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Evaluation of a Lower-Energy Energy Storage System (LEESS) for Full-Hybrid Electric Vehicles (HEVs)

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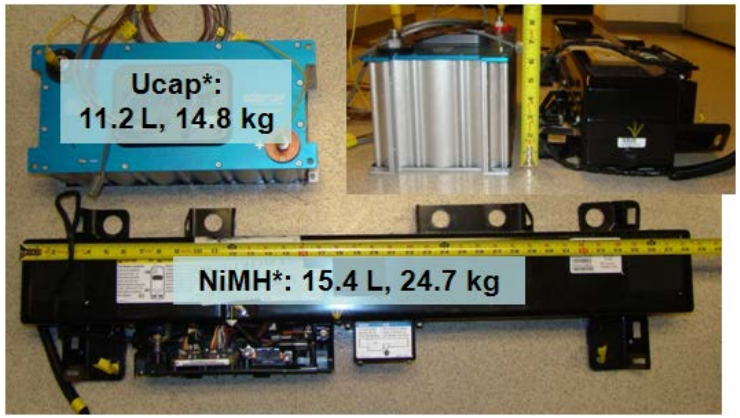
Motivation

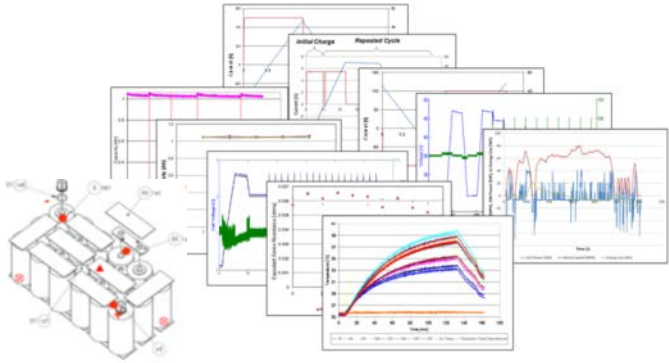
- HEVs are effective at reducing per-vehicle fuel use
- Incremental cost remains a barrier to wider market penetration
  - Energy storage system (ESS) arguably the largest contributor
- ESS cost reductions/performance improvements → improved vehicle-level cost vs. benefit
  - Increase market demand and aggregate fuel savings
- Lower-energy ESS (LEESS) considerations
  - Technical evaluation—can it do the job?
  - Potential for lower cost with less energy?
  - Potential benefits from alternative technology?
    - Better life, better cold temperature performance

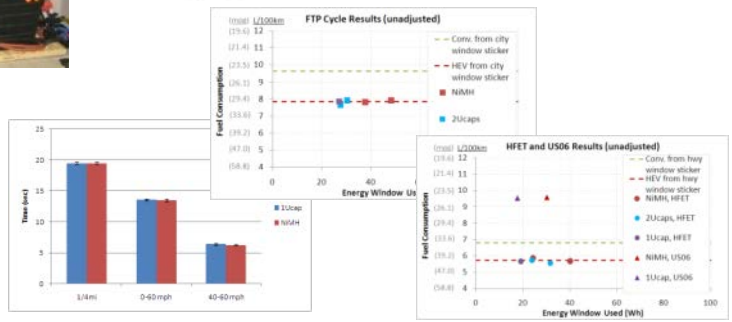
(Past SAE HEV Symposium Presentation)

Related Background Work: NREL evaluation for GM of replacing NiMH batteries with ultracapacitors in the 42-V Saturn Vue BAS HEV

- Motivation: Ucap potential for superior cycle life, cold temperature performance and long-term cost reductions
- Bench tested Ucaps and retrofitted vehicle to operate in 3 configurations







Photos by Jeff Gonder and Jason Lustbader, NREL

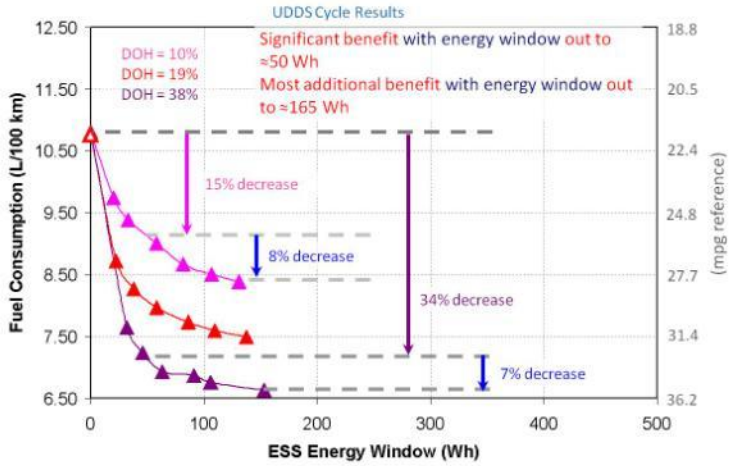
Findings: HEV with ultracapacitors performed at least as well as the stock configuration with a NiMH battery

