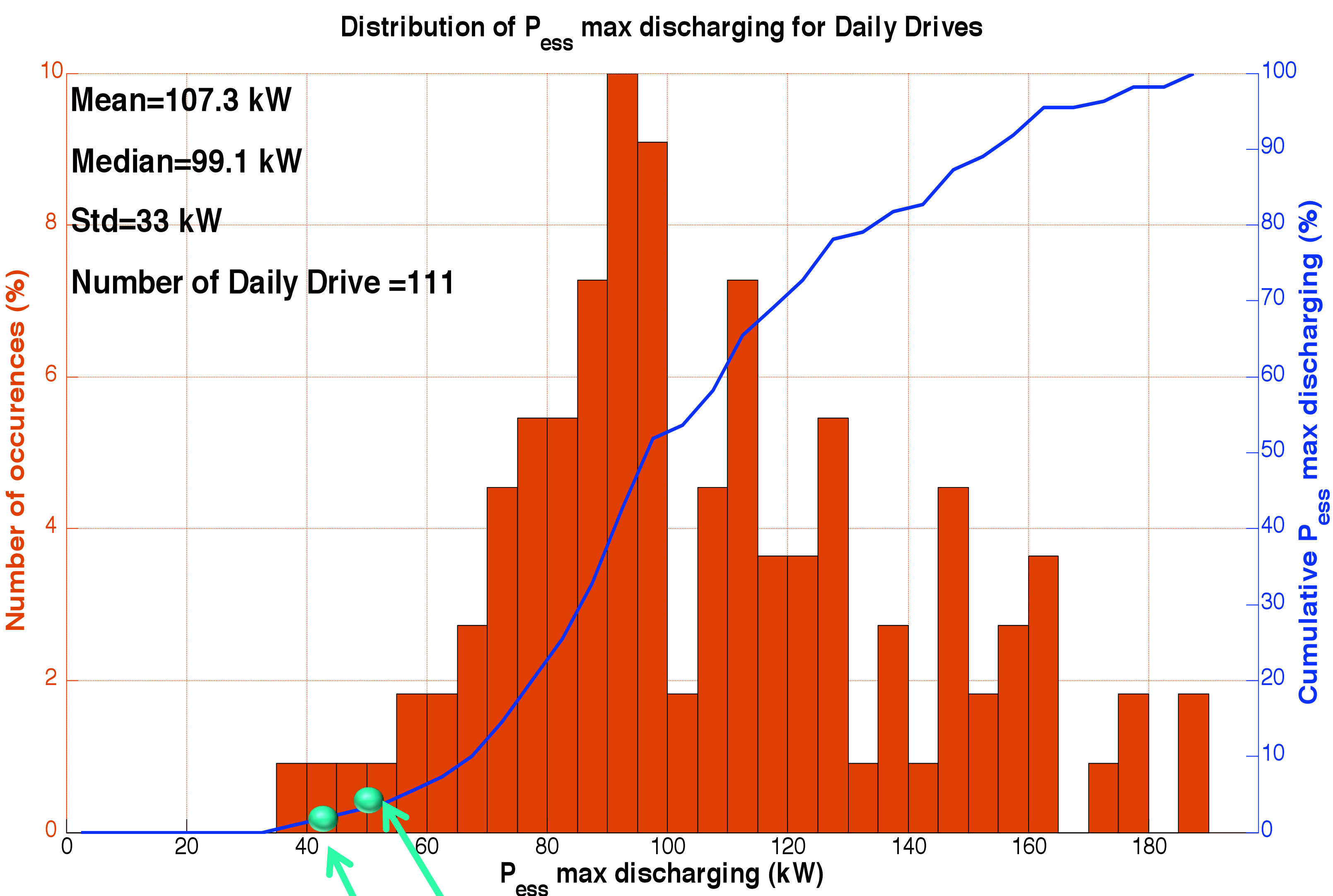


Trips Characteristics

- 364 trips (trip = get in and out of the car)



