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NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

PHEV Energy Storage and Drive Cycle Impacts

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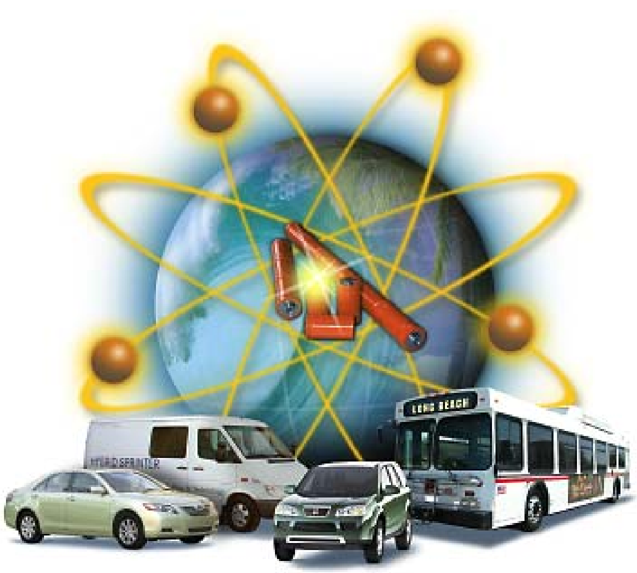

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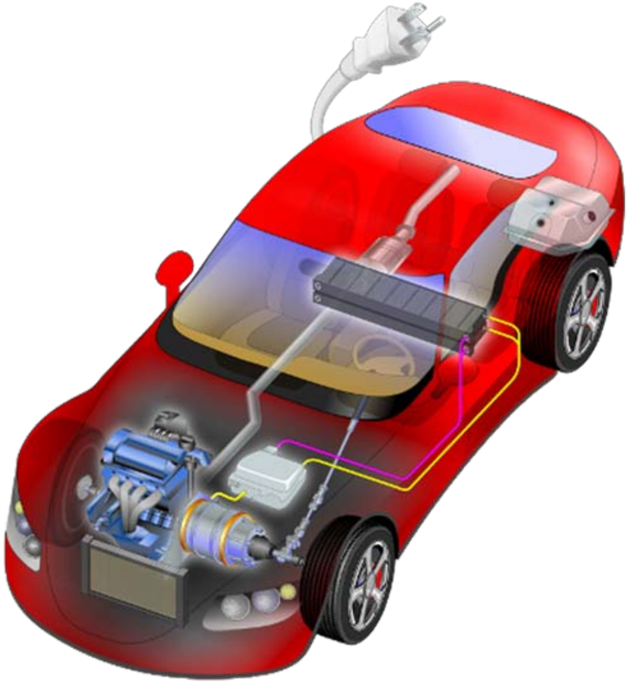
Outline

- Background - Summary of Previous Work
- Key Messages of this Study
- Real-World Drive Cycles
- PHEV Recharge Options
- Operational Impacts on
  - Pulse Power
  - State of Charge
- Conclusions

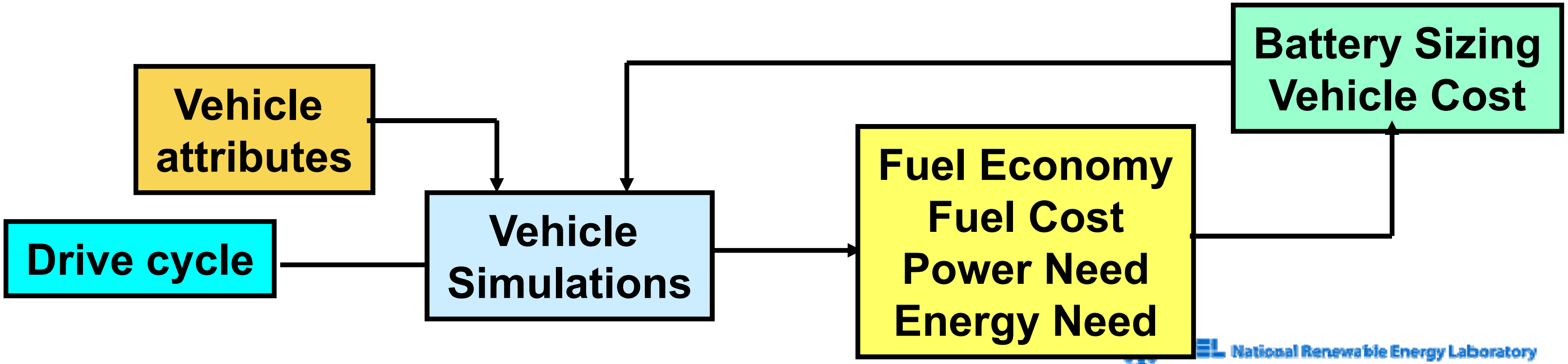


Key Messages of this Study

- Petroleum Consumption
  - The fuel displacement benefits of PHEVs will be influenced by the frequency of recharging events
- Pulse Power Attributes
  - PHEVs are likely to encounter long pulse power events during real-world duty cycles
  - PHEV experiences similar power levels but much longer pulses than HEV
- State of Charge
  - Time at specified state of charge varies significantly with platform and recharge scenario

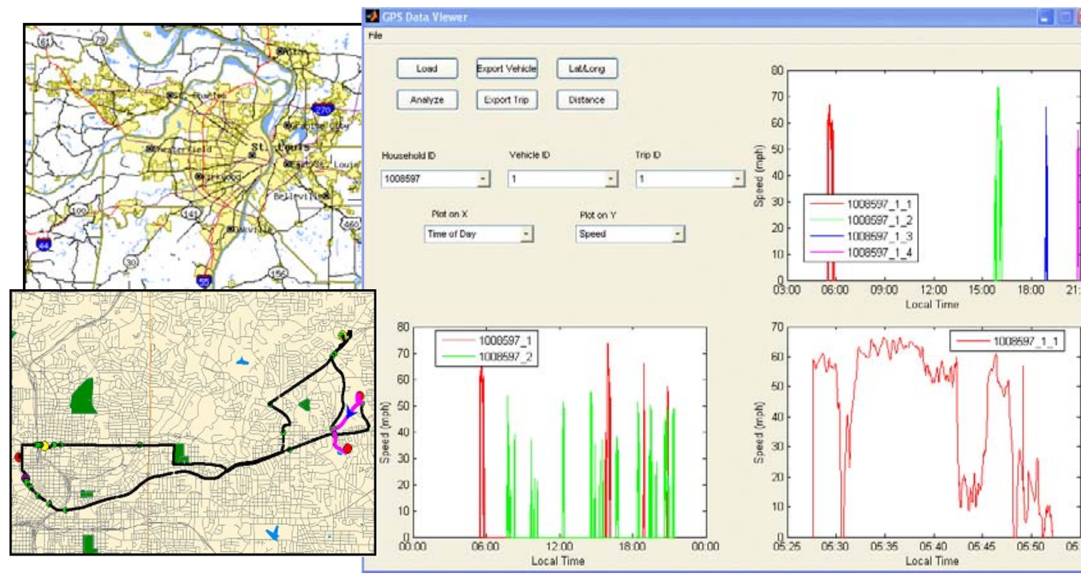
Standard and Real-World Drive Cycles

- Standard drive cycles used for certification/comparison purposes,
  - UDDS, HWFET, US06, SC03
  - Japan-1015
  - NEDC
- These drive cycles are meant to be representative for test efficiency
  - Fuel economy labeling under revision and likely to be based on broader set of cycles to address differences between labels and consumer experience
- Real-world driving patterns provides insight on in-use speed and acceleration characteristics
  - PHEV recharge scenarios and grid impacts can be better analyzed with time of day information