BAS = belt alternator starter ("mild" HEV); NiMH = nickel-metal hydride; Ucap = ultracapacitor

Additional Background: NREL analysis for USABC of full-HEV fuel savings sensitivity to energy storage size

- NREL performed simulations and analyzed test data in conjunction with an EES TT Workgroup
  - Re-evaluating ESS targets established in the late 1990s / early 2000s

- Results suggested power-assist HEVs can still achieve high fuel savings with lower energy and potentially lower cost ESS – see:
  - Gonder, J.; Pesaran, A.; Howell, D.; Tataria, H. "Lower-Energy Requirements for Power-Assist HEV Energy Storage Systems—Analysis and Rationale." *Proceedings of the 27th International Battery Seminar and Exhibit*; Mar 15-18, 2010, Fort Lauderdale, FL. http://www.nrel.gov/docs/fy10osti/47682.pdf



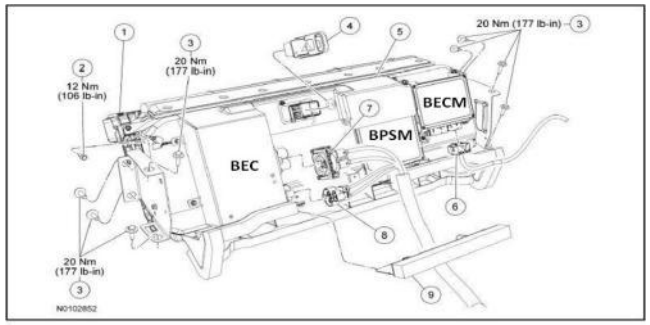
- USABC established targets and issued a Request for Proposal Information (RFPI) to support LEESS development
  - See: http://www.uscar.org/guest/article_view.php?articles_id=87
  - Open to any ESS technology (very high power batteries, electrochemical double layer capacitors, or asymmetric supercapacitors)

USABC = United States Advanced Battery Consortium
EES TT = The FreedomCAR/USDRIVE Electrochemical Energy Storage Technical Team

Current Project:
Hardware evaluation of potential full-HEV LEESS devices

- Setting up a reusable vehicle test platform using a 2012 Ford Fusion Hybrid
  - CRADA with Ford to facilitate
- Second set of production subcomponents to interface with LEESS cells
  - Custom state estimator sends instantaneous state-of-charge (SOC) and power capability information to vehicle controller
- Maintain stock operating capability (using production NiMH cells)
  - Able to switch between operation using the stock battery and using the LEESS device under test
  - Provides back-to-back performance comparison

Photos by John Ireland, NREL

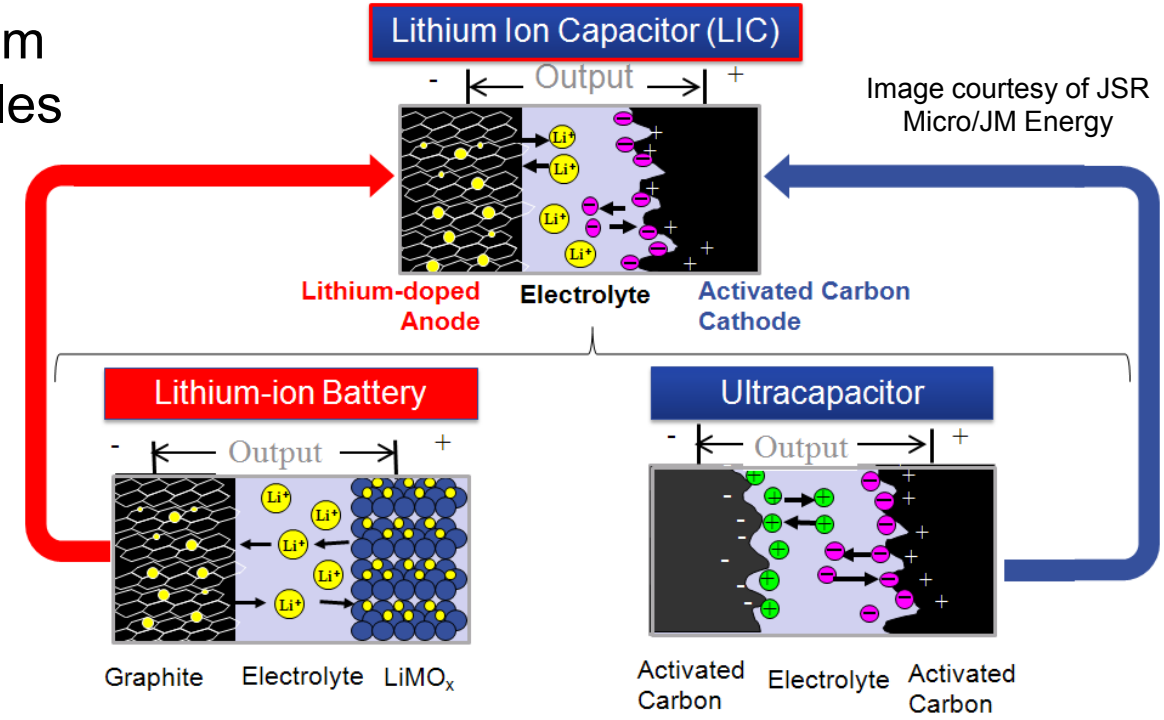


Fusion test platform and traction battery with Bussed Electrical Center (BEC), Battery Pack Sensor Module (BPSM) and Battery Energy Control Module (BECM)