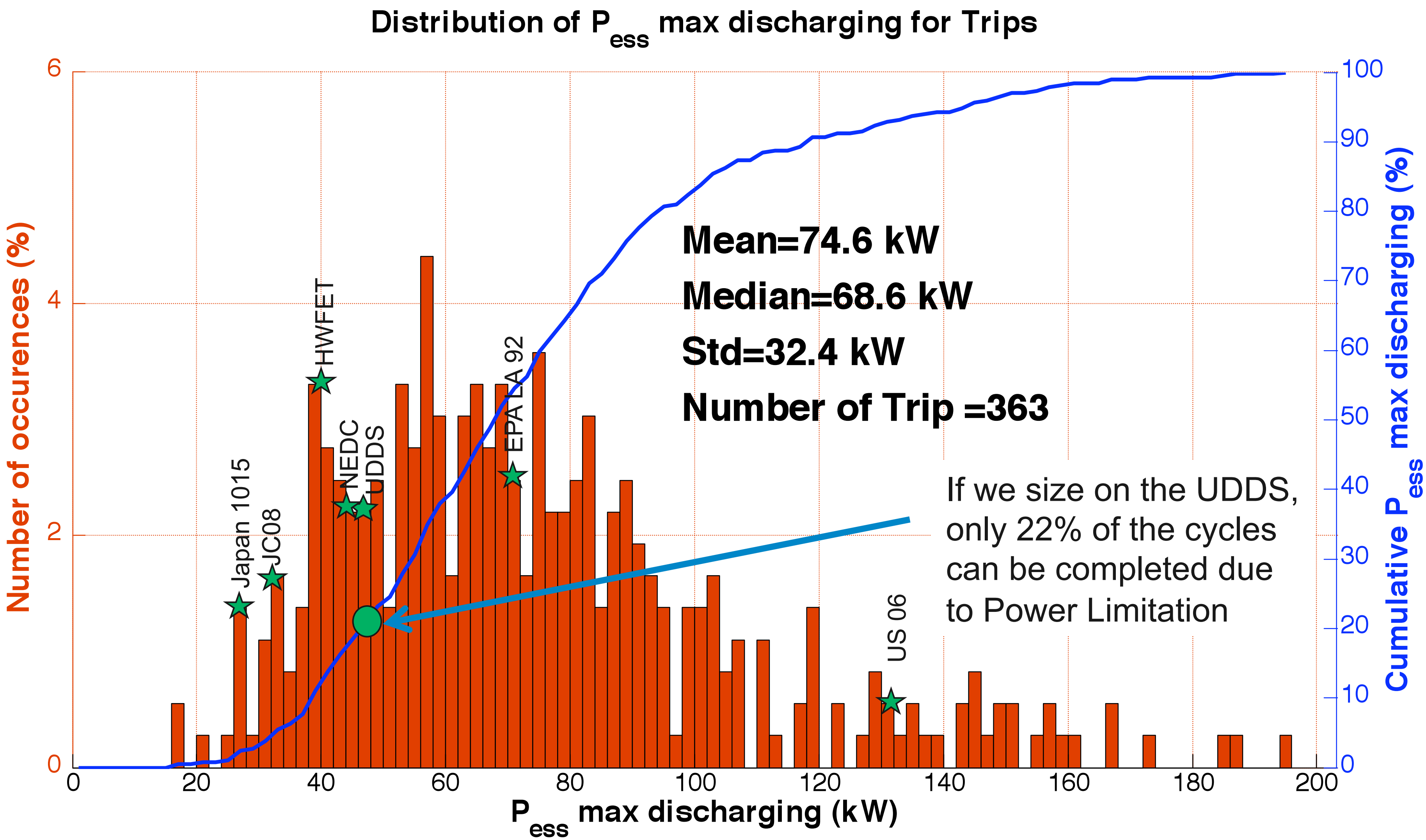
50% of the Daily Trips Require >100 kW



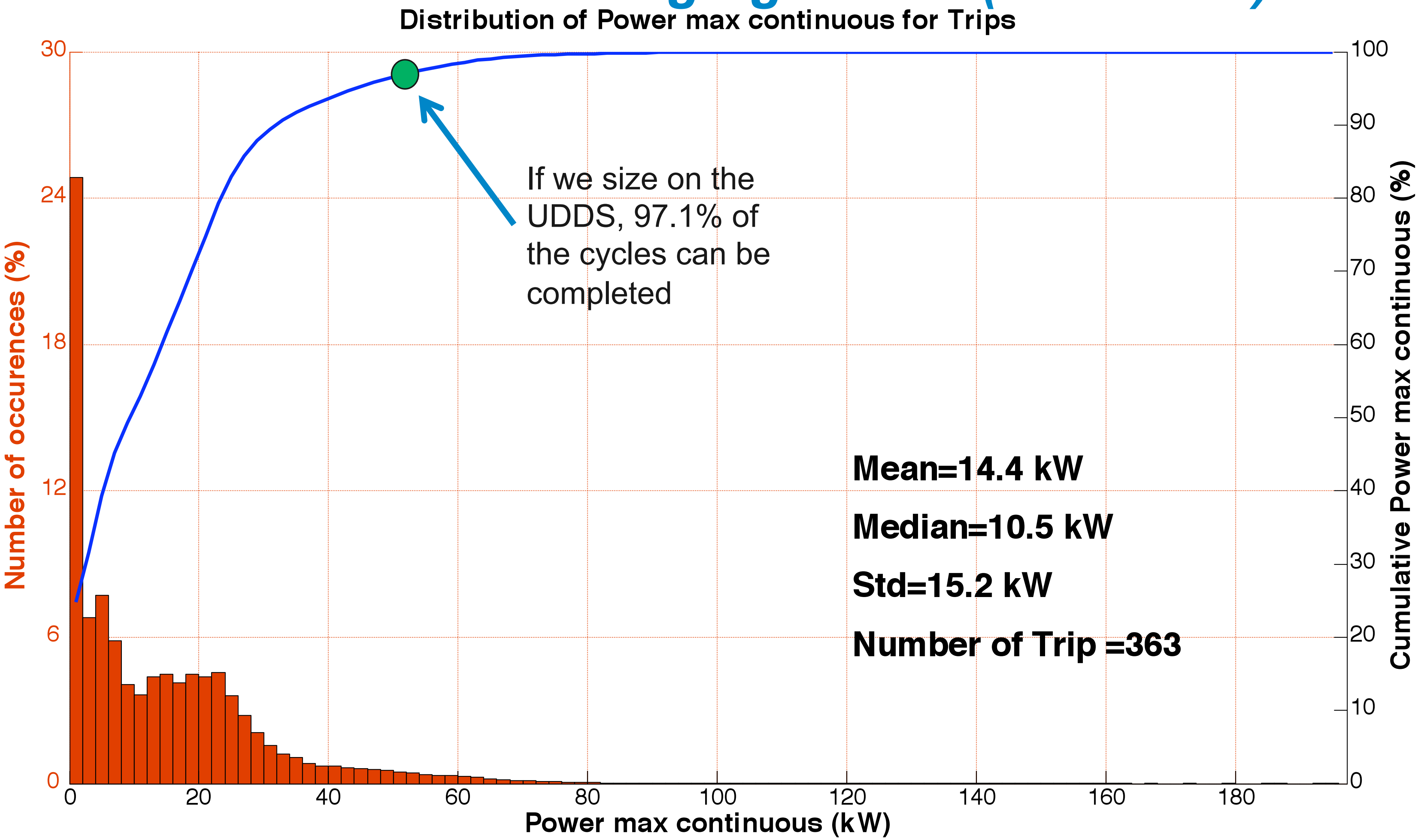
DOE Requirement (50 kW) => 3.5%

