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Lithium Ion Battery Systems for Plug-In Hybrid Vehicles

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Presentation Outline

- Company Introduction
- Lithium Ion Cell Technology
- Traction Battery Design
- Performance of ALP Battery Systems in PHEV Applications

Cell Technology

- E-One Moli 2.7 Ah 26700 cylindrical cell based on proven power tool cell design
- New manganese spinel blend cathode for PHEV applications - high power density/high energy density, extended cycle and calendar life
- Reformulated electrolyte for better low temperature performance
- Cylindrical cell manufacturing technology well understood
- 3 Ah size practical for high volume production – low material cost and volume production
- Excellent cell containment – no issues with volume changes
- Compared to laminated prismatic cell – comparable volumetric energy density thanks to low cooling requirements, better power density thanks to distributed current collection
- Very good thermal performance – high power capability at low cooling requirements
- Currently in high volume production in fully automated environment with strict quality control.

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IBR26700 Cell Specifications

Capacity (1C)	2800 mAh
Voltage (100% SOC)	4.2 V
Voltage (nominal)	3.7 V
Energy	10 Wh
Size (diameter x length)	26.4 x 70 mm
Weight	100 grams
Energy Density (volumetric)	285 Wh/L
Energy Density (gravimetric)	100 Wh/kg
Operating Voltage	4.2 V to 2.5V
Temperature range	-25° C to 60° C
Peak Discharge Current (10 sec)	80 A
Continuous Discharge Current	20A
Peak Charge Current	20 A
Continuous Charge Current	3 A

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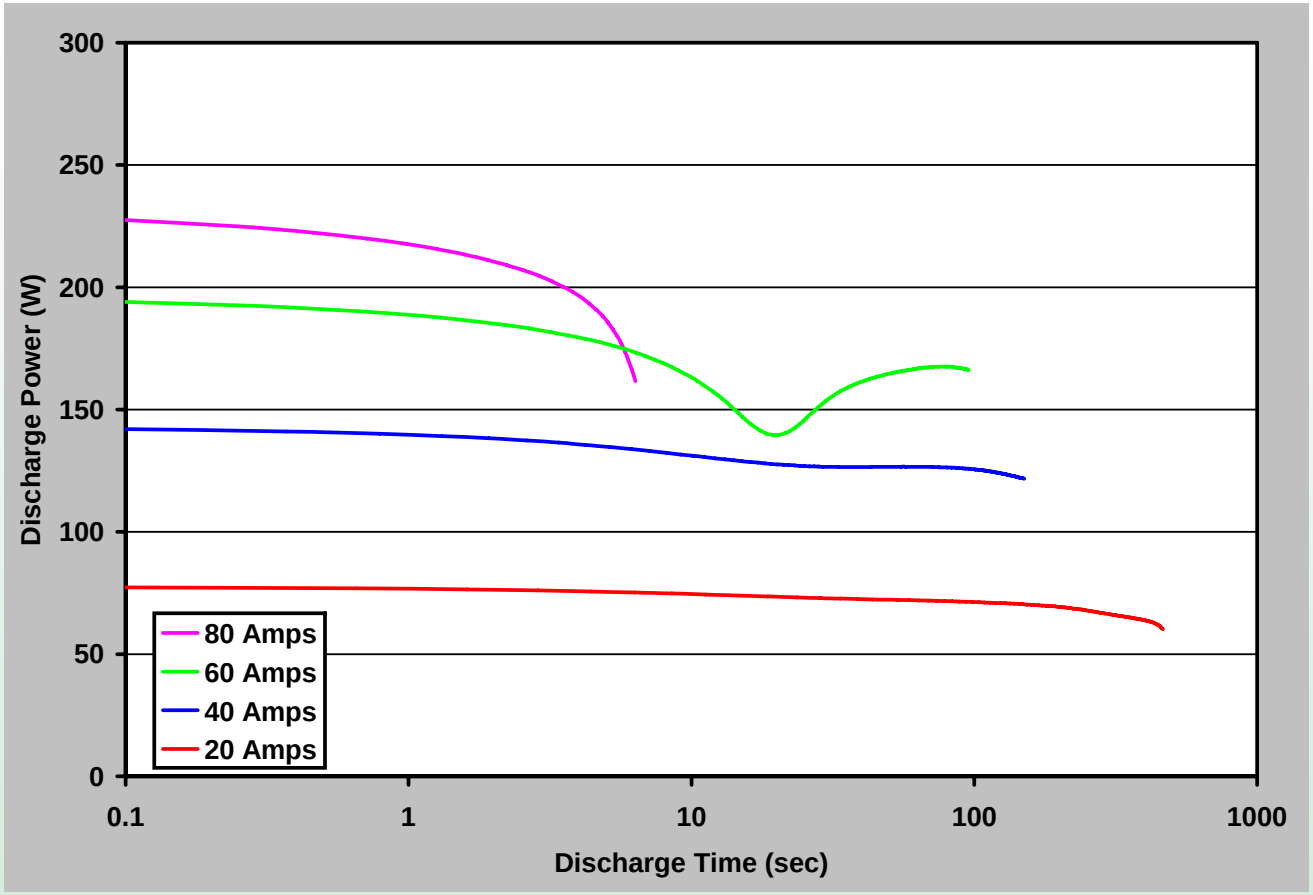
IBR-26700A, 2.8Ah



- Up to 2300 W/kg in specific power
- Constant current discharges from 100% SOC
- 23°C

Courtesy of E-One Moli

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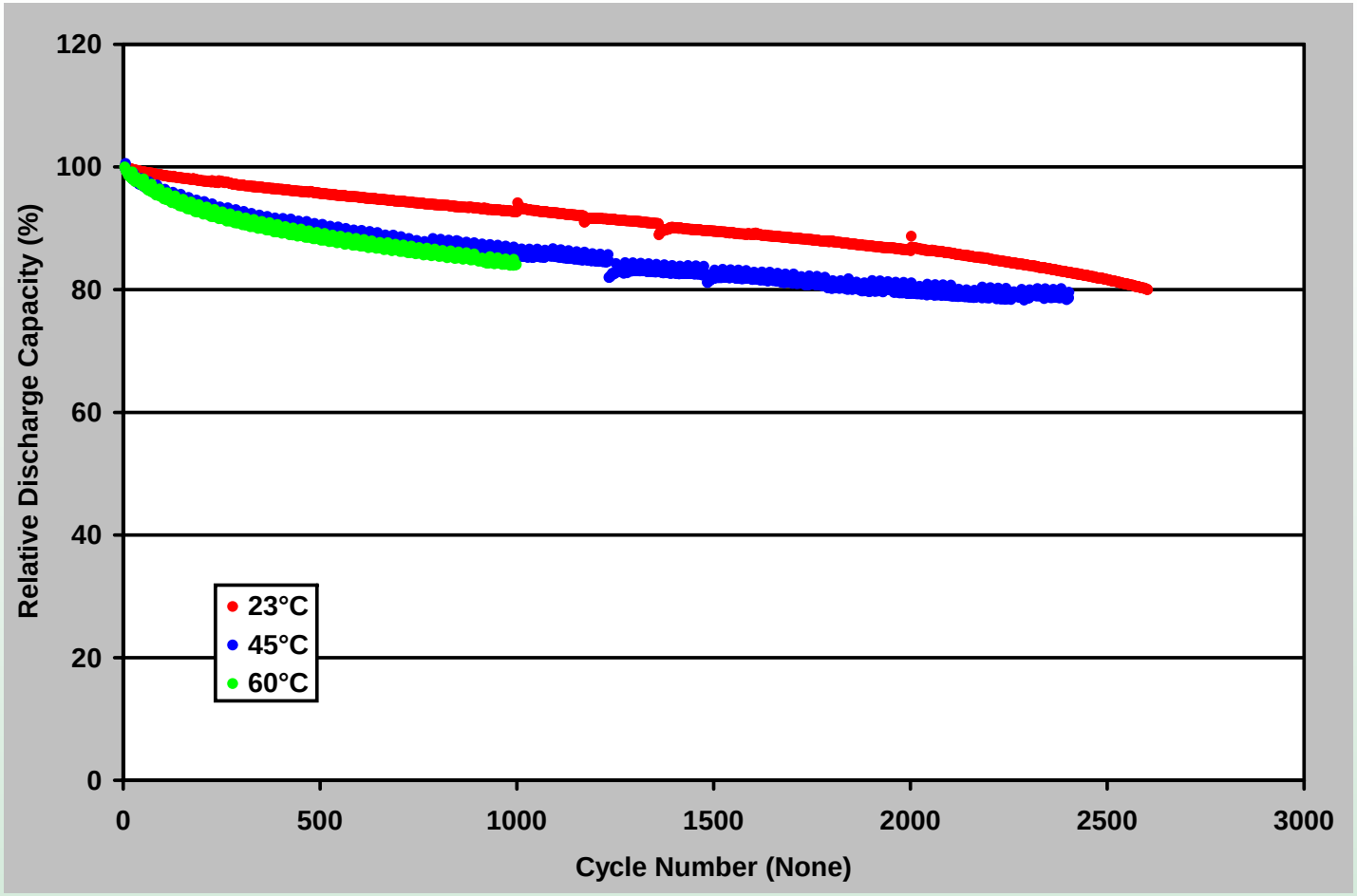
IBR-26700A, 2.8Ah