CRADA = Cooperative Research and Development Agreement

Focus of Results Shown Here: Bench testing of first LEESS under evaluation

- JSR Micro provided lithium ion capacitor (LIC) modules
  - Asymmetric storage device with battery and ultracapacitor-type characteristics
  - 3.8 V max/cell, and doubled volumetric capacitance due to lithium doping



- Conversion pack sizing

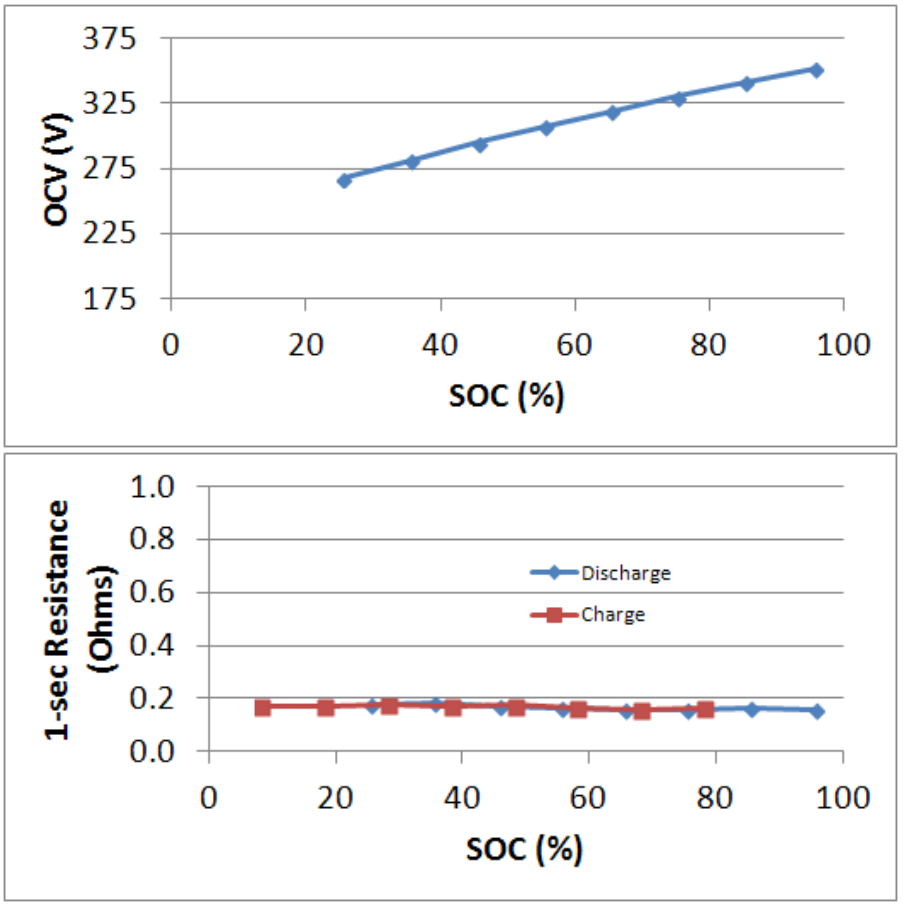
	# of Cells	Nominal Voltage	Total Energy (Wh)
Stock Sanyo NiMH*	204	275	1,370
8 JSR 192 F LIC Modules	96	300	260**
6 JSR 192 F LIC Modules	72	225	180**

*Based on fact sheet published by Idaho National Laboratory (INL)
**Assuming 175 V – 350 V maximum in-vehicle operating window