DOE Requirement (46 kW) => 2.9%

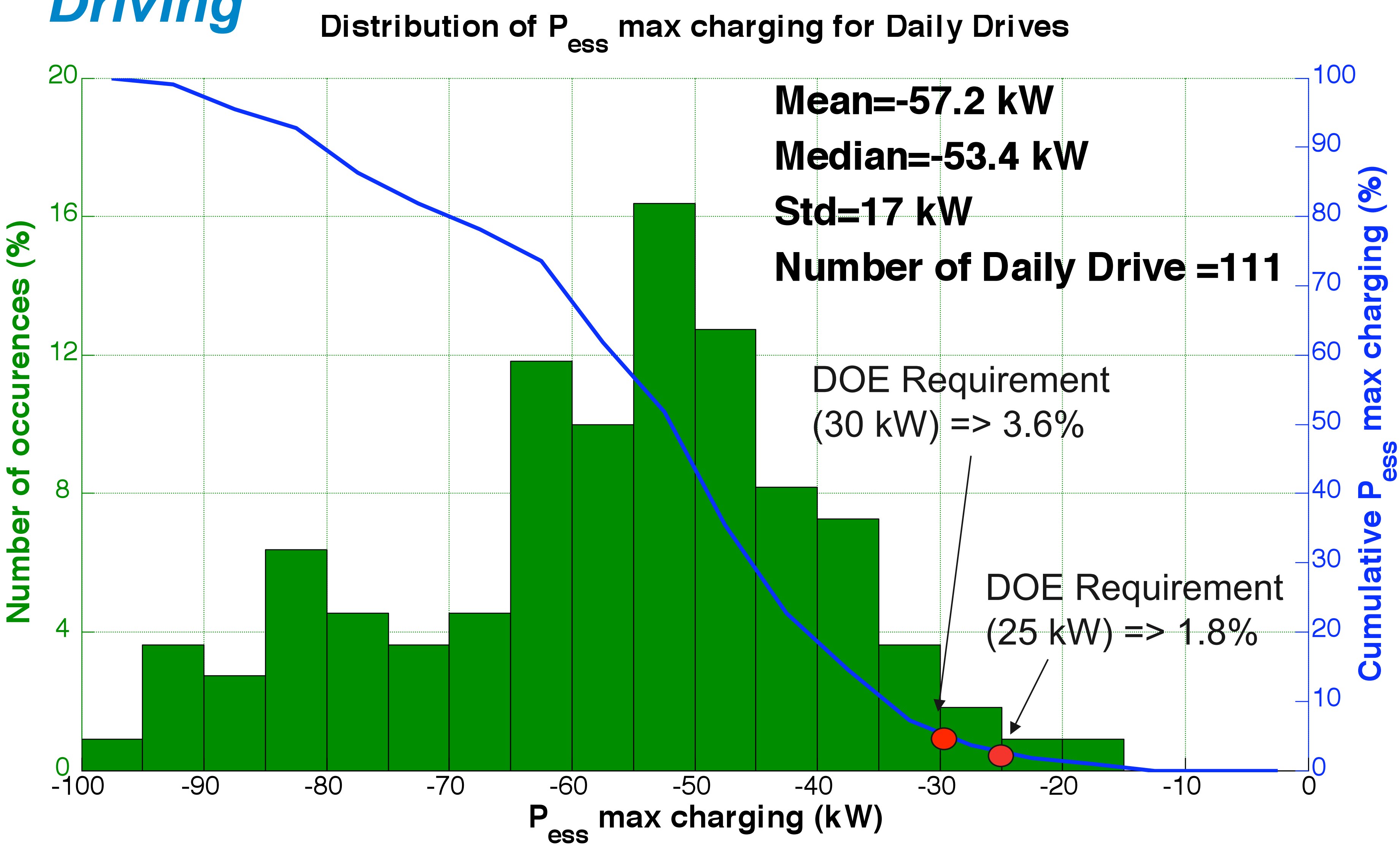
Distribution of Discharging Peak Power Per Trip