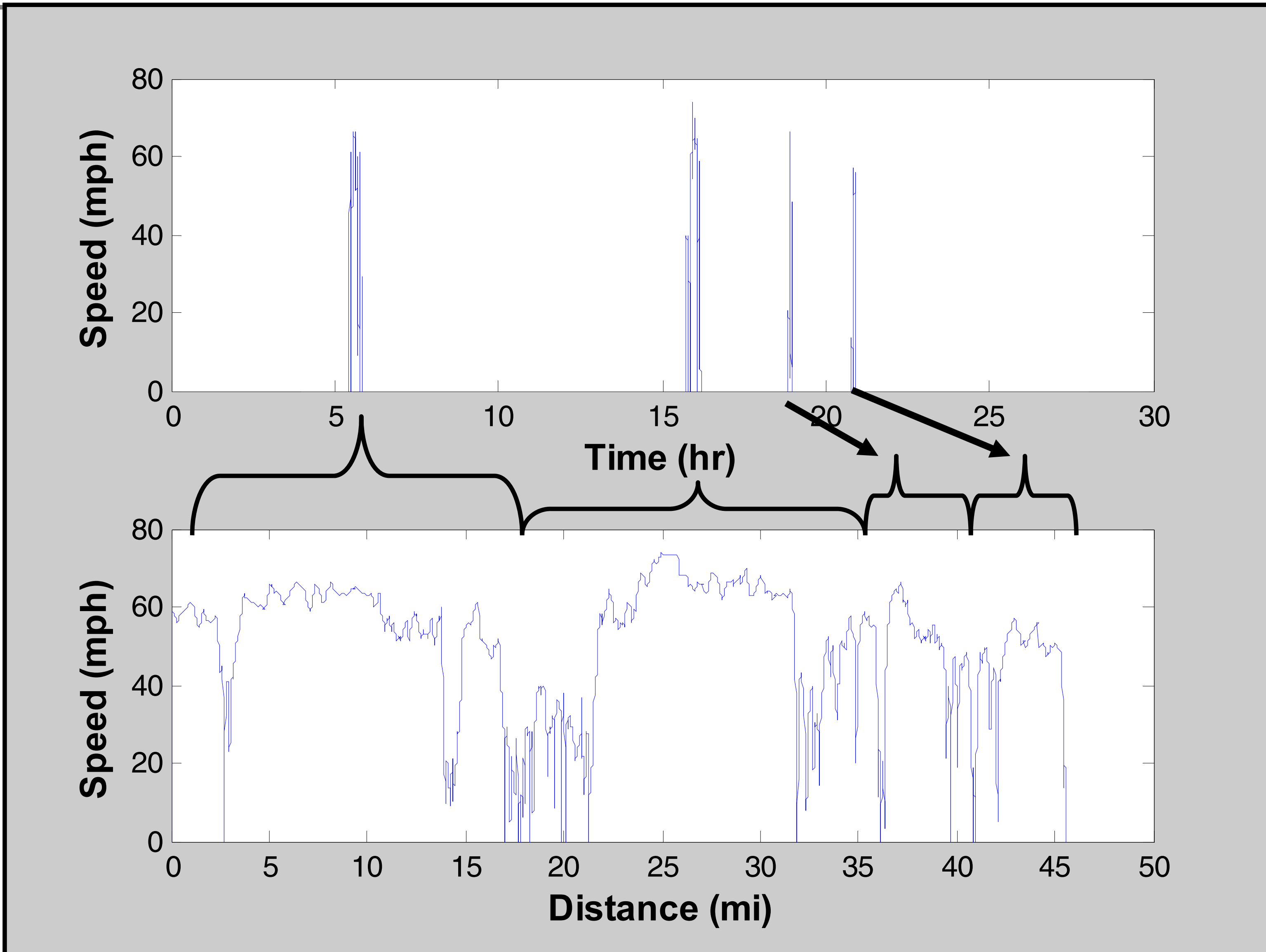
Real-World Drive Cycle Resources

- Driving/travel survey is ongoing in many cities (e.g., St. Louis)
- Augmenting these surveys with GPS information from individual vehicles provide details needed for simulation



- 1Hz data collected
  - Time of day
  - Speed
  - Altitude
  - Latitude
  - Longitude
- Key insights
  - Speed and acceleration distributions
  - Time of day usage for recharge analysis
  - Combined impact of speed and grade
  - Location and duration of stops for recharge opportunities

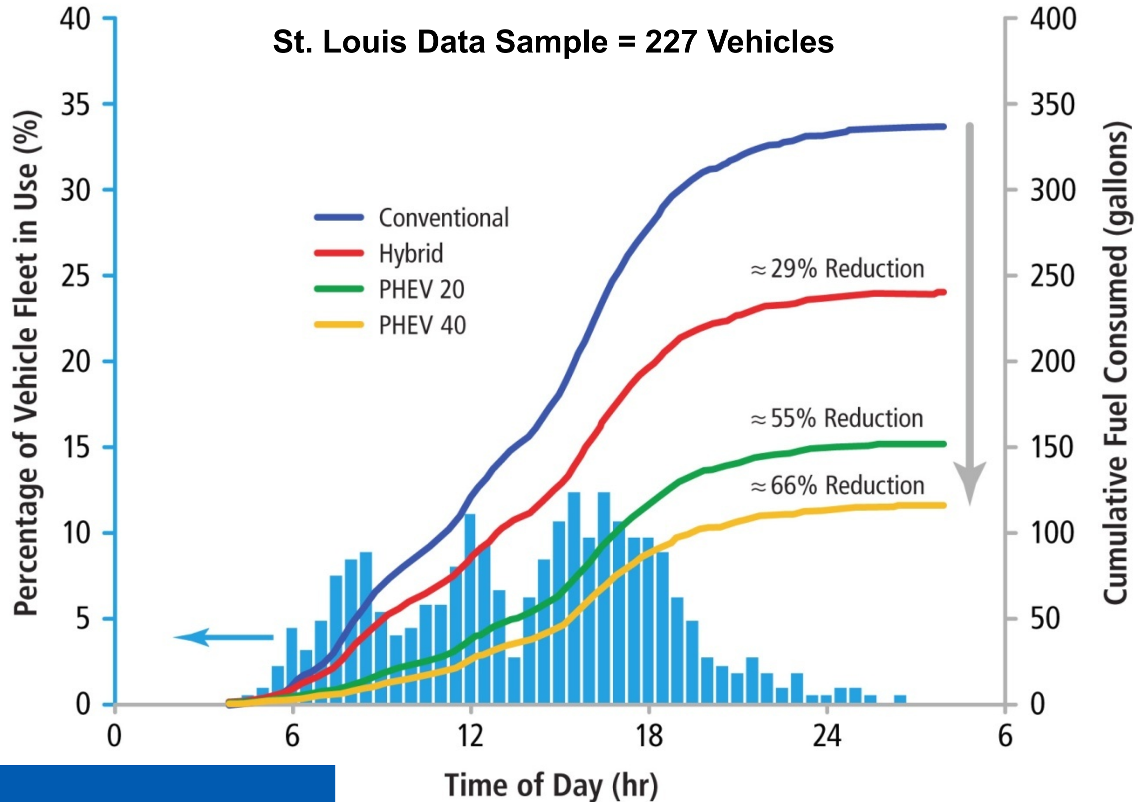
Sample Real World Duty Cycle



PHEVs Reduce Fuel Consumption By >50% On Real-World Driving Cycles

Vehicle in-use activity pattern and simulated fuel consumption

- In-use bars show morning, midday and evening usage peaks; at most 12% of vehicles in use at once
- Cumulative fuel consumption lines consider entire fleet using specified architecture

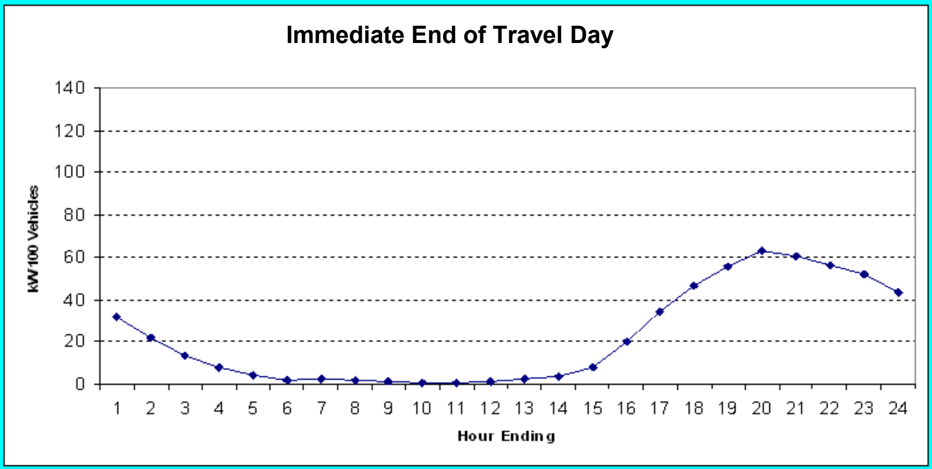


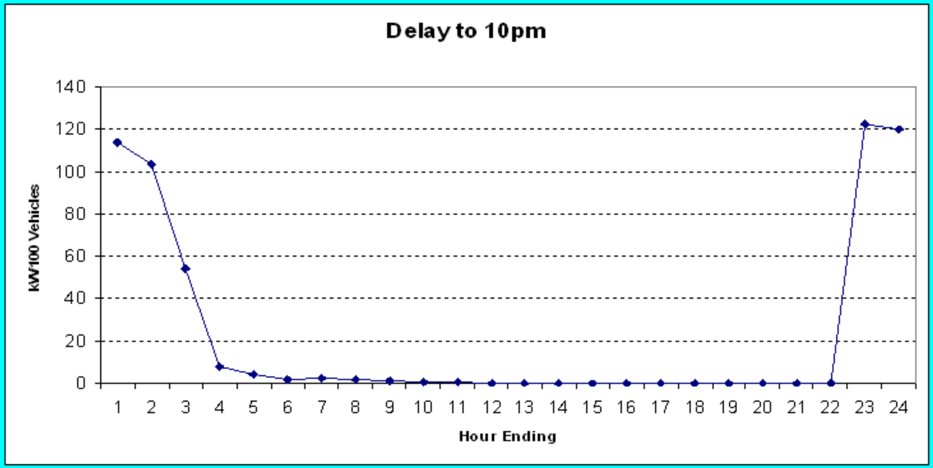
Fleet Averages				
	MPG	L/100km	Wh/mile	¢/mile
Conventional	26	9.05	-	9.1
Hybrid	37	6.36	-	6.5
PHEV 20	58	4.06	140	5.4
PHEV 40	76	3.10	211	5.1

