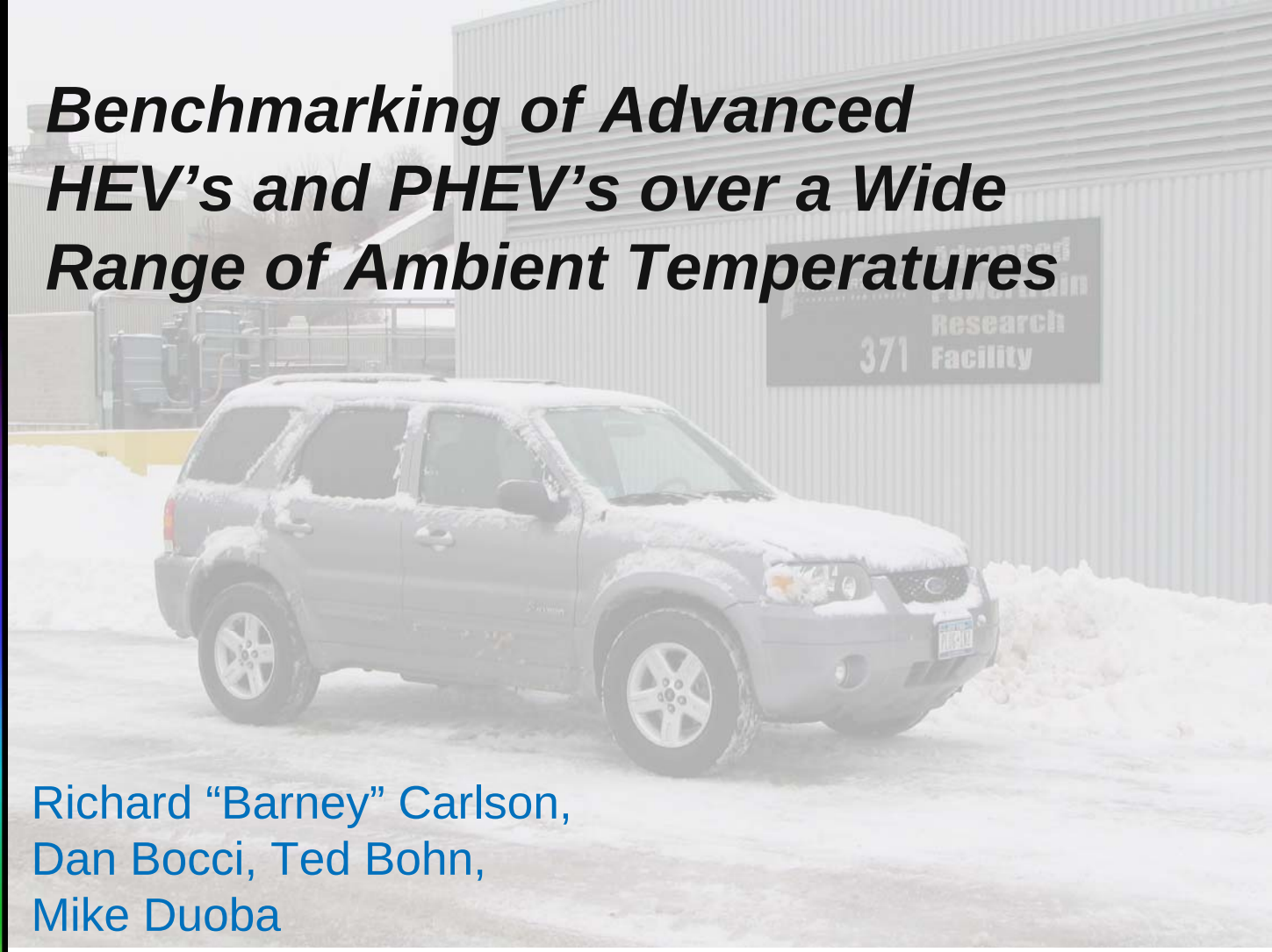
Argonne NATIONAL LABORATORY

… for a brighter future

Benchmarking of Advanced HEV's and PHEV's over a Wide Range of Ambient Temperatures



