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PHEV Vehicle Level Control Strategy Summary

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Sponsored by Lee Slezak

U.S. Department of Energy
Energy Efficiency and Renewable Energy
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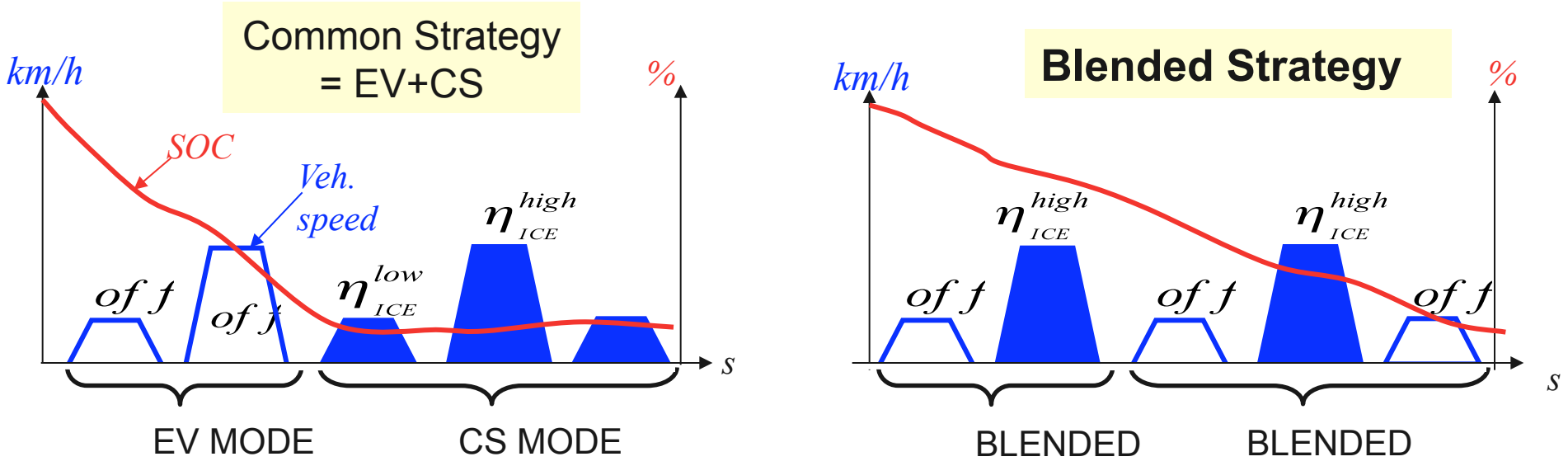
Objective: Assess Fuel Displacement Potential of Various PHEVs Control Strategies

Higher Electric Energy
Higher Electric Power
→ Higher Control Freedom → **Fuel Savings Potential**

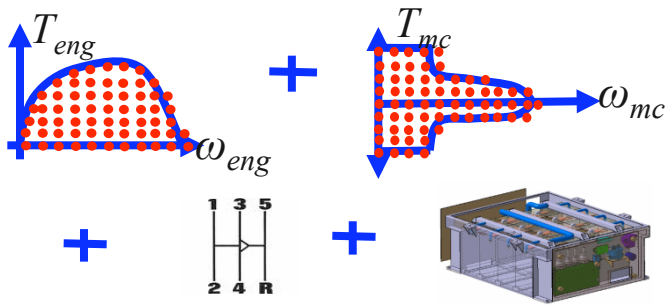
- Depending on various driven distance, several possible modes:
  - Below AER (**A**ll-**E**lectric **R**ange) : Electric-only (EV)
  - Above AER: EV? CS(***C**harge **S**ustaining*)? Blended?



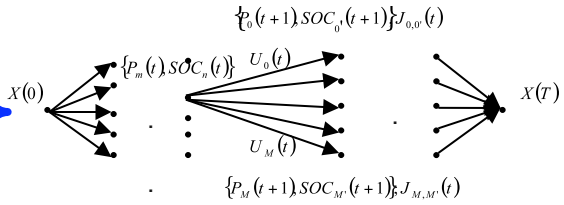
Control Optimization/Design Investigates Strategies Potential

Innovative 3-way Approach to Control Optimization

Global Optimization



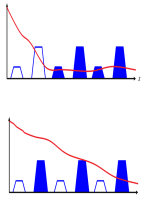
Backward model (not PSAT)



Bellman Principle

⇨ Optimal Control, Minimal Fuel Cons.

Control Design



Various Control Principles

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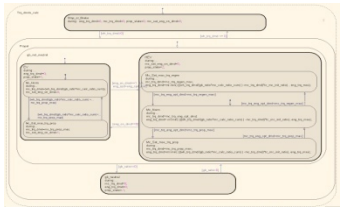

Rule-Based Control Design

⇨ Various PSAT Control Strategies

Heuristic Optimization

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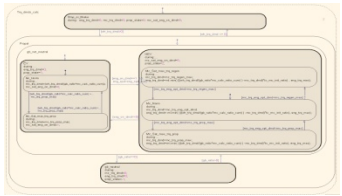
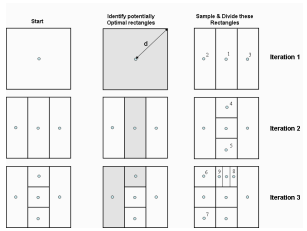