Assumptions

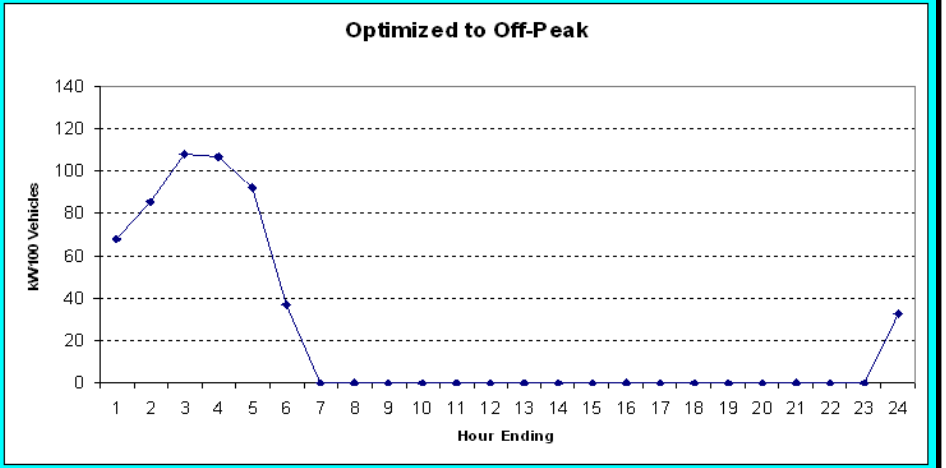
- PHEVs begin fully charged and do not charge until they finish driving for the day
- Gasoline is $2.41/gallon and electricity is $0.09/kWh for energy cost comparison (purchase price differences not included)

Four Potential Daily Recharge Strategies

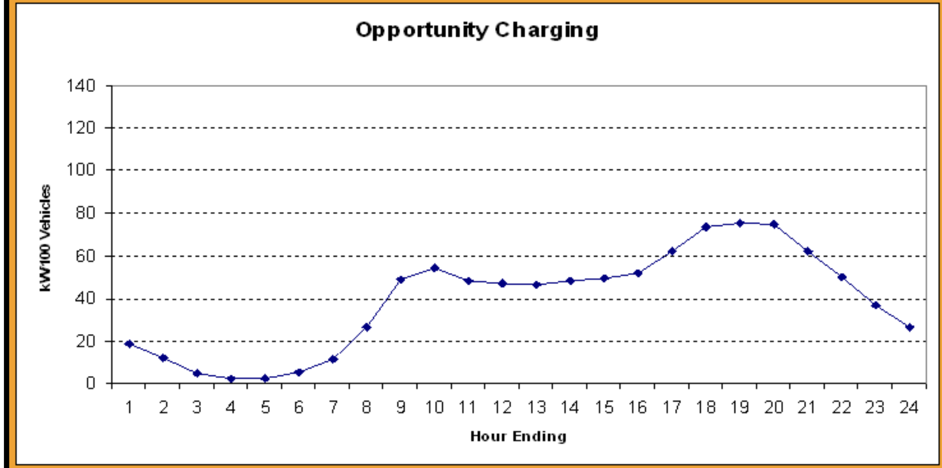




3 ways to control a single daily charge

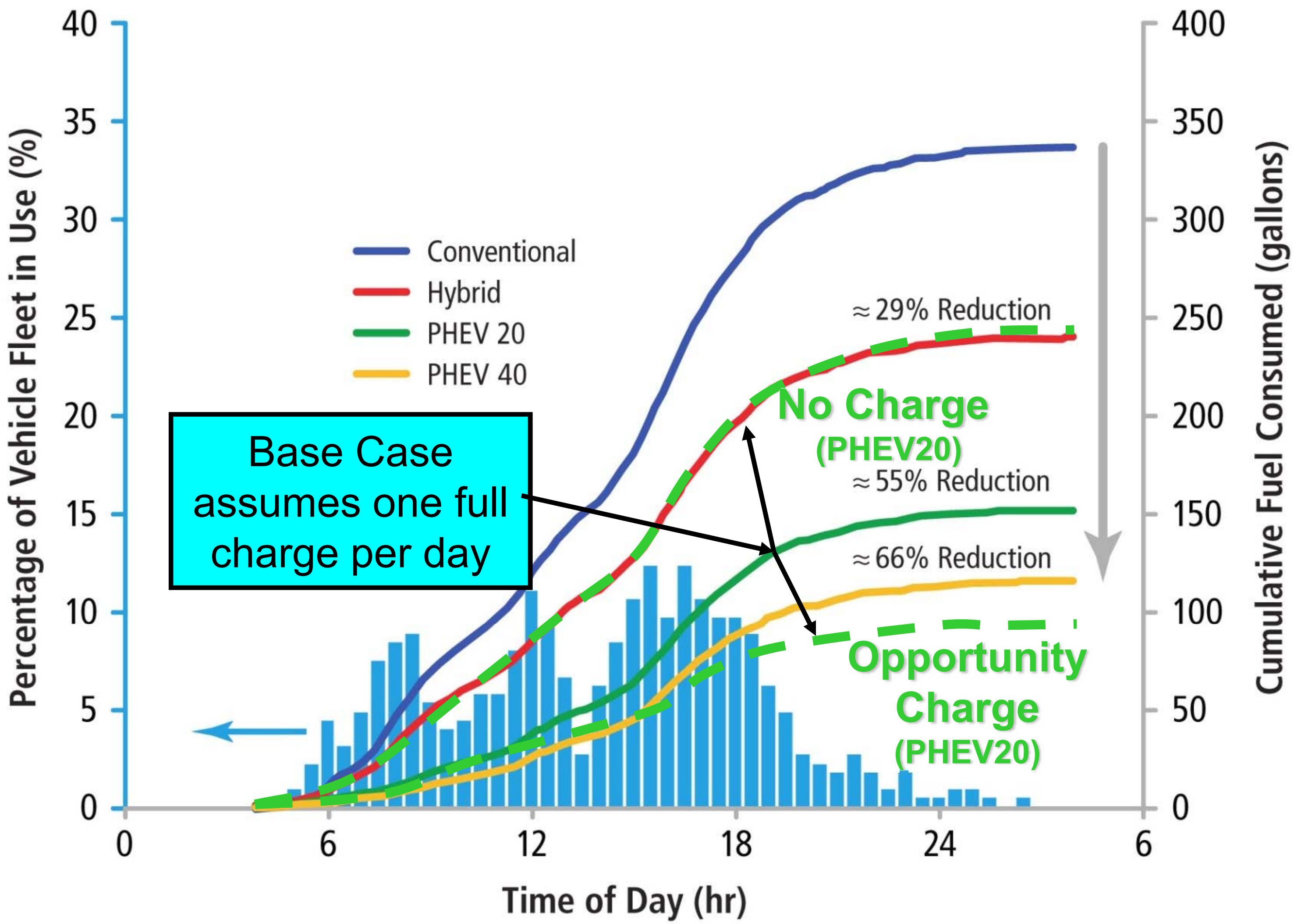


Multiple charging events per day



Recharge Scenario Impacts on PHEV Petroleum Consumption Benefits

Opportunity charge: connect PHEV charger to grid any time that the vehicle is parked.