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Argonne National Laboratory

Sponsored by Lee Slezak

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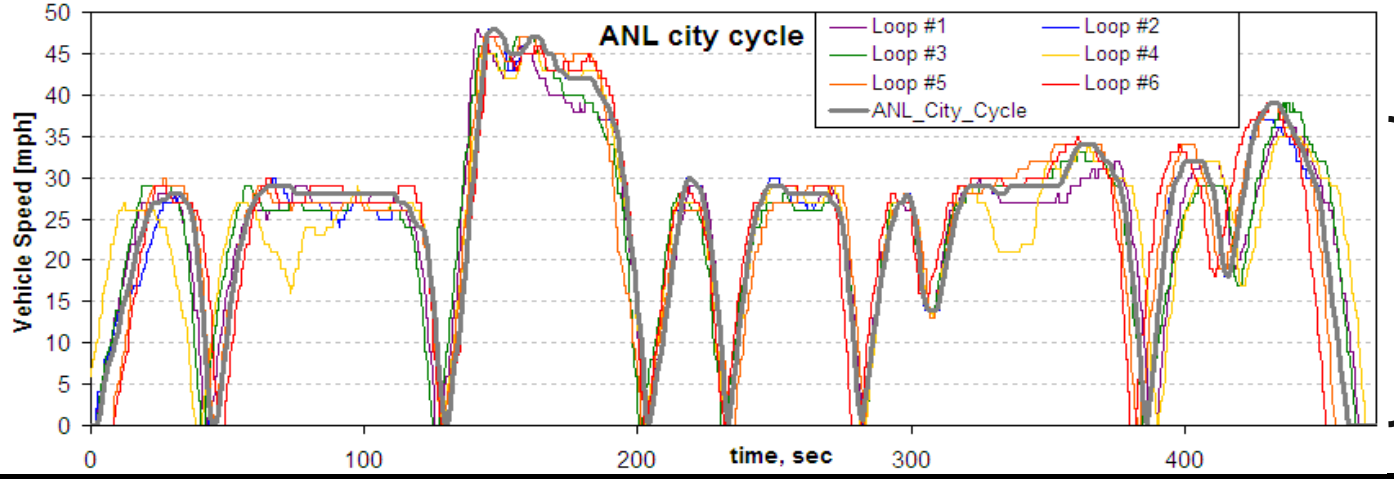
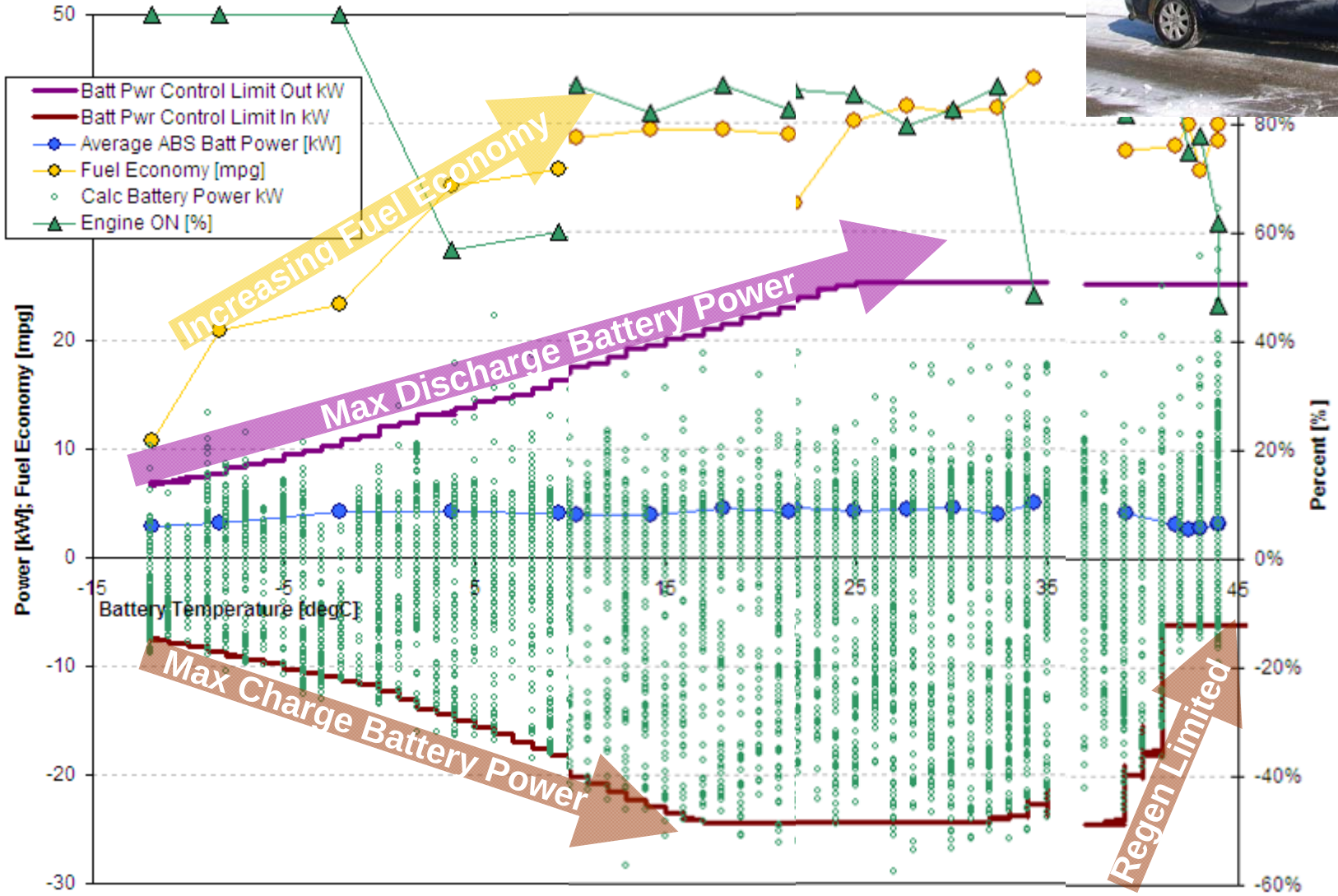
Over 15% of driving in the U.S. is at Sub-Freezing Temperatures

- On Road Testing is an Extension of the Benchmarking Activities
  - Sub-freezing ambient temperature conditions
  - High temperature conditions with real solar load
- FY07: Toyota Camry HEV and Ford Escape HEV
  - Fuel Economy
  - Battery Utilization and Characteristics
  - Powertrain Controls
- On-road testing conducted at four temperatures
  - -15°C, 0°C, 15°C, 30°C (winter, spring, summer)
  - Dynamometer testing conducted (22°C) for comparison to on-road testing