LIC Pack Characterization

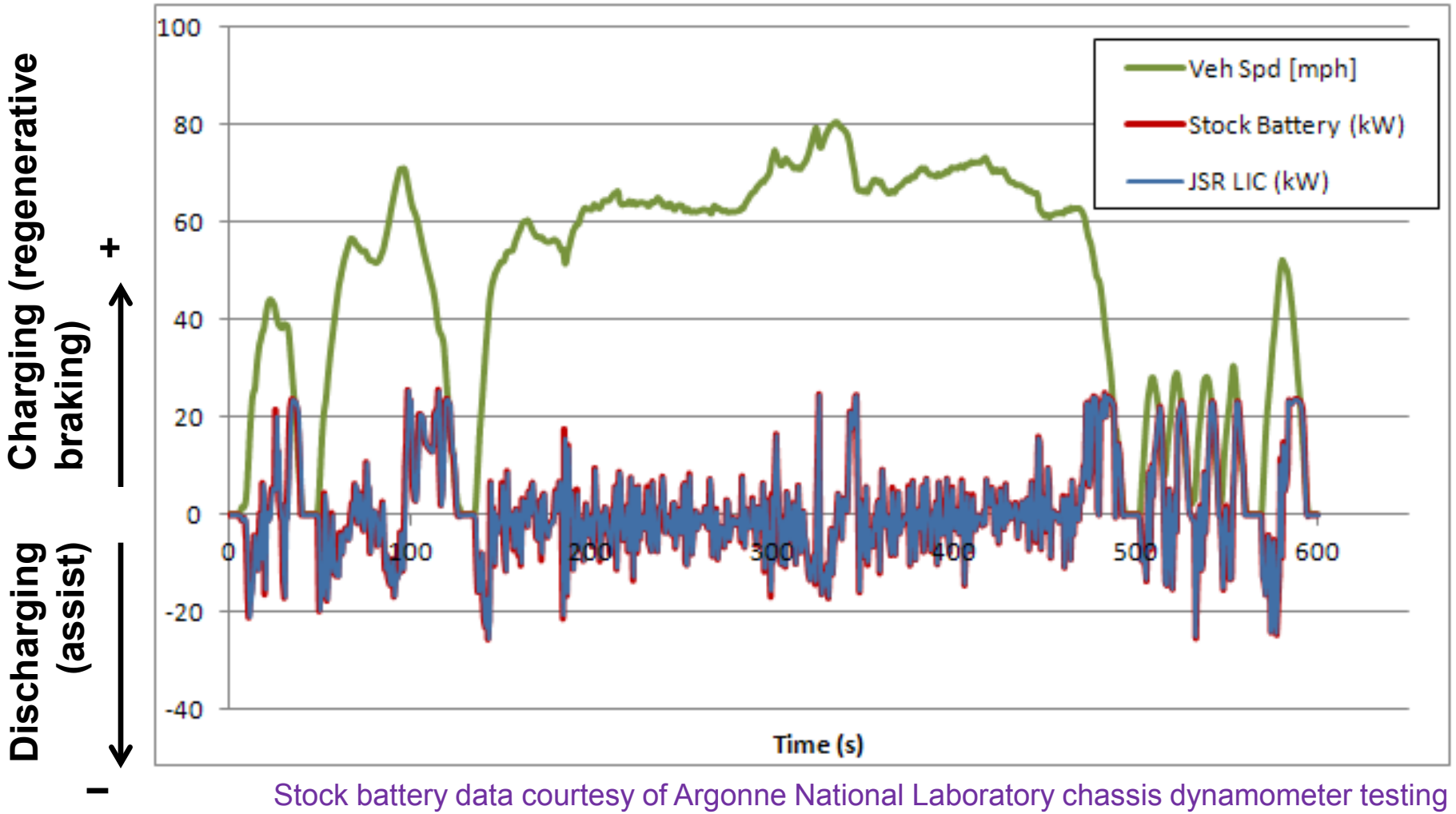
- Bench cycling at multiple temperatures
  - Static capacity test
  - Hybrid pulse power characterization (HPPC)
  - US06 drive profile
- Impedance 2-3x less than NiMH*

Photo by John Ireland, NREL



*Based on calculations from INL fact sheet
OCV = open circuit voltage

US06 Profile Comparison: Stock battery (in vehicle) vs. JSR Micro LIC (in lab)



Stock battery data courtesy of Argonne National Laboratory chassis dynamometer testing