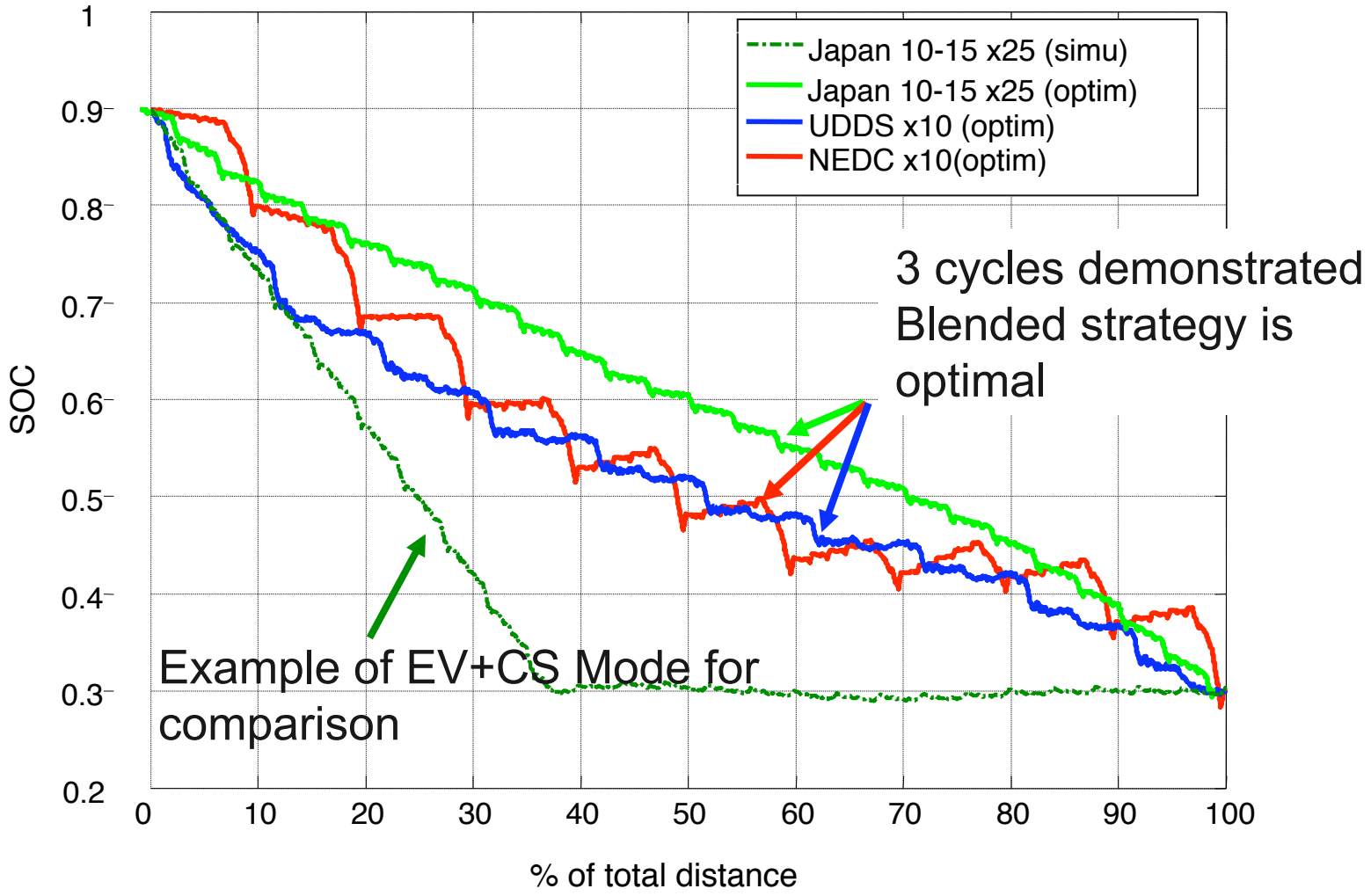
Existing Control Logic



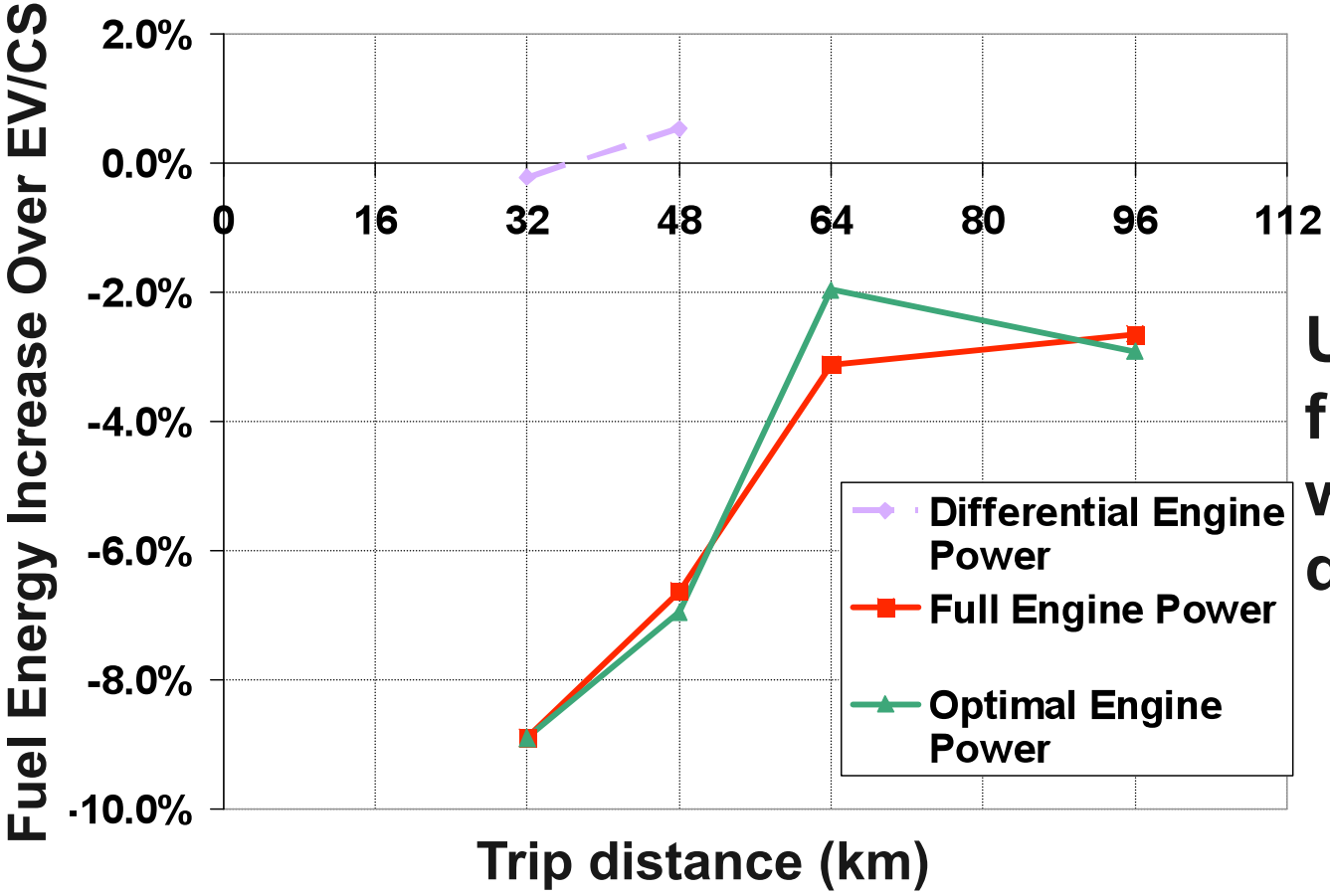
DIRECT Algorithm

⇨ Optimally tuned Parameters

Global Optimization Showed Minimal Fuel Consumption Achieved in Blended Mode



Control Strategy Design Showed Significant Improvements

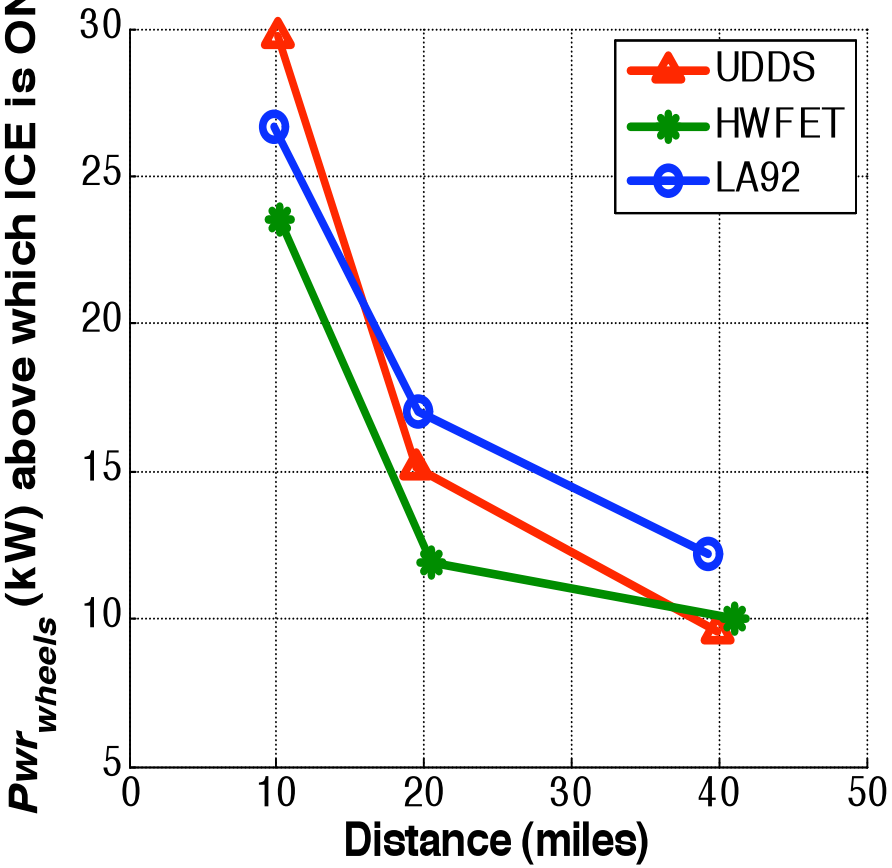


