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U.S. Department of Energy

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PHEV Laboratory Testing and Analysis

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Argonne National Laboratory

PHEV Stakeholders Meeting, Washington DC

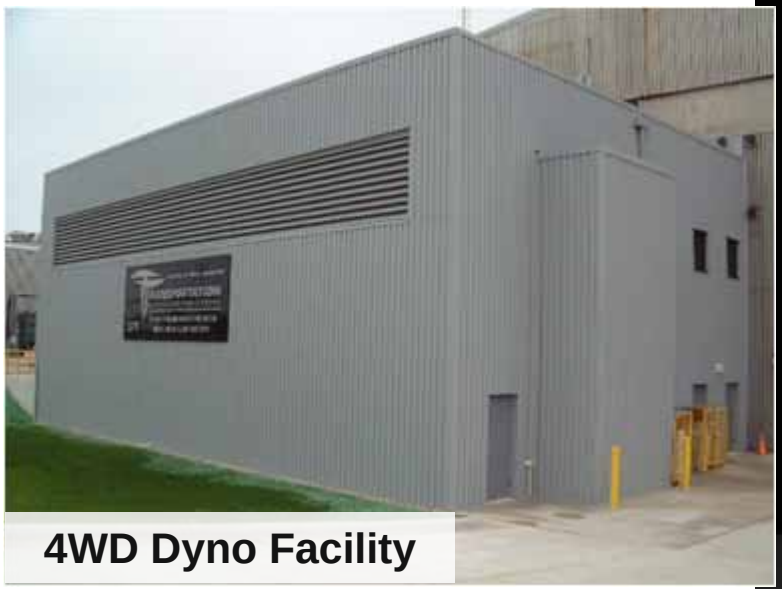
June 13, 2007

FreedomCAR & Vehicle Technologies Program

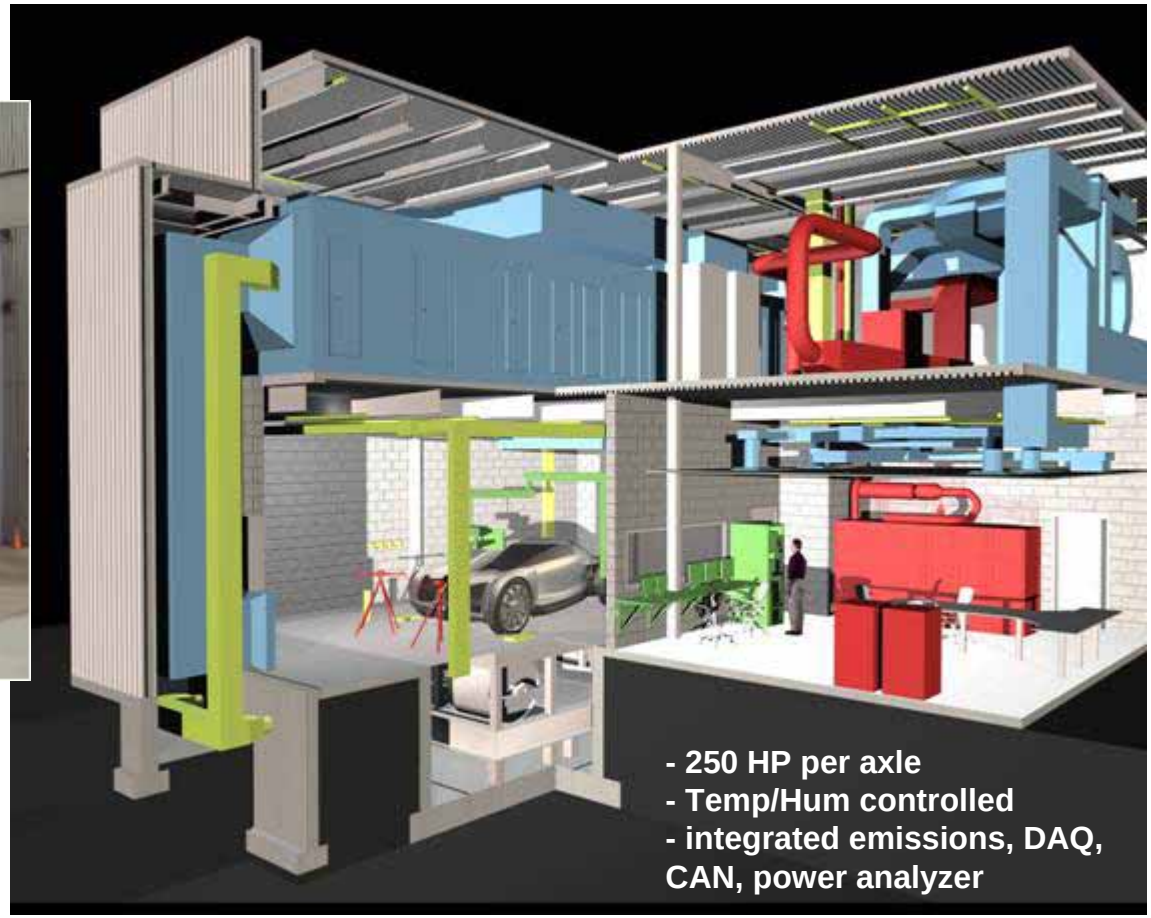
FreedomCAR & Fuel Partnership

Advanced Powertrain Research Facility

- ANL benchmarking hybrids for DOE, PNGV/FreedomCAR since 1998
- 4WD Dyno Facility is DOE's benchmark facility
- Designed from the start to test HEVs and other advanced technology (H2, diesel etc)



