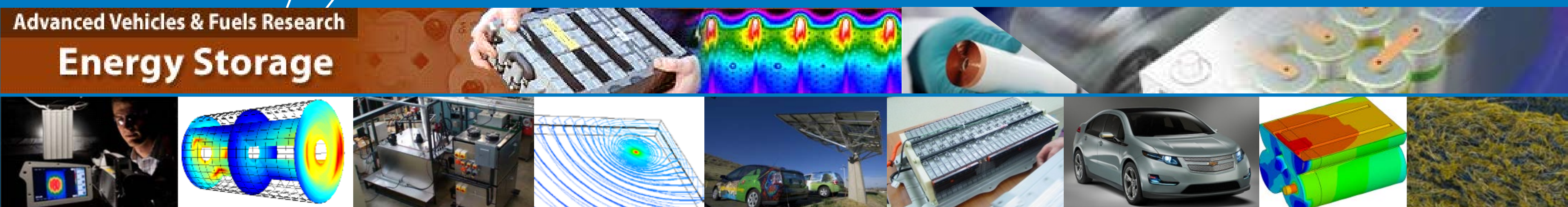
Accounting for the Variation of Driver Aggression in the Simulation of Conventional and Advanced Vehicles



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Motivation

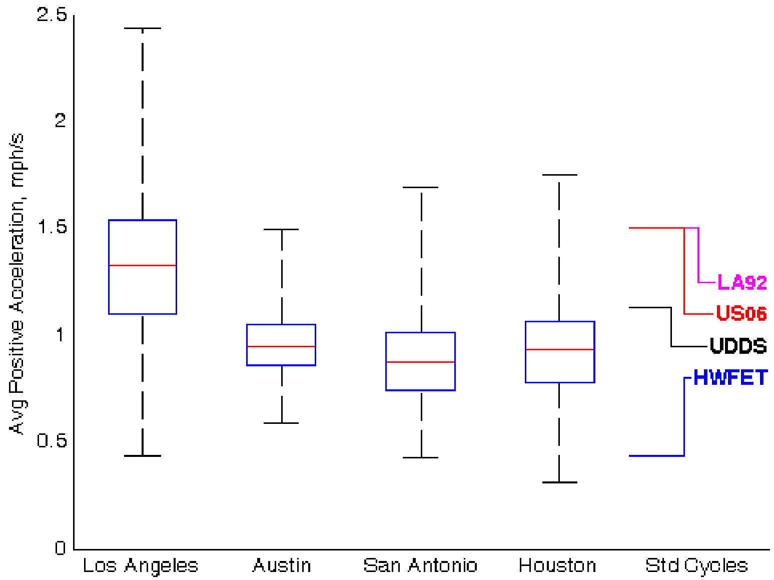
- **Provide a method of accounting for realistic levels of driver aggression to higher level vehicle studies.**
  - What is the impact of variation in real-world driving characteristics (acceleration and speed) on vehicle energy consumption?
  - Is it the same for different powertrains (e.g., conventionally powered vehicles versus electrified drive vehicles)?
  - How do standard drive cycles (UDDS, HWFET, etc.) compare to real-world driving?

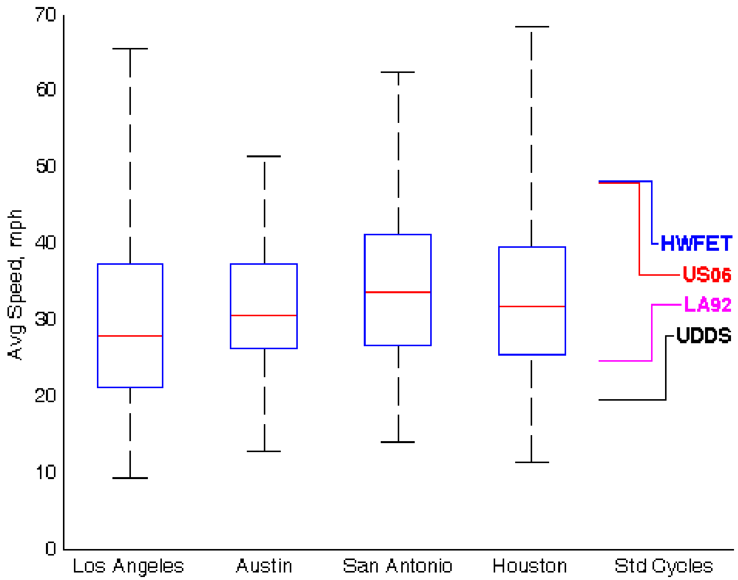
Outline

- Real-World Driving Data
- Vehicle Simulation
- Effect of Aggression on Vehicle Efficiency for Different Powertrains
- Real-World vs Standard Cycle Vehicle Efficiency
- Creating a Real-World-Representative Drive Cycle
- Comparing “Optimal” Drive Cycle Characteristics Across Powertrains

