# *Evaluating Real World Drive Cycles to Support APRF Technology Evaluations*

**2012 DOE Hydrogen Program and Vehicle Technologies**
**Annual Merit Review**
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**Project ID # VSS091**

# Overview

- **Timeline**
  - Literature search of recent real-world cycles and assessment procedures
  - Coordination with M&S for test schedule and vehicle behavior insight
  - Evaluation of Argonne test vehicles over select real-world cycles
  - Analysis of select cycles
  - Refinement of real-world testing cycles/procedures
  - Continued vehicle testing

- **Budget**
  - FY 2011 $200k
    - $100k Vehicle Testing and Analysis
    - $100k Modeling and Simulation

- **DOE strategic goals/barriers addressed**
  - **F:** Constant advances in technology
    - Fuel /energy consumption variability of different technologies to driving variation
  - **D:** Lack of standardized test protocols
    - Existing test protocols evaluate specific facets of vehicle operation…to the exclusion of others
    - Regulatory developments toward harmonized real-world cycle

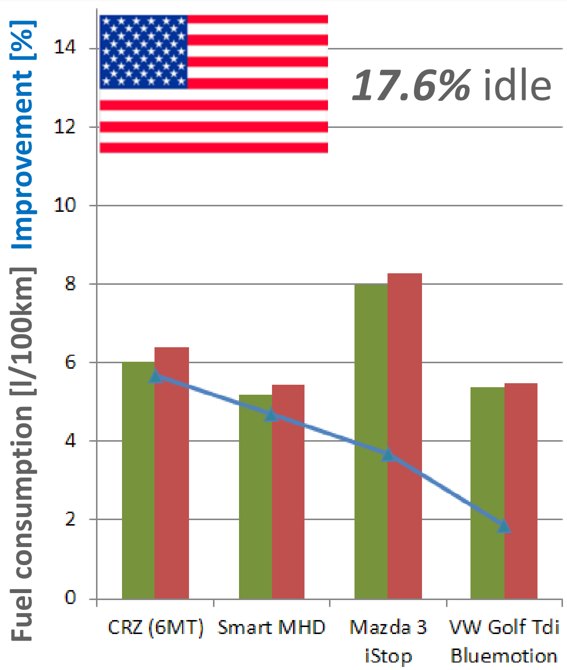
- **Partners**
  - DOE and other National Laboratories
  - USDrive, OEMs, and Suppliers
  - World Forum for Harmonization of Vehicle Regulations (WP.29)
  - EU, DOT, EPA

# Relevance: The Importance of Real-world Cycles

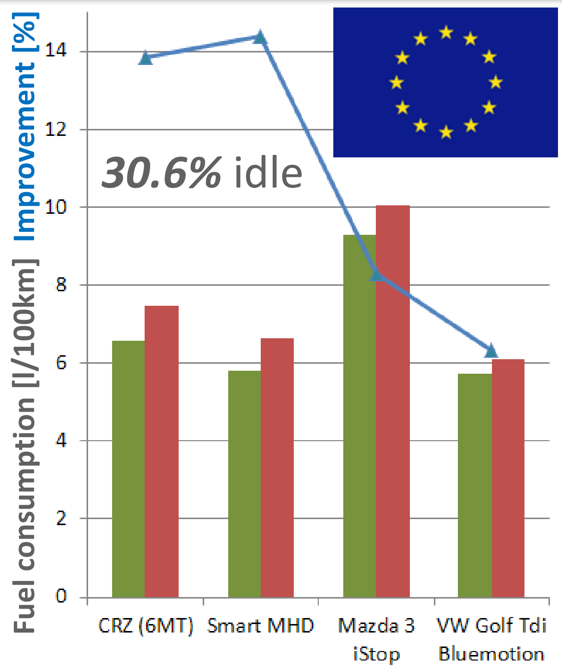
- **Research has consistency shown that the benefit of a particular vehicle technology is dependent on the evaluation cycle**

**UDDS** | **NEDC (City)**

→ Average start stop improvement ***4%***




→ Average start stop improvement ***10%***

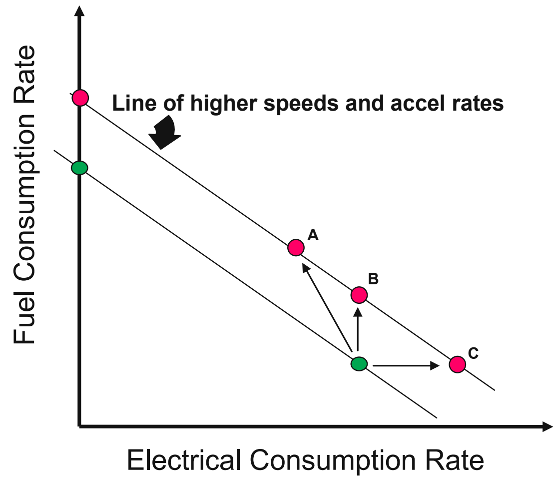


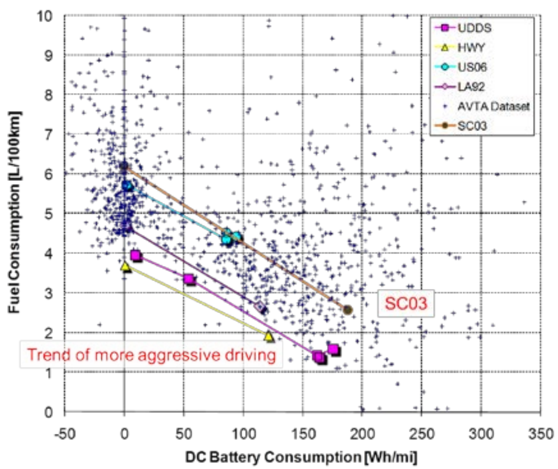

- **Manufacturers are continually seeking to improve real-world fuel consumption:**
  - "This system was developed with the main purpose to improve fuel consumption, especially for better real world fuel consumption" – Toyota 2010 SAE Paper [1]