- 23°C - 80% initial capacity at ~C2600
- 45°C - 80% initial capacity at ~C1950
  - 78% at C2400
- 60°C – 81% initial capacity at ~C1150

Courtesy of E-One Moli

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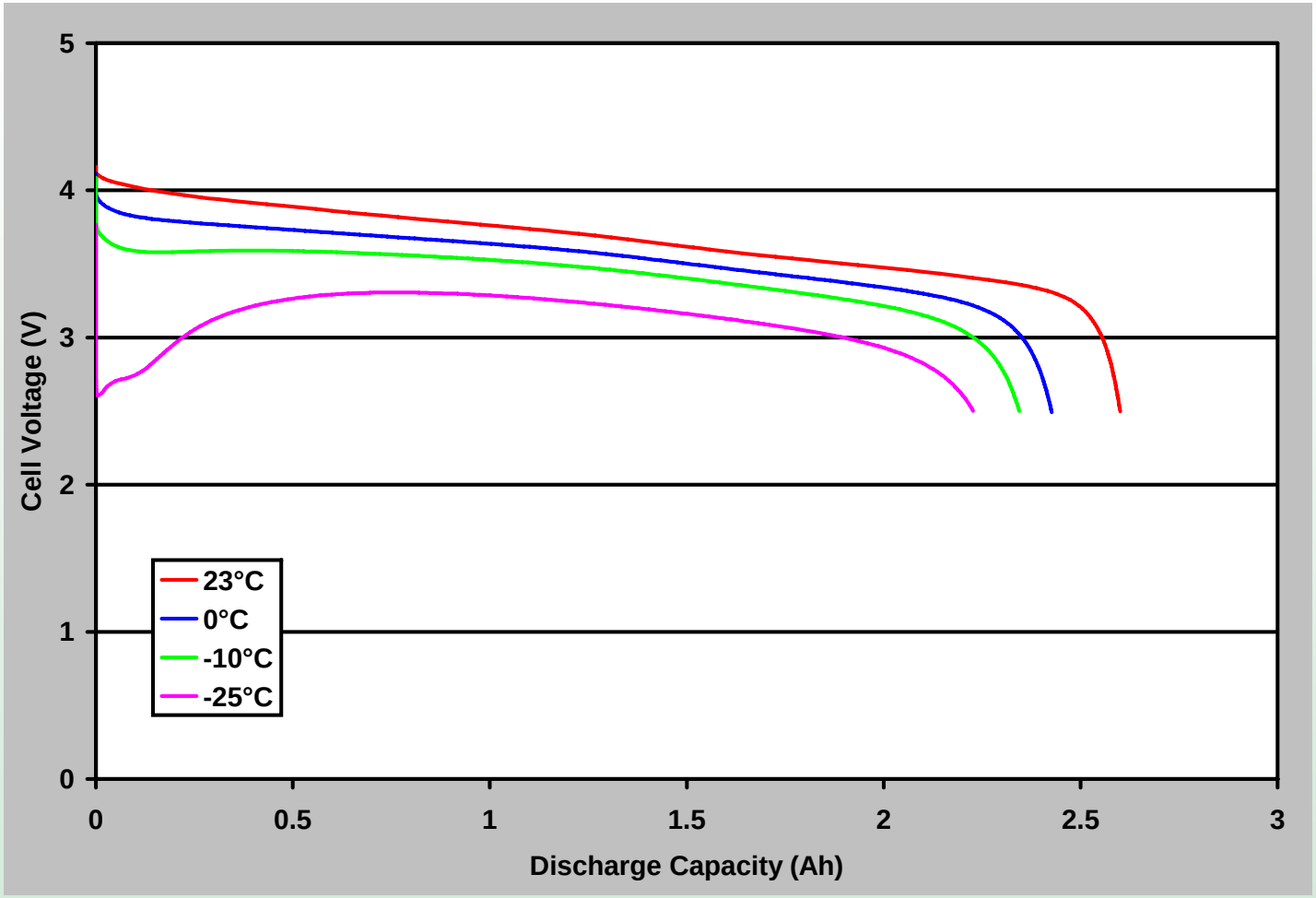
IBR-26700A, 2.8Ah



- 5 Amp discharges down to –25°C
- Charge at 23°C
- Cool for minimum 2 hours before discharge

Courtesy of E-One Moli

Applications

- Ford Escape HEV
- Ford Escape PHEV10
- Ford Escape PHEV30

- Military HEV
- Fisker Karma PHEV50
- 40 ft Transit Bus HEV

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Hybrid Vehicle Applications

PLATFORM	EDrive Size (kW)	System Voltage (V)	Capacity (kWh)	Config
Full Size Car/SUV				
HEV	80	330	2.5	84S3P
PHEV10	80	330	4.2	84S5P
PHEV30	100	370	12.6	84S15P
Performance Sedan				
PHEV50	200	370	21.1	96S22P
Military/Commercial				
HEV/PHEV10	100	370	5.8	96S6P
Transit Bus				
HEV	200	660	17.6	160S11P

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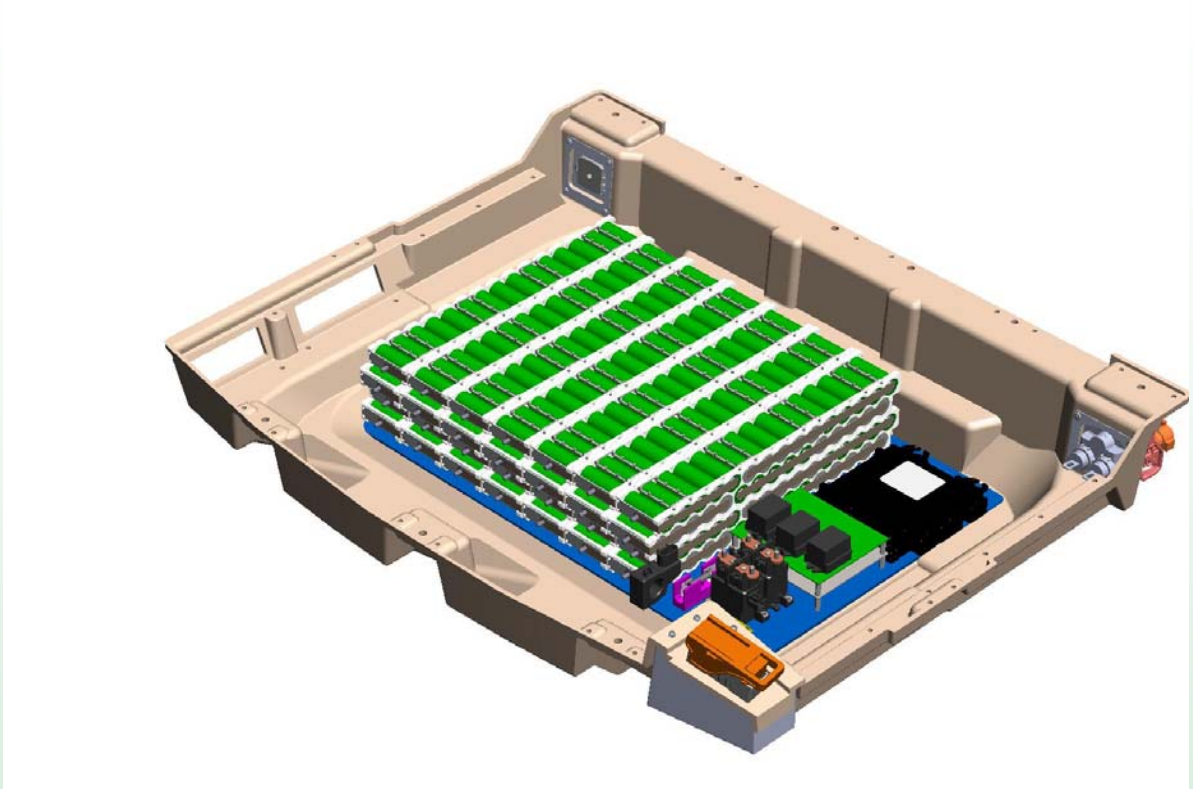
Pack Design



- Integrated cell voltage and temperature monitoring.
- Cell voltage balancing
- Integrated BCM with 3 channel CAN
- Thermal management system – cooling/AC/heating.
- Multiple levels of safety features – manual disconnect, connector interlock, inertial switch, CAN and hardwired protection.