Real World Driving Data

- Real-world, high-accuracy, and high-resolution vehicular velocity histories are needed to predict the actual on-road variation in vehicle efficiencies of different driver and powertrain combinations.
- 2,154 unique vehicle records (spanning 1–2 days each) were sourced from the NREL Secure Transportation Data Center: a composite of data from Los Angeles, CA; Austin, TX; San Antonio, TX; and Houston, TX travel studies.
- The data were recorded using on-board global positioning system data acquisition systems filtered down to second-by-second acceleration and velocity histories.





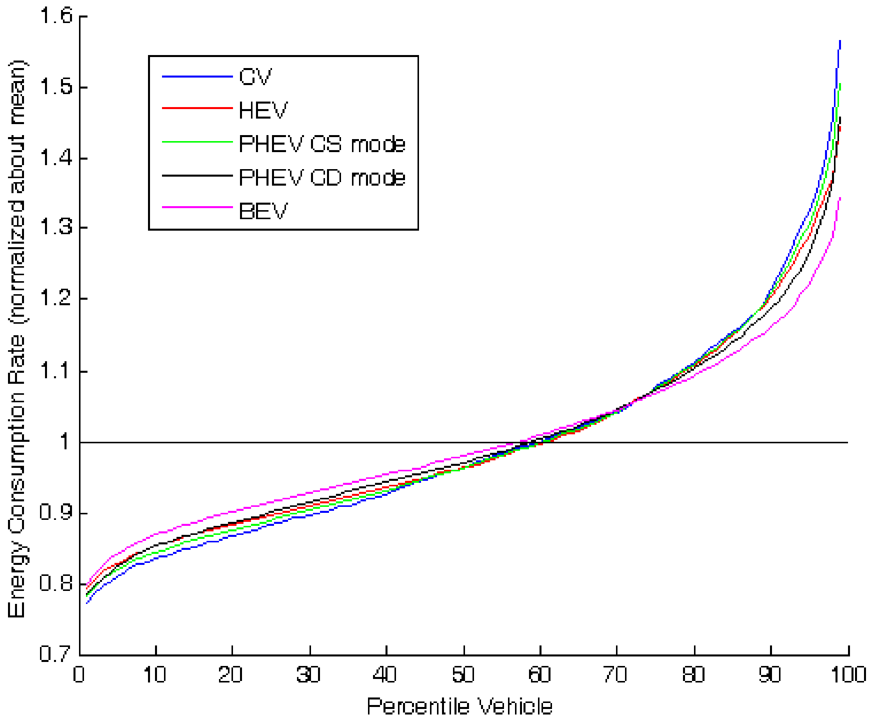
Vehicle Simulation

- All vehicles simulated using ADVISOR and the following specifications

Powertrain	CV	HEV	PHEV40	BEV75
Accessory Load (W)	700	300	300	300
Vehicle Mass (kg)	1,679	1,613	1,794	1,611
Internal Combustion Engine Power (kW)	121	62	69	n/a
Electric Motor Power (kW)	n/a	41	46	95
Battery Total Energy (kWh)	n/a	1.67	17.6	25.5
Battery Maximum State of Charge	n/a	80%	95%	95%
Battery Minimum State of Charge	n/a	60%	25%	5%
Vehicle Efficiency	27.0 mpg	38.6 mpg	34.2 mpg (CS) 308 Wh/mi (CD)	305 Wh/mi