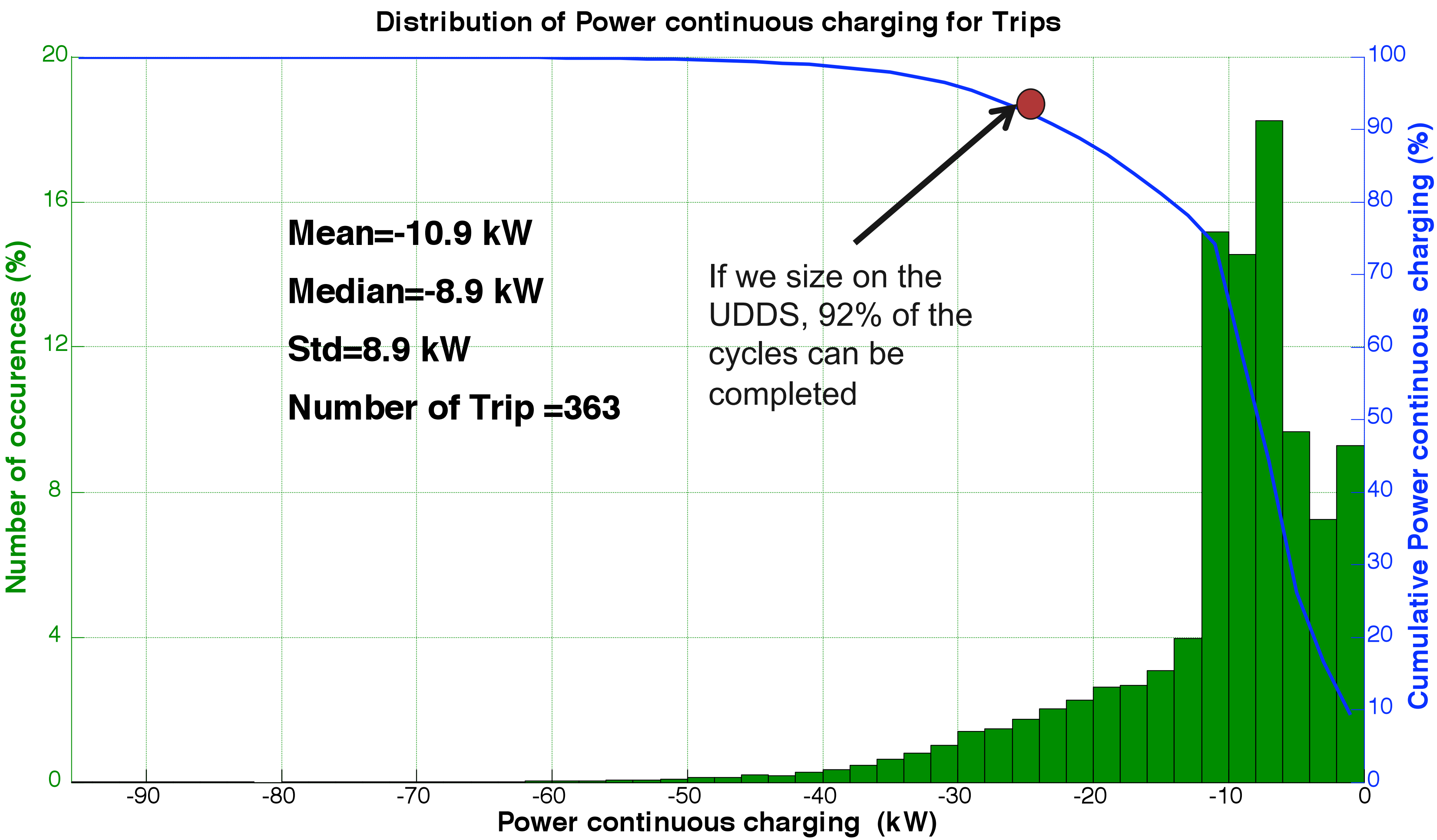
Distribution of Discharging Power (All Points)



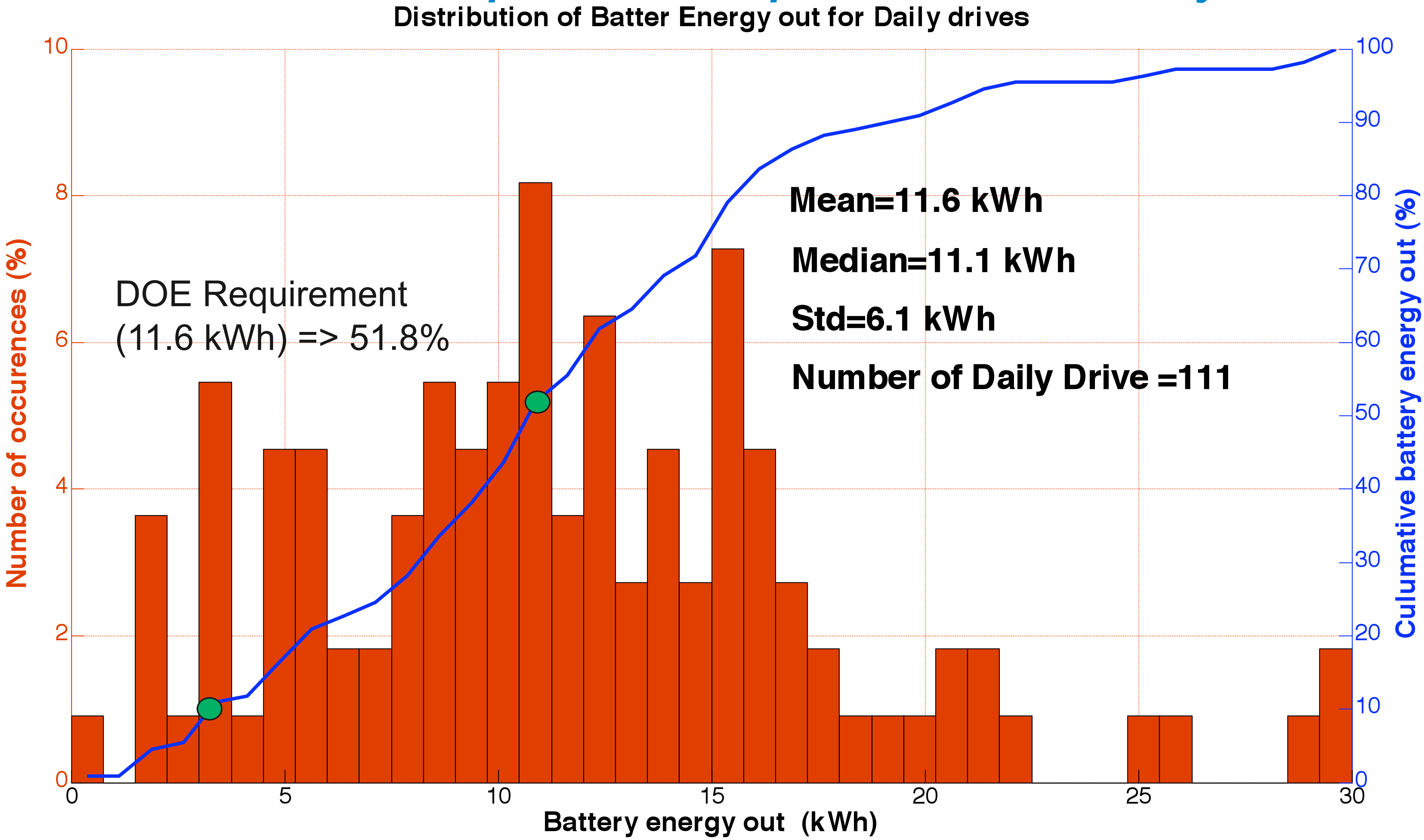
Distribution of Charging Peak Power Per Daily Driving