4WD Dyno Facility

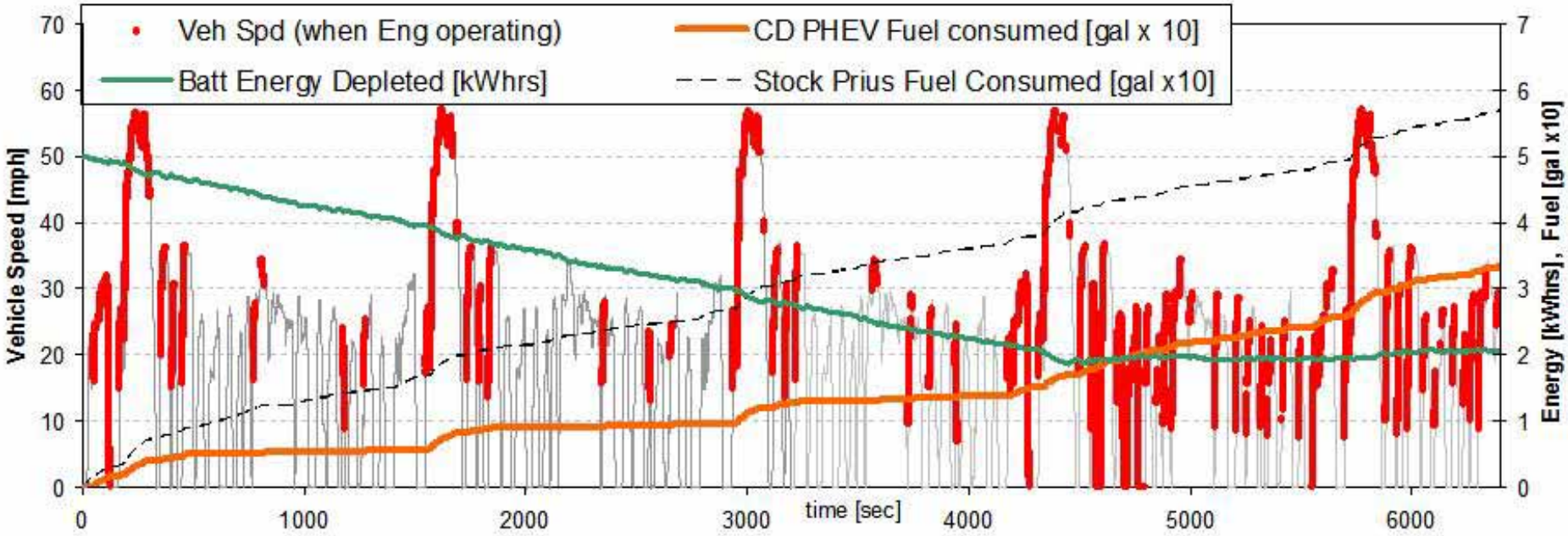


PHEV Vehicle Testing at Argonne National Lab

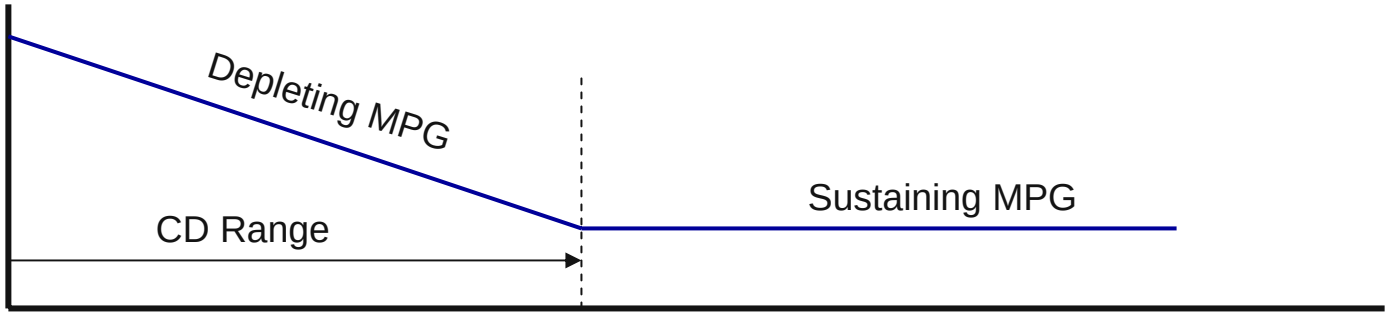
- **Testing Completed**
  - Kokam Hymotion Prius, dedicated test vehicle
  - EnergyCS Prius ver.1 and ver.2, AVTA vehicle
  - A123 Hymotion Prius, AVTA vehicle
  - Renault Kangoo, AVTA vehicle
- **Future PHEV testing**
  - AVTA and NYSERDA PHEV's
  - Hybrids Plus Prius (Level 2)
  - Hybrids Plus Escape (Level 2)
  - ANL prototypes
    - *Through-the-road parallel PHEV*
    - *Series PHEV (S10 EV with gen-set)*

How Were They Tested/Evaluated?