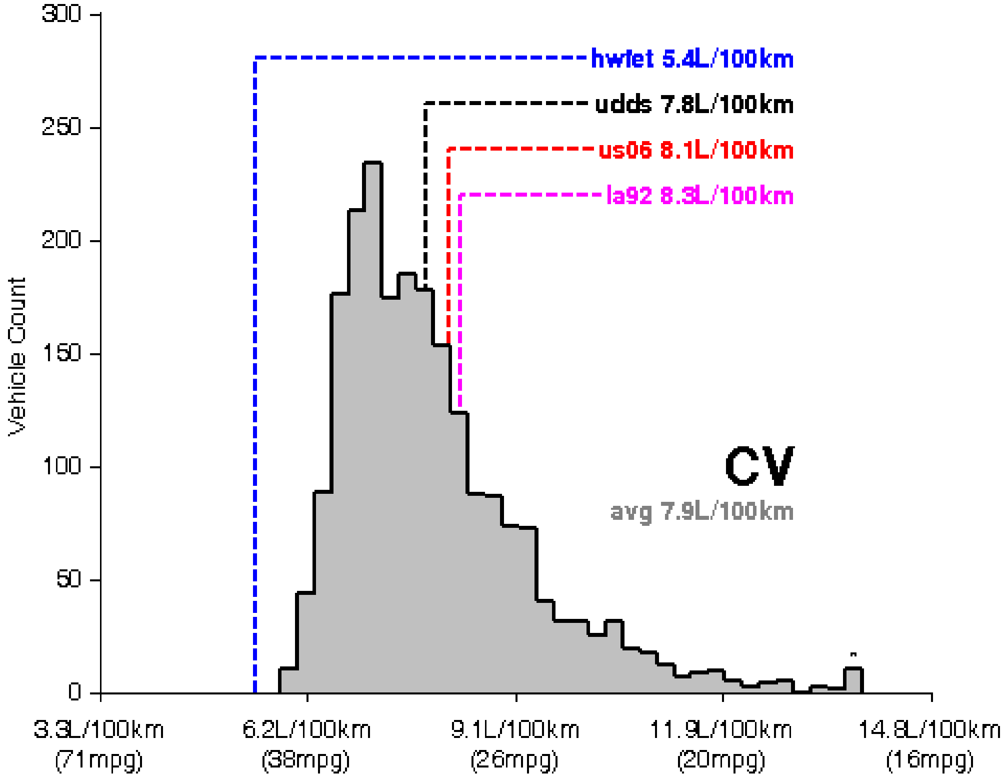
Effect of Driver and Vehicle

- Median and mean values are similar.
- Asymmetric distribution: overly aggressive drivers see a larger penalty than benefit observed by overly passive drivers.
- Powertrain type has minimal effect on the distribution.