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Battery Management System

Battery Control Unit (BCU)	**Integrated Motorola Power PC565**
Power Supply Requirements	**12/24 V/ 15A peak**
CAN Interface	**3 channels 250 or 500 Kbs**
Control functions	
	Cell voltage monitoring
	Cell temperature monitoring
	Cell balancing
	Pack voltage monitoring
	Pack current monitoring
	Voltage limits
	Current limits
	SOC calculation
	Power limits calculation
	Contactor control
	Thermal management system control
	Safety shutdown
	Vehicle control system communications
	Charger control
Thermal Management	
	Air cooling (integrated fans)
	External air conditioning optional
	Battery heating optional

HEV Battery

	Ford Escape OEM	ALP 9-300	Change
Stack configuration	250S1P	80S3P	
No. of cells	250	240	-4%
Nominal Voltage (V)	330	320	-3%
Capacity (Ah)	6.1	8.1	+33%
Energy Capacity (kWh)	1.7	2.4	+41%
Stack Volume (L)	36	22	-39%
Stack Weight (kg)	50	30	-40%

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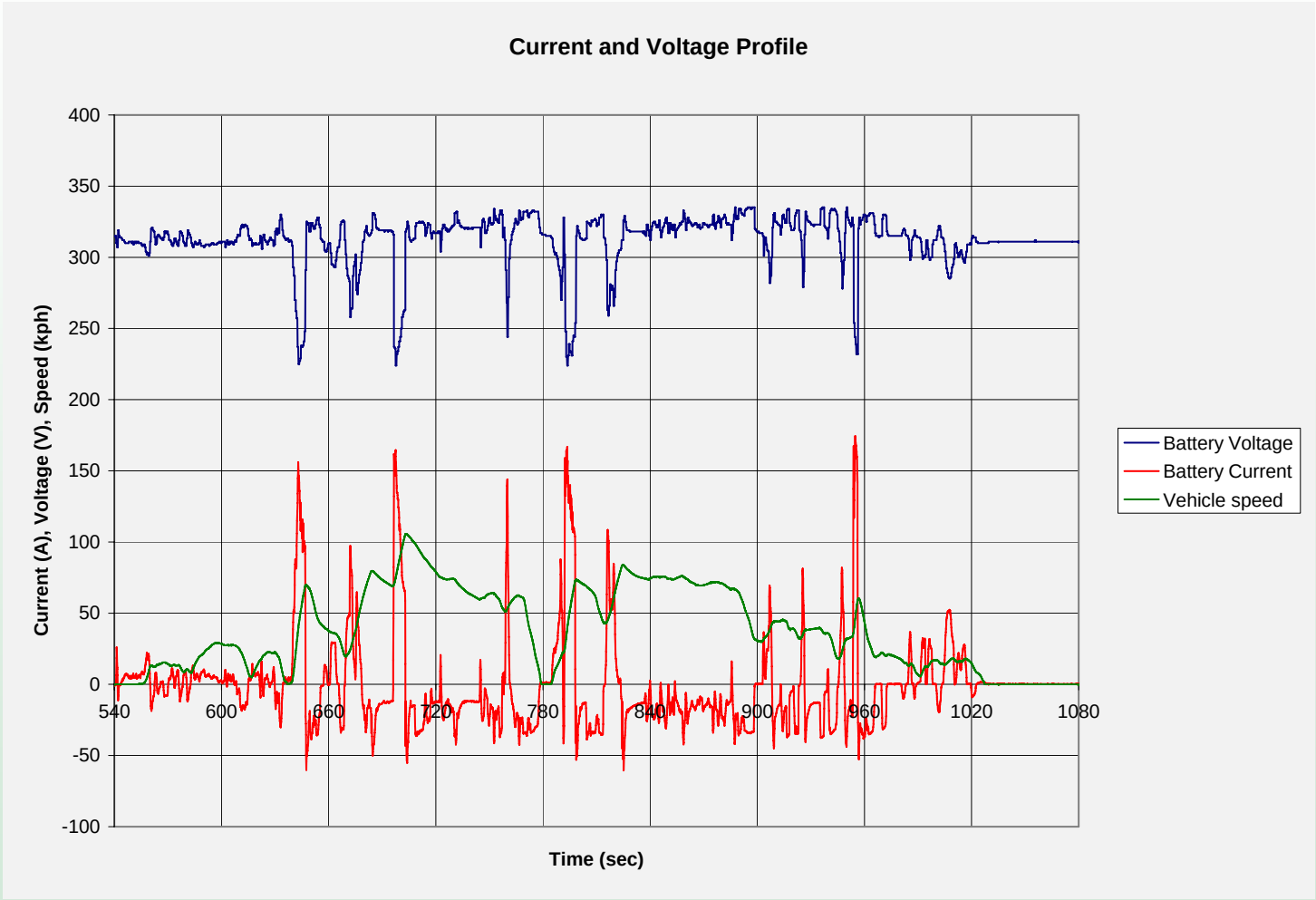
HEV – City Driving – Battery Load Profile



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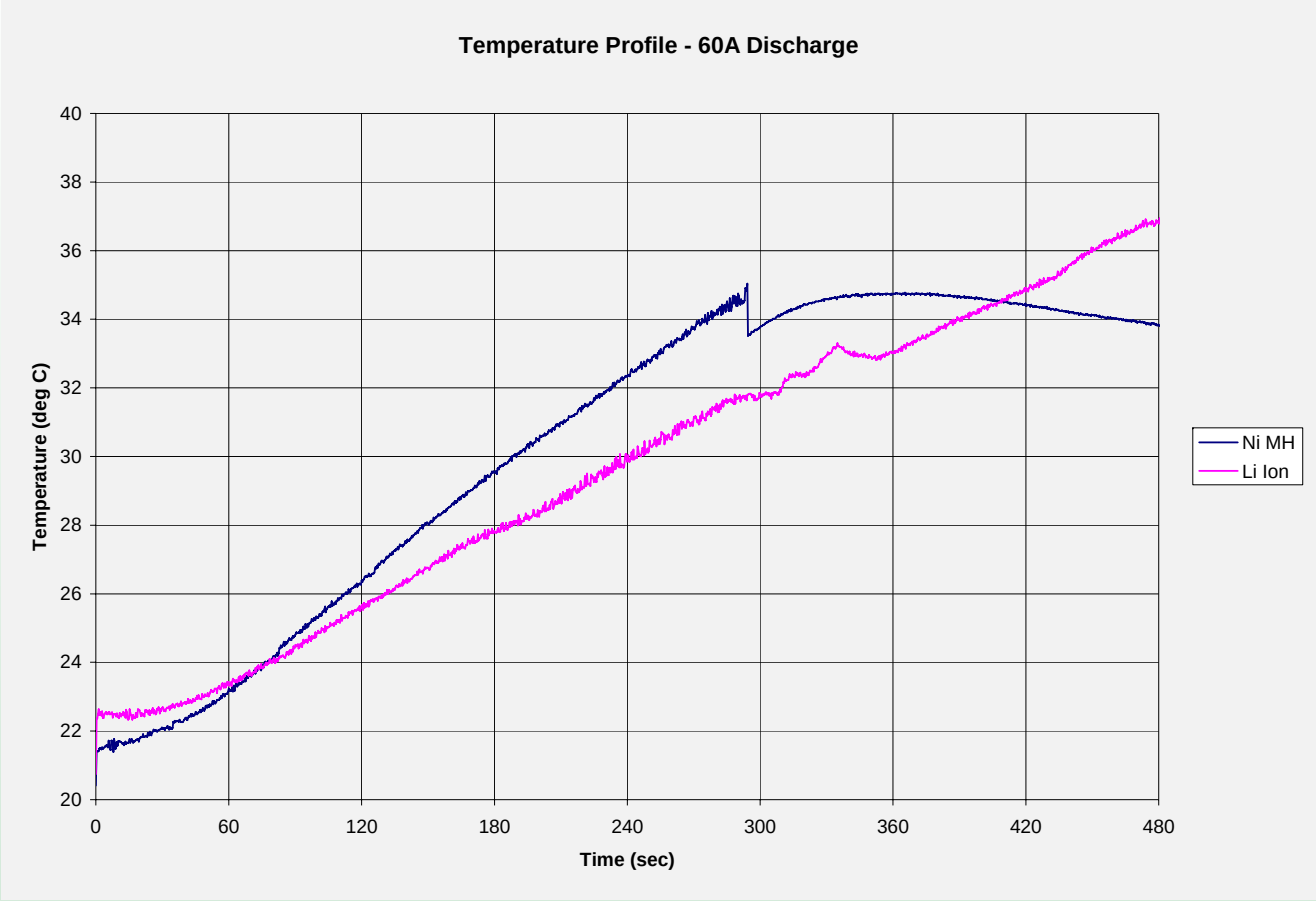
HEV – Thermal Performance – Ni MH vs. Li Ion



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PHEV 10 / PHEV40 Battery

	Ford Escape OEM	ALP 15-300	Change	ALP 45-300	Change
Stack configuration	250S1P	84S5P		84S15P	
No. of cells	250	420	-4%	1260	+405%
Nominal Voltage (V)	330	332	+1%	332	+1%
Capacity (Ah)	6.1	13.5	+221%	40.5	+664%
Energy Capacity (kWh)	1.7	4.2	+247%	12.6	+741%
Stack Volume (L)	36	35	-1%	90	-1%
Stack Weight (kg)	50	52	+4%	140	+4%