- "5-Day PHEV Test Procedure" developed for AVTA vehicles
- Used "Full Charge Test" (FCT) for UDDS and HWY
- Tested charge-sustaining UDDS pair (for emissions)
- US06 tests in depleting and sustaining modes



How Did They Perform? - Full Charge Test Results

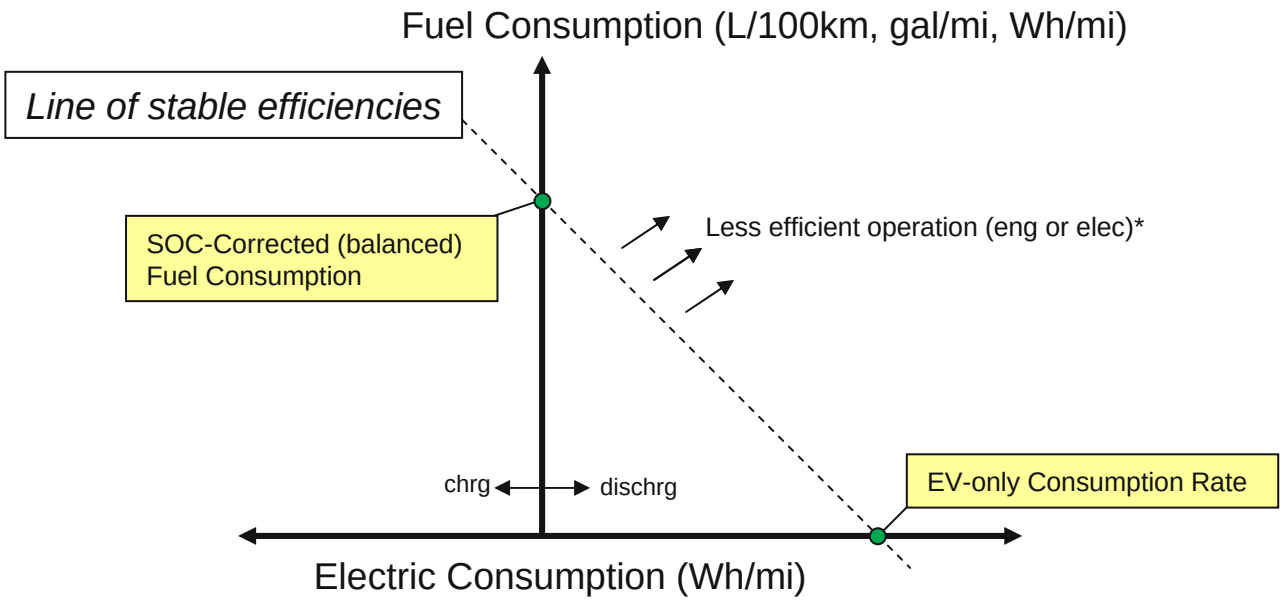


UDDS Cycle Charge Depletion Operation	Average Depleting MPG	Ave Battery Usage [Whr/mi]	CD range [miles]	Usable Energy [kWhrs]	Petroleum Displacement Factor [%]	Charge-Sustaining MPG
Kokam Hymotion Prius	178	126	24	2.9	61%	66.4
A123 Hymotion Prius	160	129	25	3.1	60%	64.4
EnergyCS Prius	139	131	34	4.5	55%	62.2