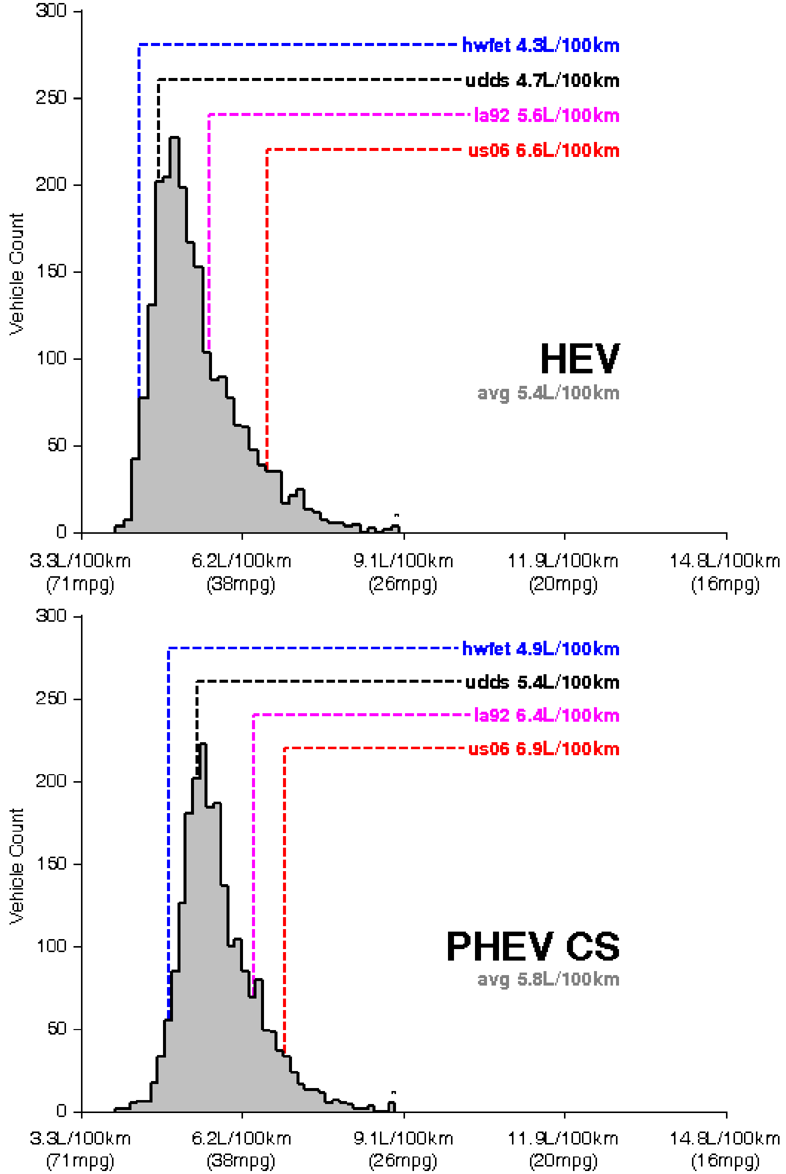
CV: Real-World vs Standard Drive Cycles

- HWFET: very low consumption
- UDDS: near the mean
- US06 & LA92: slightly higher consumption than the mean



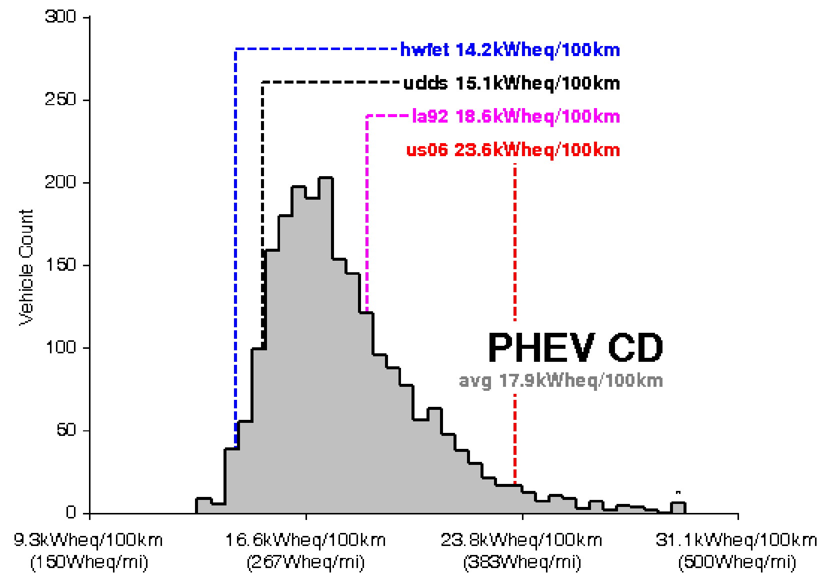
HEV & PHEV-CS: Real-World vs Standard Drive Cycles

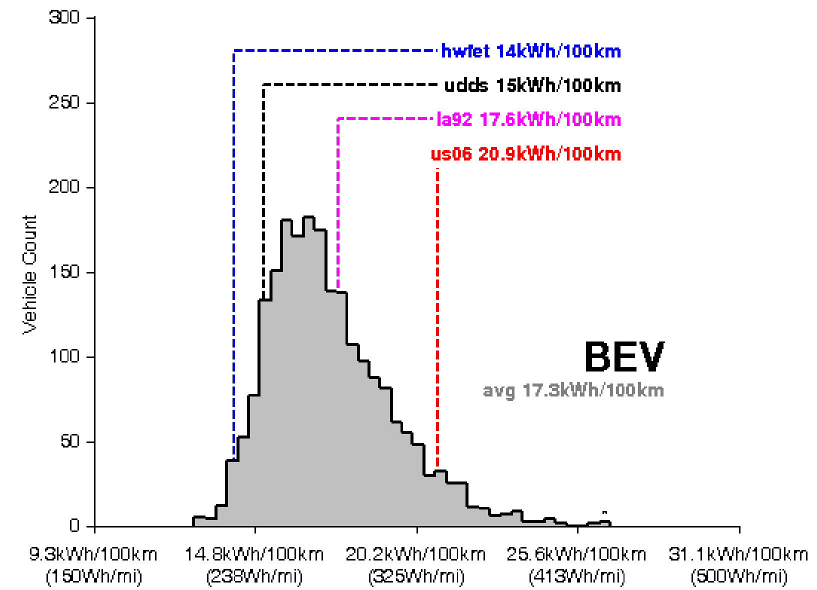
- HWFET: low
- UDDS: near the mode, below the mean
- LA92: slightly higher than the mean
- US06: higher than the mean