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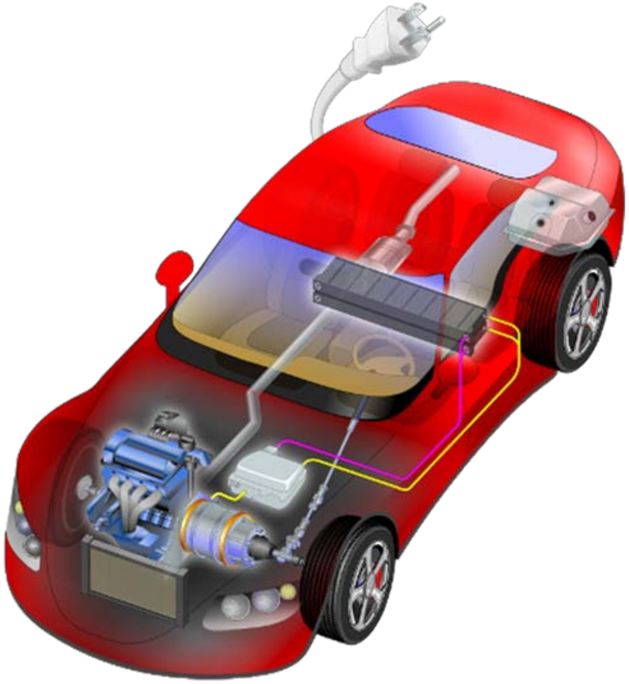
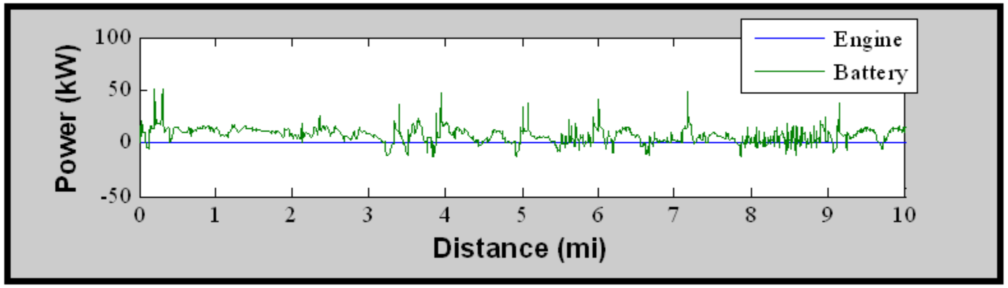


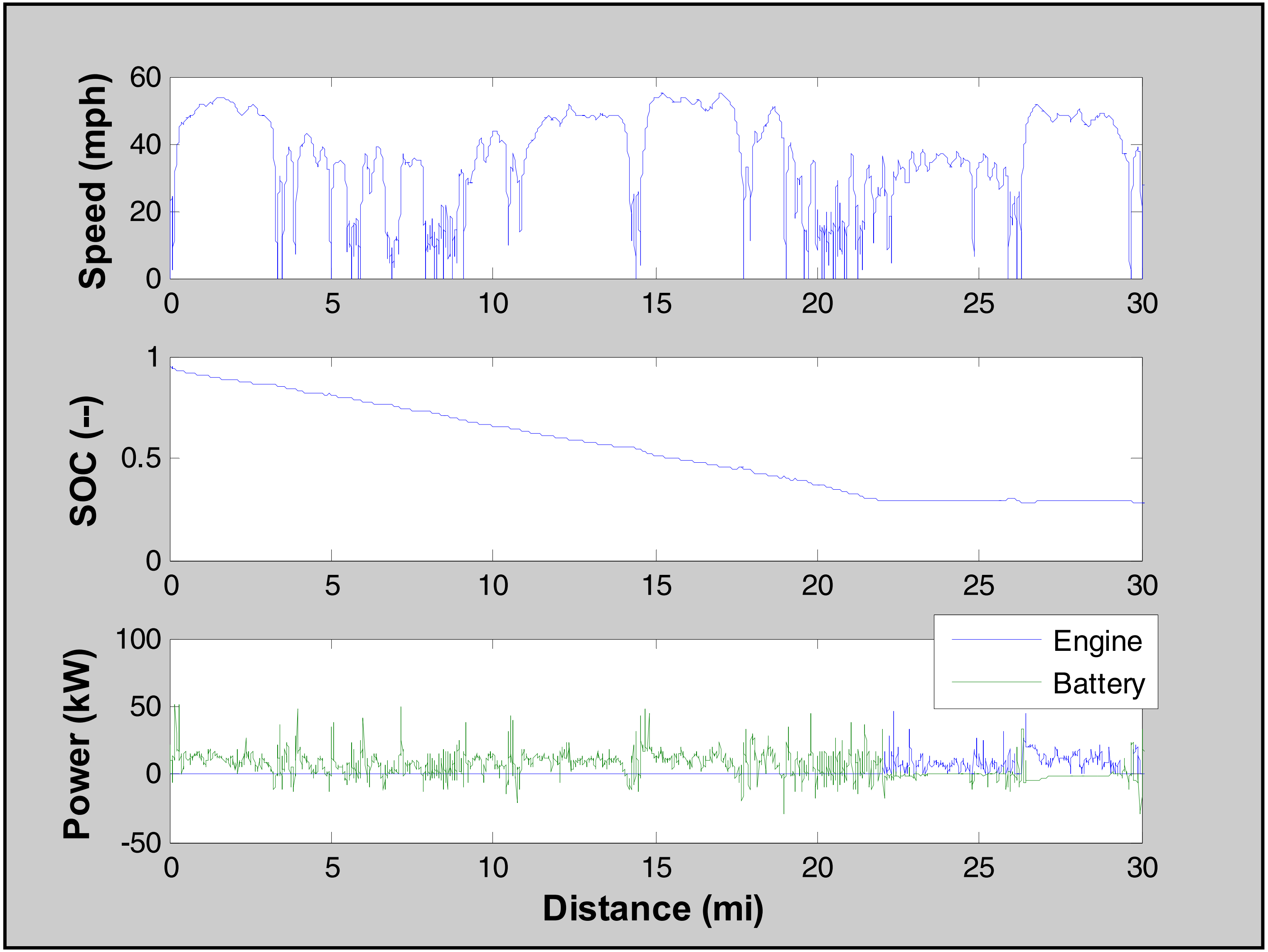
Two Ways to Analyze Battery Power Profiles



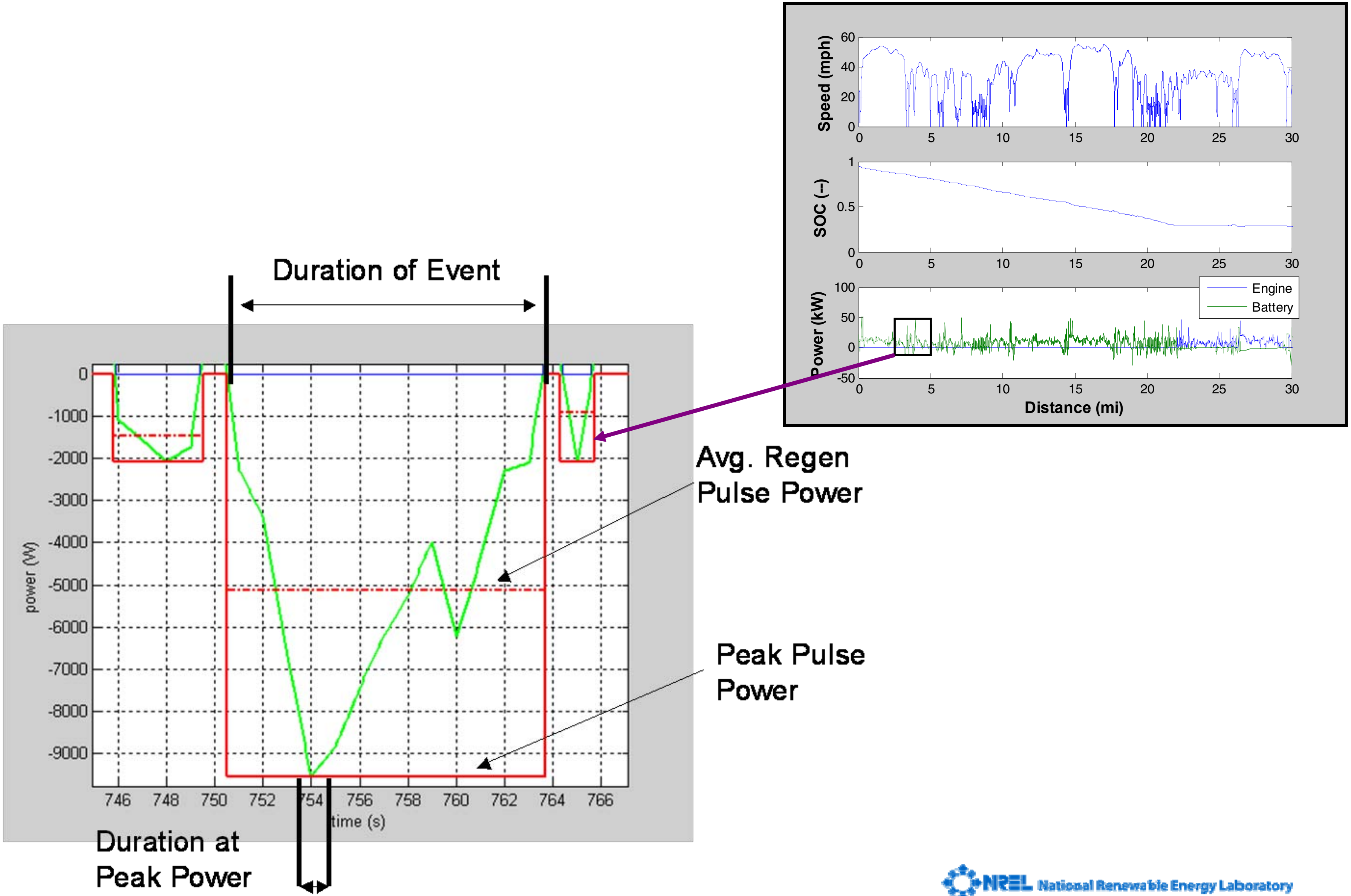
- Power Pulse event
  - — Start - first non-zero
  - — End – next non-zero
- Attributes
  - — Peak power and peak power duration
  - — Energy equivalent average power and duration
- *Provides detail on specific events*