Up to 9% less fuel consumed when driving distance is 20 mi

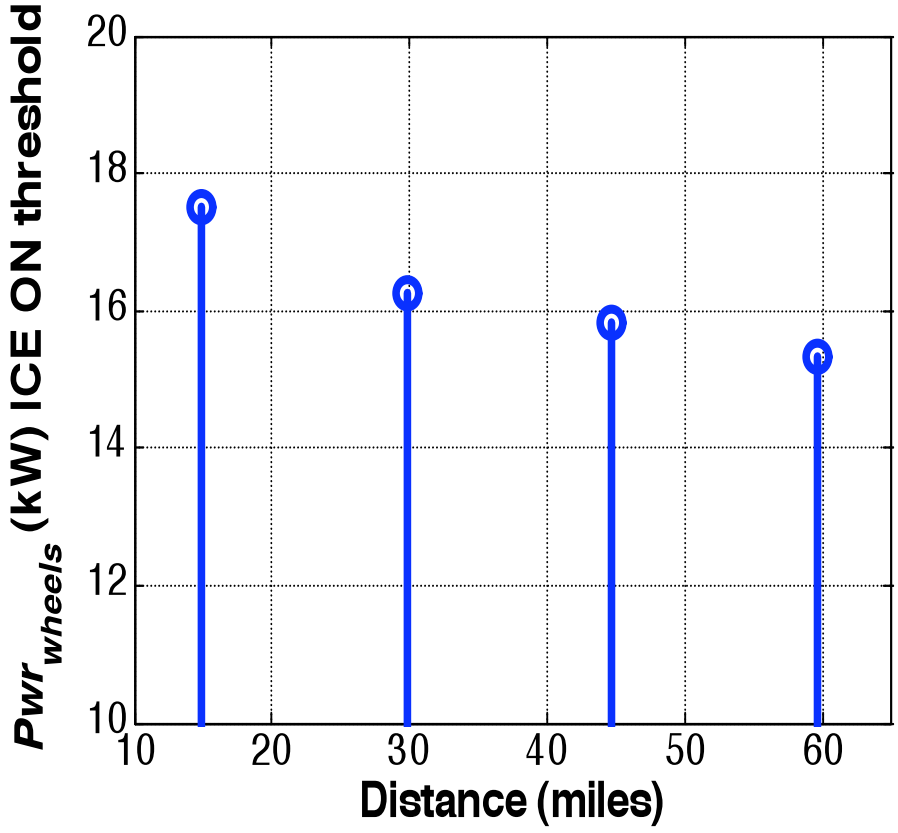
Power Split 10 miles AER (Prius), run on several UDDS cycles

Different Optimization Methods Showed Control Depends on Distance

Global Optimization



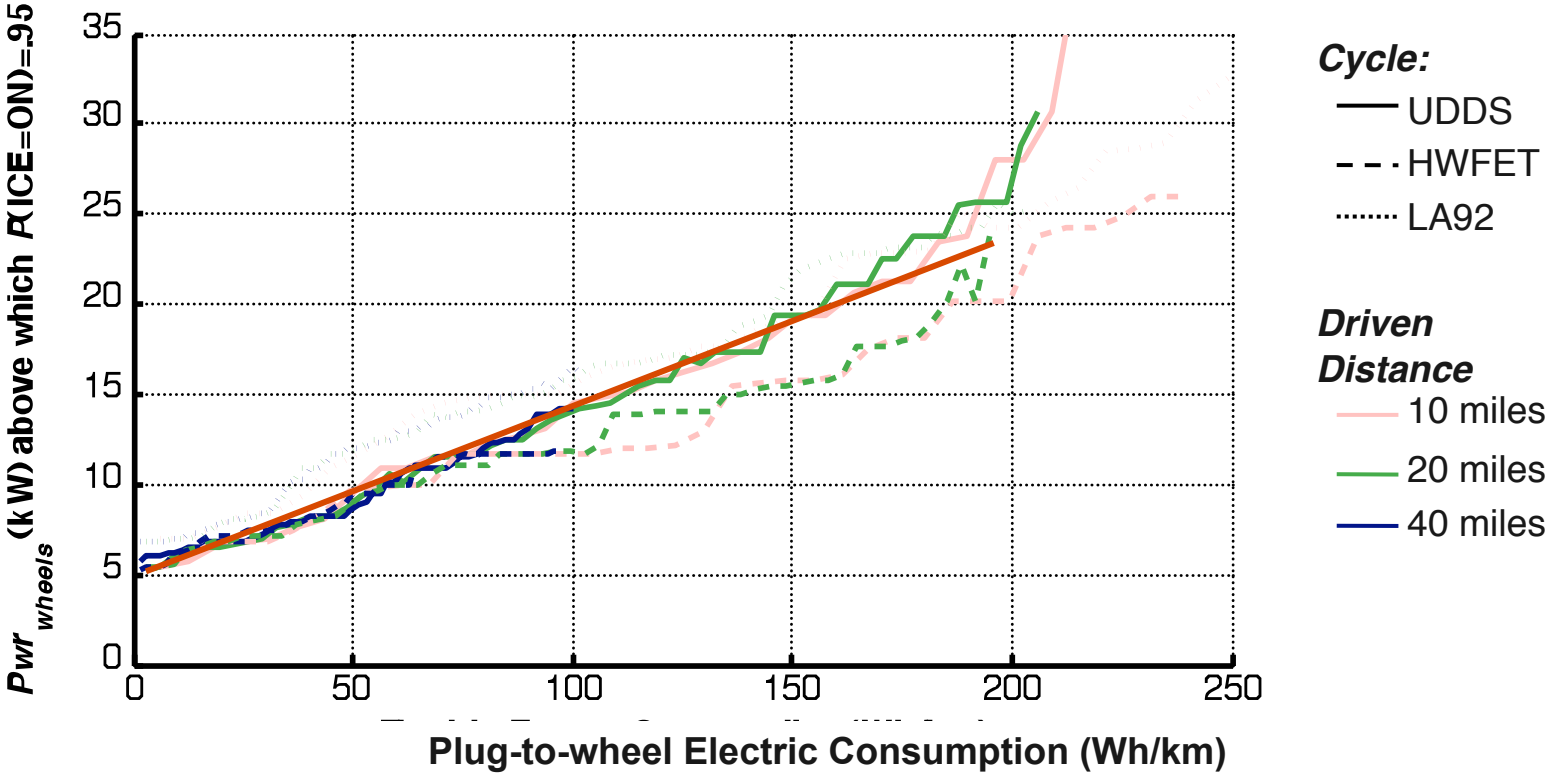
Heuristic Optimization (UDDS)