[1] T. Matsubara, et el, Development of New Hybrid System for Compact Class Vehicles, SAE World Congress, 2009-01-1332

# Relevance: The Importance of Real-world Cycles

- **Generally, these issues become more complicated with greater vehicle electrification**
  - Blended PHEVs are particularly sensitive to driving style




- **Worldwide, regulatory agencies are seeking to update procedures for real-world usage**
  - WLTP Drive cycle will likely become a regulatory cycle for multiple countries (EU, China, India)
  - EPA 5-cycle adjustment for real-world driving and ambient conditions
  - Utility weighting assumes all distances are driven in a similar style, this is typically not the case
  - The technology implications of real-world regulatory cycles needs to be compared to the existing regulatory procedure and cycles

# Approach/Strategy: Real-world Cycle Selection Process

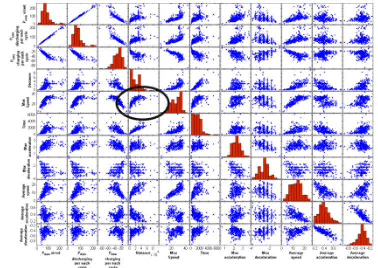
**Simulation assessment of various technologies over numerous cycles**

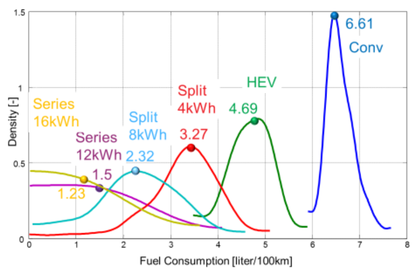
**Distribution analysis of energy consumption trends**

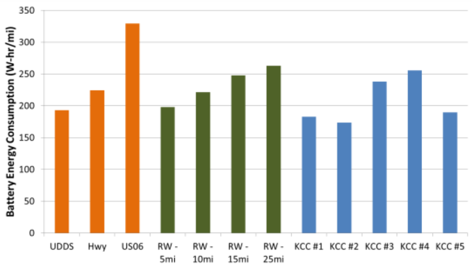
**Assessment of select cycles**

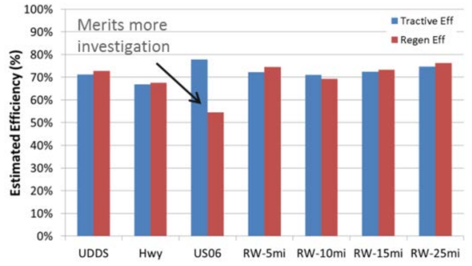
**Confirmation of efficiency trends**

**Selection of APRF evaluation cycles**





# Approach/Strategy: Dynamometer Based Vehicle Evaluation

- **Real-world cycles are typically evaluated in large batches using vehicle simulation:** What are the implications for dynamometer testing?
  - Technology and energy consumption implications
  - Practical issues related to real-world cycle testing on a dynamometer
  - Selection method for applicable/useful supplemental real-world cycles and overlap
  - Behavior and performance due to vehicle warm-up and related issues

- **Leverage APRF research vehicles to evaluate several sets of real-world drive cycles on a range of vehicle technologies**

**Conventional Vehicle**

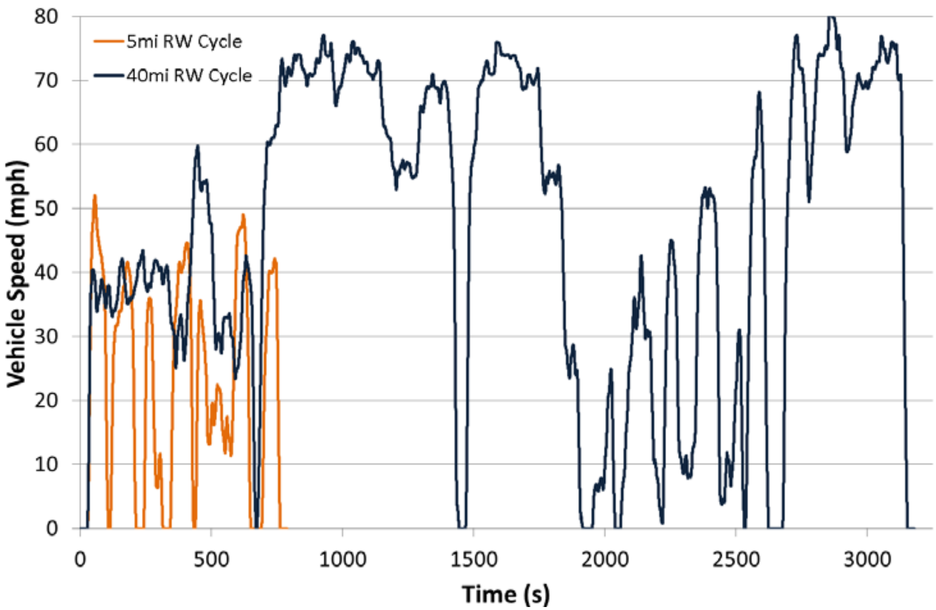
**Hybrid**

**BEV**

  - On-going assessment with Chevrolet Volt, Hyundai Sonata Hybrid, and VW Jetta TSI
  - Supplement dynamometer testing with Modeling and Simulation results/analysis

# Approach/Strategy: Stochastic Driving Cycle Assessment

- **Leverage University of Michigan developed Stochastic Drive Cycles [1] for preliminary assessment of real-world cycles**
  - Drive cycles developed using a statistical procedure to create a representative cycle having similar characteristics to real-world driving
  - 5, 10, 15, 25, 40 mile distance cycles evaluated
  - > 5mi real-world cycles exhibit much less idling
    - UDDS ~18% idle