Distribution of Charging Power (All Points)

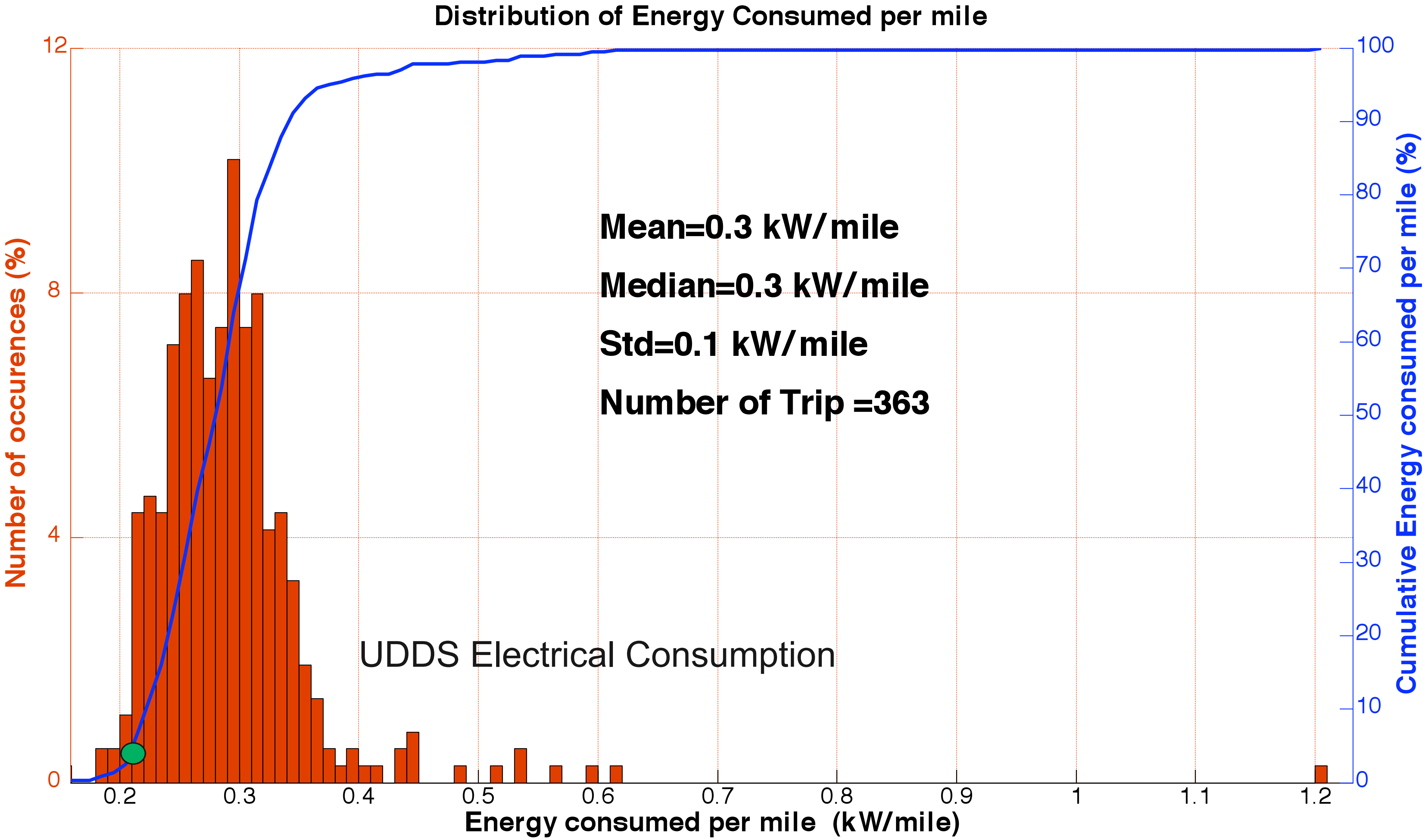


12 kWh Usable is Required to Complete 50% of the Daily Drives