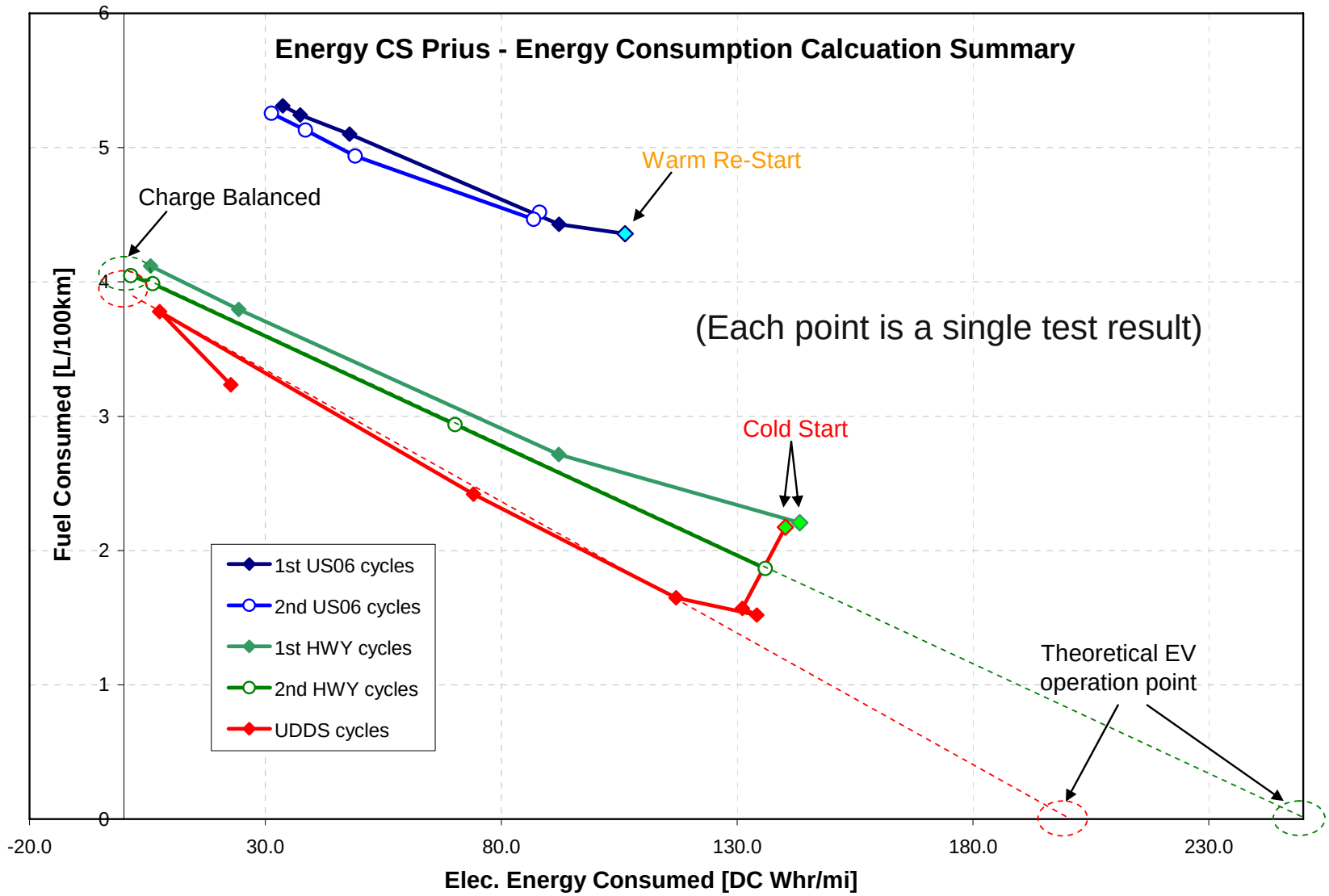
HWY Cycle Charge Depletion Operation	Average Depleting MPG	Ave Battery Usage [Whr/mi]	CD range [miles]	Usable Energy [kWhrs]	Petroleum Displacement Factor [%]	Charge-Sustaining MPG
Kokam Hymotion Prius	122	98	33	3.2	48%	64.0
A123 Hymotion Prius	101	113	31	3.4	46%	55.0
EnergyCS Prius	103	103	50	4.9	44%	58.1