### Short Distance Statistics

| Statistical parameters | Real Cycles* | Synthetic Cycle |
|---|---|---|
| Distance (mile) | - | 6.077 |
| Mean pos. vel. (mph) | 28.9463 | 28.9764 |
| std . vel. (mph) | 17.6774 | 17.7453 |
| Mean pos. acc. ($m/s^2$) | 1.0599 | 1.0787 |
| std. acc. ($m/s^2$) | 1.3535 | 1.3388 |
| Perc. driving time under pos. acc. (%) | 40.3848 | 39.8714 |
| Perc. driving time under neg. acc. (%) | 39.5487 | 36.8703 |
| Perc. Idle time (%) | 21.1607 | 19.0782 |
| # stops/mile (1/mile) | 1.3866 | 1.3164 |

* Mean values are presented for real cycles

### Moderate Distance Statistics

| Statistical parameters | Real Cycles* | Synthetic Cycle |
|---|---|---|
| Distance (mile) | | 23.2247 |
| Mean pos. vel. (mph) | 47.5074 | 48.0236 |
| std . vel. (mph) | 22.7512 | 23.5011 |
| Mean pos. acc. ($m/s^2$) | 0.6693 | 0.7312 |
| std. acc. ($m/s^2$) | 1.0931 | 1.0296 |
| Perc. driving time under pos. acc. (%) | 46.3879 | 38.9124 |
| Perc. driving time under neg. acc. (%) | 44.9012 | 32.6822 |
| Perc. Idle time (%) | 8.6135 | 8.0781 |
| # stops/mile (1/mile) | 0.3058 | 0.1722 |

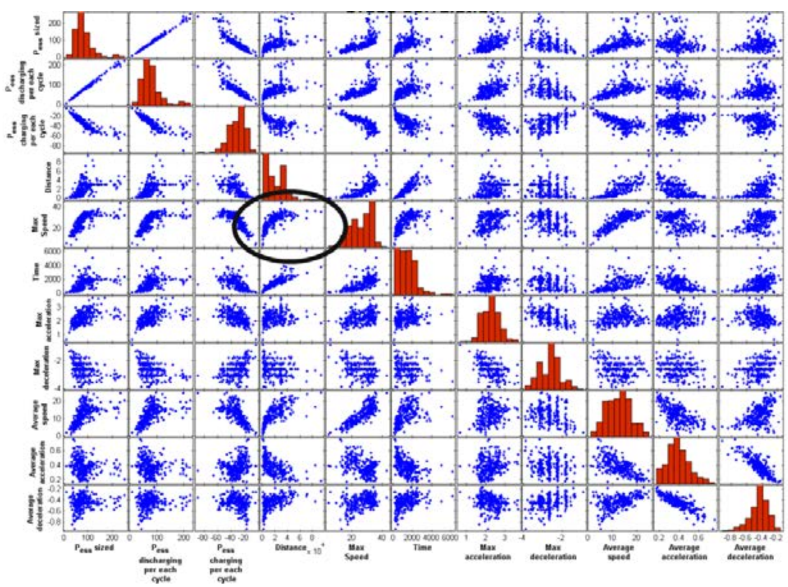
* Mean values are presented for real cycles


[1] T.-K. Lee, and Z.S. Filipi, "Synthesis of Real-World Driving Cycles Using Stochastic Process and Statistical Methodology", in the review of the Int. J. Vehicle Design, 2010

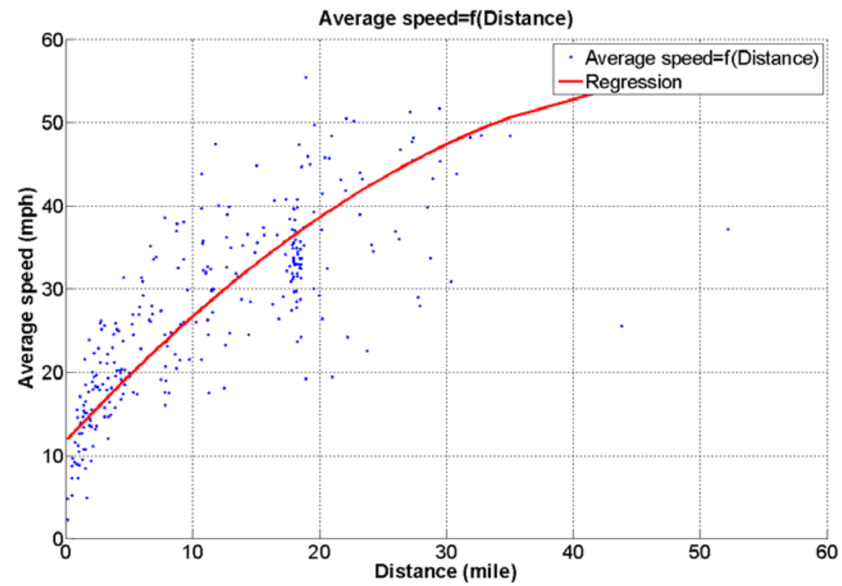
# Approach/Strategy: Select EPA real-world Cycles Assessment

- **In addition to the stochastic cycles, assess a sub-set of EPA's real-world drive cycles from vehicle data collection in and around Kansas City**
  - Wide range of distances, speeds and driving styles
  - Evaluate methodologies to select "relevant" dynamometer cycles
  - Leverages previous Modeling and Simulation analysis efforts