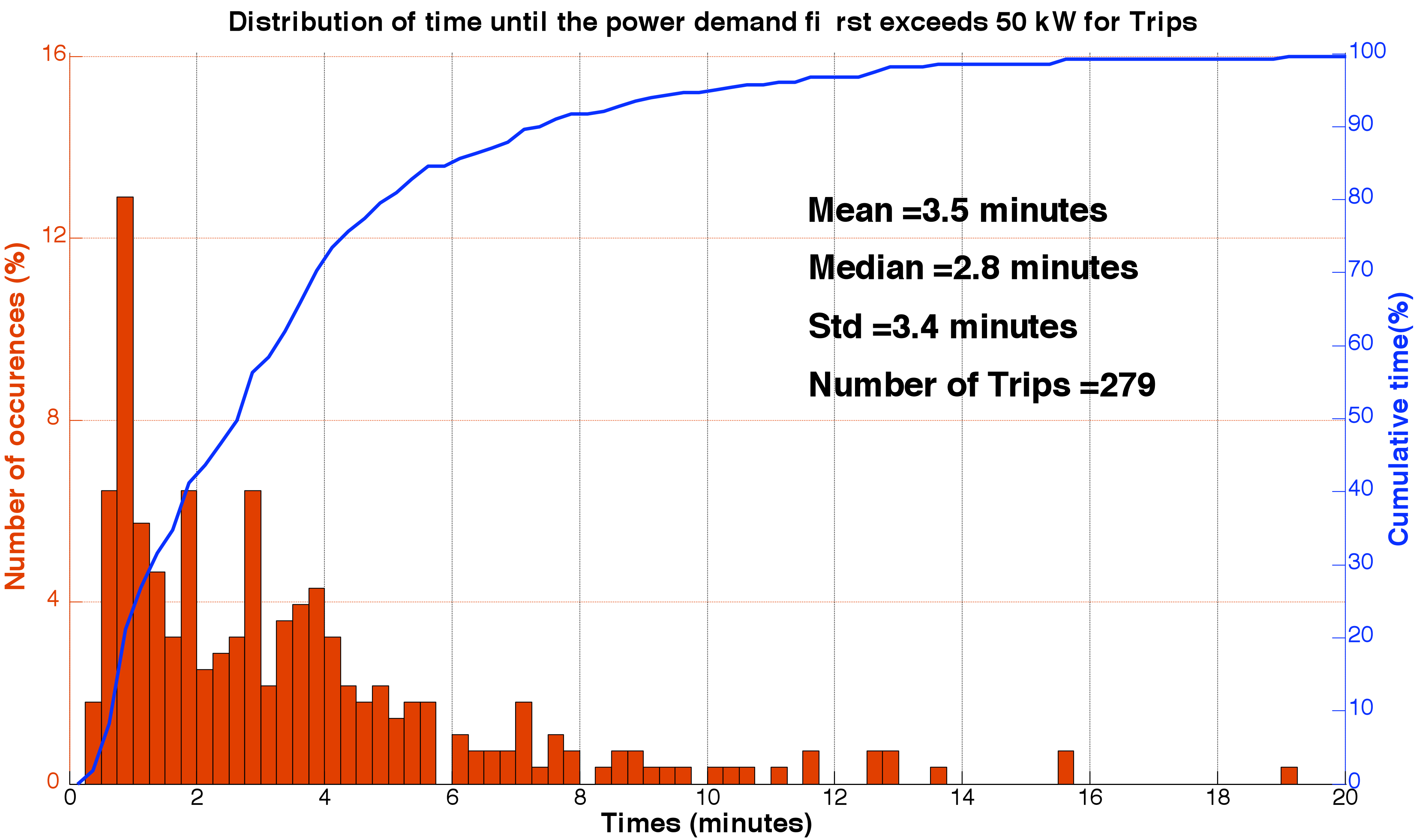


DOE Requirement (3.4 kWh) => 10.0%

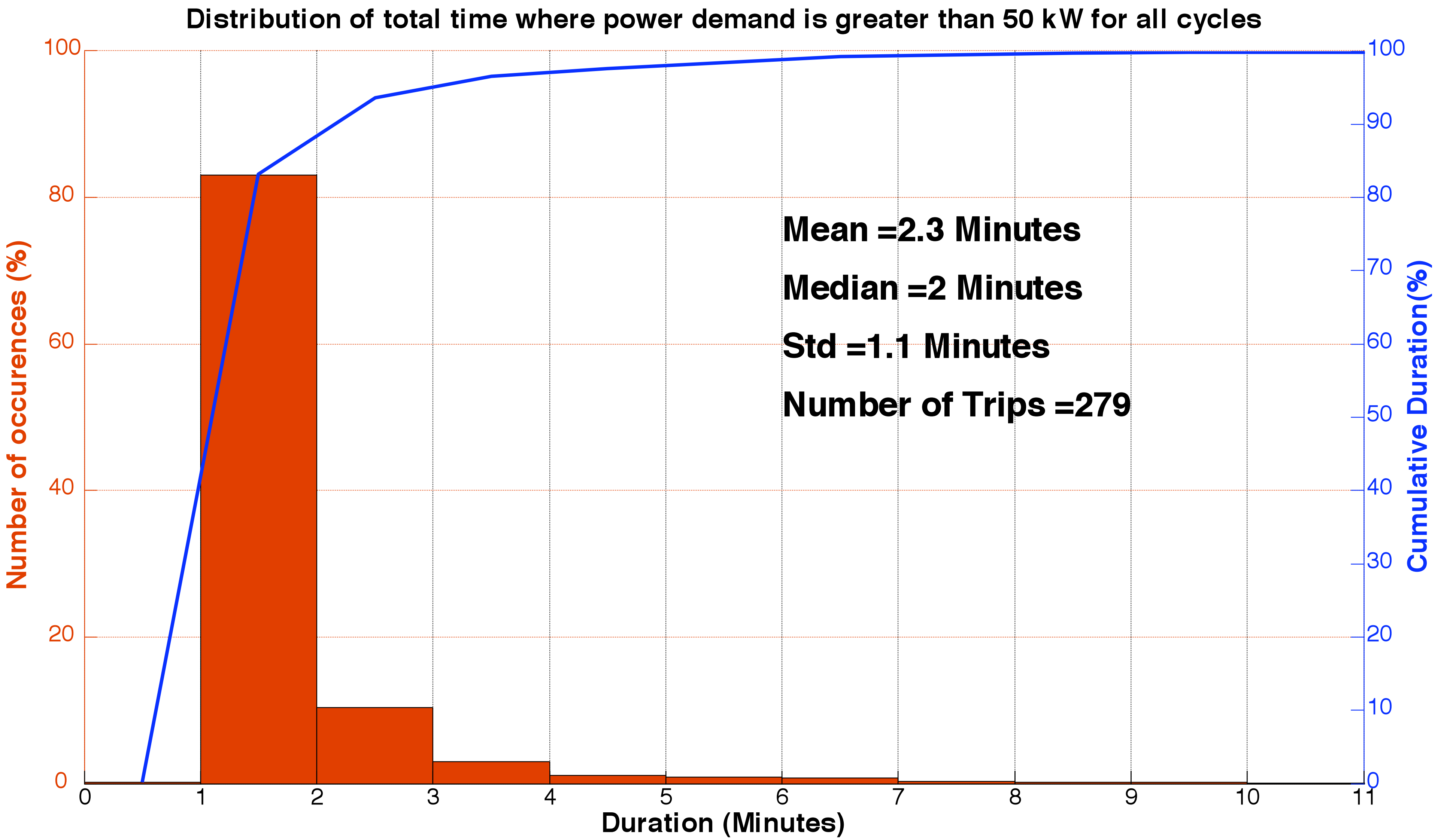