Small SUV, Parallel Pre-tx, 10 miles AER

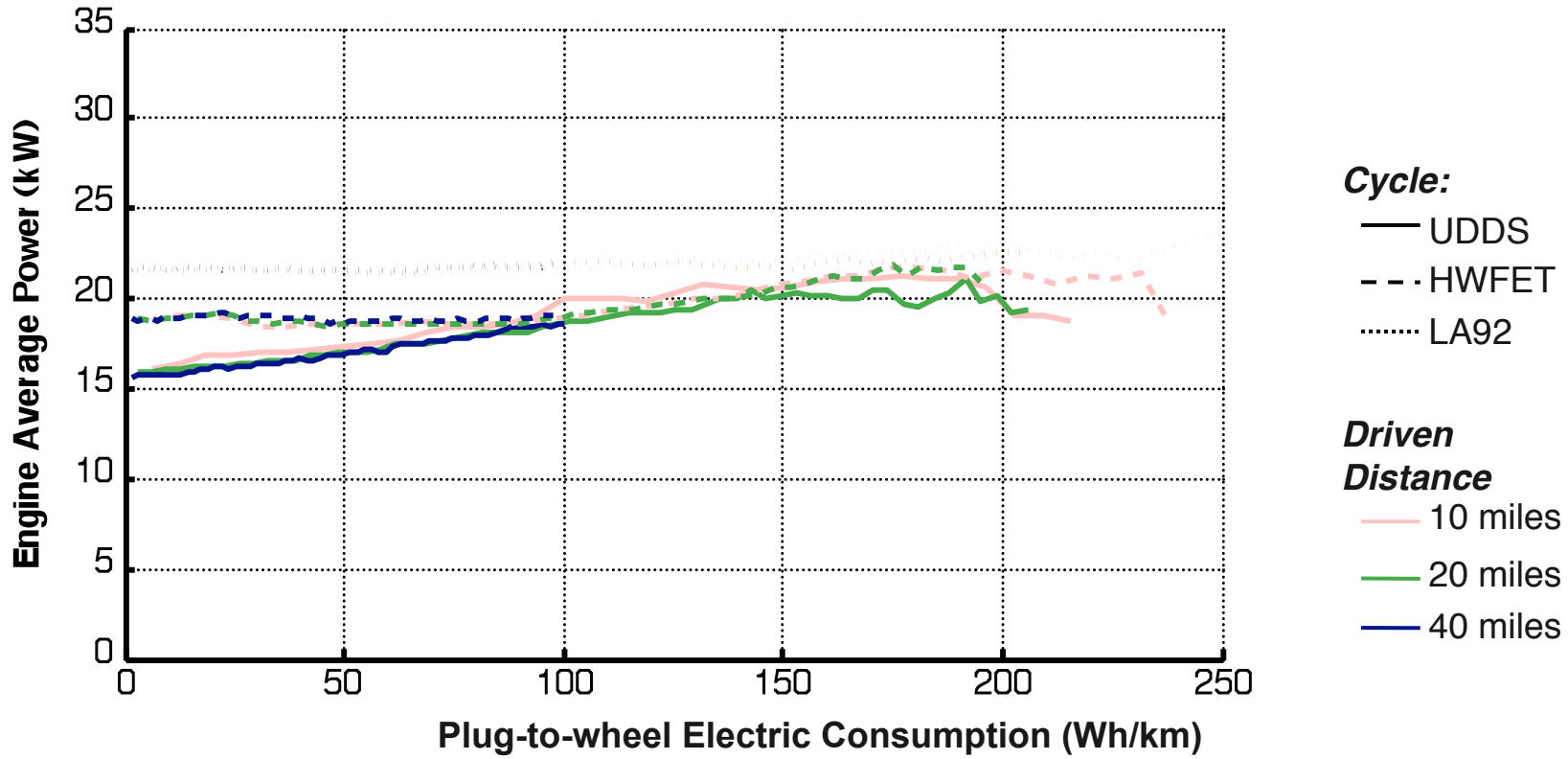
“ Engine On” Is Linked to Wheel Power

Global Optimization



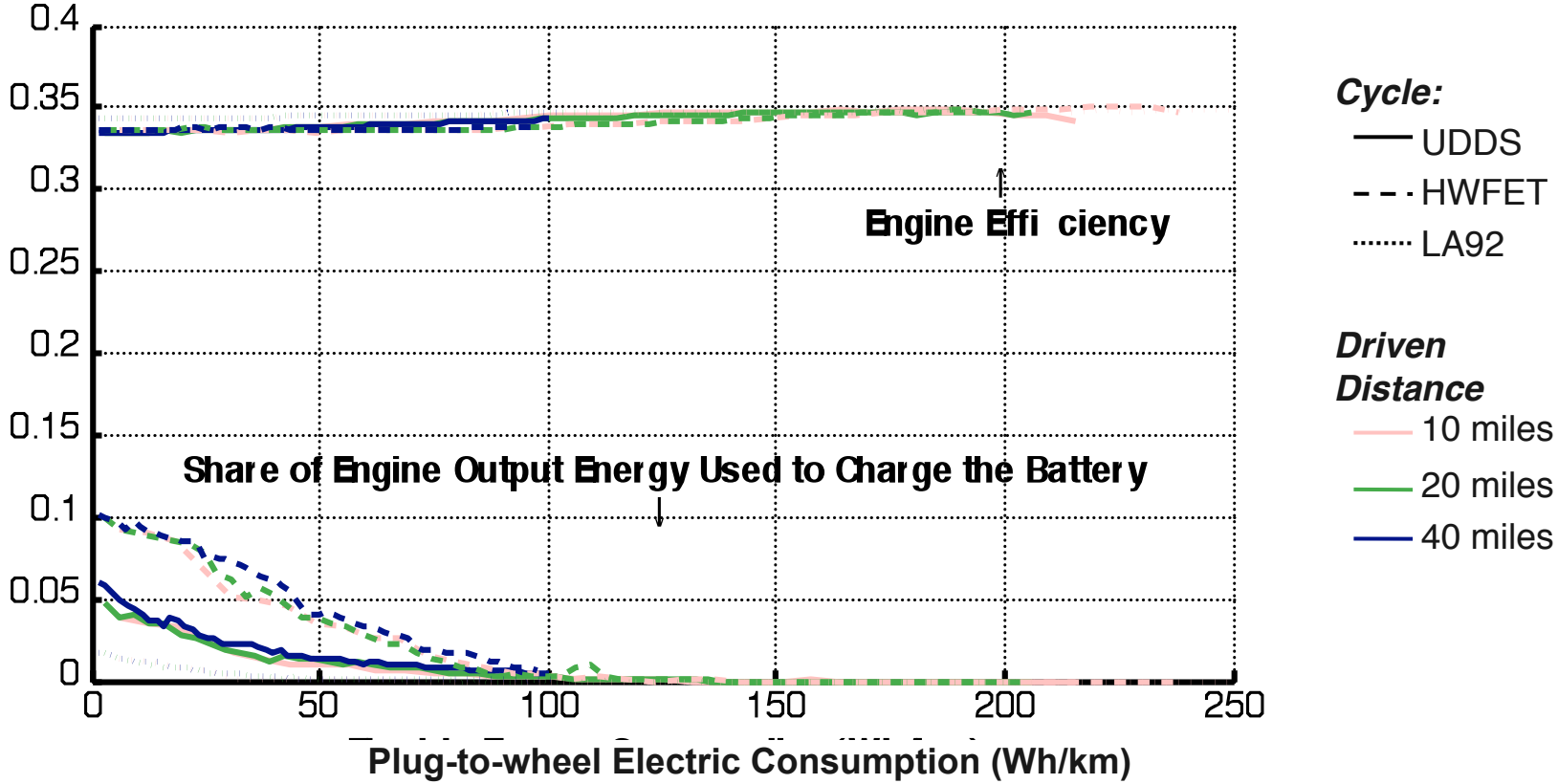
- Power at wheels above which ICE is on 95% of the time, similar to wheel power threshold used in rule-based controls
- Higher Electric Energy Use → ICE starts “later”
- Wheel Power Threshold follows linear trend
- Little influence of driving cycle

Engine Power Depends on Cycle and Electricity Use



- UDDS: ICE power increases with Wh/km