M&S Cycle Cross Correlations



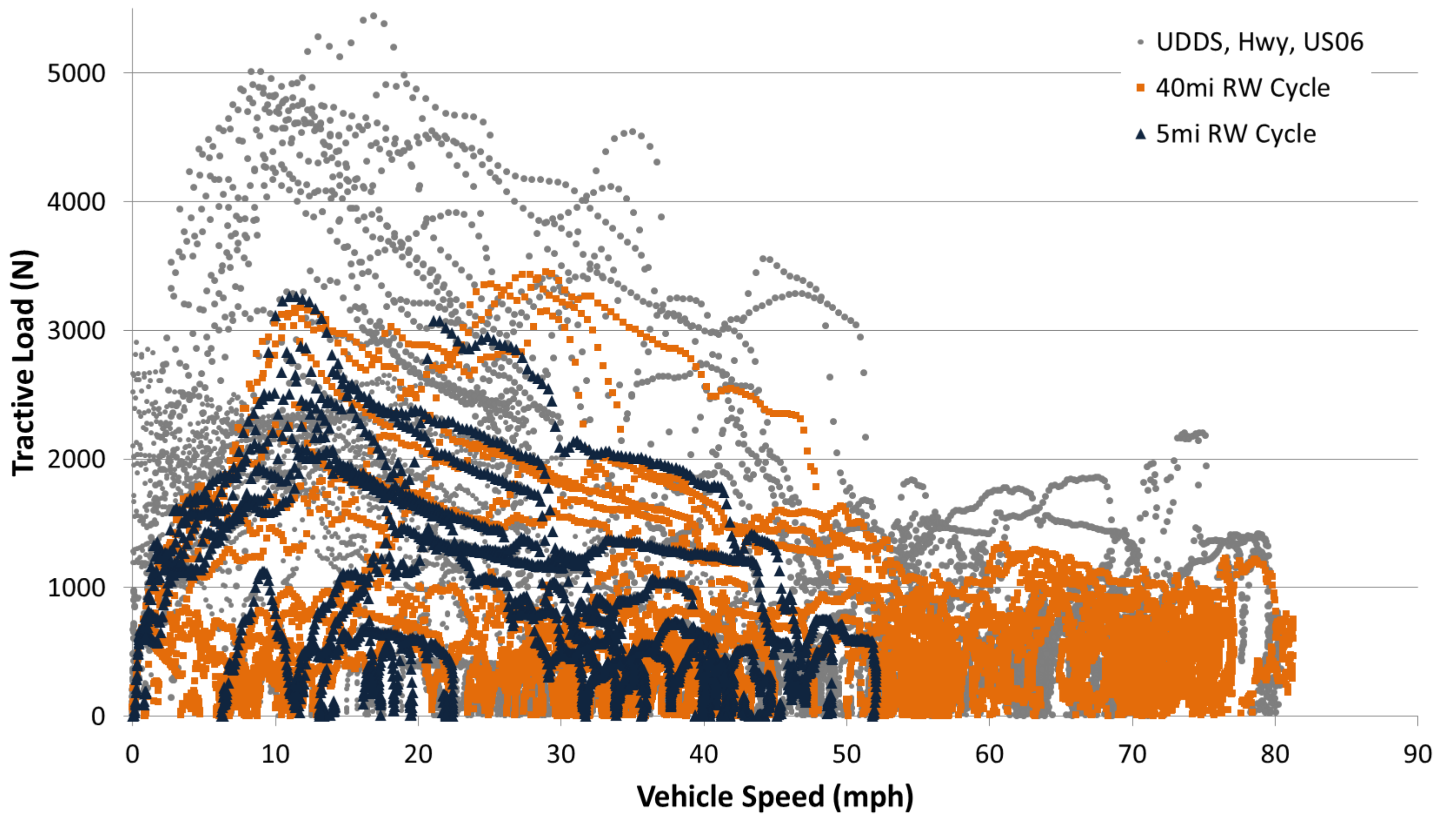
Increasing Average Speed with Distance



# Accomplishments: Basic Insights from Real-world Cycles

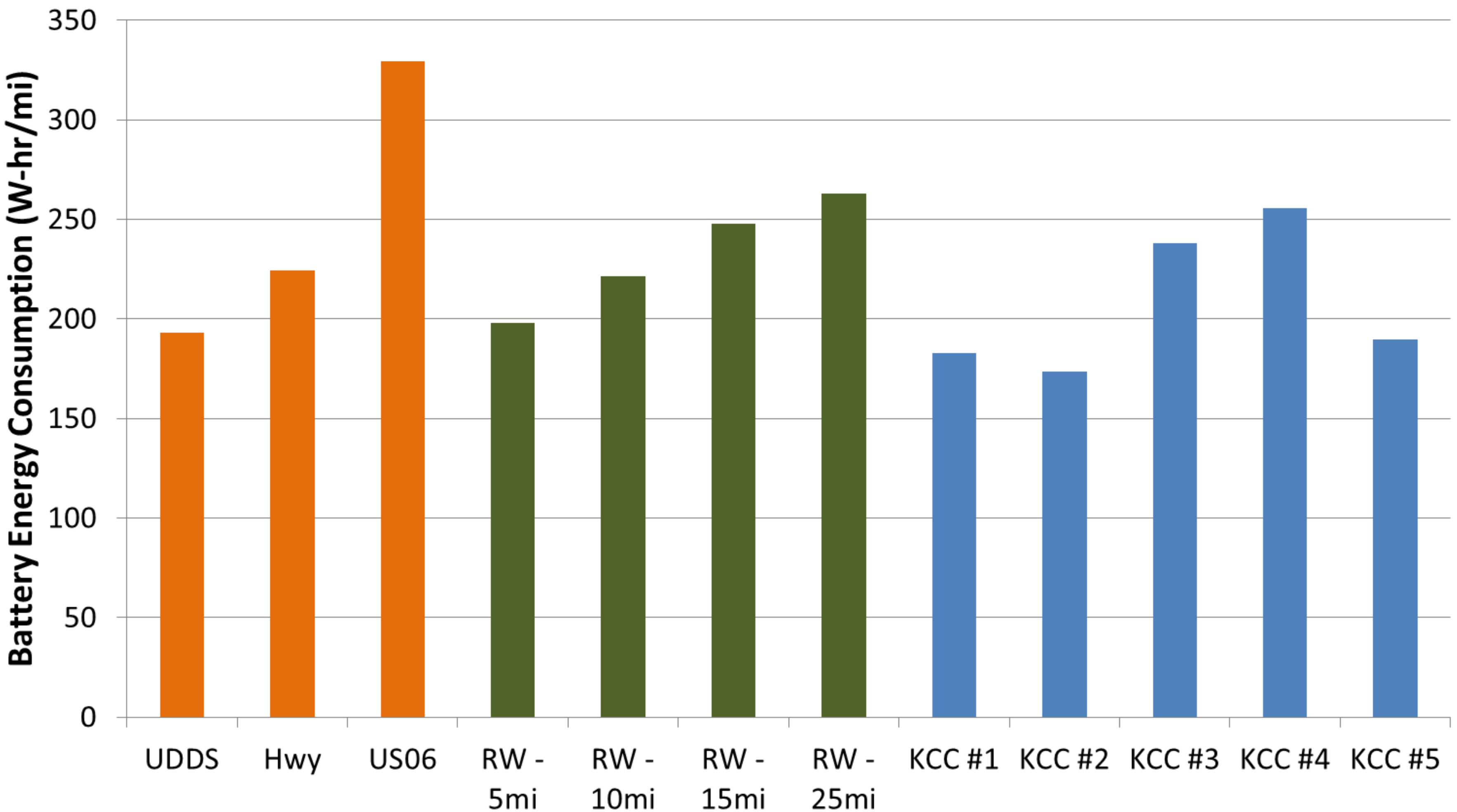
**Real world cycles provide improved coverage of moderate load points across a wide range of vehicle speeds (especially moderate/high speeds)**