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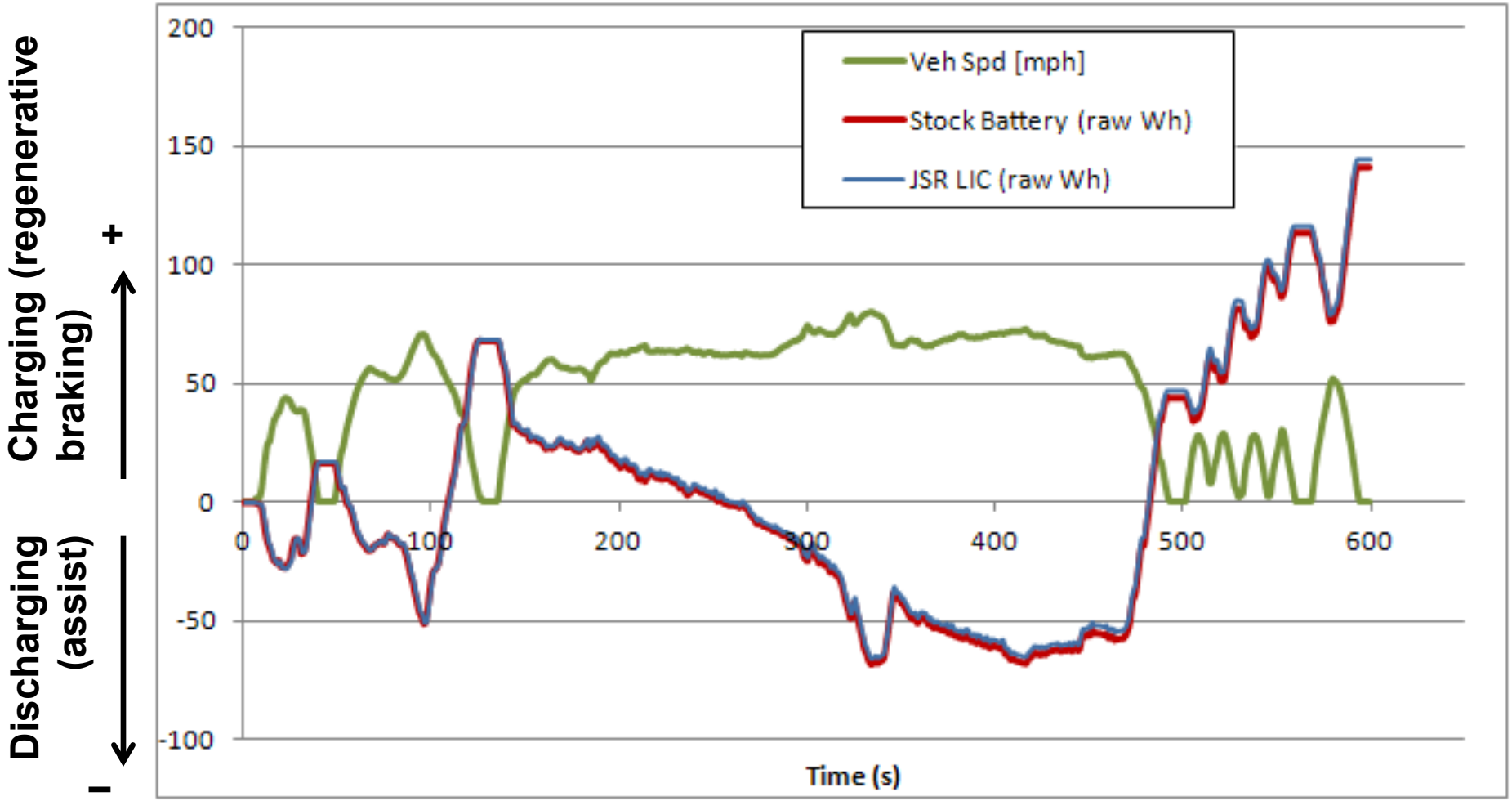

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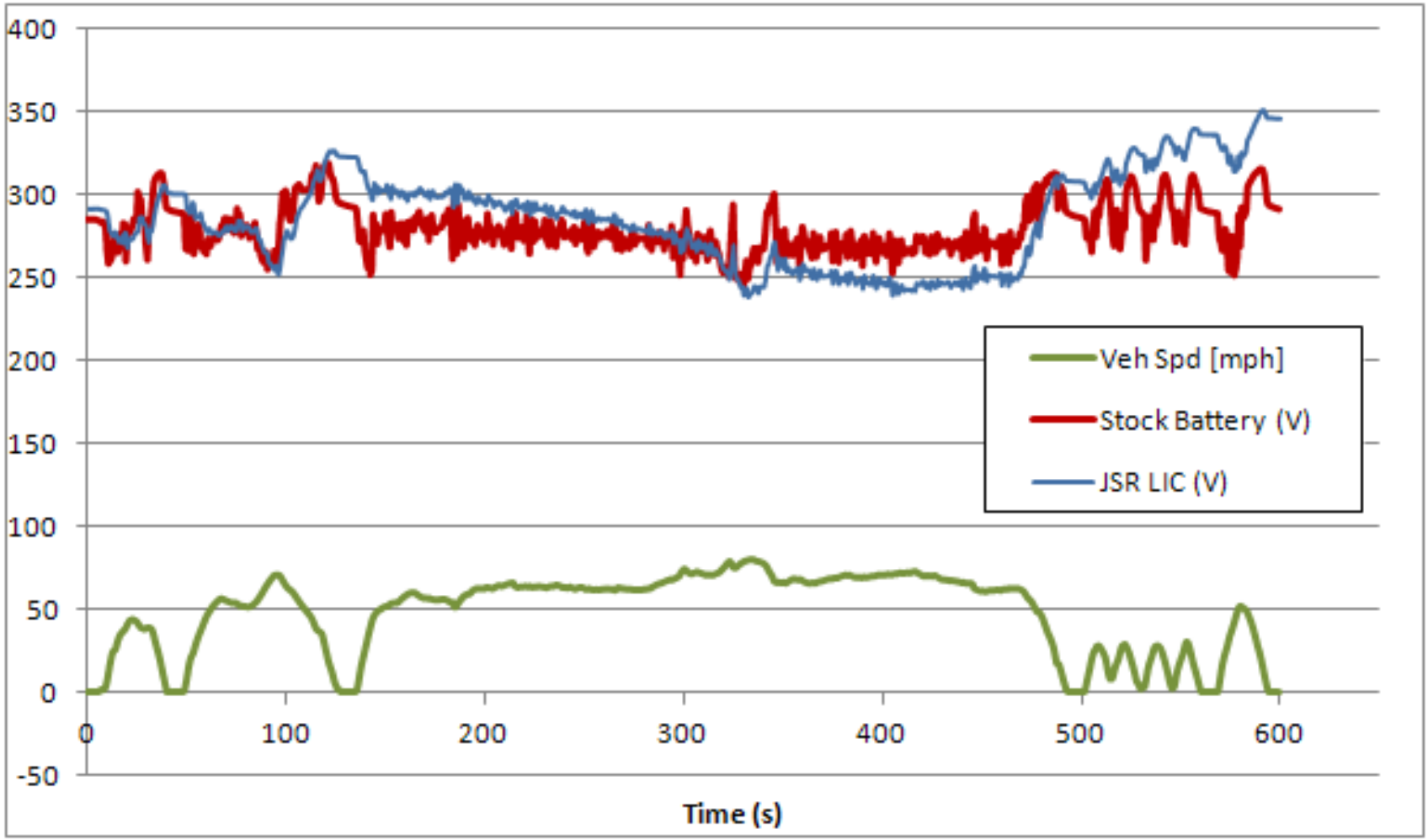