PHEV-CD & BEV: Real-World vs Standard Drive Cycles

- HWFET: low
- UDDS: lower than the mode and the mean
- LA92: slightly higher than the mean
- US06: much higher than the mean

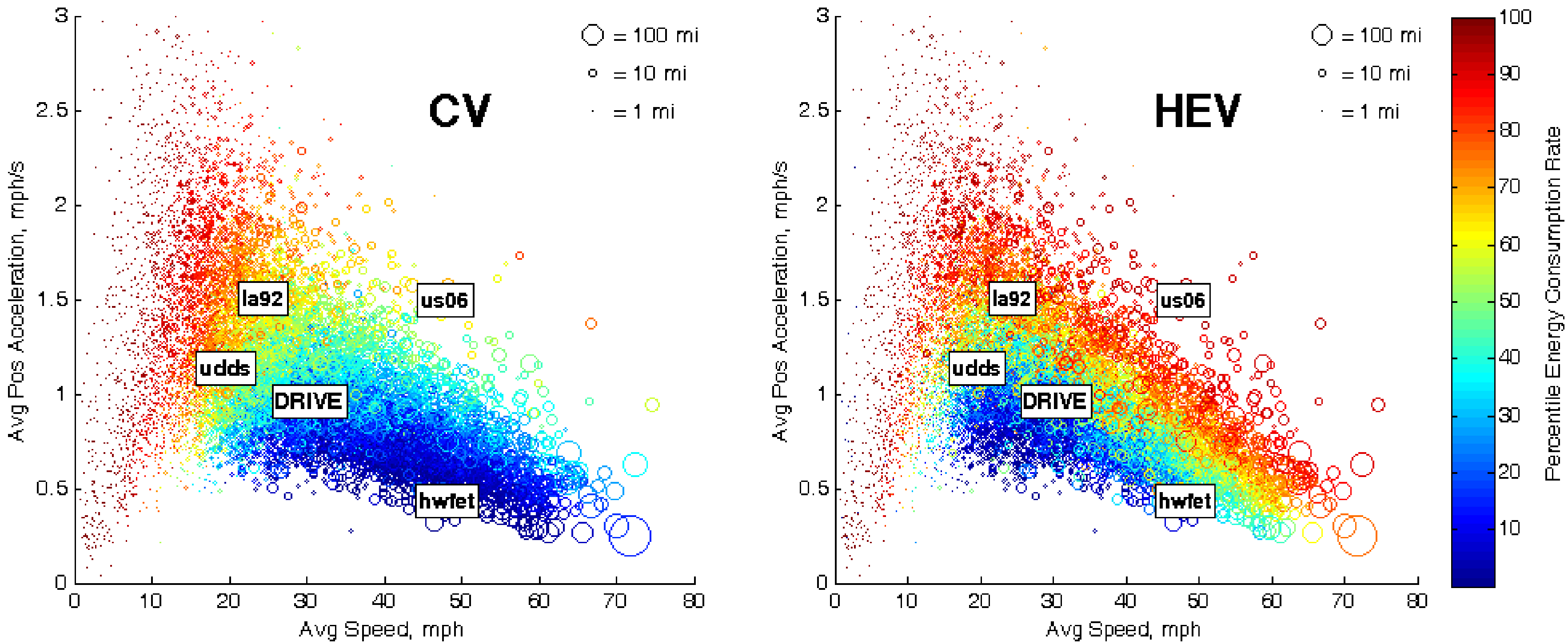




Real-World vs Standard Drive Cycles

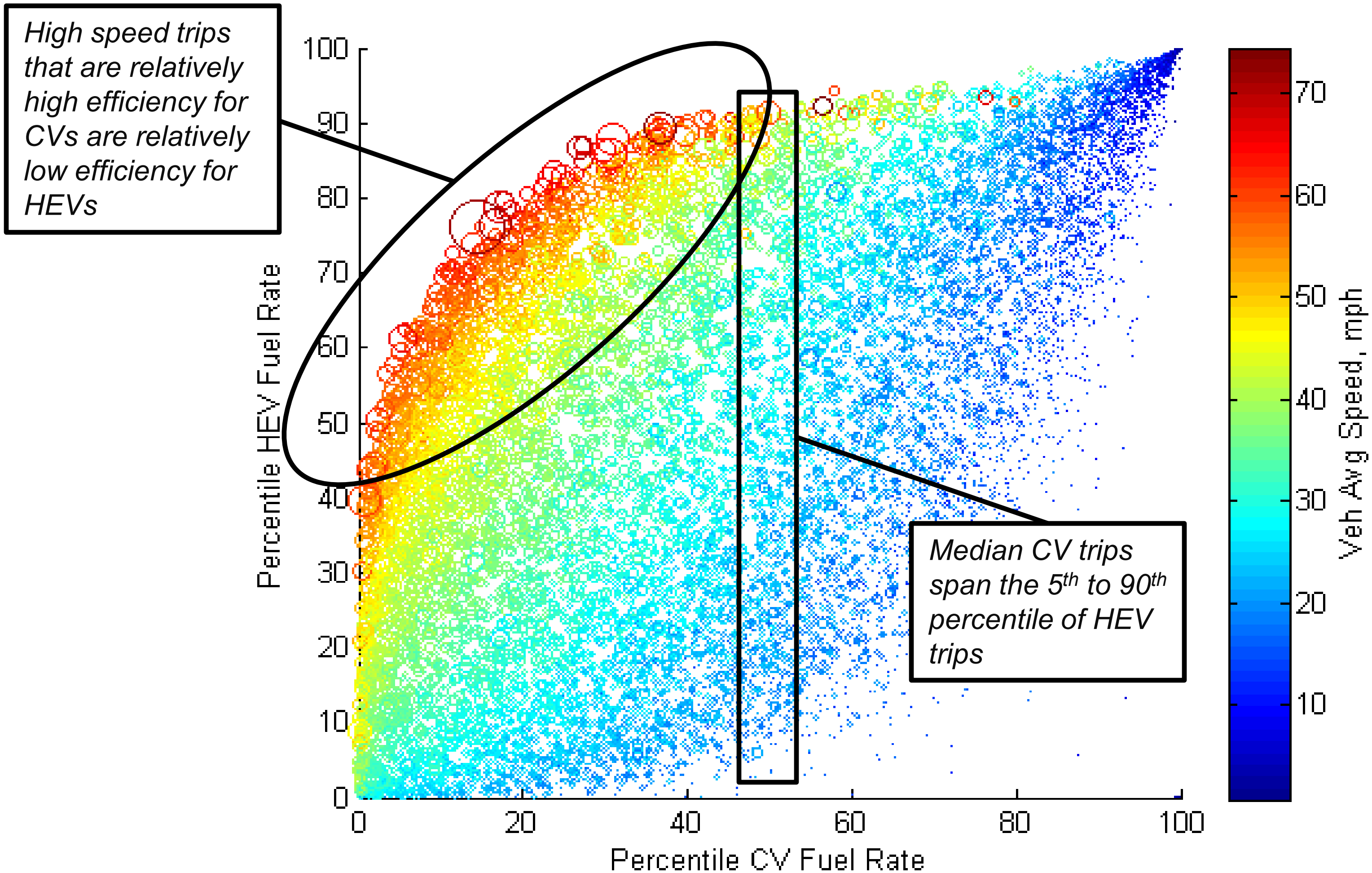
- CV:
  - HWFET strongly under-predicts mean consumption.
  - UDDS captures the *mean* well.
  - LA92 and US06 slightly over-predict consumption.
- HEV & PHEV-CS:
  - HWFET under-predicts mean consumption.
  - UDDS captures the *mode* well and under-predicts mean slightly.
  - LA92 and US06 over-predict consumption.
- PHEV-CD & BEV:
  - HWFET & UDDS under-predict consumption.
  - LA92 slightly over-predicts mean consumption.
  - US06 strongly over-predicts consumption.
- **Take-Away:** The relative accuracy of standard drive cycles is different on different drivetrains.