- Limited information regarding component operational limits
- Improved information for efficiency map generation
- Many cycles much too long for frequent dynamometer operation
  - Need to develop process to synthesize shorter (time) cycles



# Accomplishments: Leaf Real-world Evaluation

**Real-world cycles are fairly comparable in terms of energy consumption…US06 still appears to represent the upper threshold of an aggressive, higher consumption cycle**

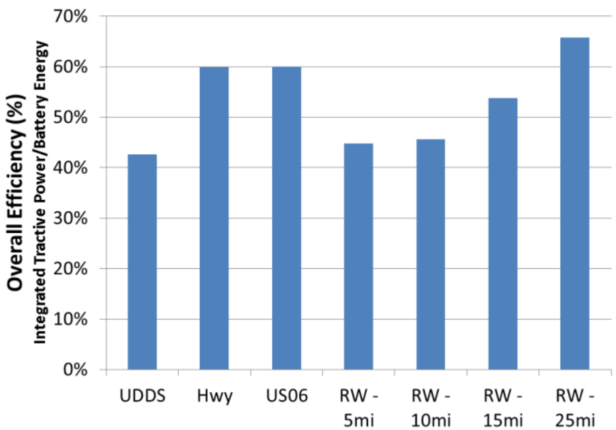


# Accomplishments: Leaf Real-world Evaluation

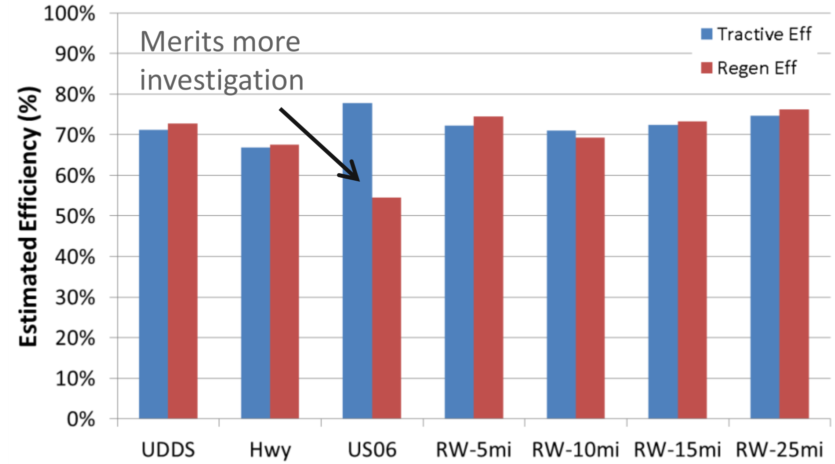
**Using some intelligent processing, real-world energy efficiency trends can be fairly well estimated for cycles similar to the UDDS and outliers can be further investigated**

### Overall efficiency trends appear scattered

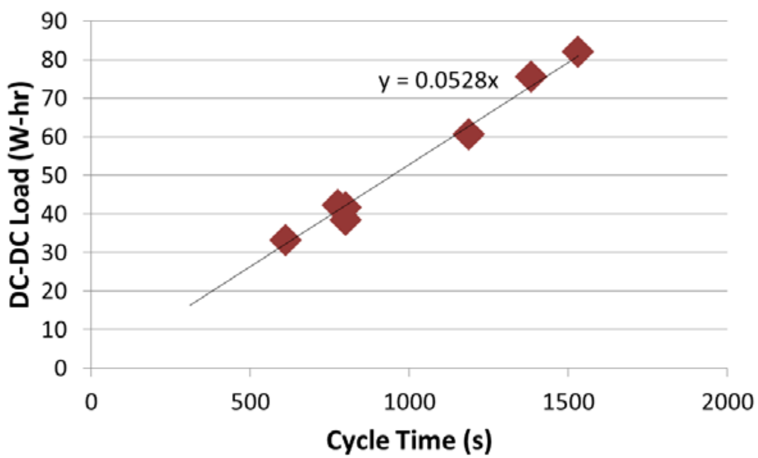
Integrated tractive power / Battery energy