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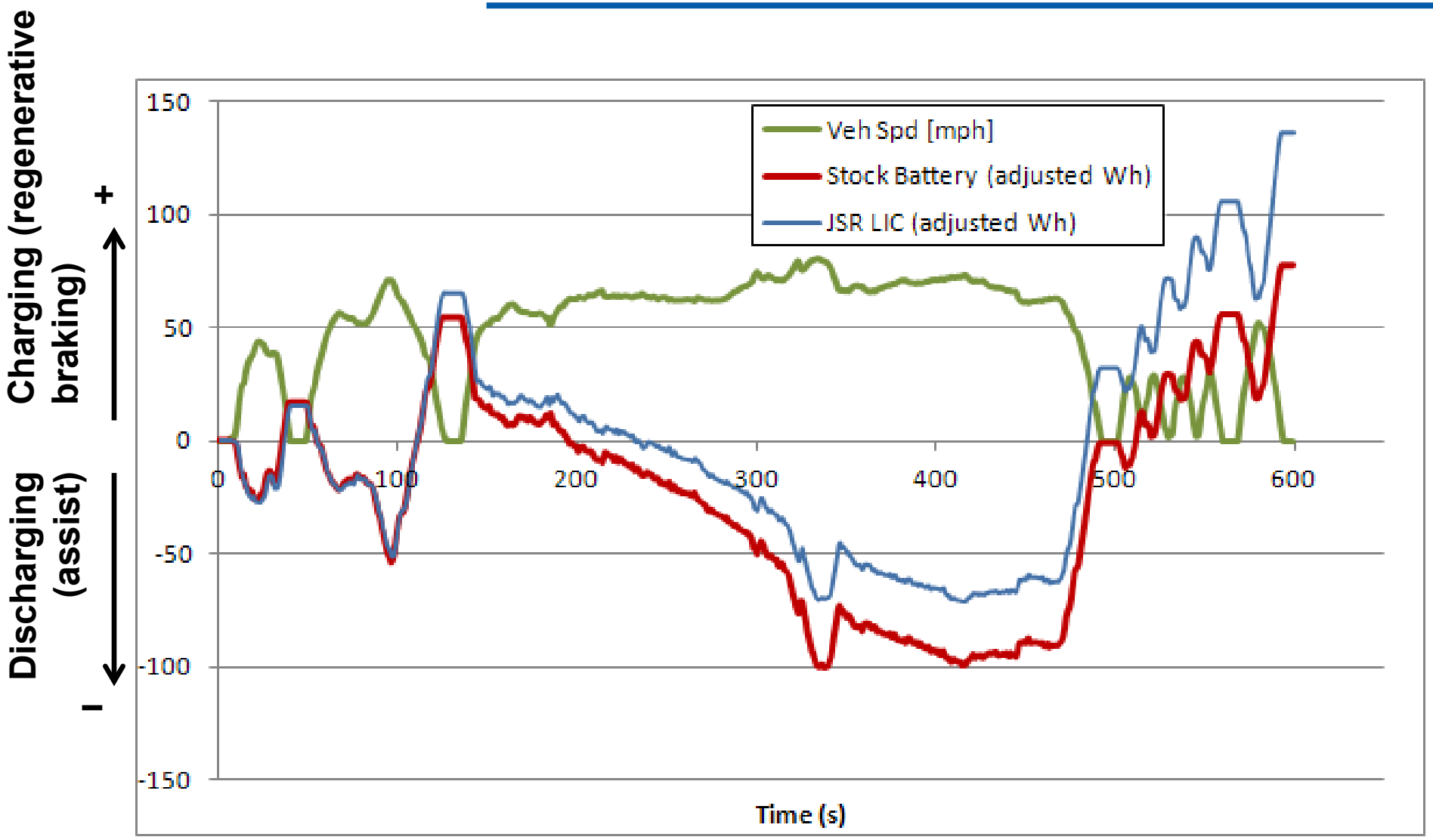