- LA92: ICE power constant, because cycle is aggressive enough for the ICE to operate efficiently

Charging from ICE Likely When ICE is Predominant and Wheel Power is Low



- UDDS: when ICE is used often, it has to operate often above requested wheel power
- LA92: ICE operates efficiently, even in CS mode because average ICE power is high

5 Vehicles with Different Energy and AER

Power to meet EV-mode requirements on UDDS…

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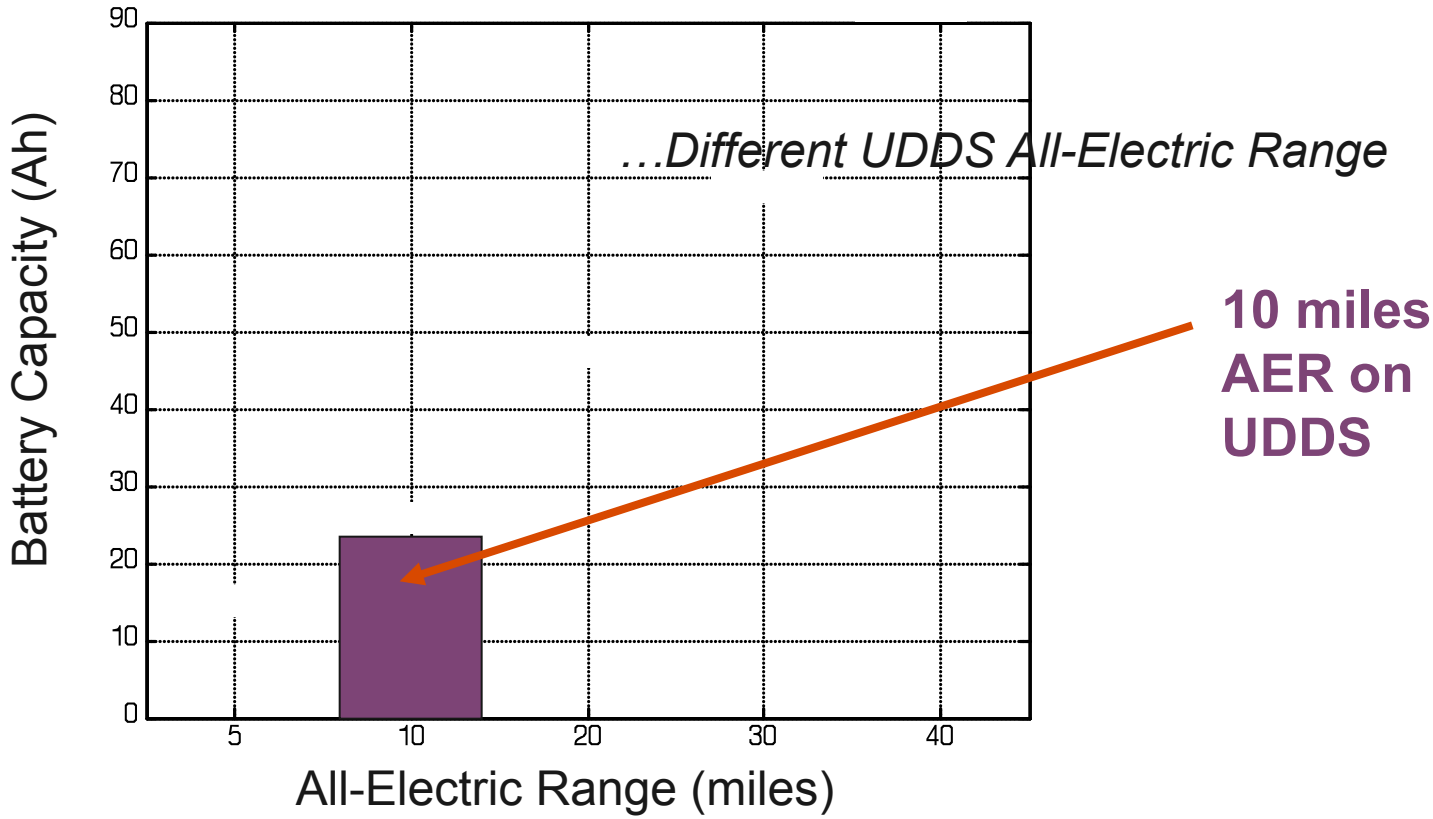
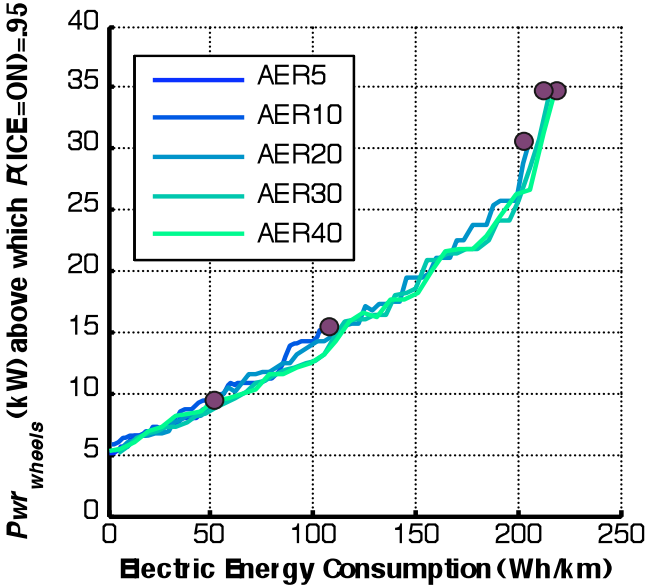
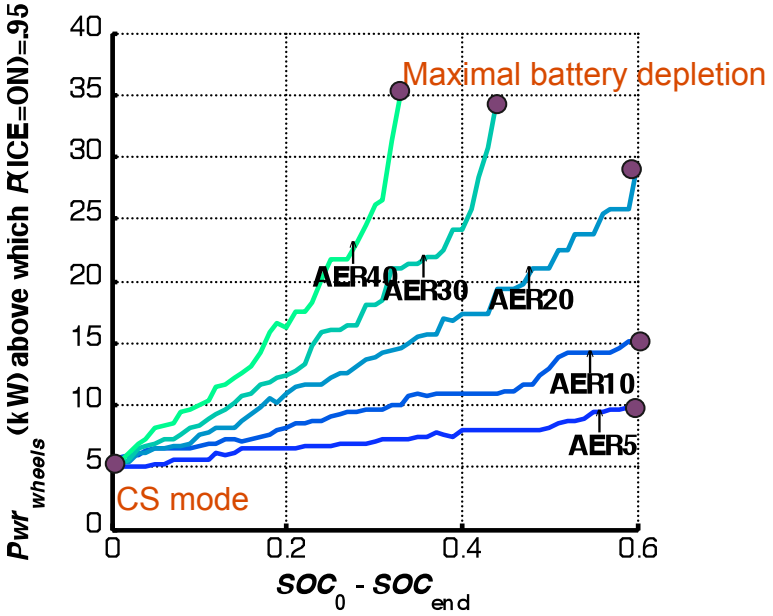