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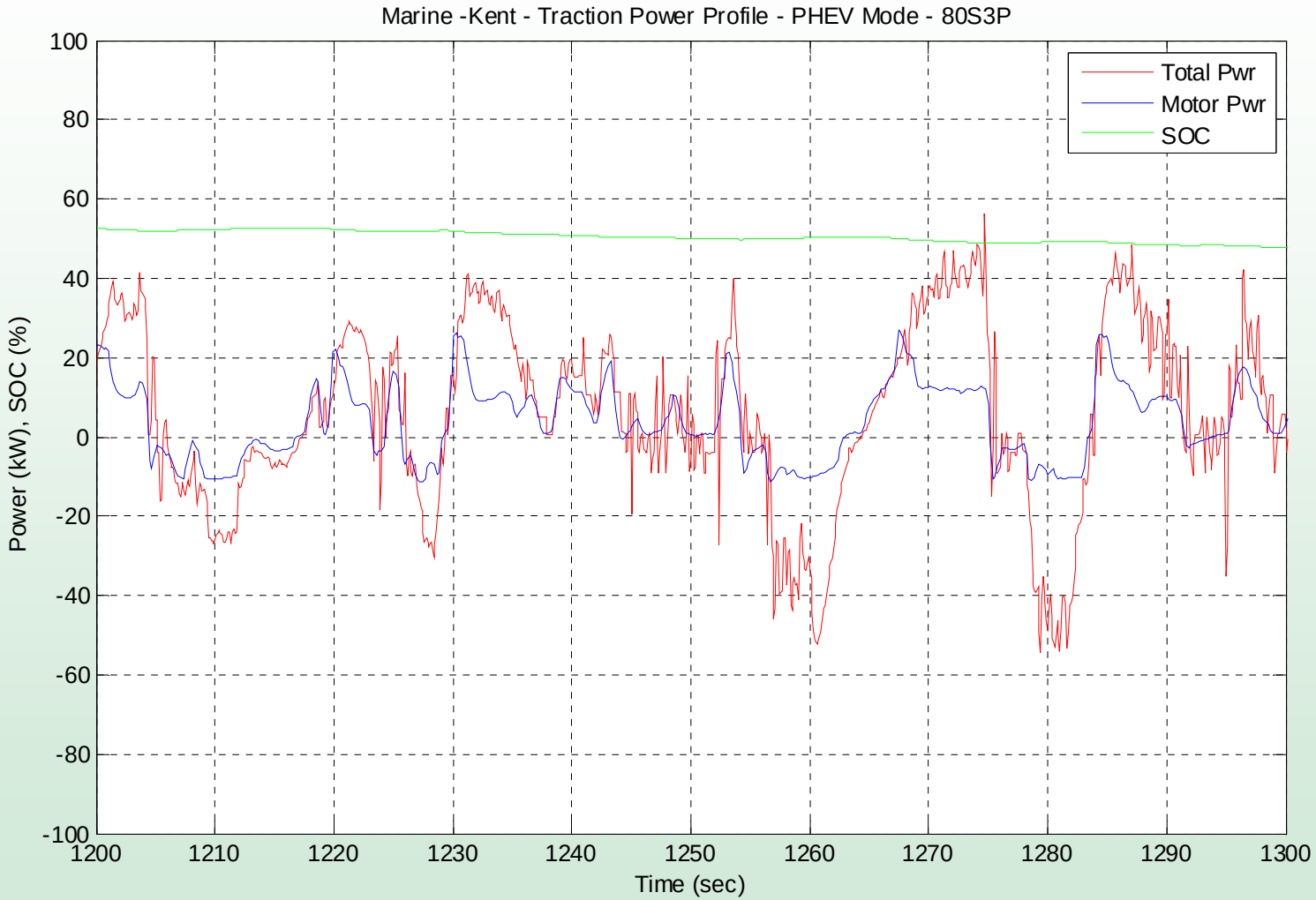
Vancouver City Driving – Blended PHEV Mode
Traction Power and Battery Load Profile



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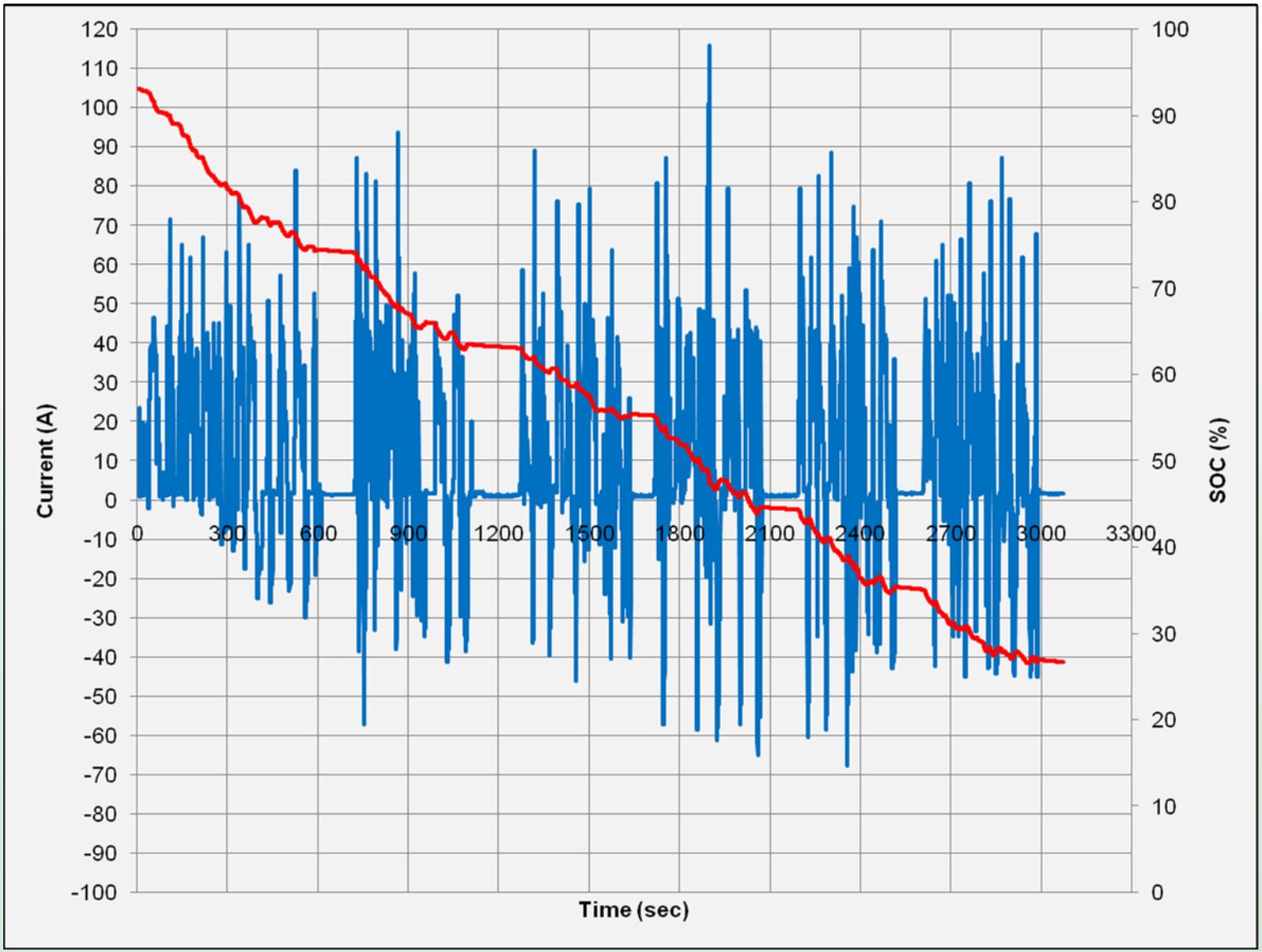
PHEV10 – City Driving – PHEV Mode – Current and SOC