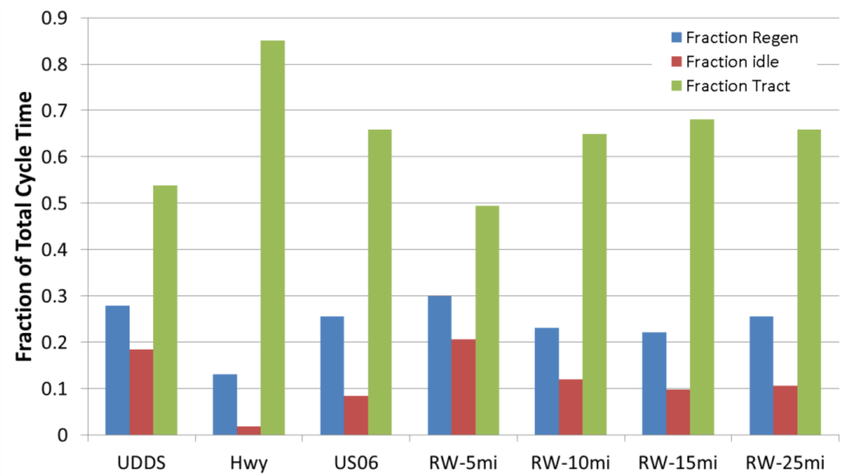



### Improved Efficiency Estimates




### Excluding accessory loads and allocating braking vs. propulsion energy greatly aids in clarifying efficiency trends



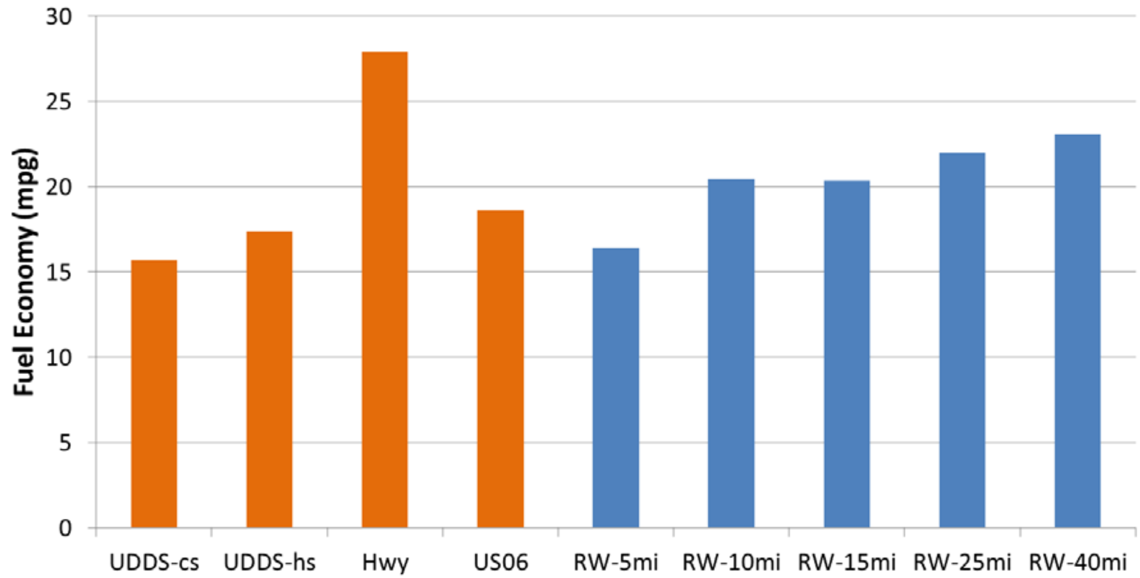



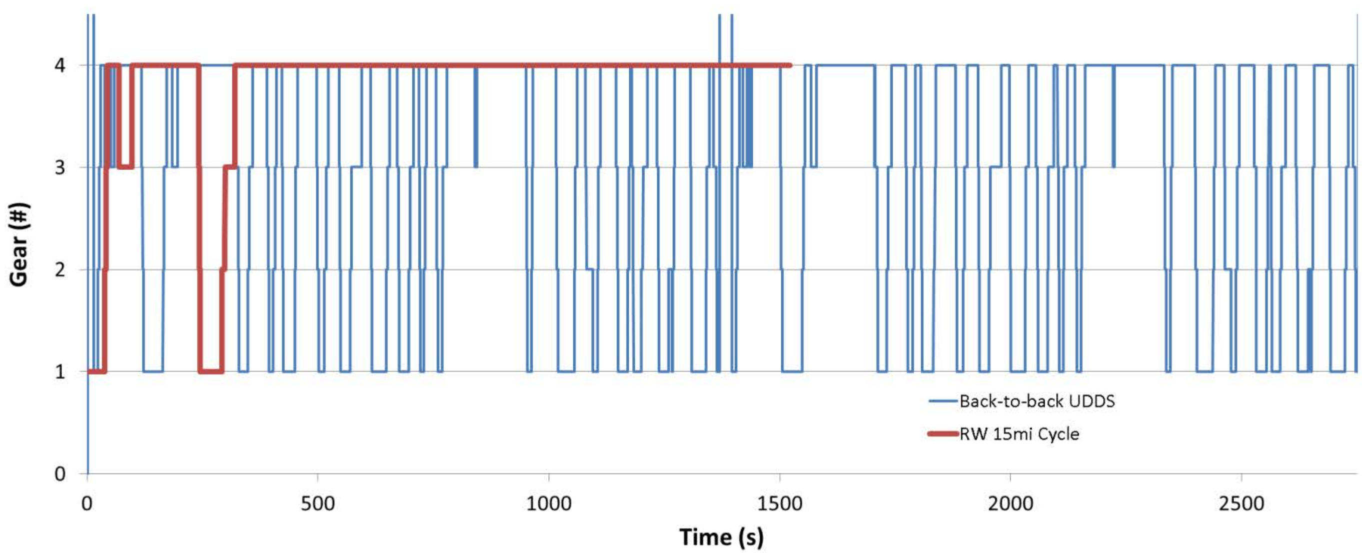
# Accomplishments: Conventional Vehicle Analysis

**Conventional vehicle operation differs dramatically between Hwy and RW operation**

- Conventional vehicle shows elevated Highway fuel economy compared to real-world cycles

- Vehicle also shows considerably different transmission operation for two 15 mile trips: UDDS 2X (15mi) and RW-15mi cycle