- Moving window approach
  - — Integrate power profile over a specified window to find net, positive only, and negative only equivalent powers
  - — *Captures interaction between multiple events*

Characteristics of an Individual Pulse Power Event

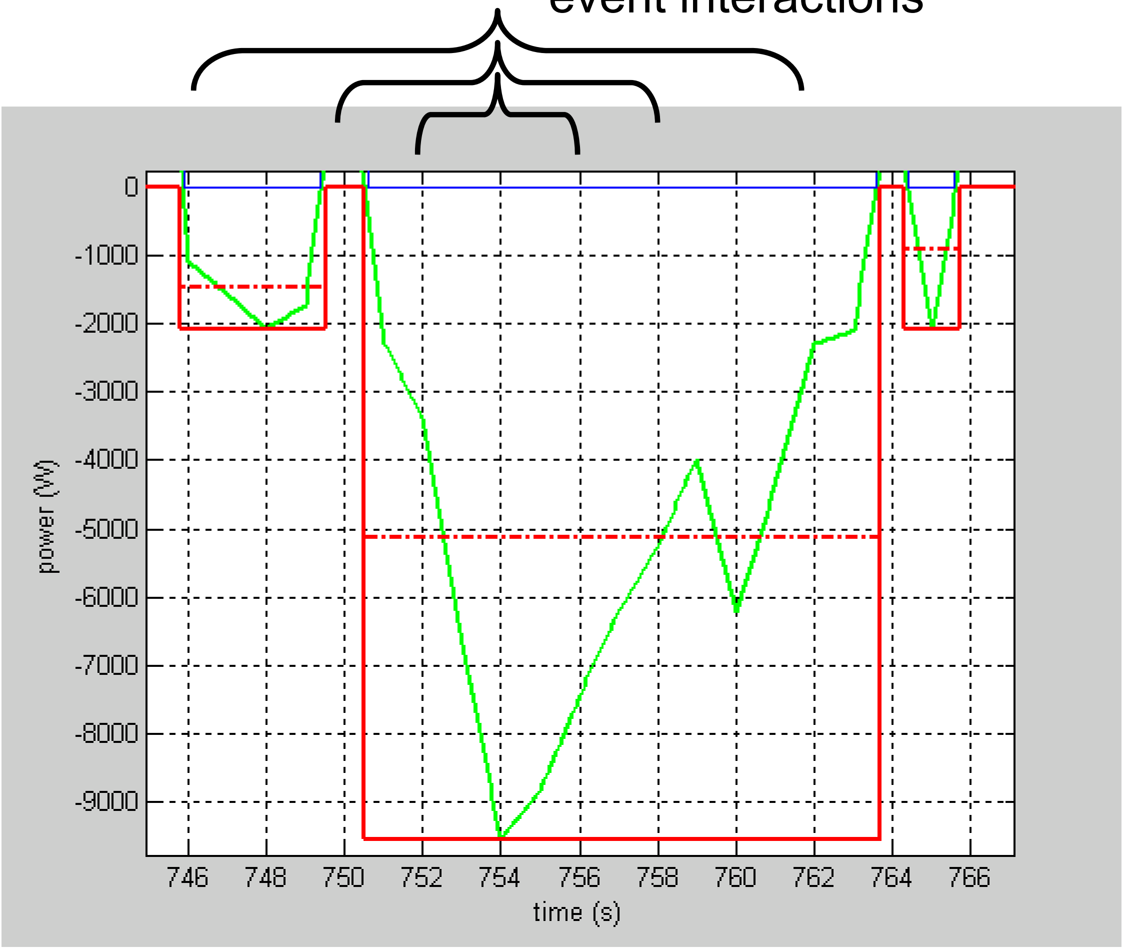


Characteristics of an Individual Pulse Power Event



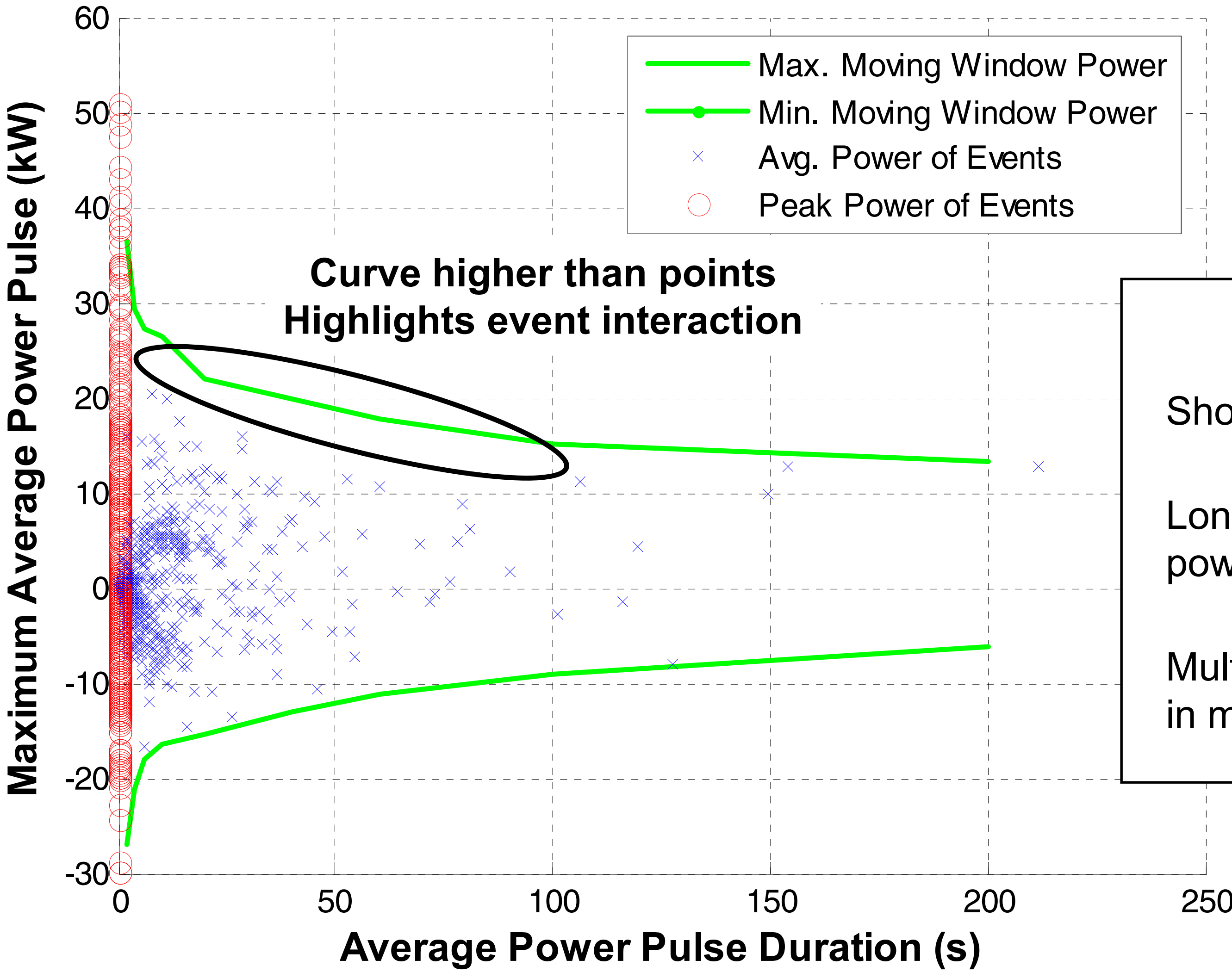
Moving Window Analysis of ESS Power Profile Quantifies Interaction Between Individual Events