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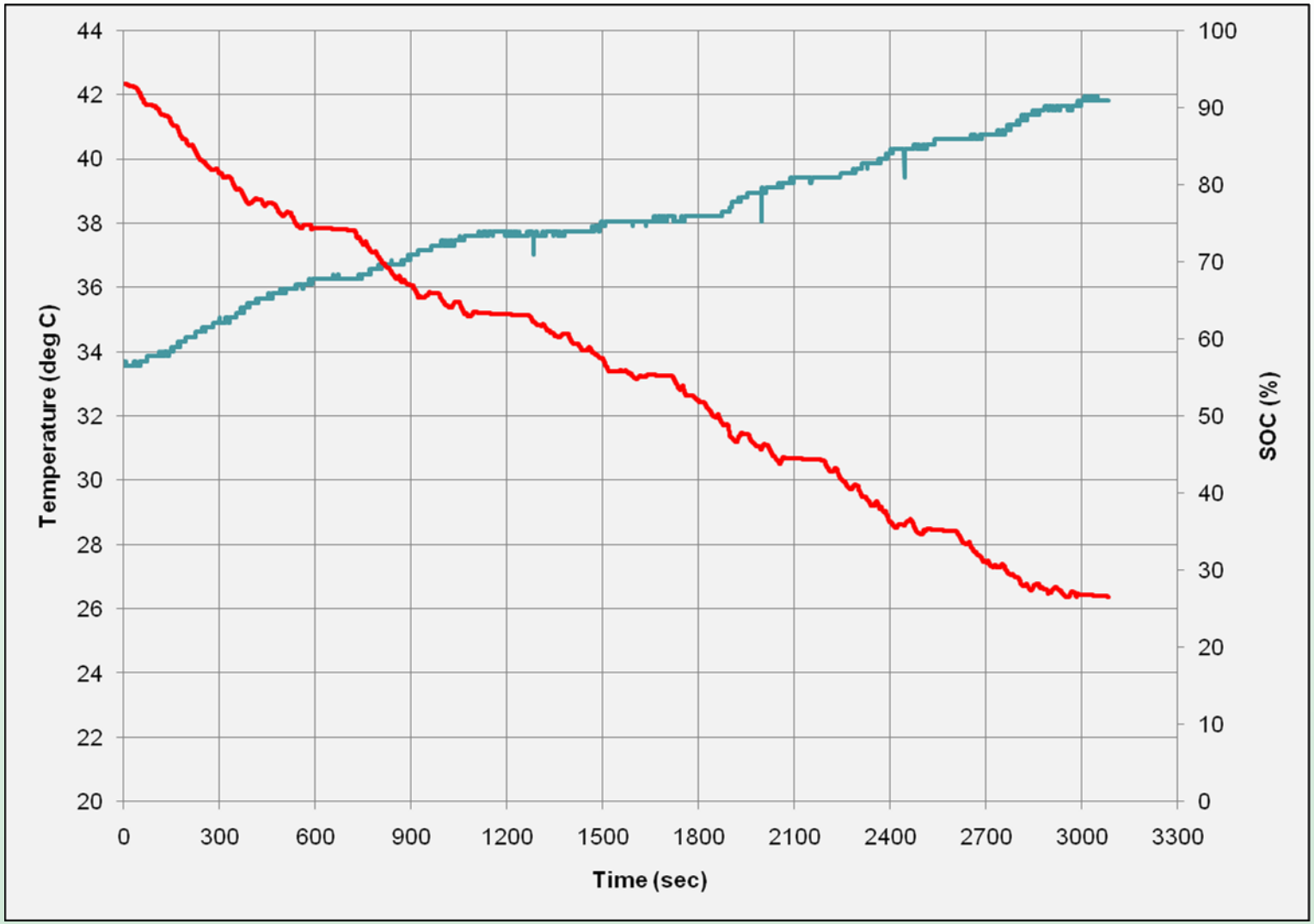
PHEV10 – City Driving – PHEV Mode – Battery Temperature and SOC



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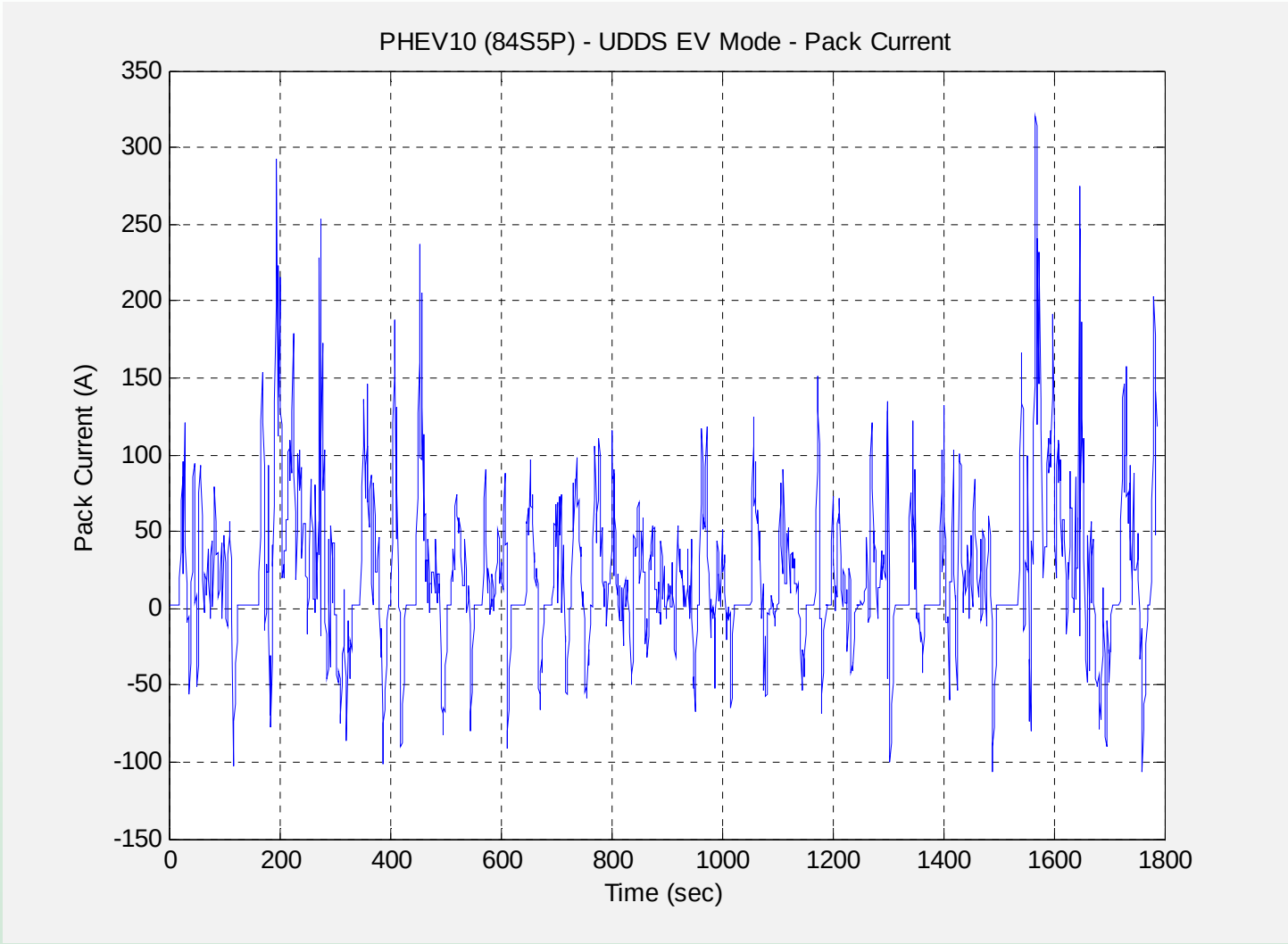
PHEV 10 – UDDS – EV Mode
Battery Current



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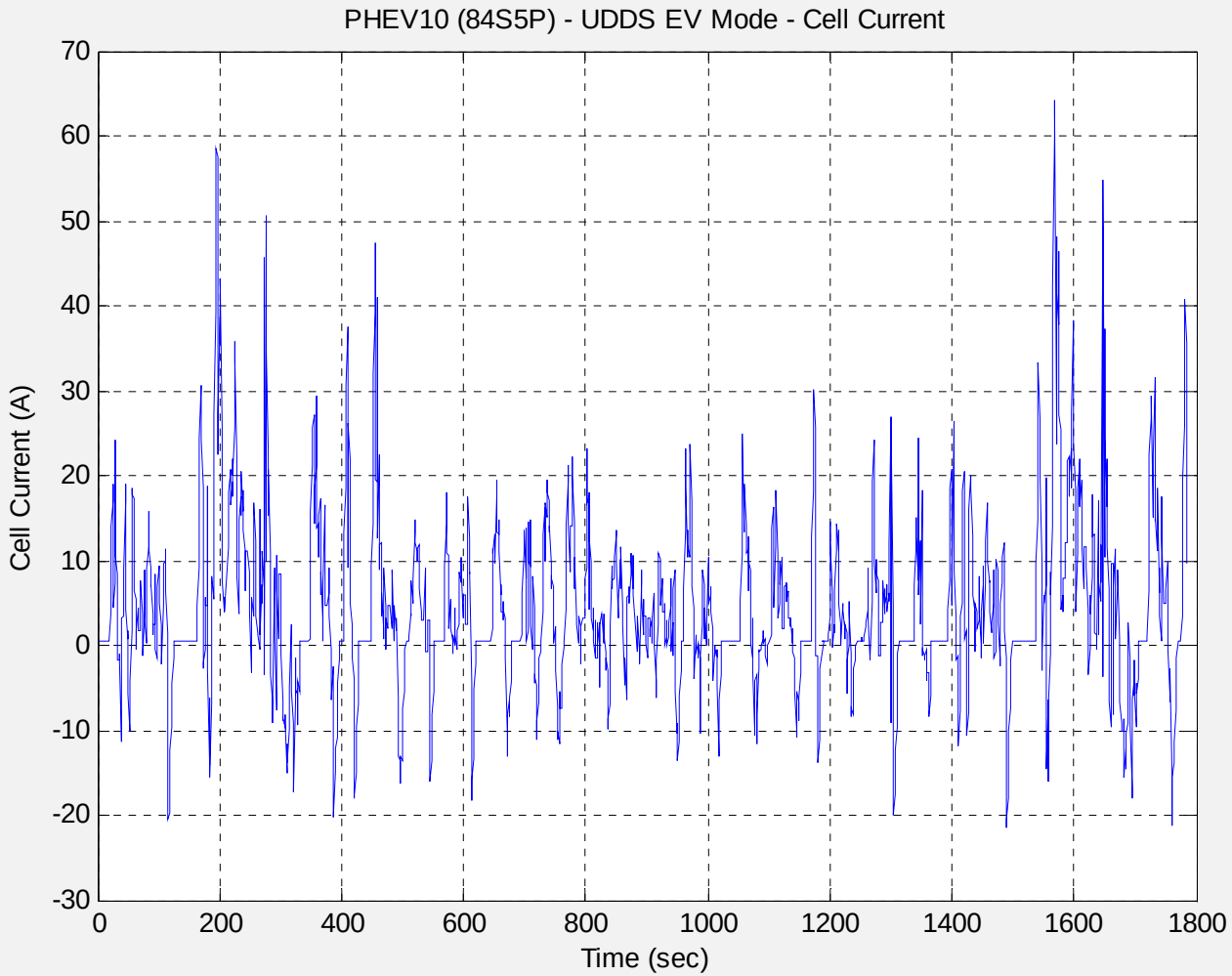
PHEV10 – UDDS – EV Mode
Cell Current