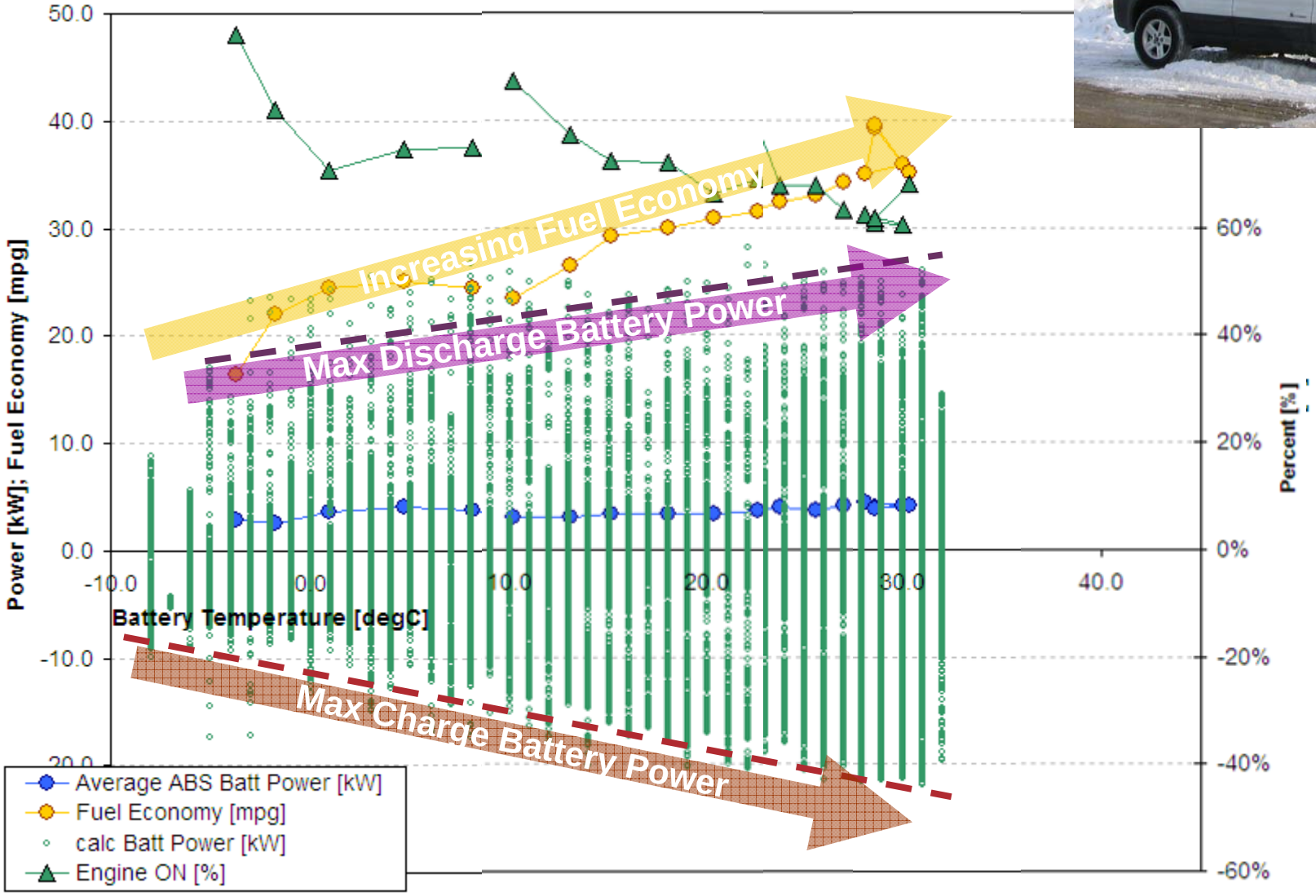


Good Repeatability

Camry HEV:
Fuel Economy is Dependant on Battery Power



Escape HEV:
Fuel Economy is Dependant on Battery Power



Summary FY07:
HEV Fuel Economy depends upon Battery performance

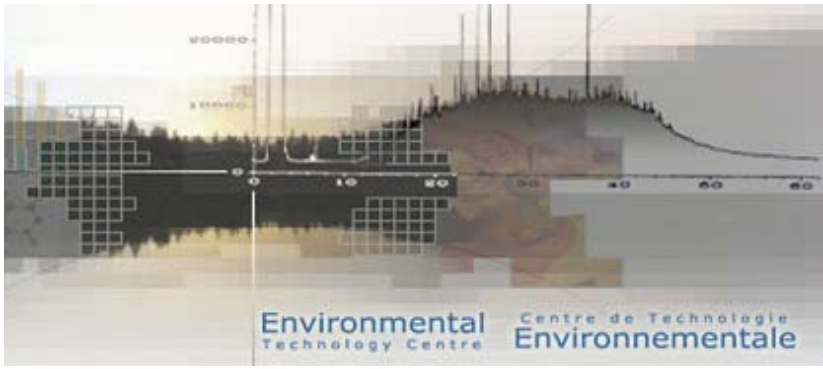
- Both vehicles
  - Battery power is very limited at low temperatures
  - Dramatically reduced fuel economy (nearly 2X) at cold temperature (from - 15°C to 20°C)
  - Minimal change in fuel economy at high temperatures (from 20°C to 35°C)
- Improved low temperature Battery power can improve fuel economy at low ambient temperatures

- If HEVs are dependant on battery performance, then PHEV's are even more dependant on battery performance

- This “Wide Temperature Benchmarking” study was chosen as one of the top VSATT projects of the year

FY08 Wide Temperature Range Benchmarking => PHEV's

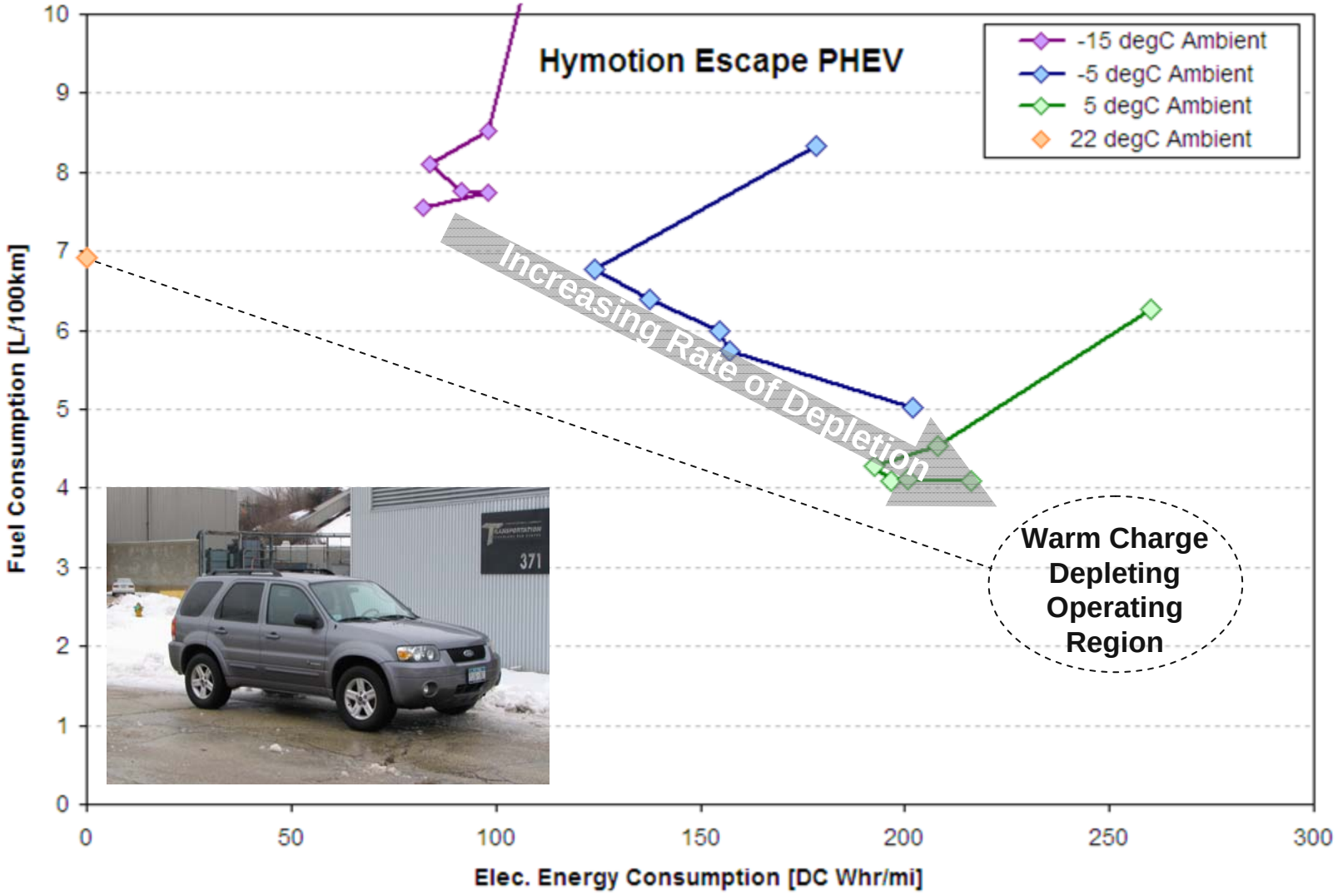
- On road Testing of PHEV Conversions (Prius and Escape)
  - On Road evaluation at Argonne (ANL City Cycle)
    - *Hymotion A123 Escape*
    - *Hymotion A123 Prius*
      - Hymotion is provided A123 Ver.1 system
    - *HybridsPlus 4.5kWhr Prius*
      - Current road-block: inoperative due to current sensor module failure; replacement soon to be shipped from HybridsPlus Inc.
- Cold Chamber Dynamometer test facility
  - Collaboration with Environment Canada – testing conducted in their cold Dyno
  - Hymotion A123 (Ver.2) Prius
  - Tests to be conducted (April - May)
    - *22 ^{o}C (baseline)*
    - *-7 ^{o}C (same as cold CO test)*
    - *-18 ^{o}C (~0 ^{o}F)*
- $200k (spent $24k to date)