Expanding window captures event interactions



- Determined Energy Equivalent Pulse Power for Spectrum of Durations
- Moving Window and Individual Event pulse power the same when window duration equals event duration

Detailed Pulse Power Analysis of Real Travel Profile Identifies Most Challenging Events



Key Events

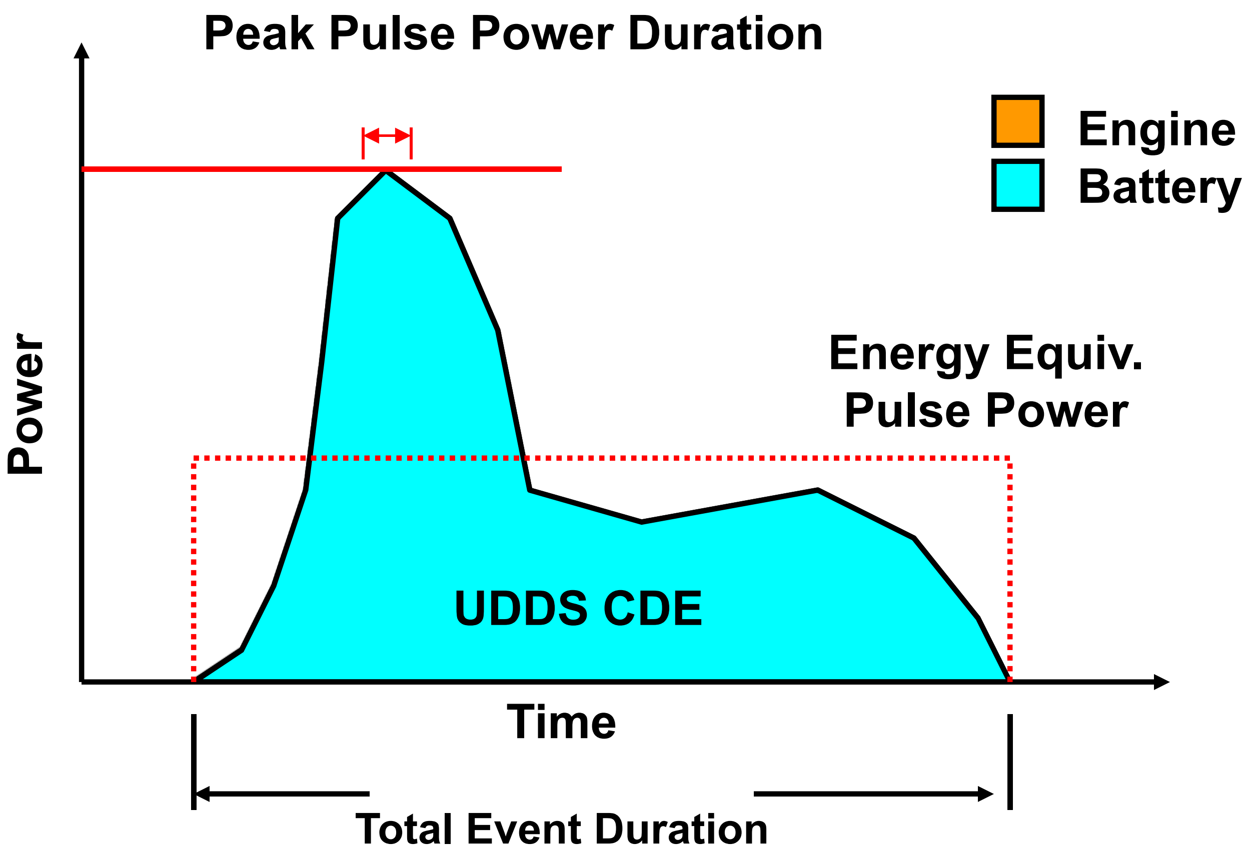
Short duration high power

Long duration moderate power

Multiple short events interact in mid duration range

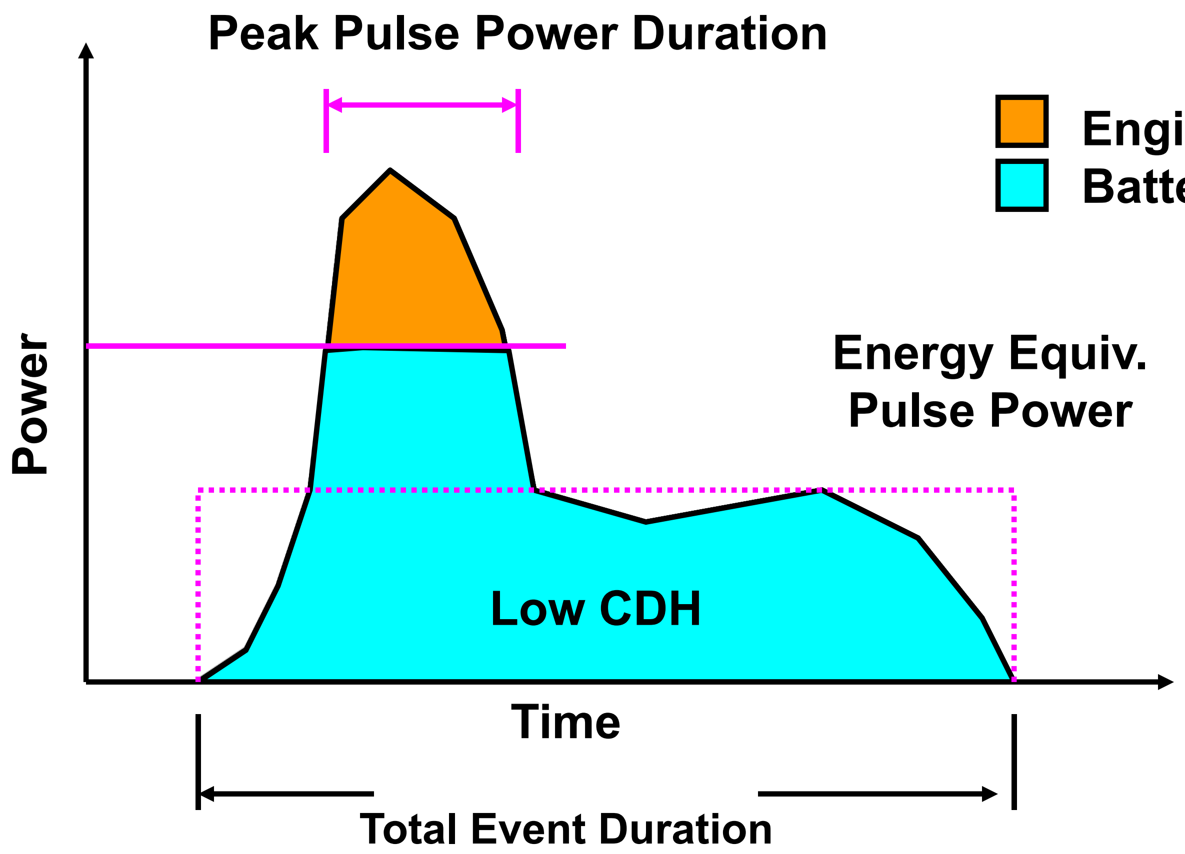
Midsize Car PHEV20 w/AER on UDDS

Pulse Power Characteristics Depend on Operating Strategy



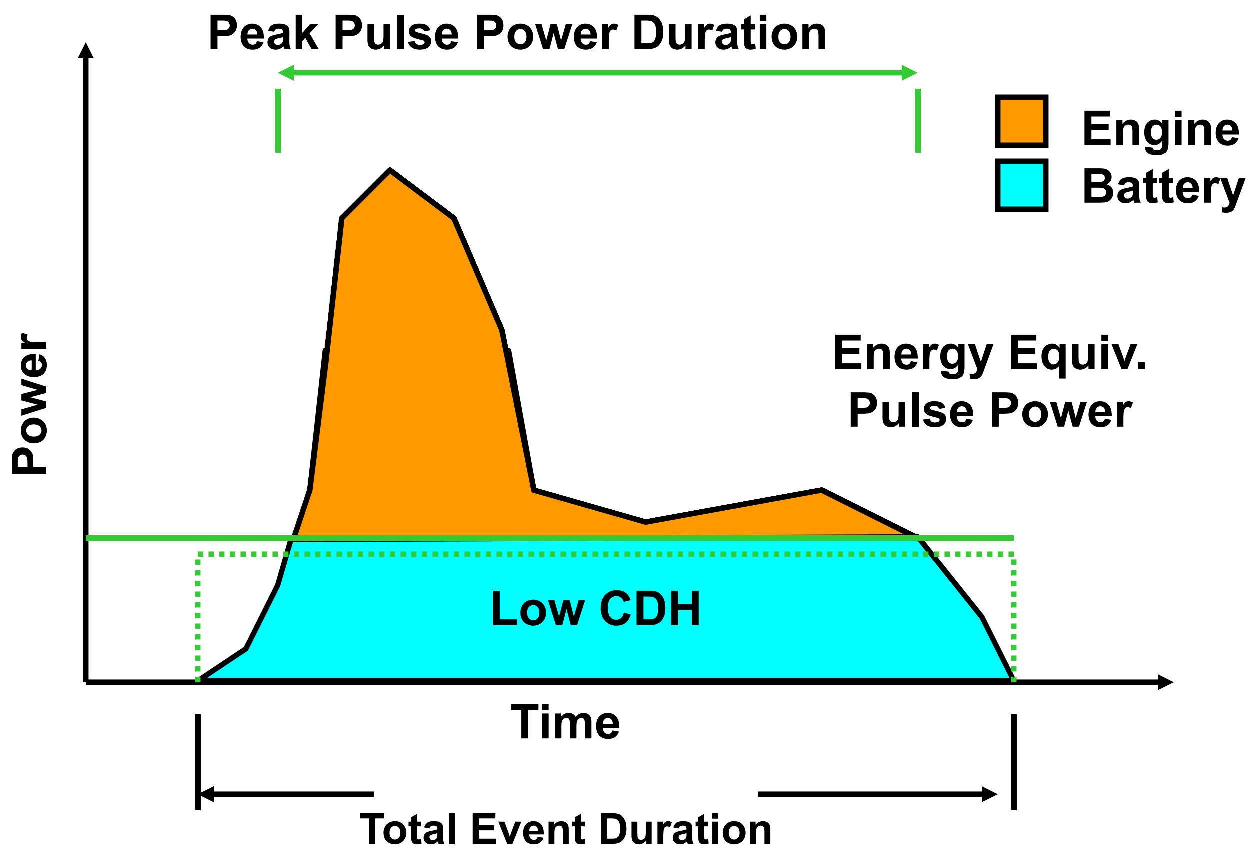