Optimal Drive Cycle Characteristics



- Data for all 13,622 trips from 2,154 vehicle records are shown.
- Low-speed trips coincide with short-distance travel and high acceleration and vice versa due to:
  - Behavioral norms (lack of driver-requested high-acceleration events during high speed travel)
  - Technical realities (inability of most vehicles to deliver high acceleration at high speed).
- The optimal CV drive cycle occupies the intersection of HWFET.
- Regenerative braking of HEVs pushes the optimal HEV drive cycle toward lower speed, low acceleration cycles.
  - This applies to PHEVs and BEVs too, as their plots are very similar to the HEV plot.

Relative Efficiency Across Powertrains

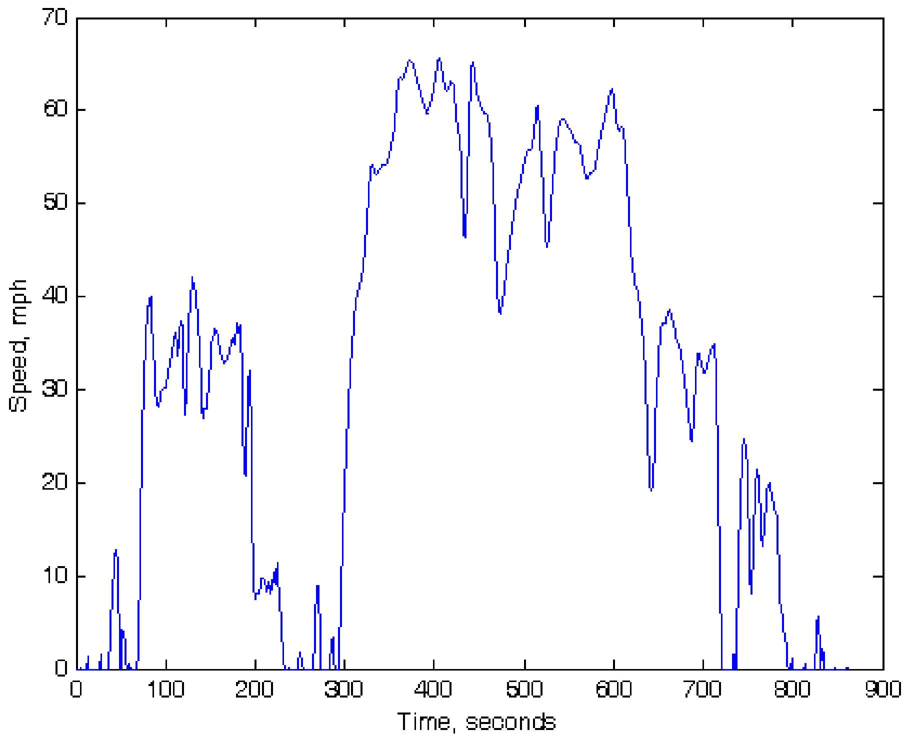


- PHEV & BEV data is similar to HEV data.
- Regarding **absolute** efficiency, the HEV is always more efficient than the CV in these simulations.

Creating a Representative Drive Cycle

- Applied NREL's DRIVE tool to synthesize a drive-cycle representative of observed real-world behavior