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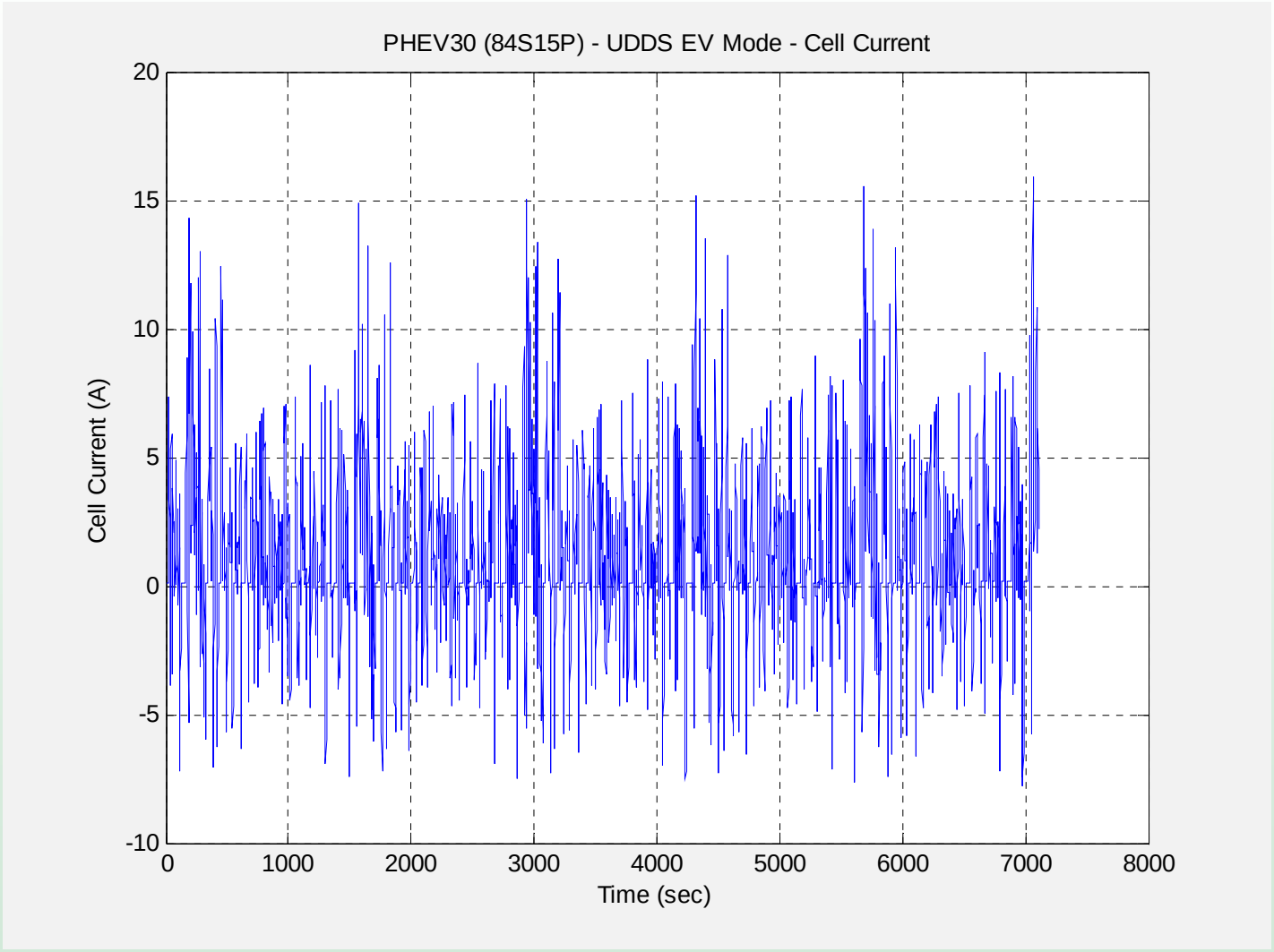
PHEV40 – UDDS – EV Mode
Cell Current



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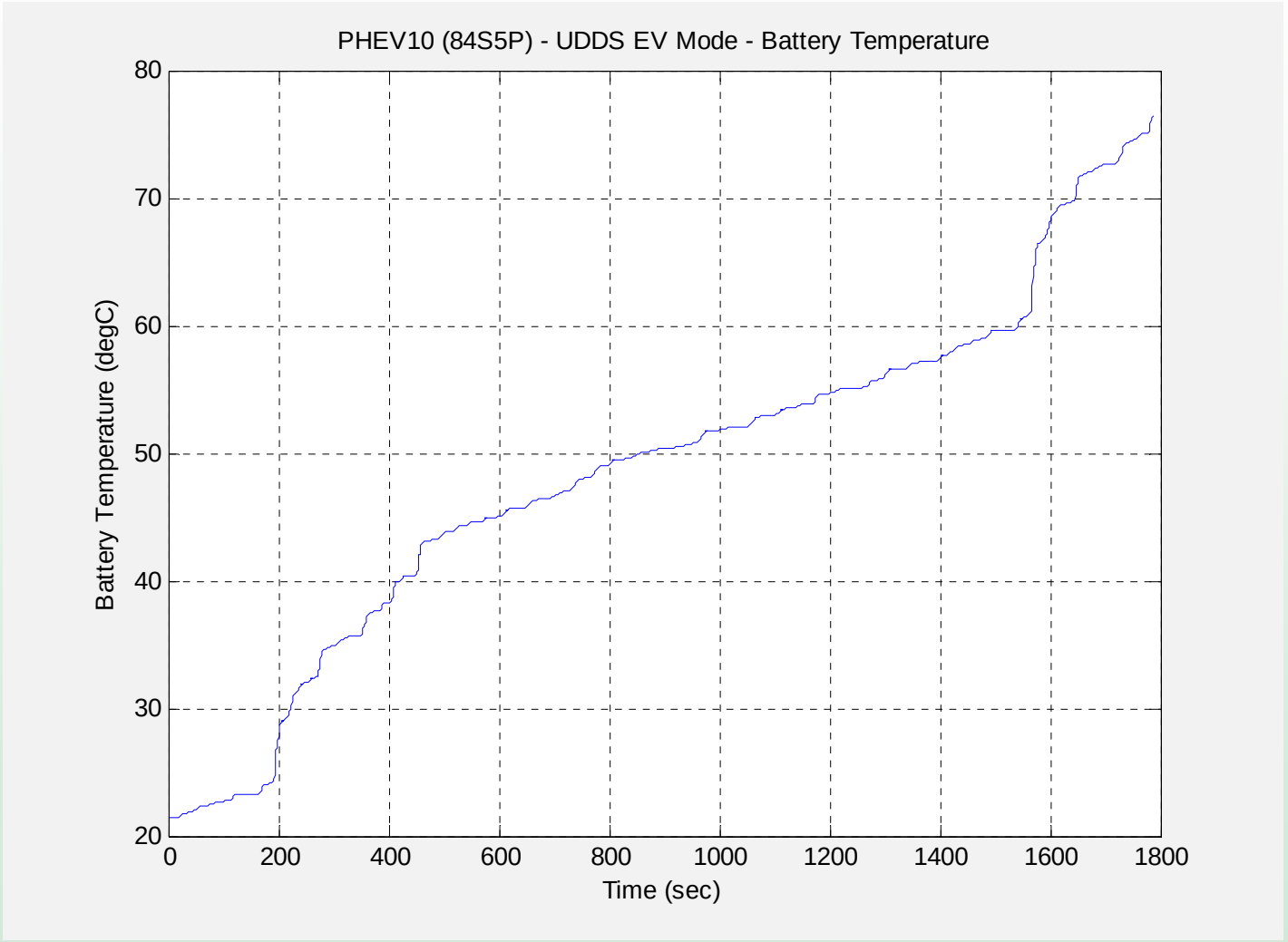
PHEV10 – UDDS – EV Mode
Battery Temperature