How Can We Analyze The Results? - 2D Energy Utilization Plot

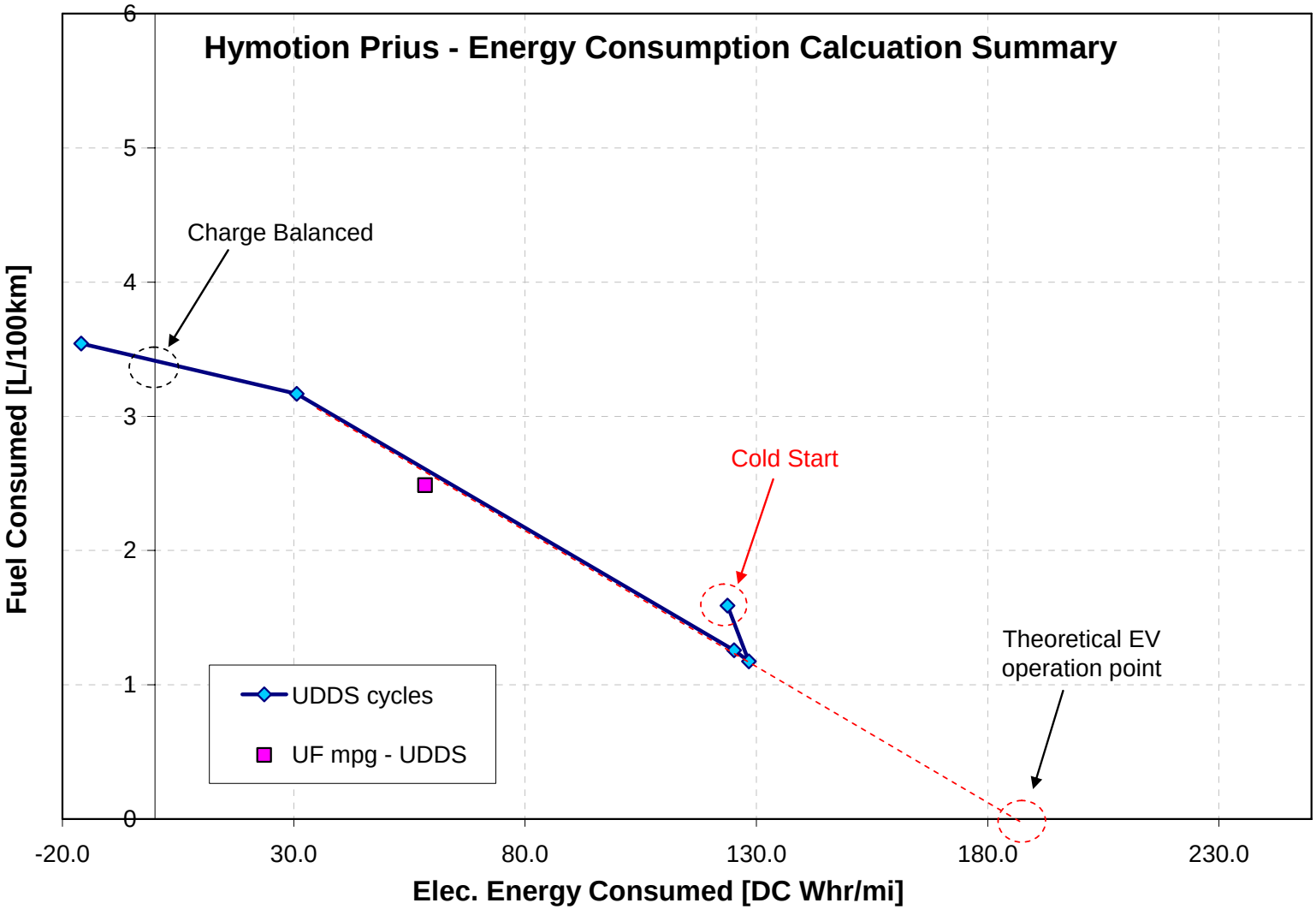
- Essentially a “SOC Correction Plot” from J1711
- Two Points of interest
  - SOC-balanced fuel consumption
  - Electric-only battery consumption
- Charge depletion rates can vary, but if fuel and battery/drive efficiencies are maintained, results fall on a single line