For a Given Electric Consumption, AER Has Little Influence on Control

- For a given electric consumption, ICE-On behavior does not depend on the energy sizing…
- …but possible electric energy consumption is limited : same electric consumption corresponds to different ΔSOC

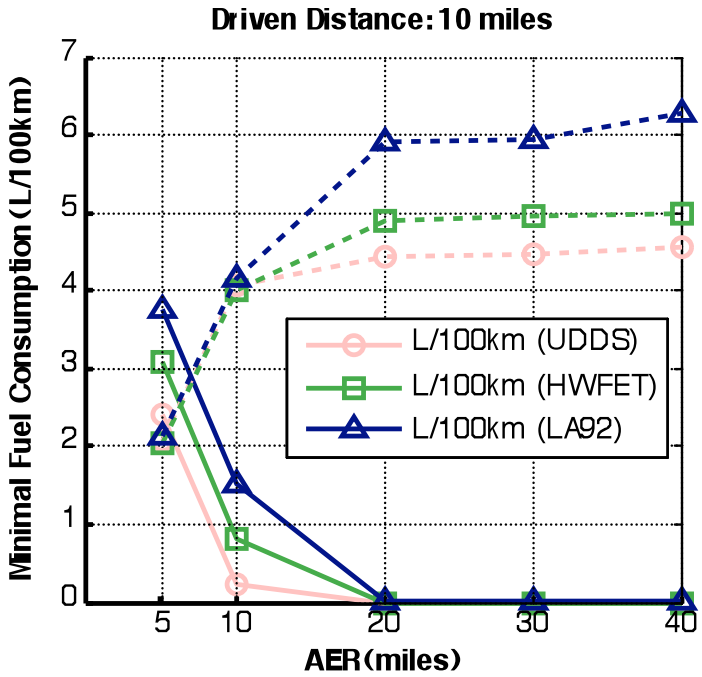


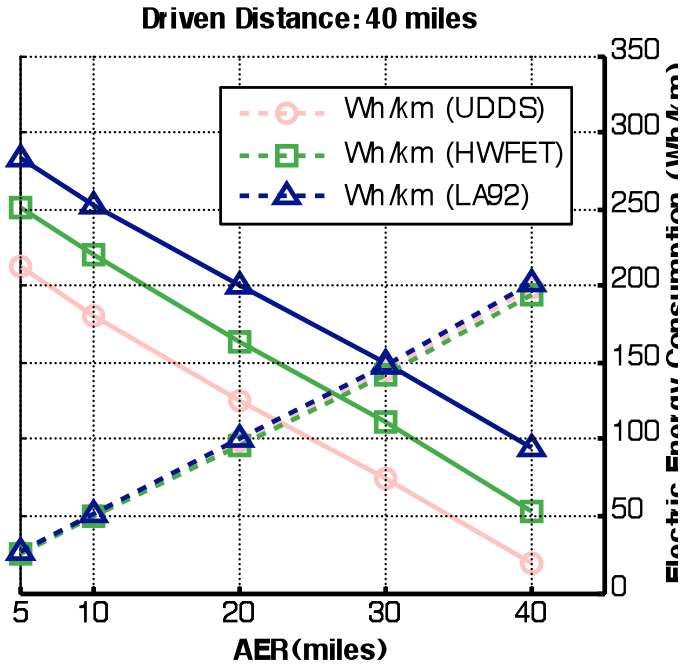


UDDS, 20 mi

Minimal Fuel Consumption

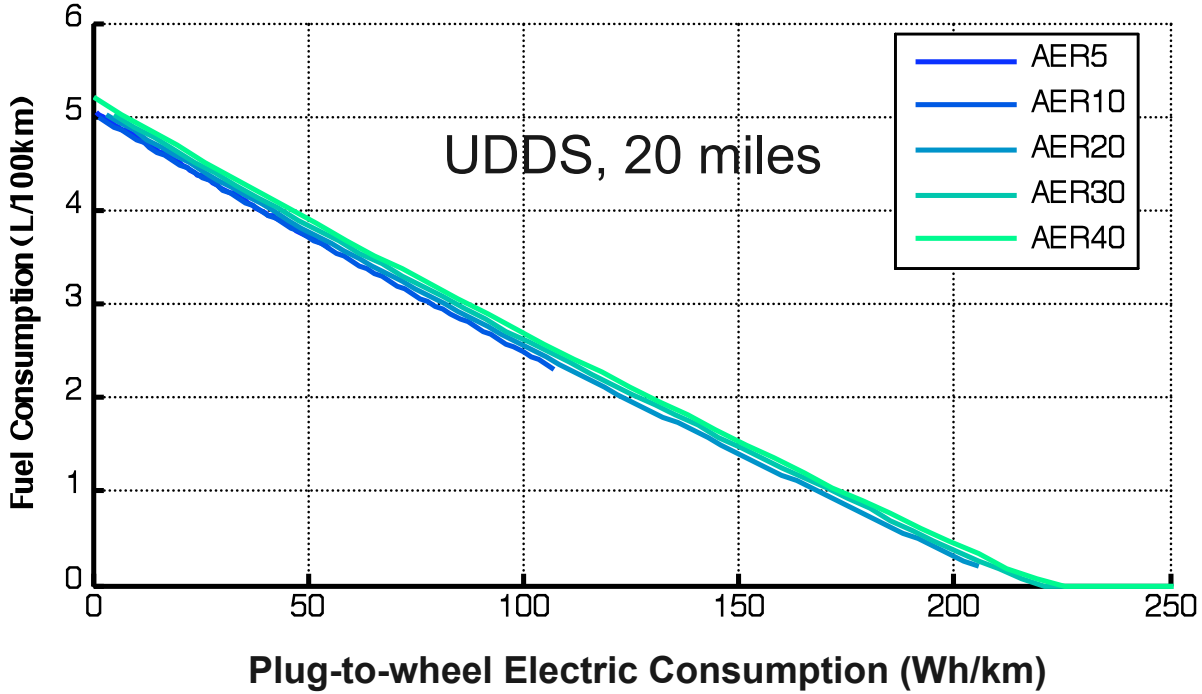