Environment Canada Environnement Canada

Hymotion Escape PHEV:
Petroleum Displacement is Dependant on Battery Temperature and Ambient Temperature

Hymotion Escape PHEV: Increasing Rate of Depletion with Increasing Battery Temperature

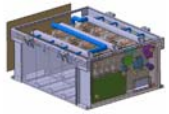


Benchmarking PHEV's at a Wide Temperature Range supports many DOE activities

SAE International

SAE International	SURFACE VEHICLE RECOMMENDED PRACTICE	J1711	REV. PropDft JUN2006
		Issued 1999-03 Revised Proposed Draft 2006-06 Superseding J1711 MAR1999	

Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles



JCI VL41M

PSAT
- Cold operation Data for model validation
- Data for 2011 EPA
- Test Procedure
- Integration

DOE technology evaluation
- Vehicle level data
- Component level data

NREL ornl INL Argonne

BHIL battery
- Cold Battery Data
- Vehicle System Data

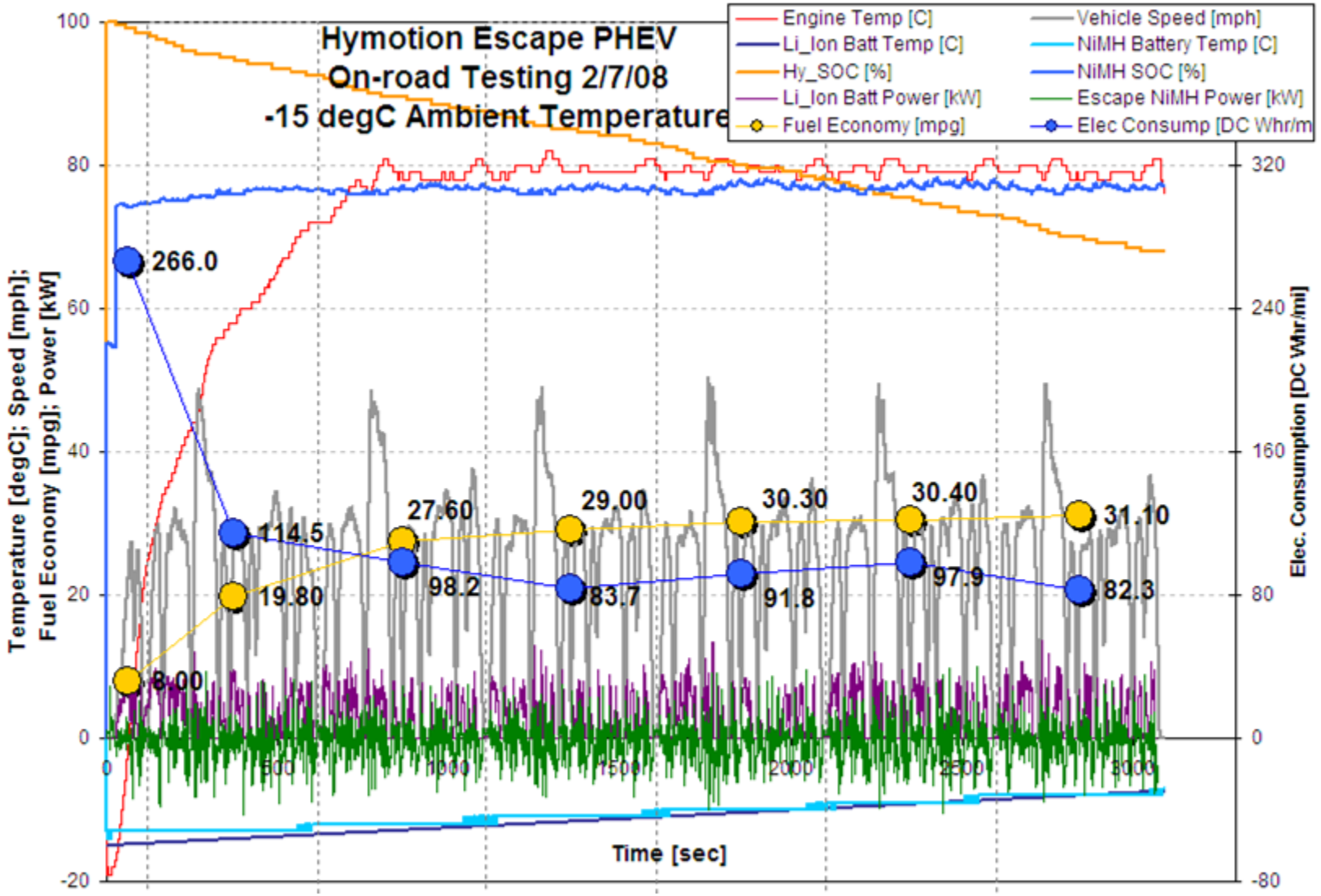
Benchmarking

- HEV
- PHEV
- Alt. Fuels

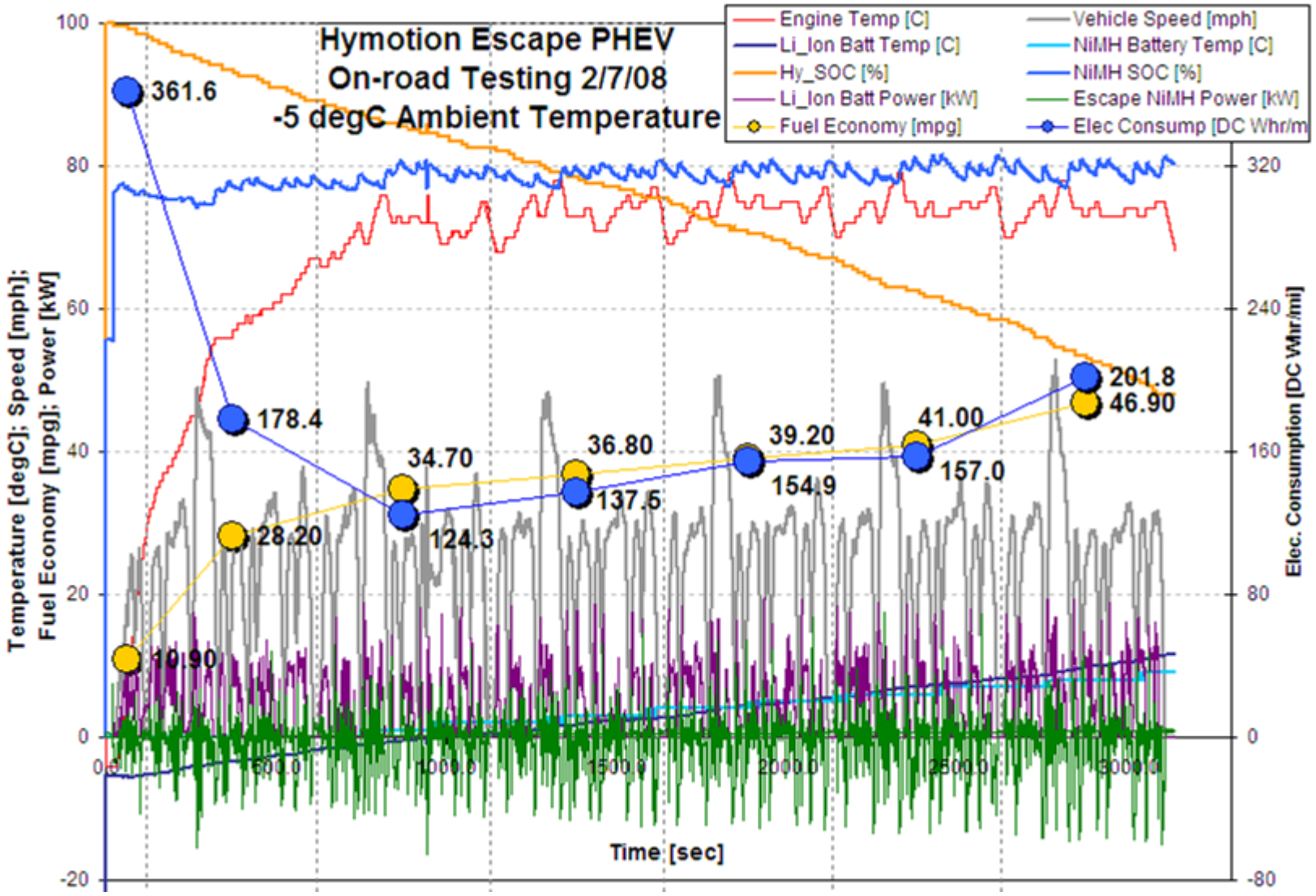
Wide Temp. Benchmarking
- Sub-Freezing
- High Temp.

Backup Slides

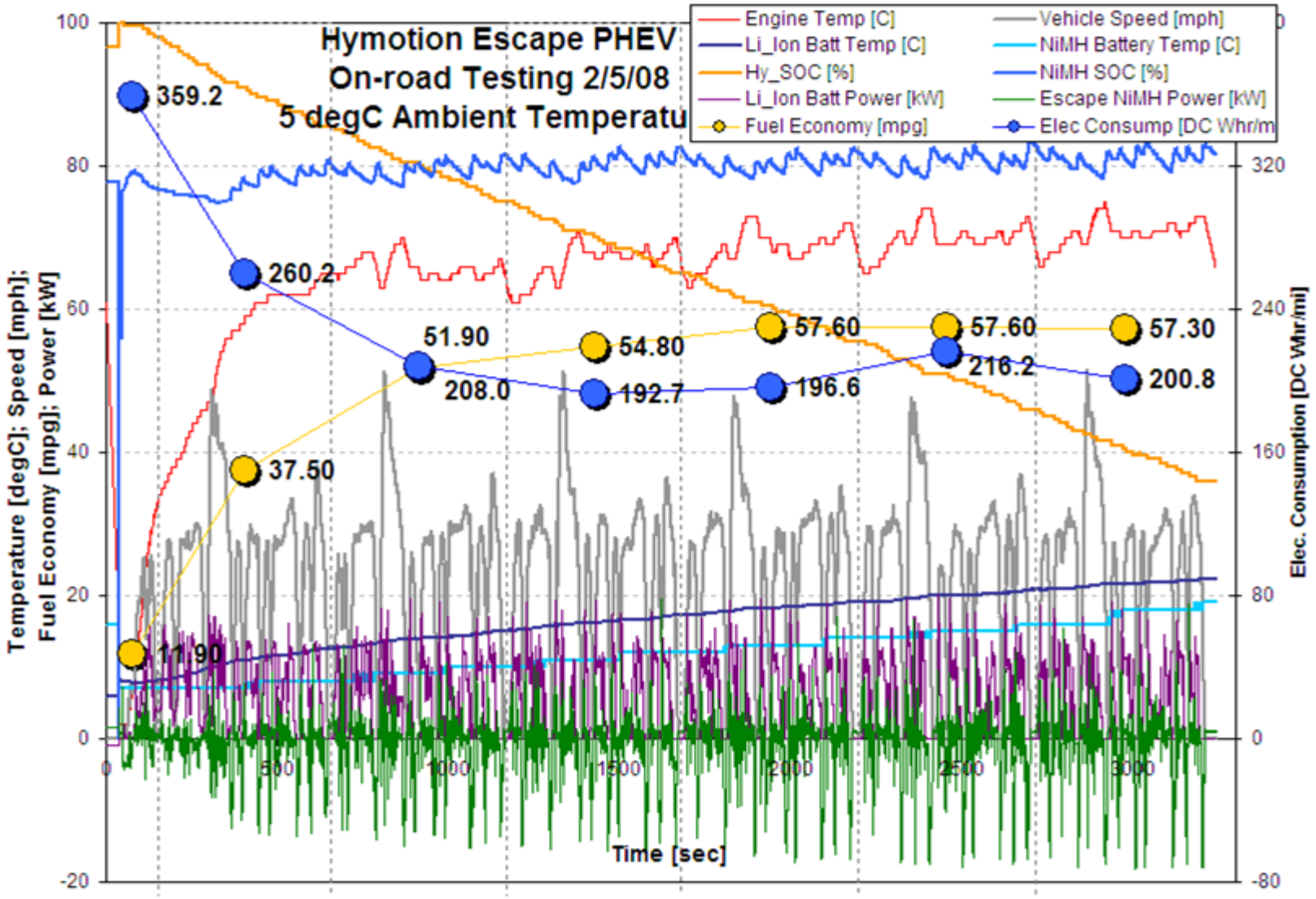
Hymotion Escape (-15 °C)