Energy Utilization Plot: EnergyCS Prius

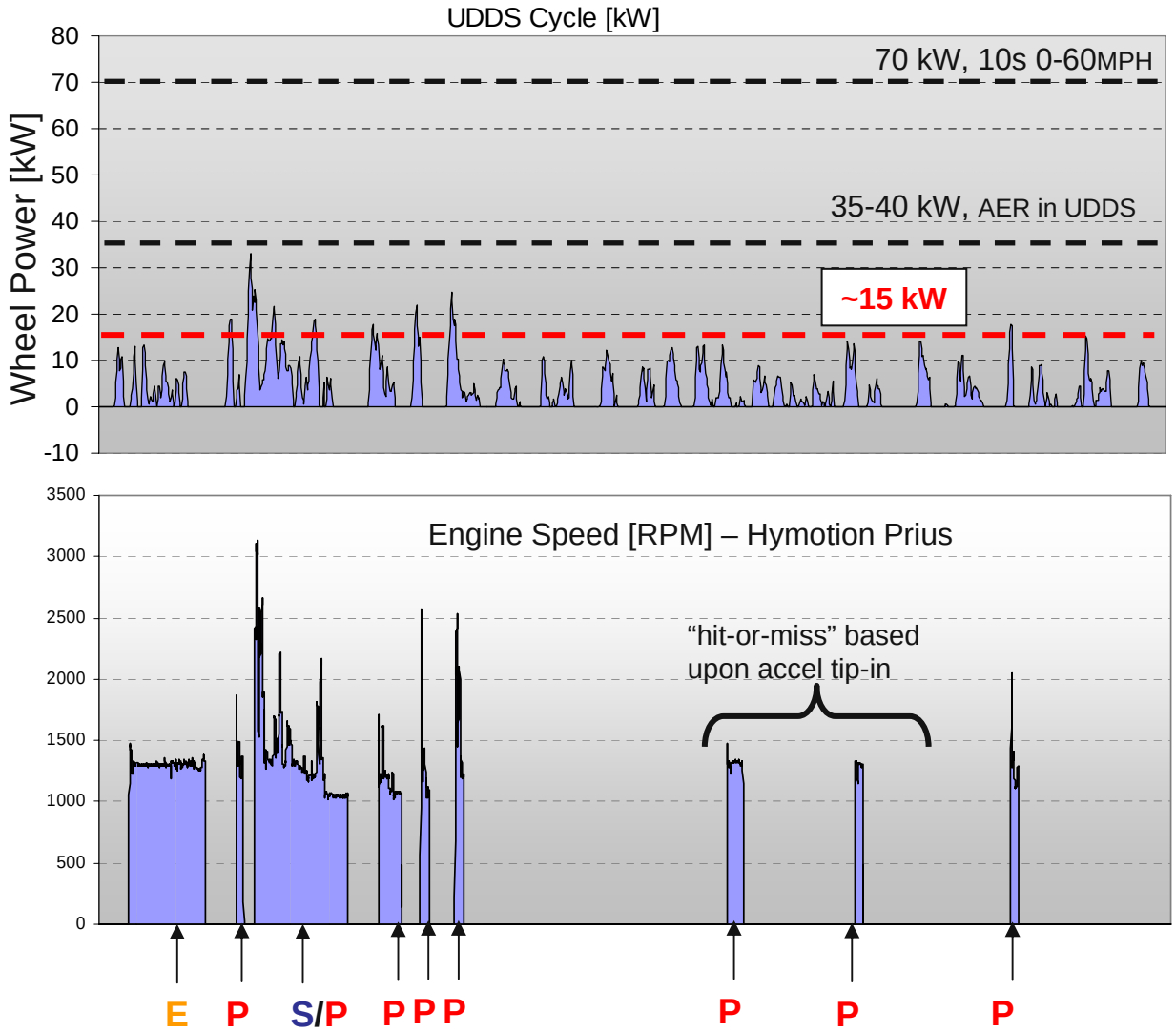


Energy Utilization Plot: Hymotion Prius



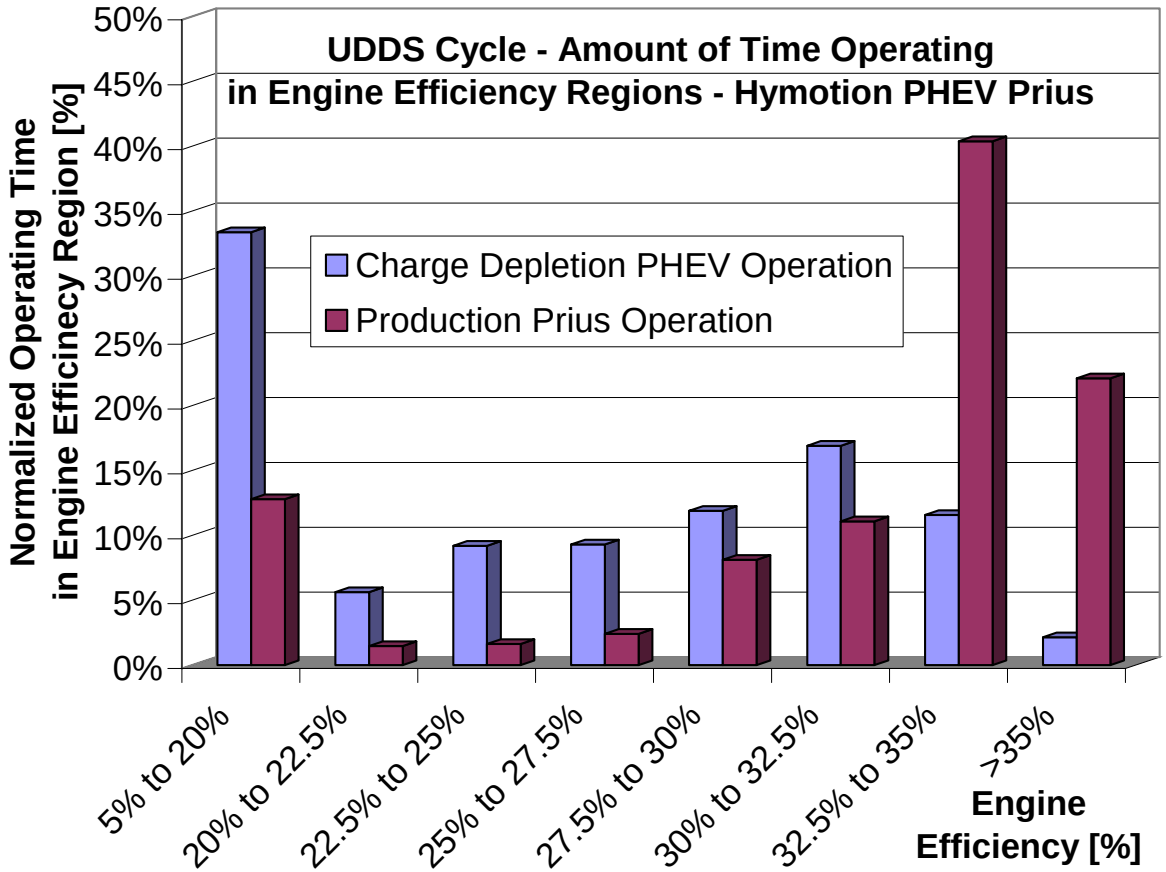
Prius Engine-On Requirements in Blended Mode

- Prius power-split not suited for engine-off in UDDS cycle
- Engine Turns On:
  - **E**missions control