- Distance Traveled < AER
  - On a given cycle, little sensitivity to energy sizing
  - LA92 leads to a 34% increase in electric Wh/km compared to UDDS
- Distance Traveled > AER
  - Decrease in fuel consumption is proportional to increase in AER
  - 1.5 L/100 km difference between UDDS and LA92





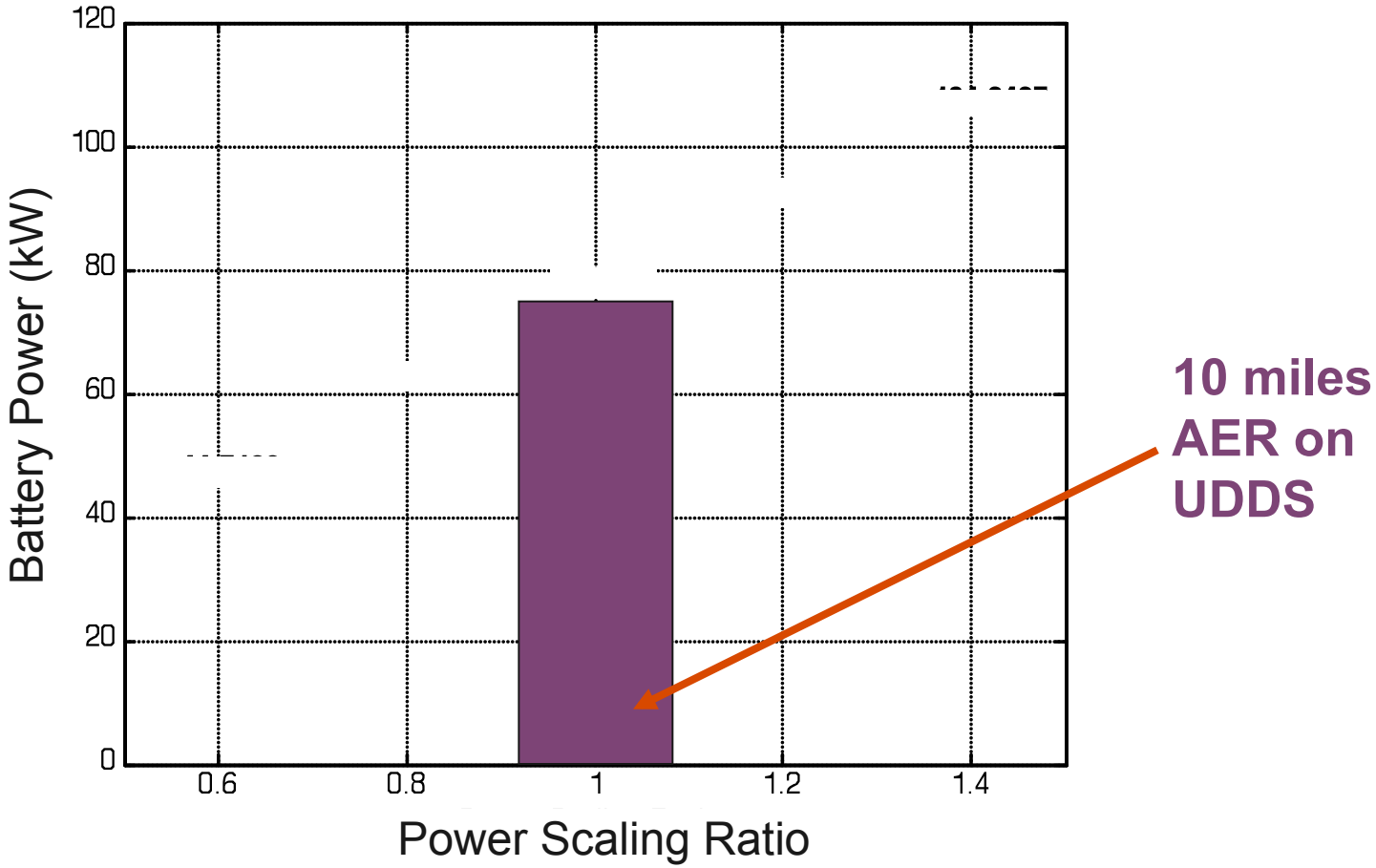
Fuel Consumption Follows a Linear Trend and Depends on Wh/km