Charge depleting electric (CDE) is likely to have short high power events and moderate long duration energy equiv. events.

Pulse Power Characteristics Depend on Operating Strategy



Charge depleting hybrid (CDH) will have lower but longer peak pulse and slightly lower energy equiv. pulse power requirements

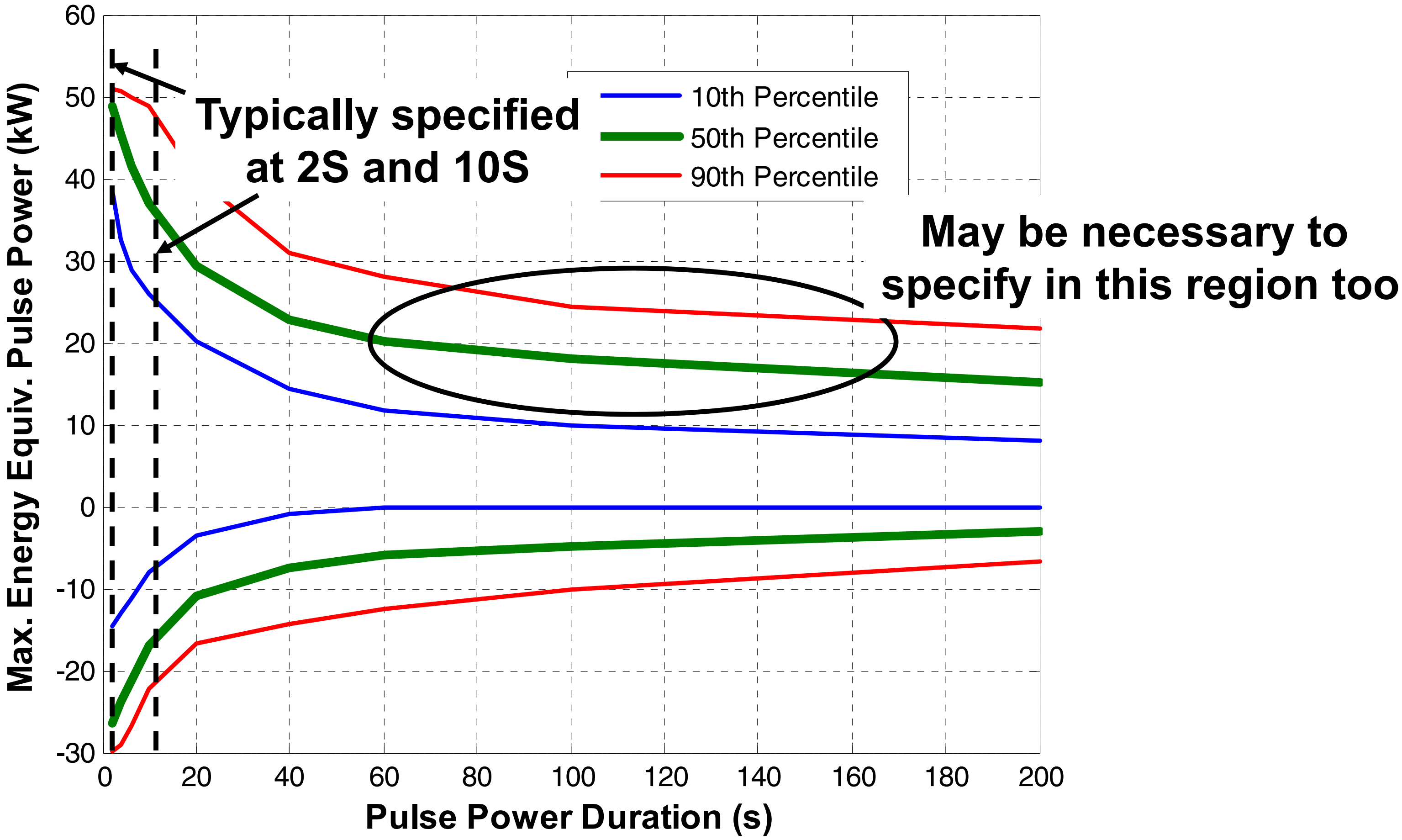
Pulse Power Characteristics Depend on Operating Strategy



In CDH lower power case, the Peak and Energy Equiv. Pulse Powers may have similar level and duration

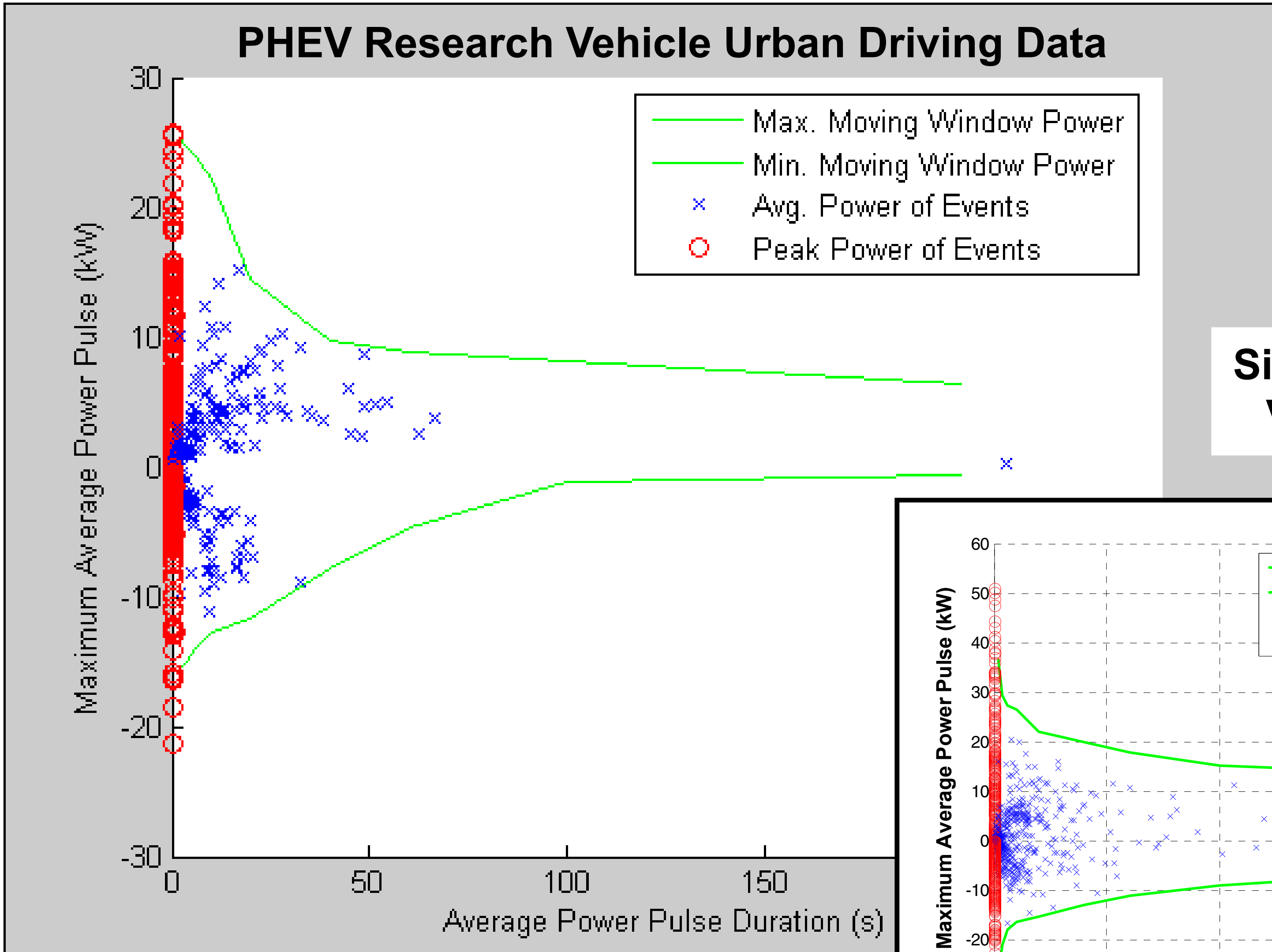
Pulse Power from Simulated PHEV Operation on 227 Real-World Travel Profiles