  - **S**peed Limitation
  - **P**ower Limitation



Optimized Charge-Sustaining Controls Compromised in Prius PHEV Retrofit

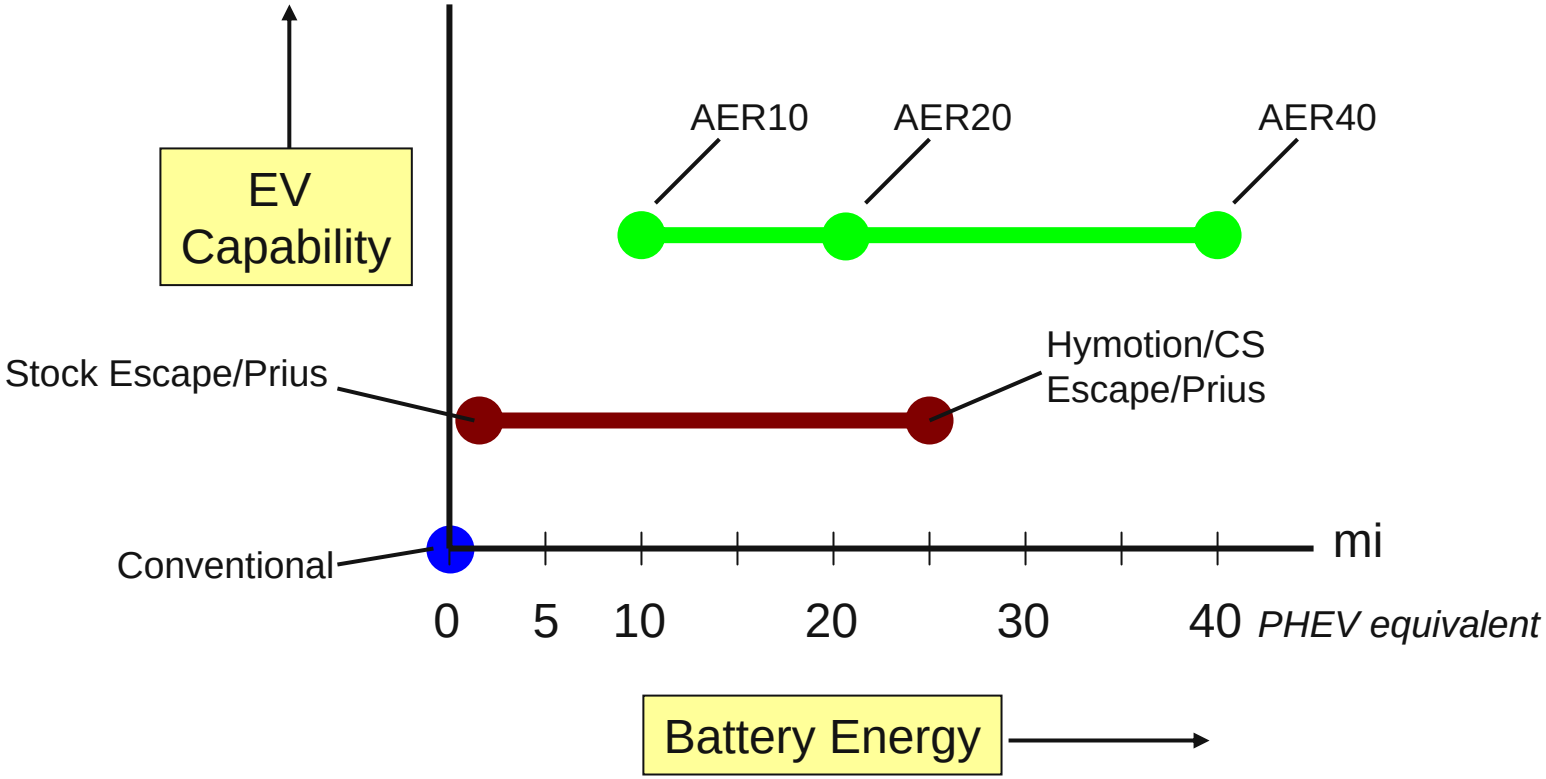
- Engine efficiency reduced due to unloading engine during depletion
- More time spent in inefficient zones, peak efficiencies are rarely utilized



