ONE FORD

ONE TEAM • ONE PLAN • ONE GOAL

Electrochemical Prozac: Relieving Battery Anxiety through Life and Safety Research

Celebrating 50 Years 1964-2014 NATIONAL ACADEMY OF ENGINEERING OF THE NATIONAL ACADEMIES

Alvaro Masias

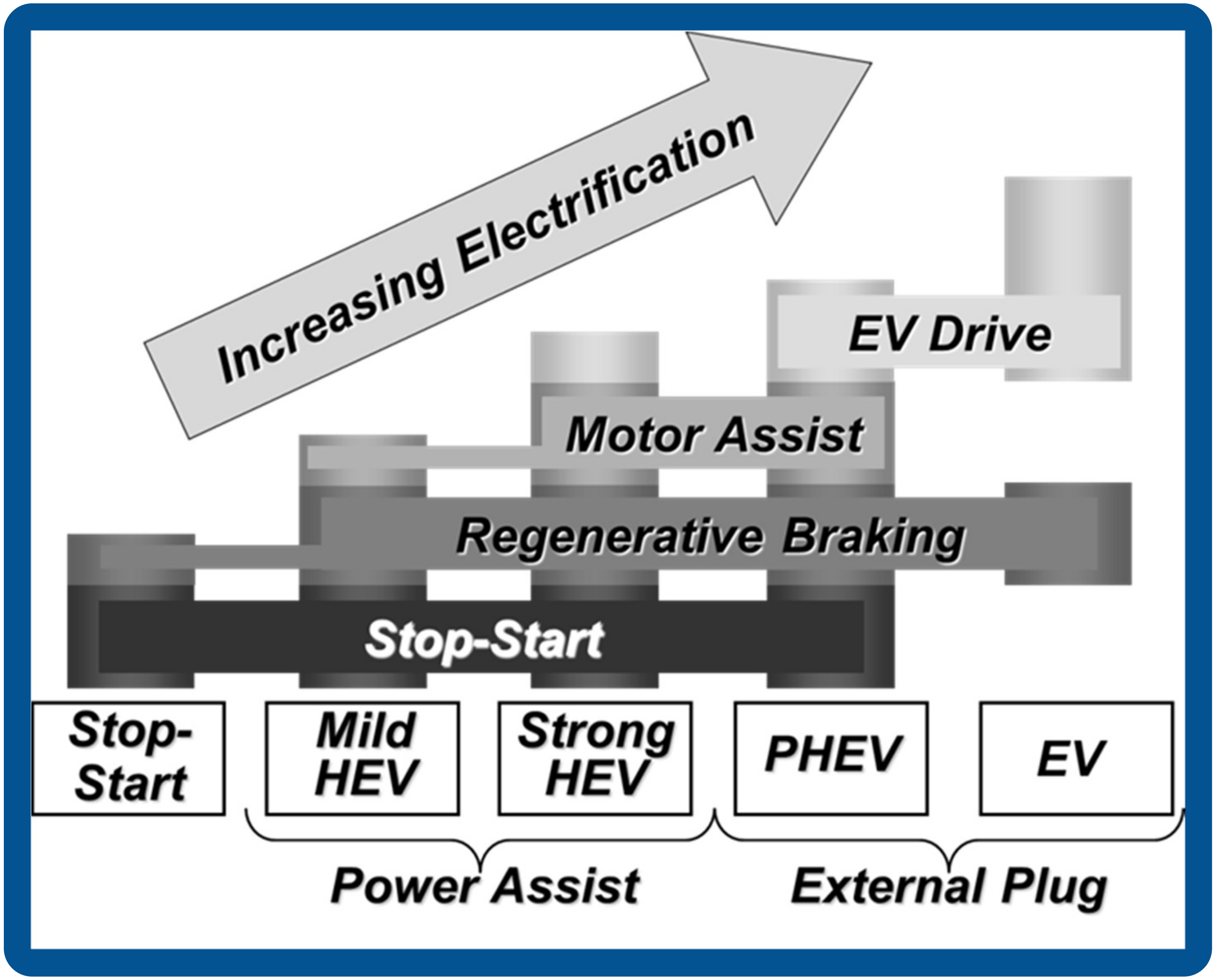
Irvine, CA – September 11-13, 2014

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

- Transportation Battery Needs
- Life Prediction
  - Low Current
  - High Current
- Safety Prediction
  - Mechanical
  - Thermal
  - Electrical
- Future

- Transportation Battery Needs
- Life Prediction
  - Low Current
  - High Current
- Safety Prediction
  - Mechanical
  - Thermal
  - Electrical
- Future