- Components sized for AER on UDDS (CDE) still encounter long duration energy equiv. power pulses

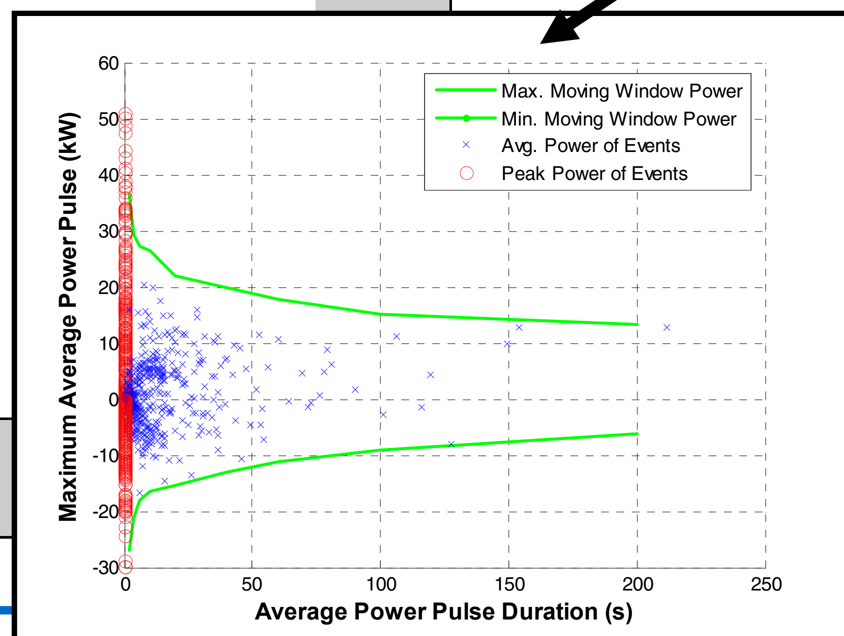


Midsize Car PHEV20 w/AER on UDDS

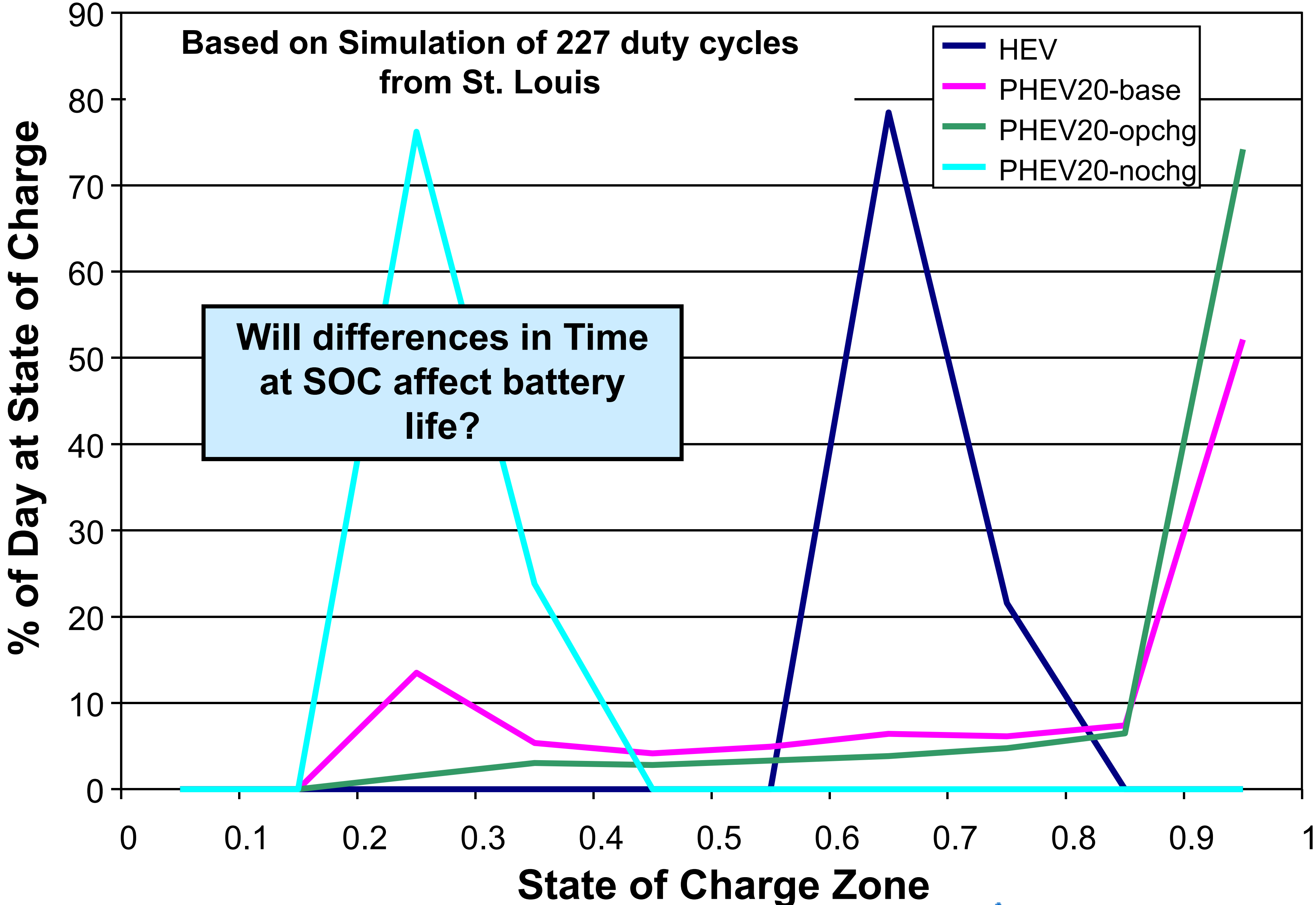
Pulse Power Analysis Methods Can be Applied to Both Simulation Results and Test Data



Simulated PHEV20 Vehicle Results



PHEV Time At SOC Impacted by Charging Scenario



Conclusions

- Pulse Power Analysis Methods
  - Moving window allows evaluation of interaction of pulse power events
- Petroleum Consumption Relative to Conventional Fleet
  - PHEV20 with single daily charge saves about 50%
  - PHEV20 without charging similar to HEV (~35%)
  - PHEV20 with opportunity charge saves 75%
- Pulse Power Attributes
  - Real-world pulse power events have longer durations than standard test cycles
  - PHEV similar power levels but much longer pulses than HEV
  - CDH peak power is lower but duration is longer than CDE
  - CDH energy equiv. power is slightly lower with duration same as CDE
- State of Charge
  - No charge leads to long periods of battery at low SOC
  - Single charge leads to mixture of high and low SOC operation
  - Multiple charges leads to more time at high SOC

Next Steps

- Use battery models representative in both short and long duration pulses
- Determine key aspects affecting battery life
- Continue to use travel data to assess impacts of PHEV technology, especially on batteries
  - Charge-depleting electric and charge-depleting hybrid operating scenarios
  - PHEV10 scenario
  - Affect of ambient conditions on fuel displacement potential
  - Assess battery usage under V2G scenario
  - Emissions impacts of engine operation
  - Use travel data from five other municipalities
- Collect on-road data with PHEV research vehicle using several battery options and compare with simulation results

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