UDDS Represents only 10% of the Electrical Consumption



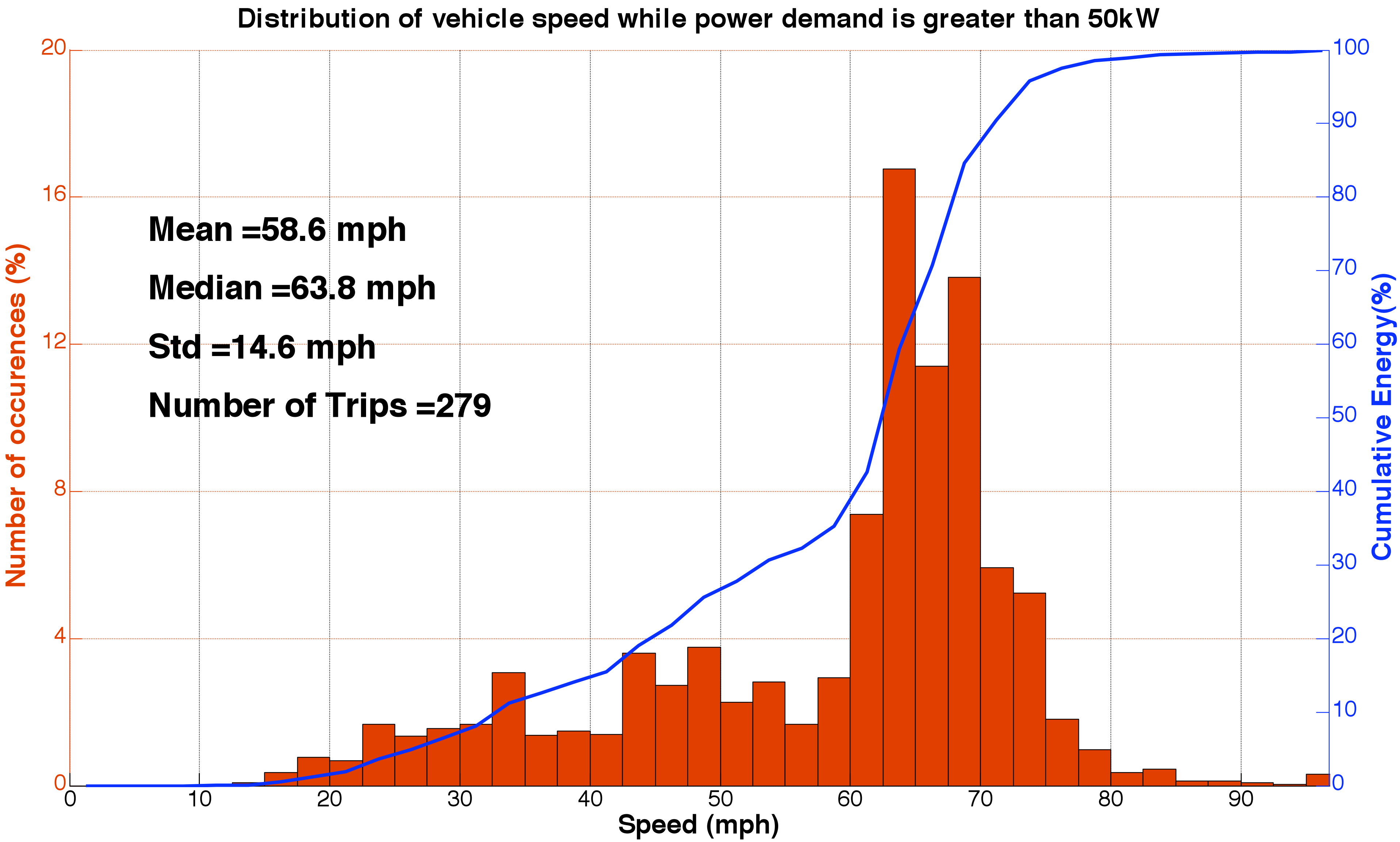
Maximum UDDS Power Reached Shortly After Departure