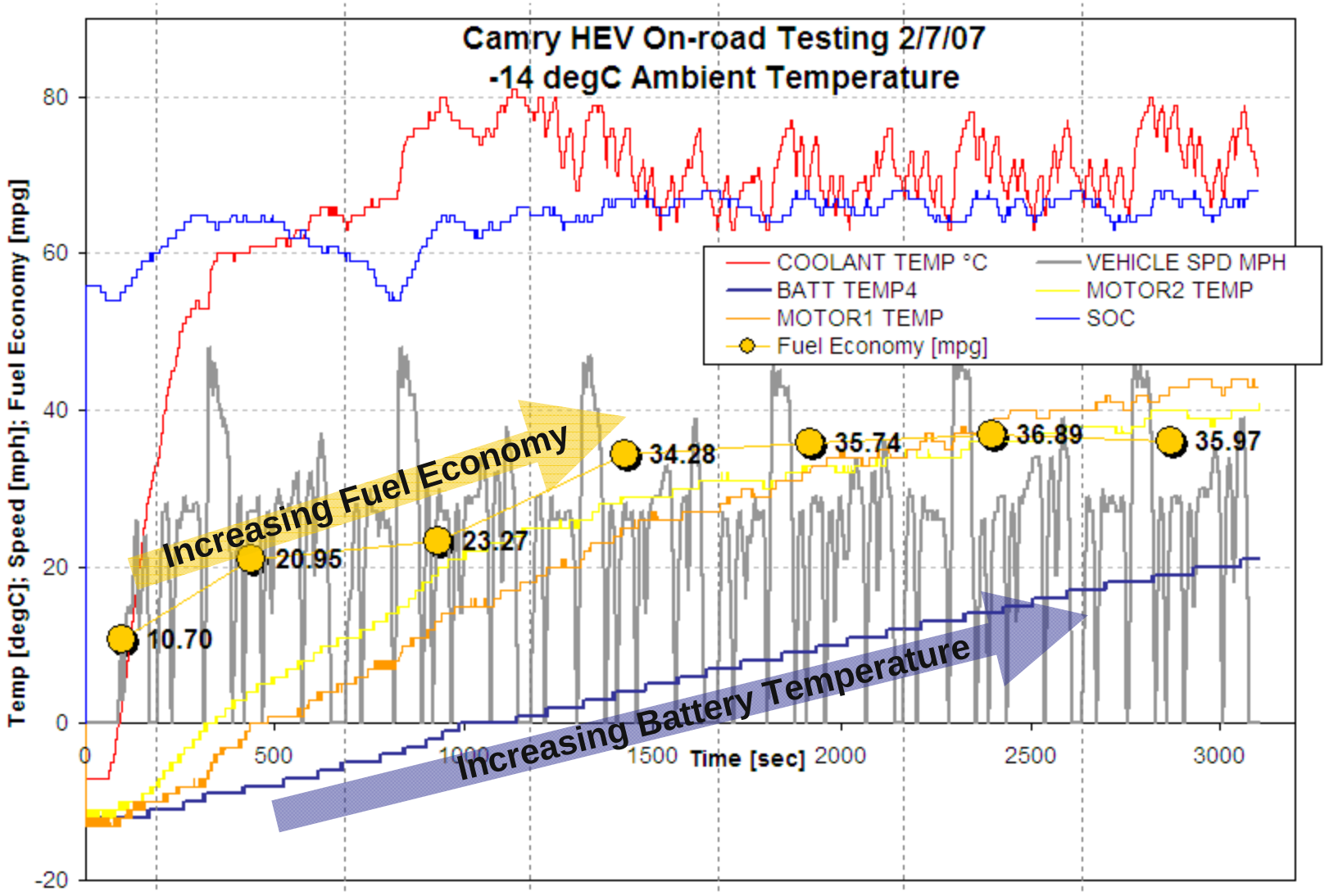
Hymotion Escape (-5 °C)



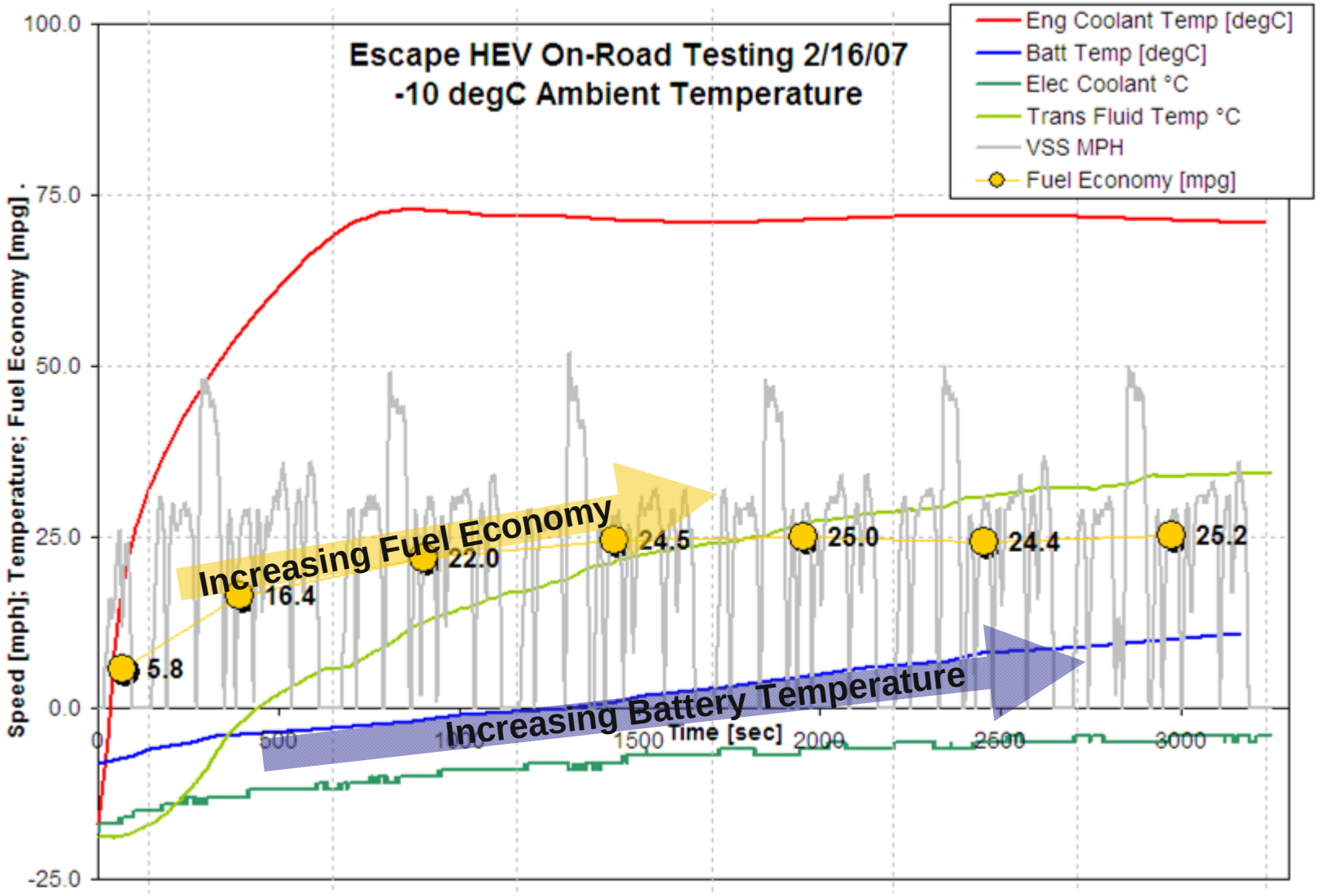
Hymotion Escape (5 °C)