Summary and Next Steps

- Reducing cost/improving performance of the ESS can improve HEV marketability and aggregate petroleum savings
- Previous analysis suggests that alternative technologies can compete in the HEV ESS space
  - High-power batteries, ultracapacitors, or asymmetric devices
- Hardware testing in current project intended to validate previous analysis and provide in-use evaluation of LEESS devices
- Bench testing results of initial LIC LEESS continue to look promising
- Next step: evaluate LIC pack in converted vehicle
  - Back-to-back testing with NiMH vs. LIC

Acknowledgments

- JSR Micro
  - Providing LIC modules for evaluation
  - Related technical information and support

- Ford Motor Company
  - CRADA facilitating vehicle conversion

- U.S. Department of Energy
  - Cost-shared support between two Vehicle Technologies Office activities
    - Energy Storage (ES)
    - Vehicle Systems Simulation and Testing (VSST)

Questions?

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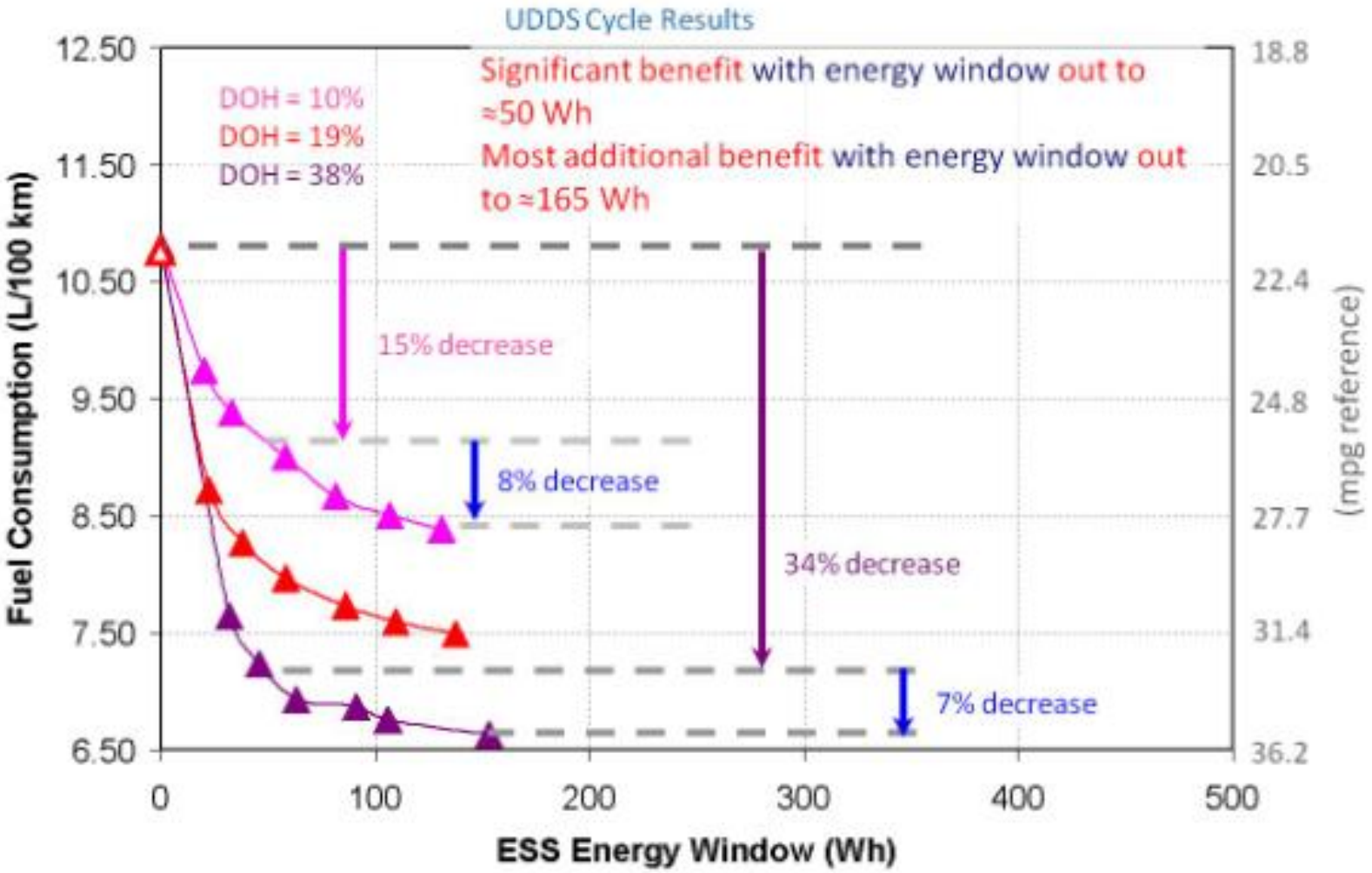