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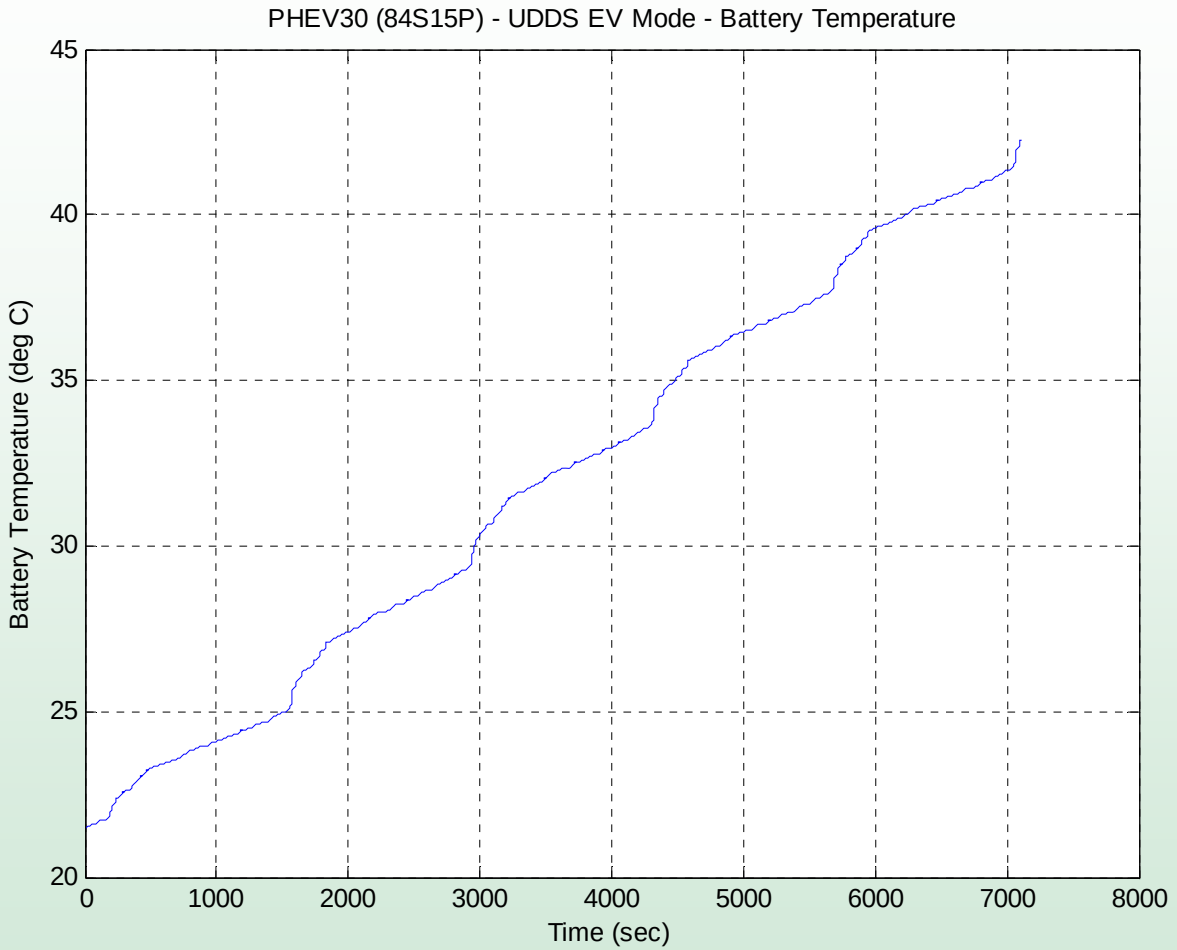
PHEV40 – UDDS – EV Mode
Battery Temperature



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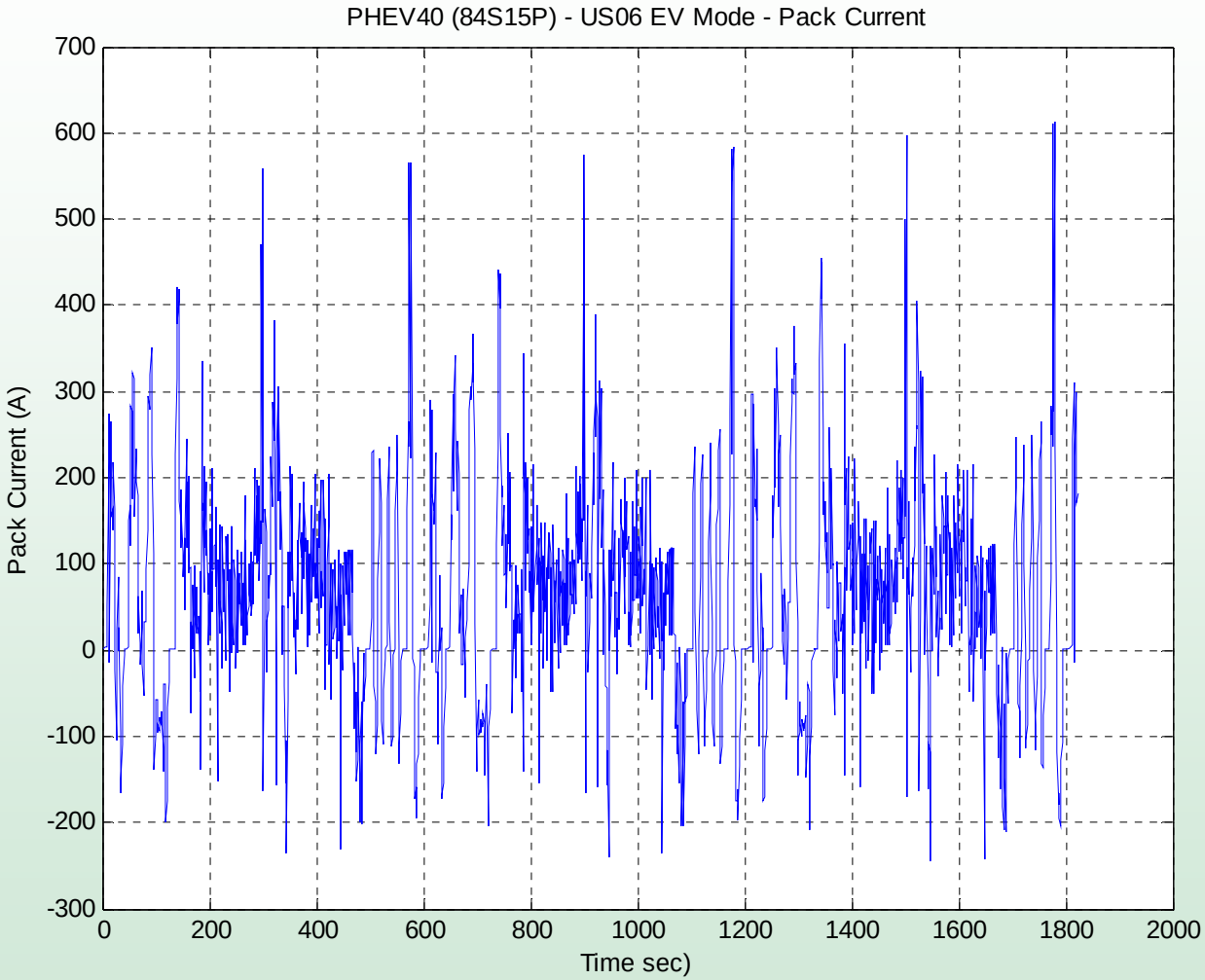
PHEV40 – US06 – EV Mode
Battery Current