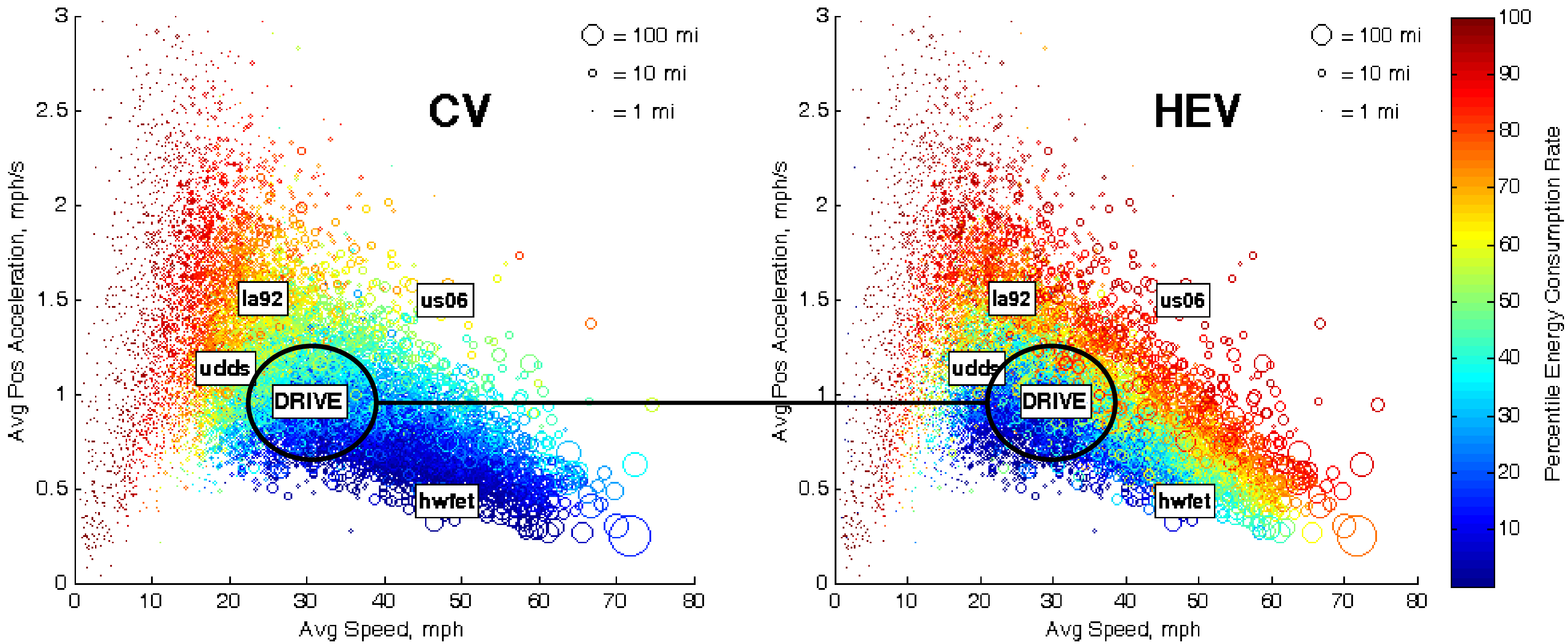
- Simulation of this new drive cycle shows that computed vehicle efficiency is within 1% of the mean for all powertrains.



Error of mean vehicle record and synthesized drive-cycle efficiency

CV	HEV	PHEV40 (CS)	PHEV40 (CD)	BEV75
-0.37%	-0.70%	0.07%	0.23%	-0.03%

Applicable to multiple powertrains



Accounting for Aggression

- After computing the **average-aggression-driver** vehicle efficiency using the DRIVE cycle, the following scaling factors can be used to represent different levels of aggression

Vehicle Day Percentile	CV	HEV	PHEV40 CS	PHEV40 CD	BEV75
5^{th}	0.810	0.828	0.847	0.826	0.841
25^{th}	0.883	0.896	0.920	0.900	0.915
50^{th}	0.962	0.963	0.977	0.969	0.980
75^{th}	1.077	1.074	1.062	1.072	1.068
95^{th}	1.325	1.290	1.220	1.266	1.223

Conclusions

- Aggression variation between drivers can increase fuel consumption by more than 50% or decrease it by more than 20% from average.
- The normalized fuel consumption deviation from average as a function of population percentile was found to be largely insensitive to powertrain.
  - I.e. the ability of aggression to impact relative fuel consumption is similar for CVs, HEVs, PHEVs, and BEVs
- However, the traits of ideal driving behavior is a function of powertrain.
  - In CVs, kinetic losses dominate rolling resistance and aerodynamic losses
  - In xEVs with regenerative braking, rolling resistance and aerodynamic losses dominate
- The relation of fuel consumption predicted from real-world drive data to that predicted by the industry-standard HWFET, UDDS, LA92, and US06 drive cycles was not consistent across powertrains, and varied broadly from the mean, median, and mode of real-world driving.
- A drive cycle synthesized by NREL's DRIVE tool accurately and consistently reproduces average real-world for multiple powertrains within 1%, and can be used to calculate the fuel consumption effects of varying levels of driver aggression.


Thanks!
Questions?