Blended Mode Test Conclusions

- Retro-fits all operate in a similar manner
  - Use of EV mode switch on Prius to quickly deplete in urban driving
  - Compromise in engine efficiency when engine unloaded for more depletion
  - Other platforms will probably deplete slower (on UDDS) in the absence of EV mode switch
- Retro-fit petroleum displacement fraction is limited by:
  - Single input power-split configuration (EV speed limitations)
  - Vehicle controls limit allowable battery power
- Low emissions can be maintained only if stock controls are left to manage initial engine starts
- Blended mode procedures were developed based upon Prius PHEV testing
  - Shortcuts were developed and are being investigated
  - Need All-electric PHEV mule for further procedure development

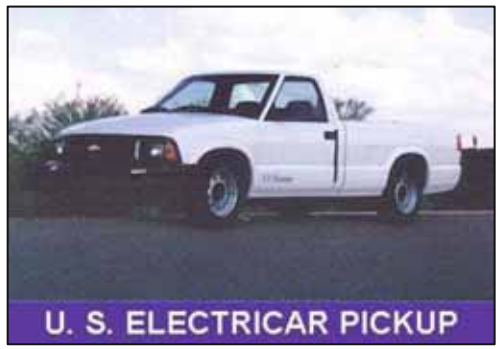
AER PHEV Platforms Needed For Procedure Development and Technology Benchmarking



PHEVequivalent = Based upon energy capacity and "theoretical EV consumption rate"

Argonne's AER Platforms: "Through The Road" Parallel Prototype and S-10 Series PHEV

- TTR: Two drive systems to choose from, several battery packs to utilize
- S-10: under-powered but useful as test procedure tool
- Also under development – Chevy "Volt" sized series prototype



SAE J1711-1999 Re-Issue Details

- Monthly meetings since Aug of 2006
- Consensus is that the PHEV parts of the procedure were under-developed and did not consider “blended” mode operation for plug-ins
- J1711 needs have expanded since 1999, now need to satisfy the following test requirements
  1. Emissions certification
  2. CAFE fuel economy calculation
  3. EPA “5-cycle” label fuel economy (includes US06, SC03, Cold CO)
  4. Definitions for all-electric range, amount of petroleum displacement, etc.
- Consensus changes to J1711
  - Do not combine fuel and electricity into a single composite MPG
  - Blended mode needs to be addressed in a different manner
- Several key issues still remain unsolved
  - Prep procedures, utility factors, hot/cold weighting, test length, AER emissions
- Timeline
  - Blended mode PHEV procedures concept available in September
  - All-electric capable PHEVs tested in Aug/Sept, draft procedures in December
  - Draft J1711 ready for balloting sometime in 2008