Electrified Vehicle Types



A. Masias and K. Tojima, "Advanced Automotive Battery Research," in *Plug-In 2009*, Long Beach, 2009.

Battery Technologies by Type

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

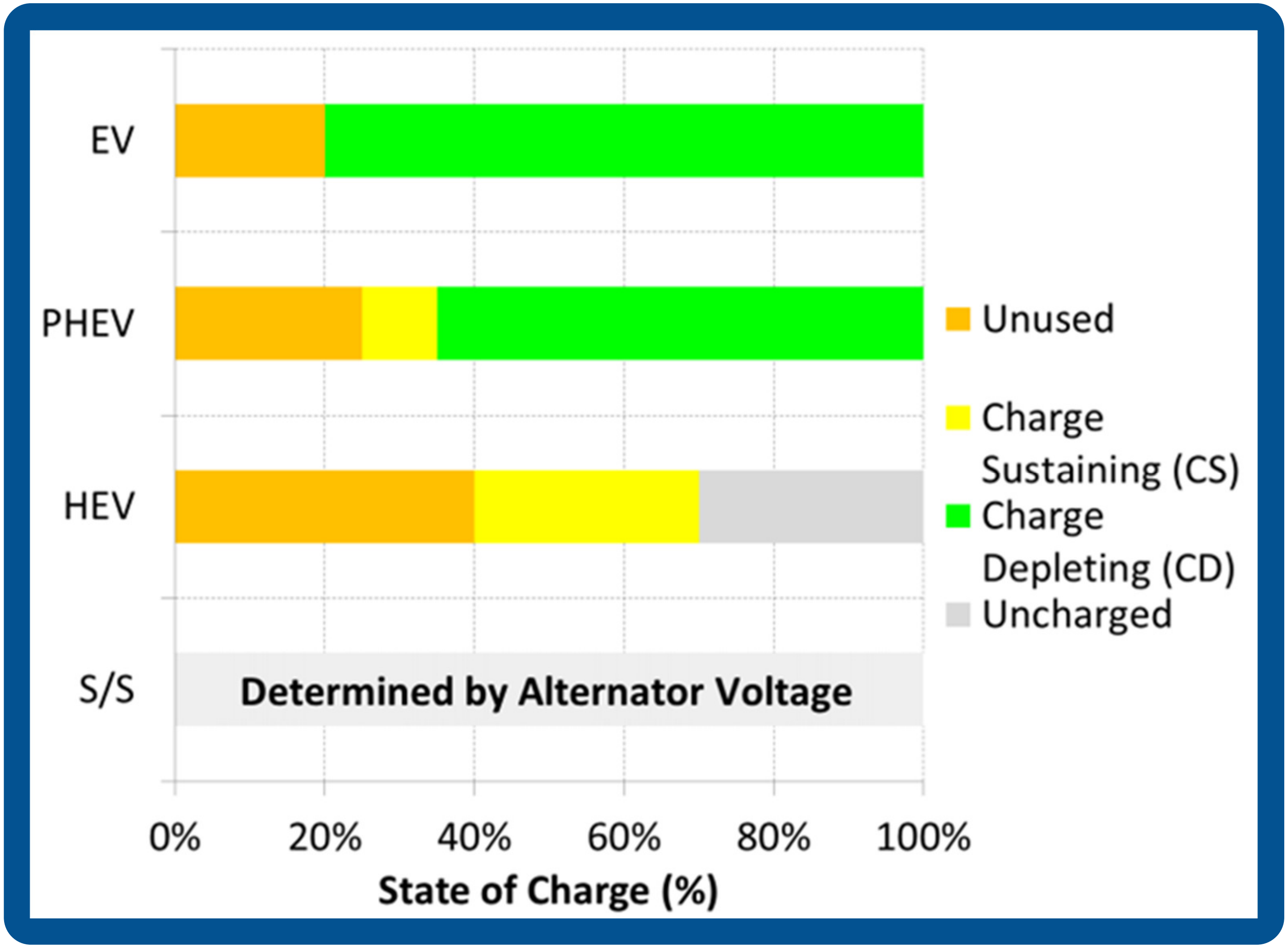
Vehicle Type	Past (1990-2010)	Near Term (2010-2015)	Future (2015+)
Stop-Start	Lead Acid	Lead Acid	Lead Acid & Lithium Ion
HEV (Mild & Strong)	Nickel Metal Hydride	Lithium Ion & Nickel Metal Hydride	Lithium ion & Nickel Metal Hydride (Toyota)
PHEV	N/A	Lithium Ion	
EV	Lead Acid & Nickel Metal Hydride	Lithium Ion	