- Small AER vehicles consume slightly less fuel due to lower weight, but difference in consumption is minimal
- For a given electric consumption, fuel consumption is comparable
- For 2 vehicles (e.g. AER 30 & AER 40) travelling less than their AER (e.g. 20 mi on UDDS), same EV mode electric consumption



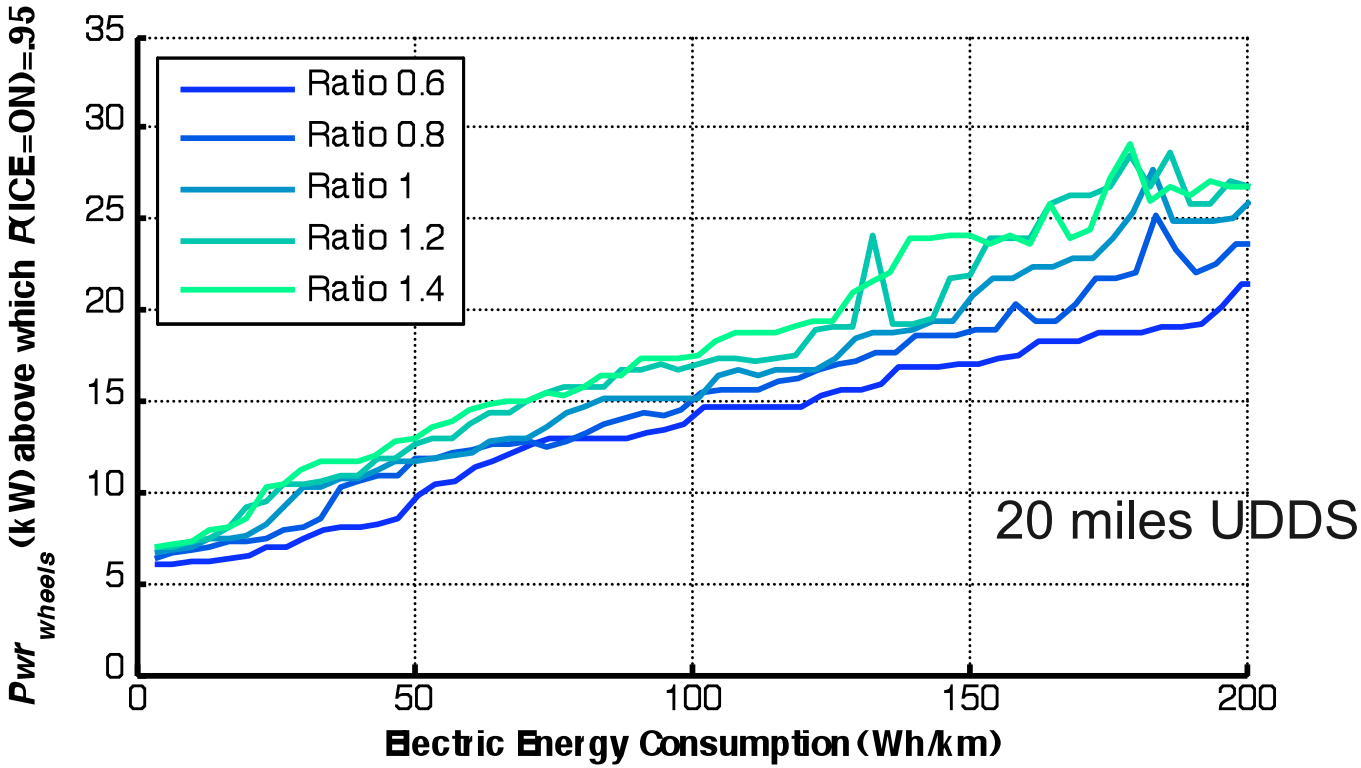
5 Vehicles With Different Power

Same Battery Energy… + *… Different Electric Power*



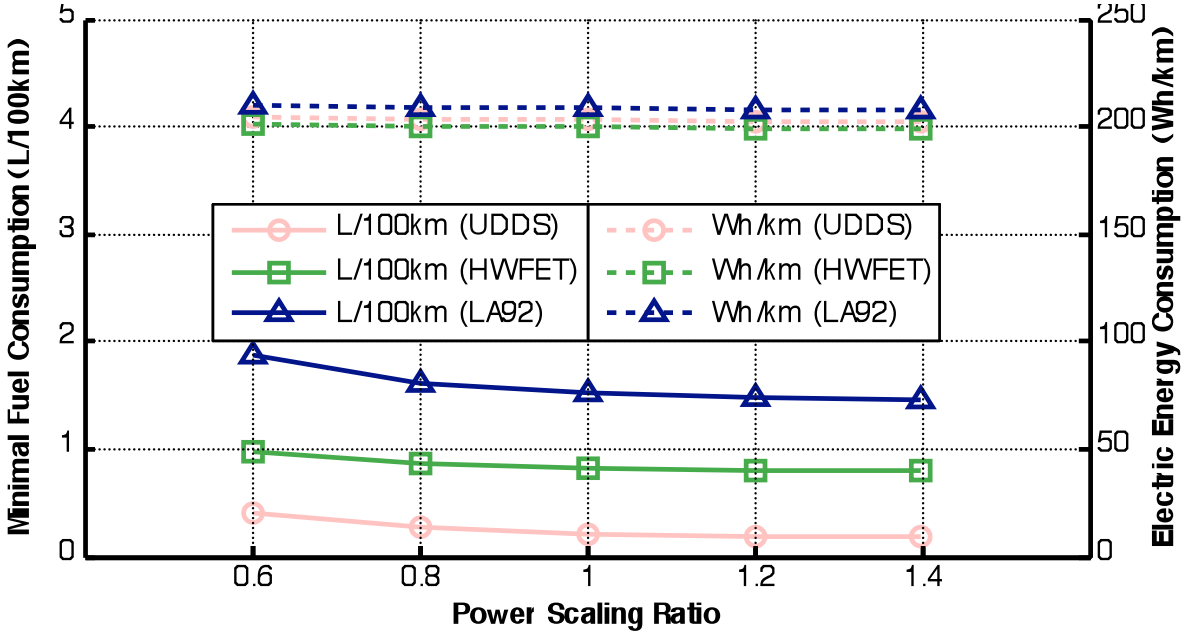
Maximum Power Impacts Wheel Power Threshold for Engine ON

- The engine starts “earlier” when the electric system has lower power



Less Electric Power Results in Higher Fuel Consumption

- Especially true on aggressive cycle (LA92), and distance traveled close to AER
- Higher electric power does not significantly reduce fuel consumption
- UDDS seems to be a good choice for power requirements (In terms of energy use)



Control Strategy Assessment Provided Insights on PHEVs Optimal Operations

- When the trip distance is greater than the All Electric Range, using the engine throughout the trip (blended control) is preferable to depleting the battery as fast as possible
- Optimum control depends on the distance
- Engine On/Off is linked to wheel power demand and available electrical energy
- When used, engine should be operated at high efficiency