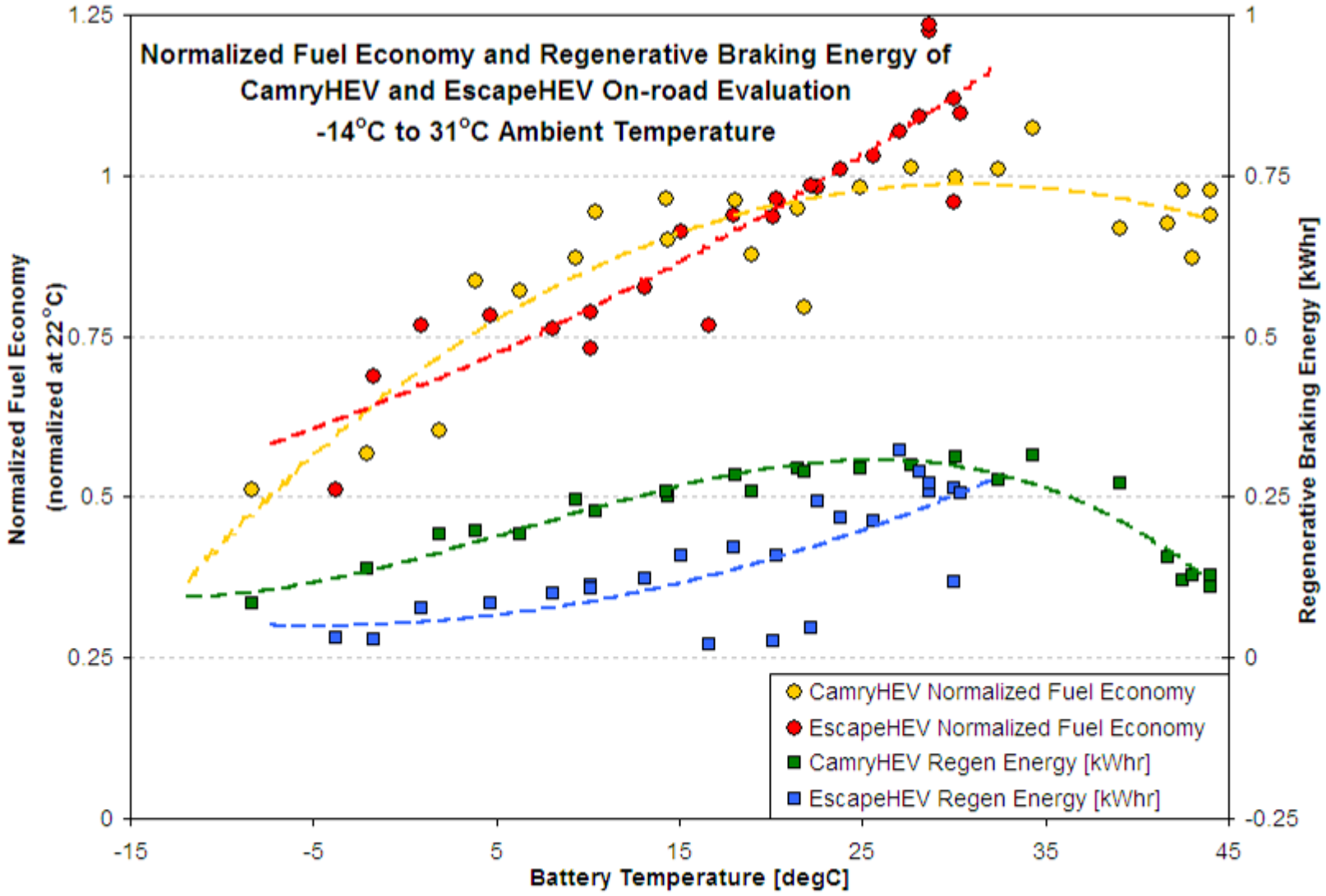
Camry HEV:
Fuel Economy is Reduced at low ambient temperature