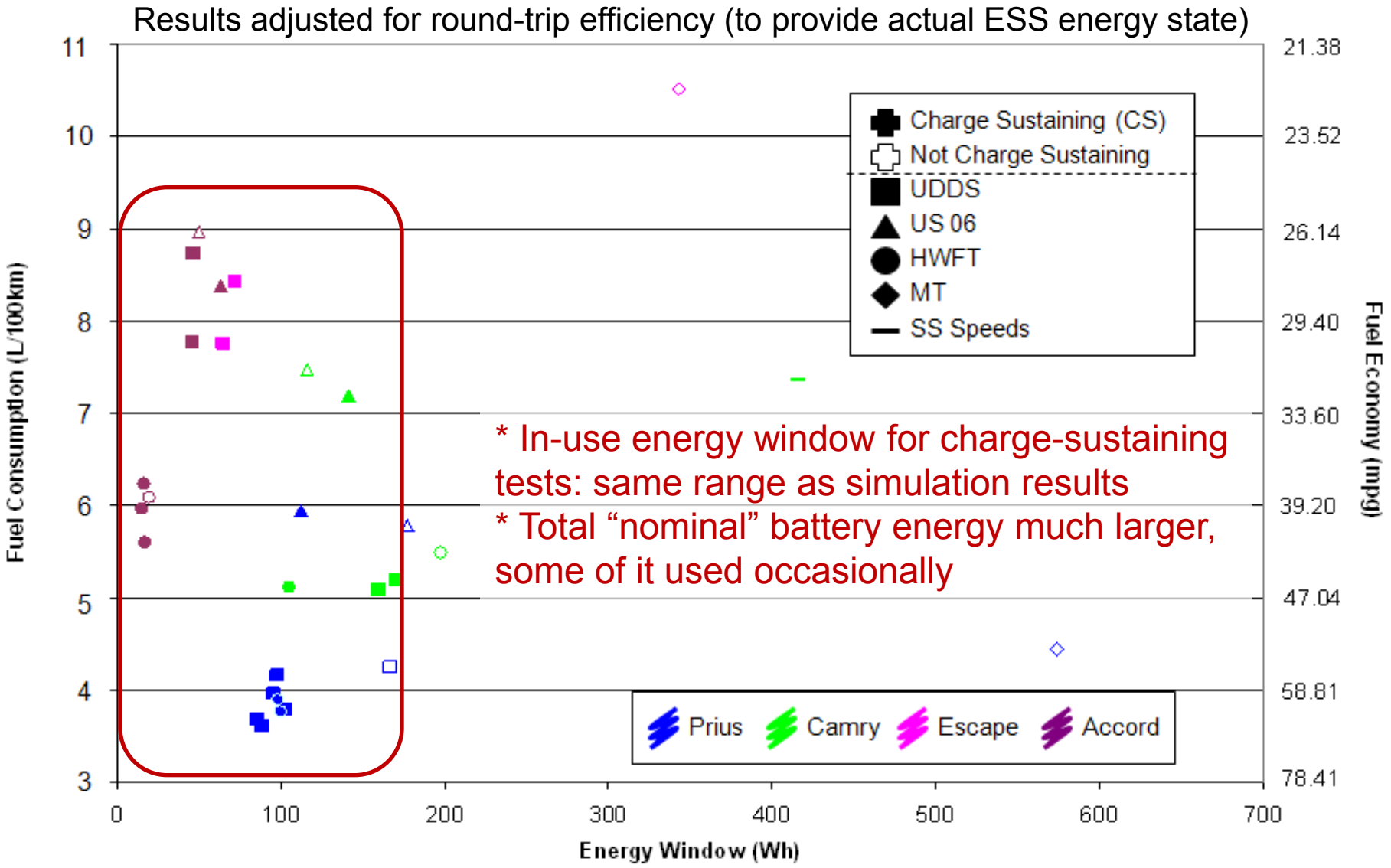
Appendix – Additional slides from supporting analysis for the new USABC LEESS goals

Full presentation: www.nrel.gov/docs/fy10osti/47682.pdf

Simulated HEV fuel savings sensitivity to energy storage size



Consistent findings from analysis of production HEV dyno data*



* Thanks to ANL for providing access to some of the raw dynamometer test data

Summary of in-use ESS energy window analysis

- Even small energy windows can provide HEV fuel savings
- Significant fuel savings can be achieved with an ≈165 Wh energy window (much less than the previous 425 Wh minimum goal)
- Reasons for large total "nominal" energy in today's production HEVs
  - Infrequent drive cycle use (e.g., long uphill/downhill grades)
  - Achieving longer cycle life from reduced SOC swings
  - Energy comes along with sizing for power capability (particularly at cold temperatures)
    - Note that power dominates cost in HEV batteries (high P/E ratio)