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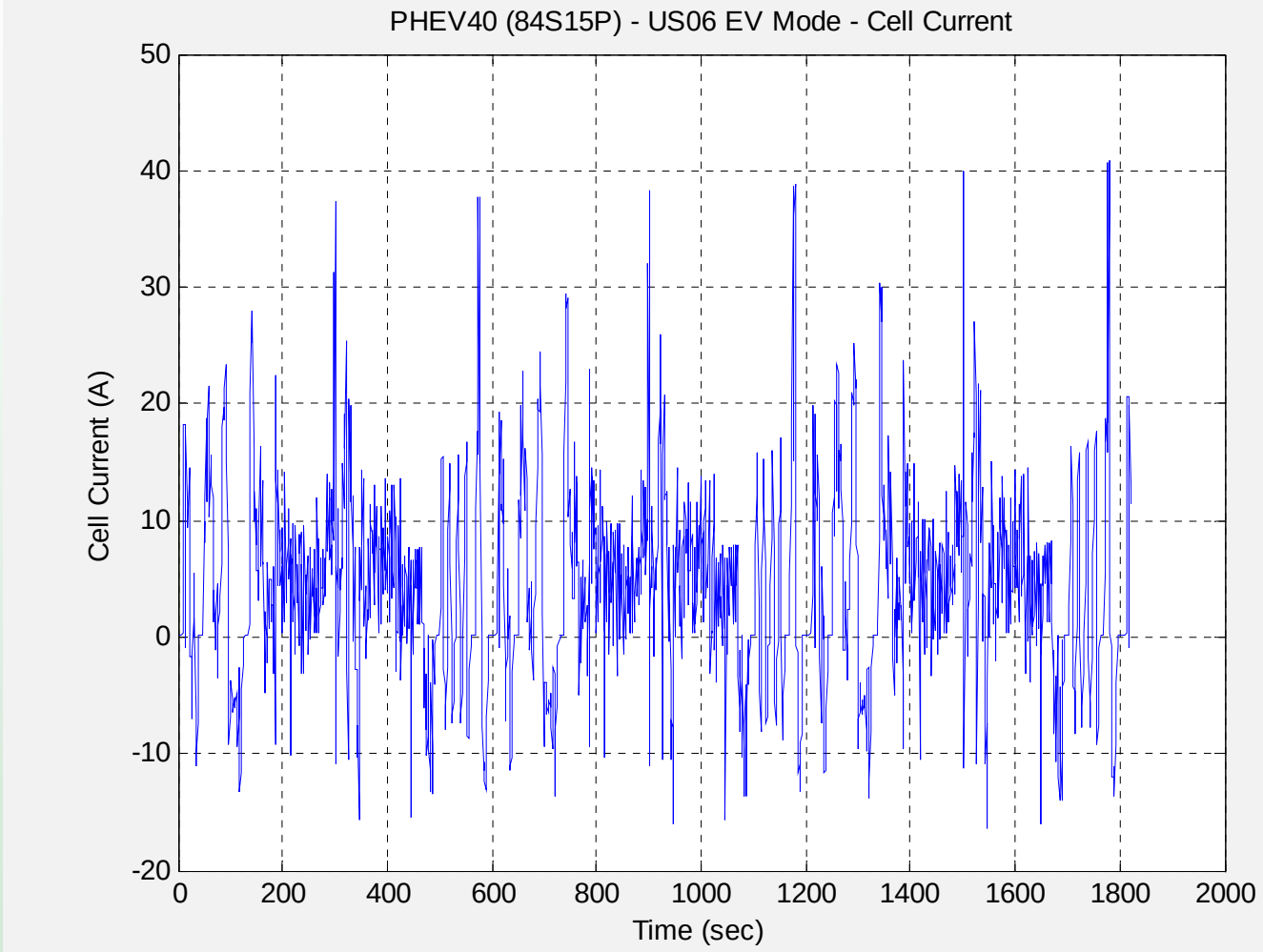
PHEV40 – US06 – EV Mode
Cell Current



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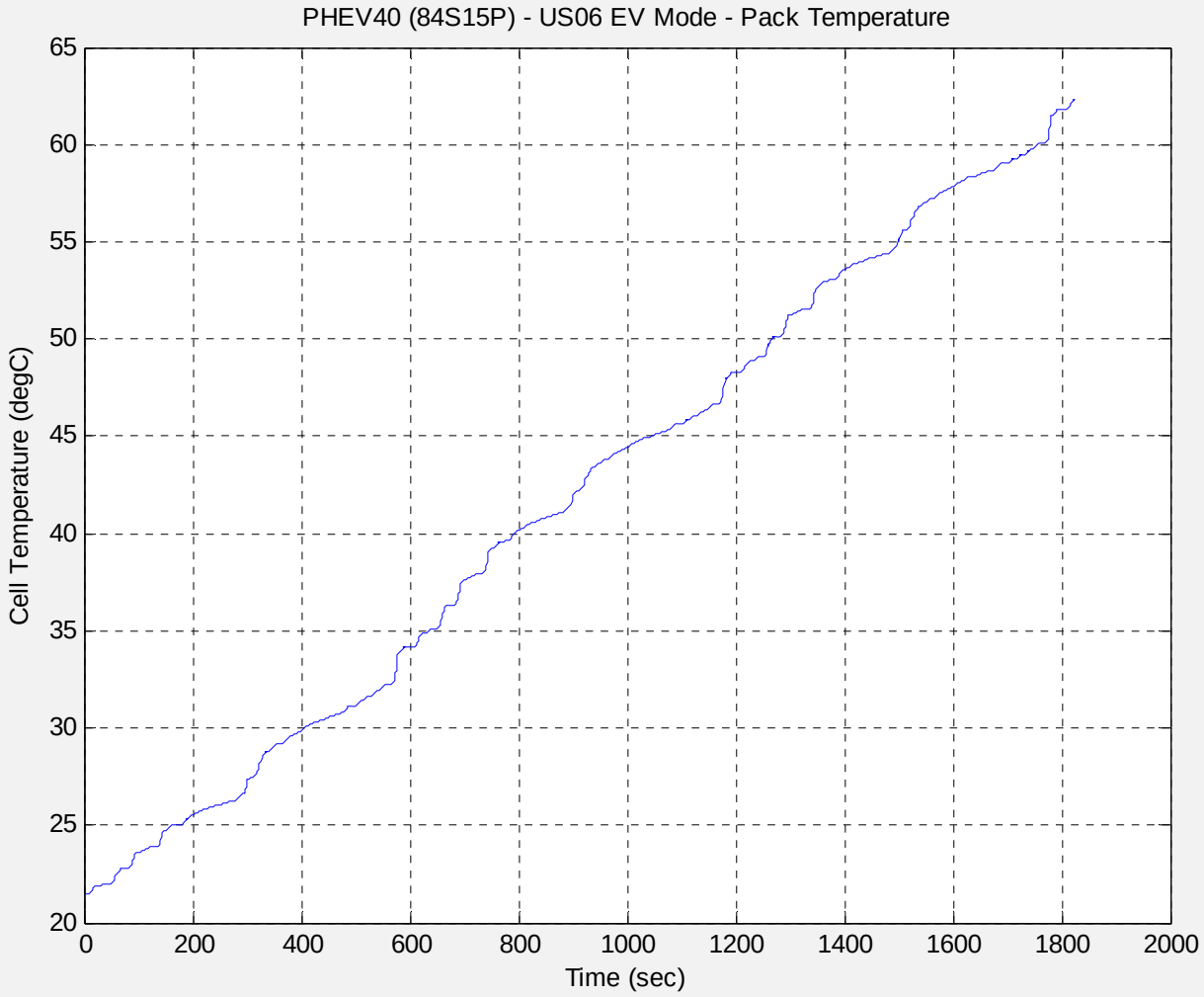
PHEV40 – US06 – EV Mode
Pack Temperature



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PHEV10/PHEV40 – EV Mode Performance Summary

	P10/UDDS	P40/UDDS	P40/US06
Range (km)	16.9	62.4	38.8
Time (sec)	1786	7107	1822
Average Cell Current (A)	7.2	2.13	6.8
Pack Heat Loss (W)	905	257	1975
Pack Temperature Increase (no cooling)	55	21	40

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PHEV10/40 Experience Summary

- PHEV10 battery option is suitable for blended mode operation. The systems meets easily power requirements for low power EV mode (UDDS) with minimum cooling and no need for air conditioning. Blended mode solves the problem of cold start emissions due to intermittent engine operation.

- PHEV40 options is suitable for full time EV operation in city traffic without significant cooling effort (ventilation is sufficient to maintain the battery temperature. High load cycles such as US06 require cooling. In the case of Ford Escape, the electric powertrain is only capable of low power EV operation (UDDS).

- It is expected that performance of both PHEV10 and PHEV40 systems could be significantly improved if the vehicle was optimized for the lithium battery characteristics. OEM engine management system is designed for small NiMH battery and does not take advantage of the benefits of larger lithium packs.

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Li Ion Battery in HEV/PHEV Vehicles

- In HEV application Li Ion technology has superior performance compared to NiMH, lower weight and better thermal characteristics. Viability of high volume commercialization will depend on cost.

- Low range PHEV option is a natural step in evolution of hybrid vehicles, offering improved performance, limited EV mode and 10-20% fuel consumption reduction at similar size, weight and low cost premium. It can be cost effective today without major changes to vehicle architecture

- High range PHEV option requires ground-up vehicle design to accommodate large battery. The battery cost remains a major obstacle in high volume commercialization and high volume battery production issues are still to be addressed.

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