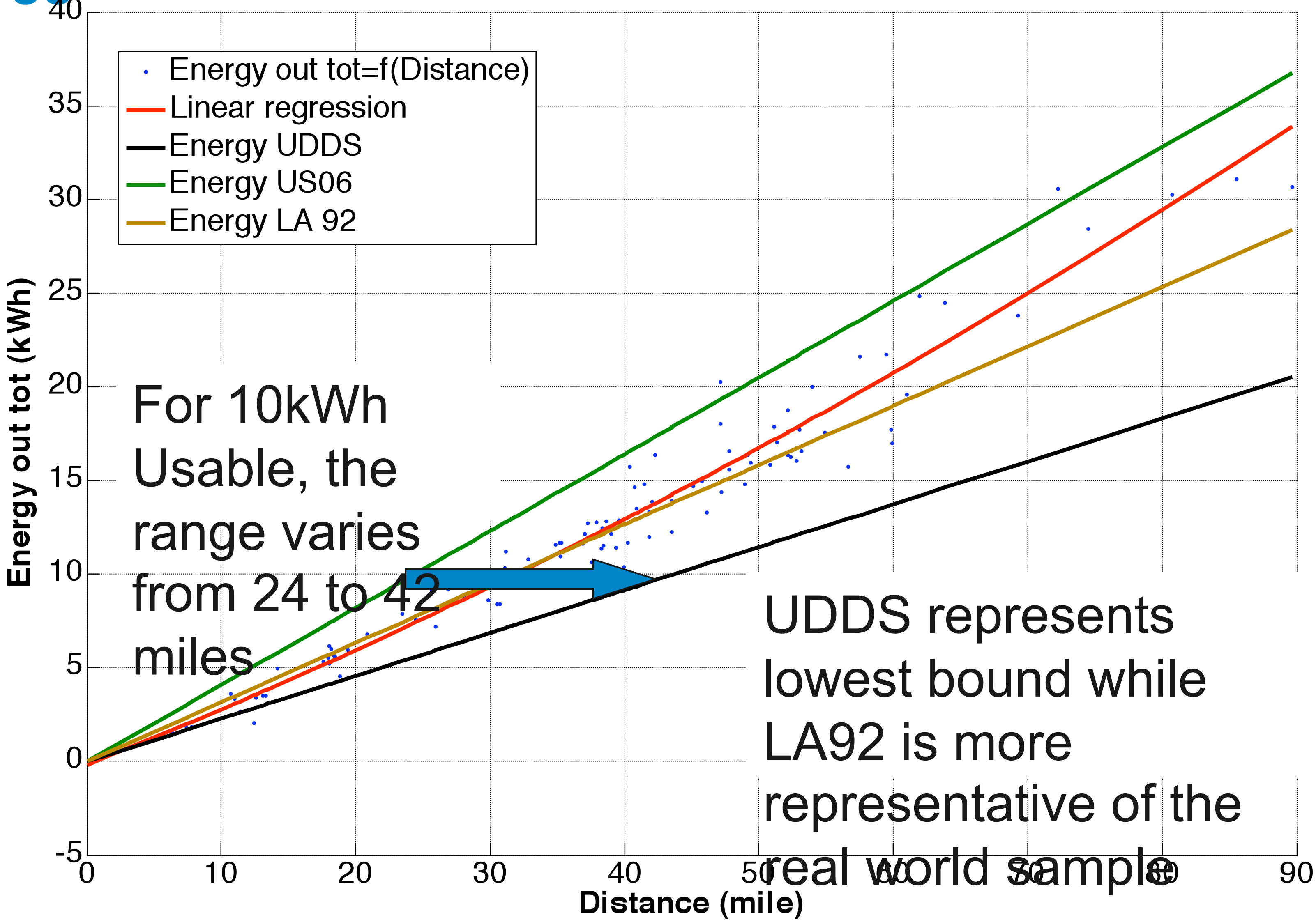
Power Demand >50 kW Occurs for Short Periods of Time



Maximum Power Demand Occurs at Highway Speeds



EV Distance Greatly Varies Depending Upon Cycles Aggressivenes



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.