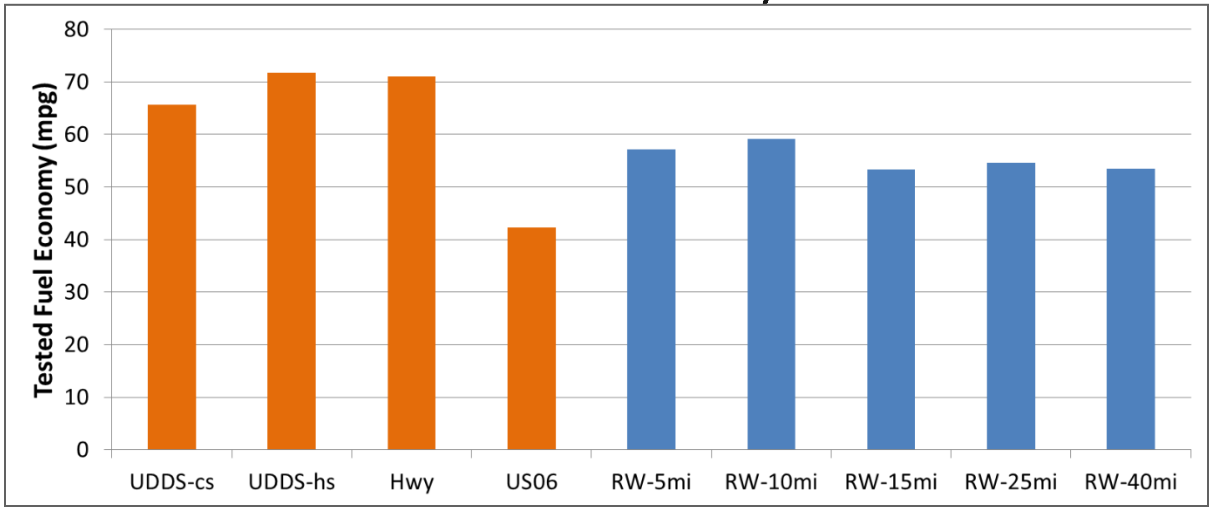


# Accomplishments: Prius Operation Analysis

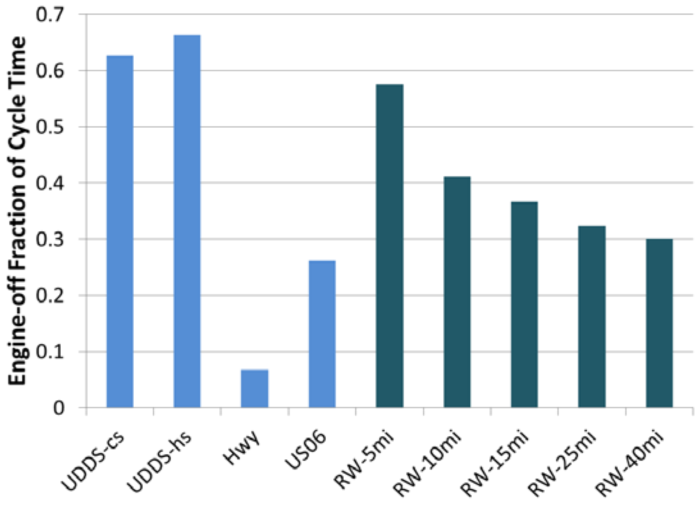
**Testing provides insight into operational and economy differences due to real-world cycles**

- Vehicle shows different trends in both engine-off fraction and maximum battery swing…suggests different vehicle operation compared to UDDS



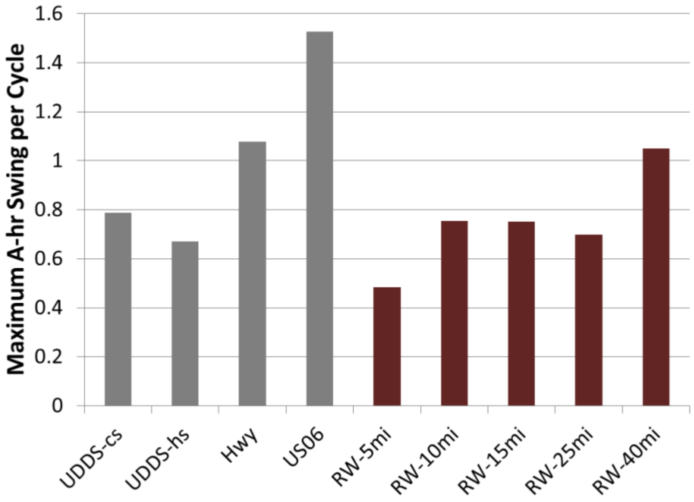

**Engine On/Off differs significantly versus UDDS**

Higher vehicle speeds results in less engine-off




**Maximum A-hr swing also indicates different operation**

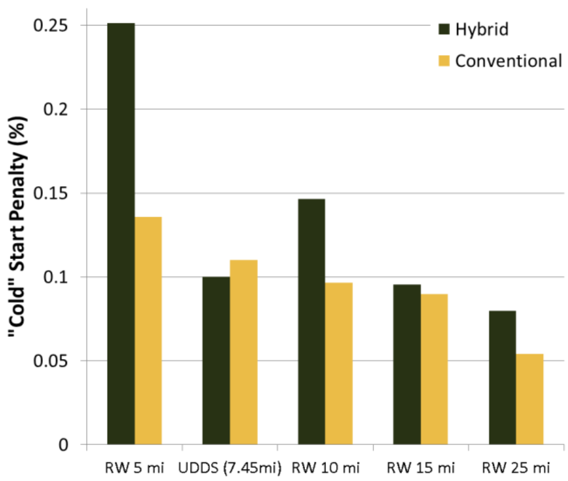
Larger A-hr swing often suggests more opportunity charging