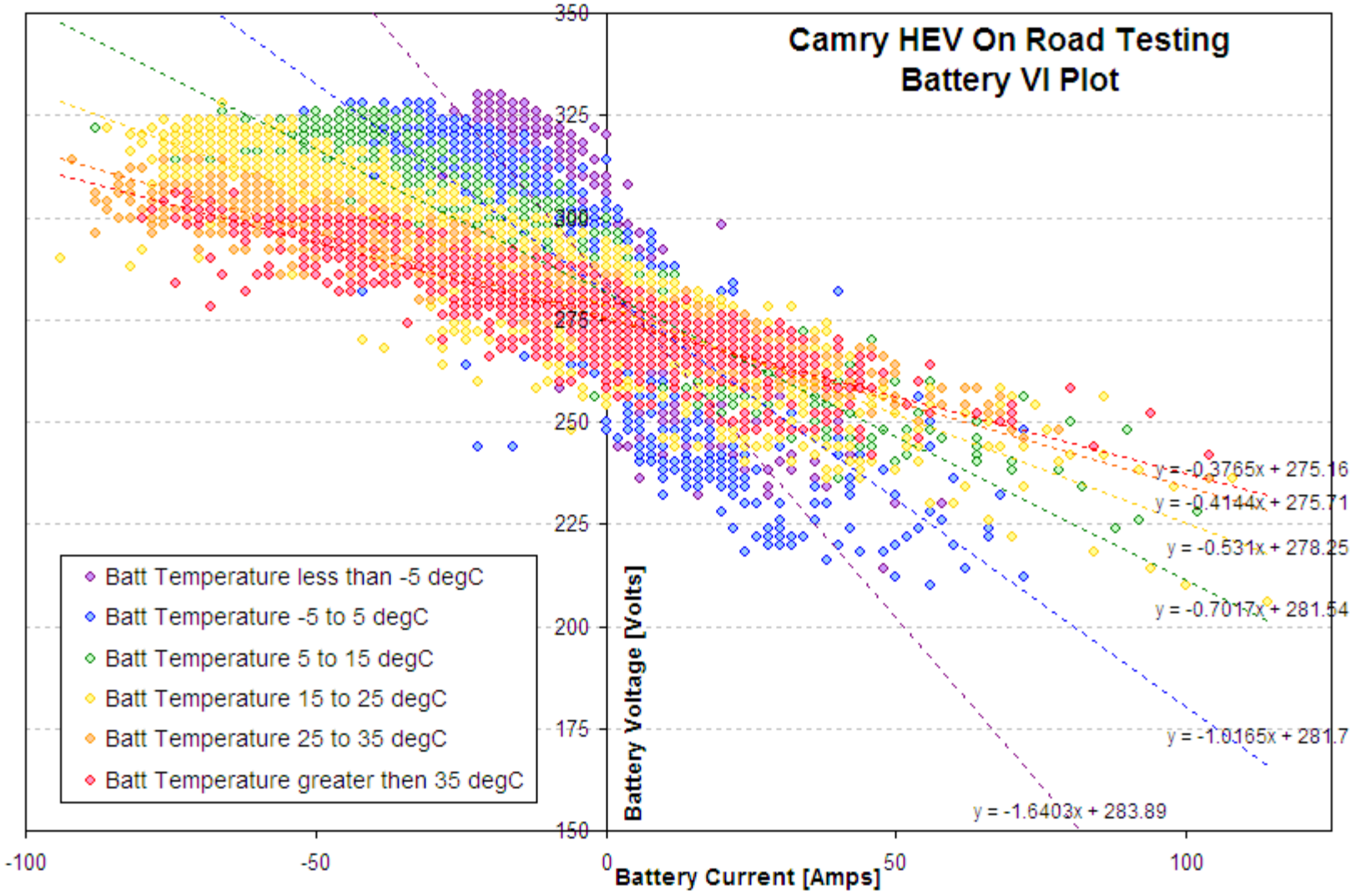
Escape HEV On Road Testing at -10 °C Ambient



Fuel Economy Trends and Regenerative Braking Energy



Camry HEV
Battery Voltage vs. Current over a wide Temperature Range



Escape HEV
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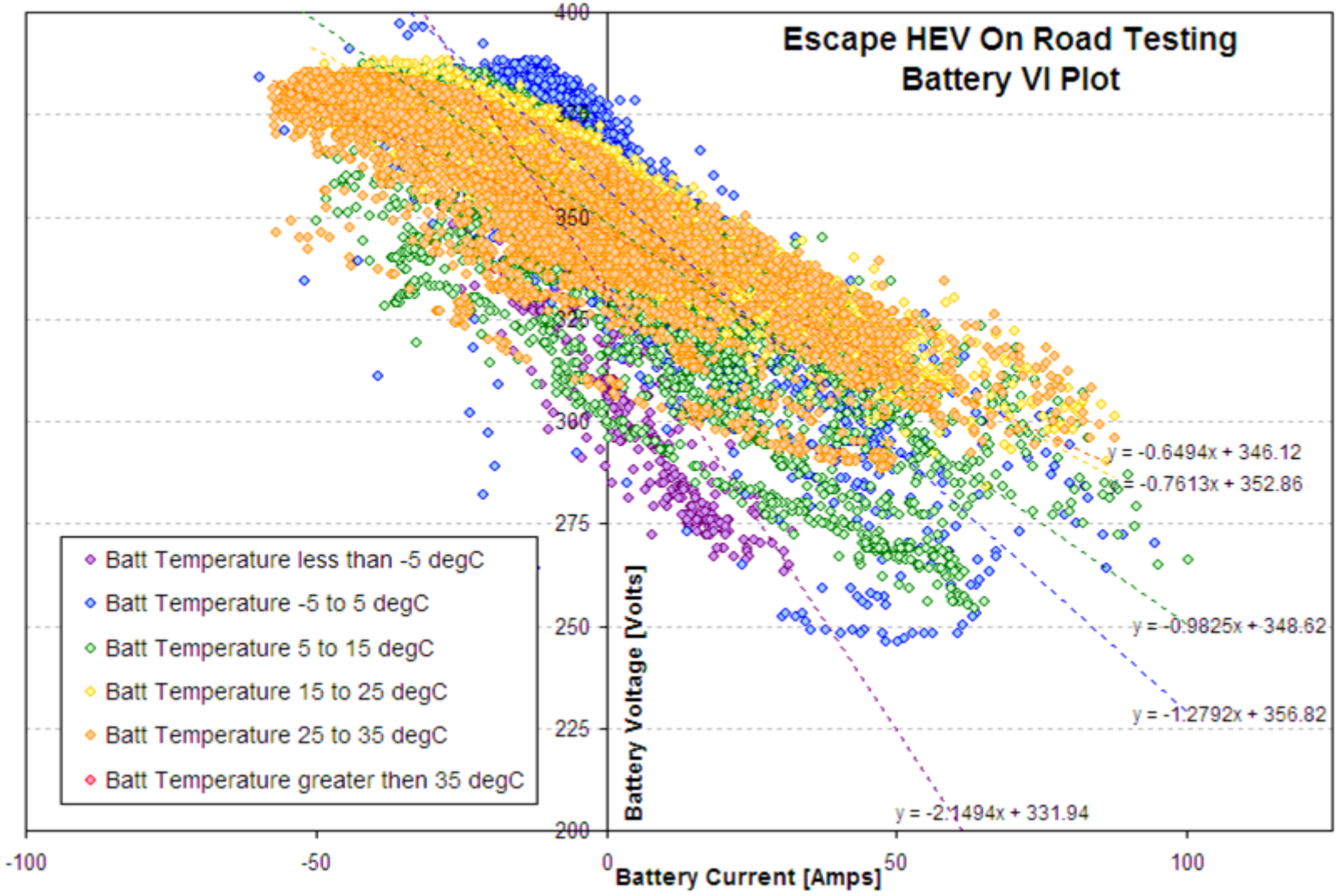

Increased Battery Utilization, Increases Rate of Temperature Rise from Heating due to Internal Losses (I^2R)