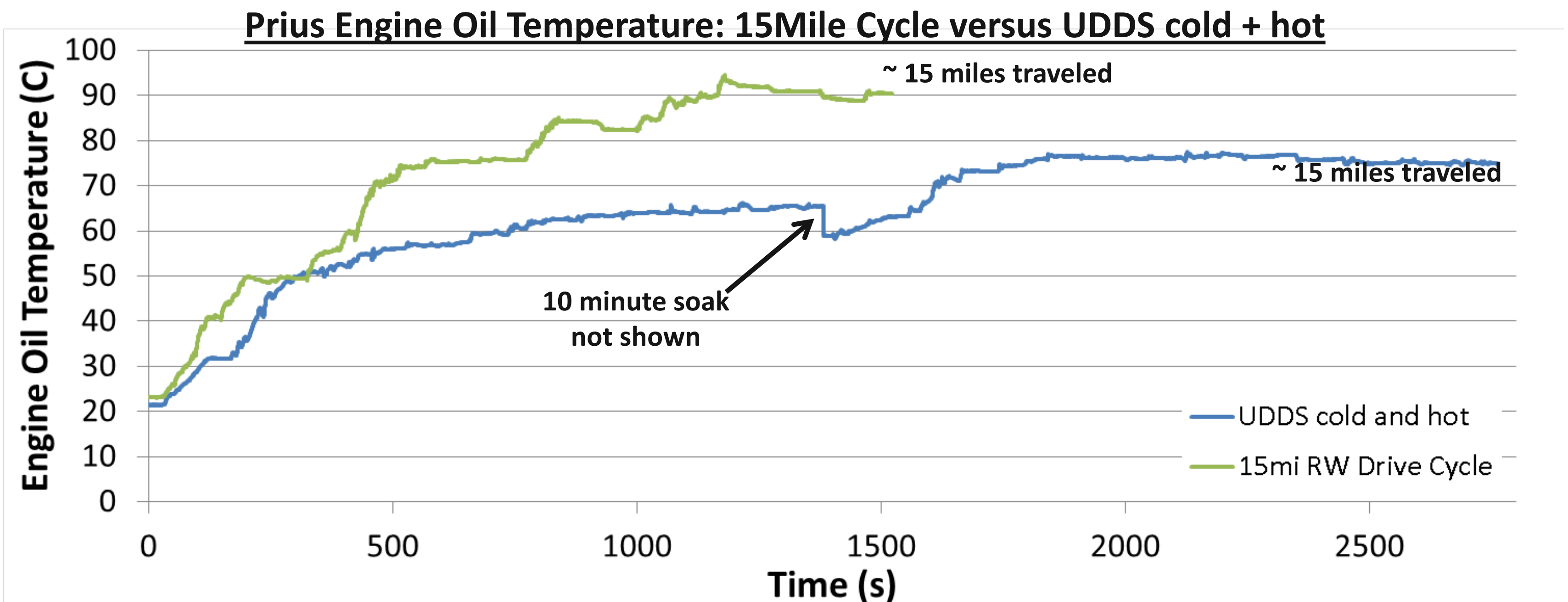


# Accomplishments: Preliminary Cold Start Analysis

**Impact of vehicle warm-up varies with distance (fraction of cold vs. warm) and engine usage/power**

- Both hybrid and conventional vehicles show a varied impact of vehicle warm-up depending on cycle driven
- Prius 5mile cycle shows a significant impact due to vehicle warm-up and a larger penalty for 10 mile cycle as well
- Conventional vehicle shows similar RW trends, but UDDS shows a larger penalty versus 10mile cycle (likely engine usage related)



# Collaboration: Real-world Testing Aids Vehicle Benchmarking

**World-wide Regulatory Agencies**
- EPA
- DOT
- WP.29 (US, Japan, Korea, EU, India, China…)

**AVTA (Advanced Vehicle Testing activities)**
Baseline dynamometer testing of vehicles

**DOE technology evaluation and improved fleet fuel consumption estimates**
- DOE requests
- National Lab requests

**Real-world Testing**

**USCAR, tech teams and OEMs**
Shared data and analysis

**Chrysler** – CTC

**GM** – Powertrain, Milford

**Ford** – Powertrain, APTL

**Autonomie**
Support of modeling and simulation with data

# Future/On-going Work

**Continued evaluation of RW cycles using APRF research vehicles**

- **Assessment of "real-world" regulatory cycles – World Lightweight Test Cycle (WLTP)**
  - Cycle is rapid gaining traction as a harmonized evaluation cycle
  - Assessment of "real-world" regulatory cycles to US driving (both regulatory and real-world)
- **Evaluation of Chevrolet Volt over real-world drive cycles**
  - Regulatory versus real-world EV to charge-sustaining transition of particular interest
  - Creation of distance-based, driving specific utility adjusted fuel consumption estimate
- **Real-world performance benchmarking of Hyundai Sonata hybrid**
  - Interesting contrast to the Prius (power-split) type system…regulatory versus real-world
- **Evaluation of real-world driving under hot/cold ambient temperatures**
  - The impact of different driving styles and distances on the impact of vehicle warm-up and cool-down is particularly relevant to estimating the impact of different technologies
- **Development of improved cycle synthesis procedures for practical dyno. testing**


# Summary

**Testing vehicles on real-world as well as regulatory cycles provides further insight into vehicle behavior, energy consumption, and important areas of operation**

- Selected real-world cycle improve coverage for efficiency maps
  - Cycles provide higher-speed moderate load points, not contained in US06
  - Many real-world cycles are extremely time-consuming
  - Additional processing/synthesis required for frequent assessment on dyno.
- BEV efficiency is fairly consistent for most real-world cycles
  - Processing to allocate energy between accessories, braking, and propulsion helpful
  - US06 shows interesting differences in efficiency and regen. capture (system limitations)
- Conventional vehicle shows dramatically different transmission operation
- Given the higher-speed/moderate load driving of the real-world cycles, selected HEV shows fairly different operation compared to the UDDS
  - Vehicle exhibits different engine on/off control and battery utilization

**Leveraging Level-1 and Level-2 research vehicles for evaluation of real-world cycles provides additional insight for both technology assessment and component map generation**