Battery Requirements by Type

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

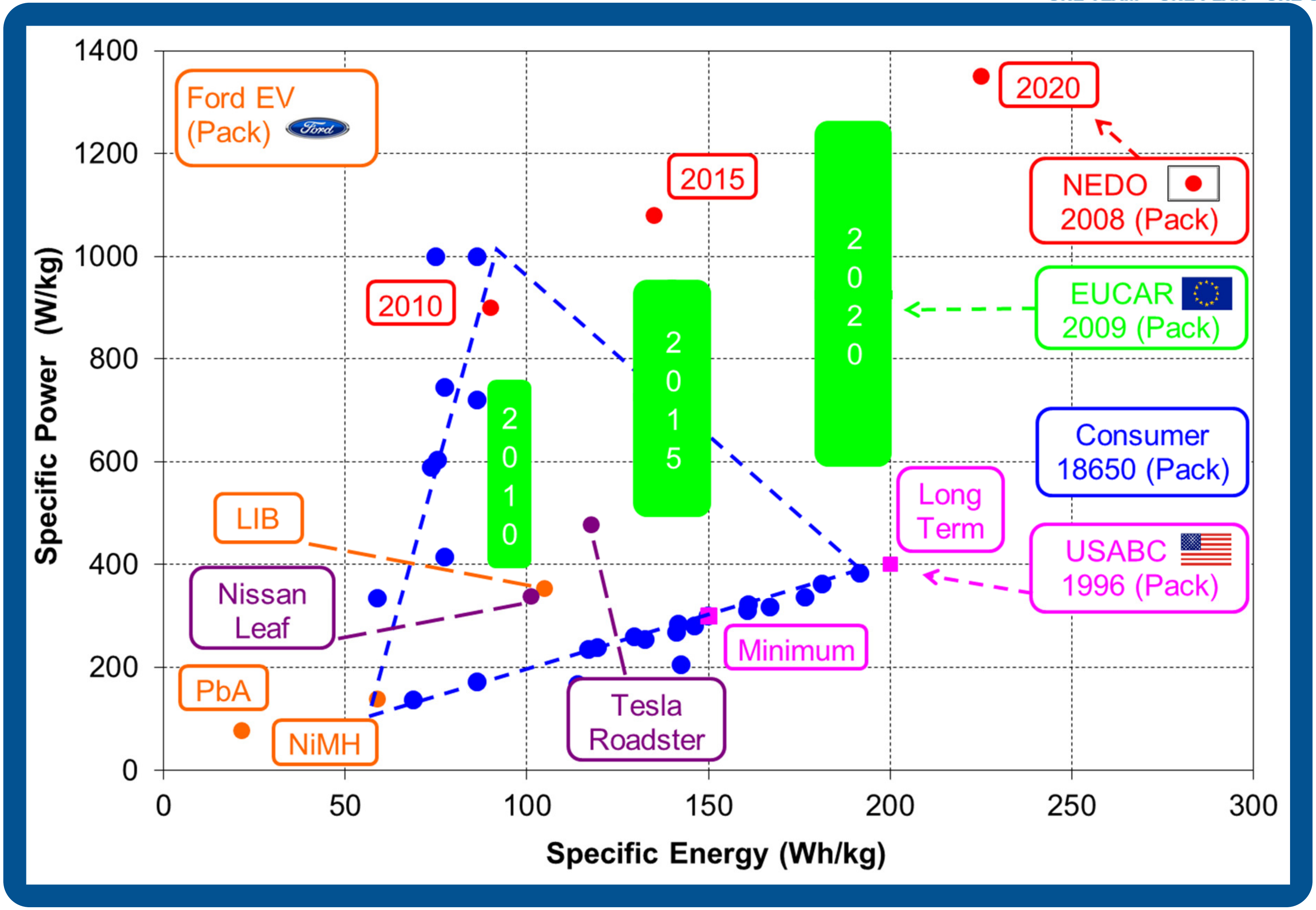
Vehicle Type	Power (kW)	Energy (kWH)	Cycles (1,000)
Stop-Start	< 10	< 0.4	75 – 450 (Charge Sustaining)
HEV (Mild & Strong)	Mild: 10-20 Strong: 20-40	Mild: < 1 Strong: 1-2	300 (Charge Sustaining)
PHEV	> 40	5 – 16	300 (Charge Sustaining) 5 (Charge Depleting)
EV	> 80	> 12	5 (Charge Depleting)

State of Charge by Type



T. Duong, "Direction for Energy Storage R&D in the Vehicle Technologies Program," in Scalable Energy Storage Beyond Li-Ion, Oak Ridge, 2010.

EV Battery Performance



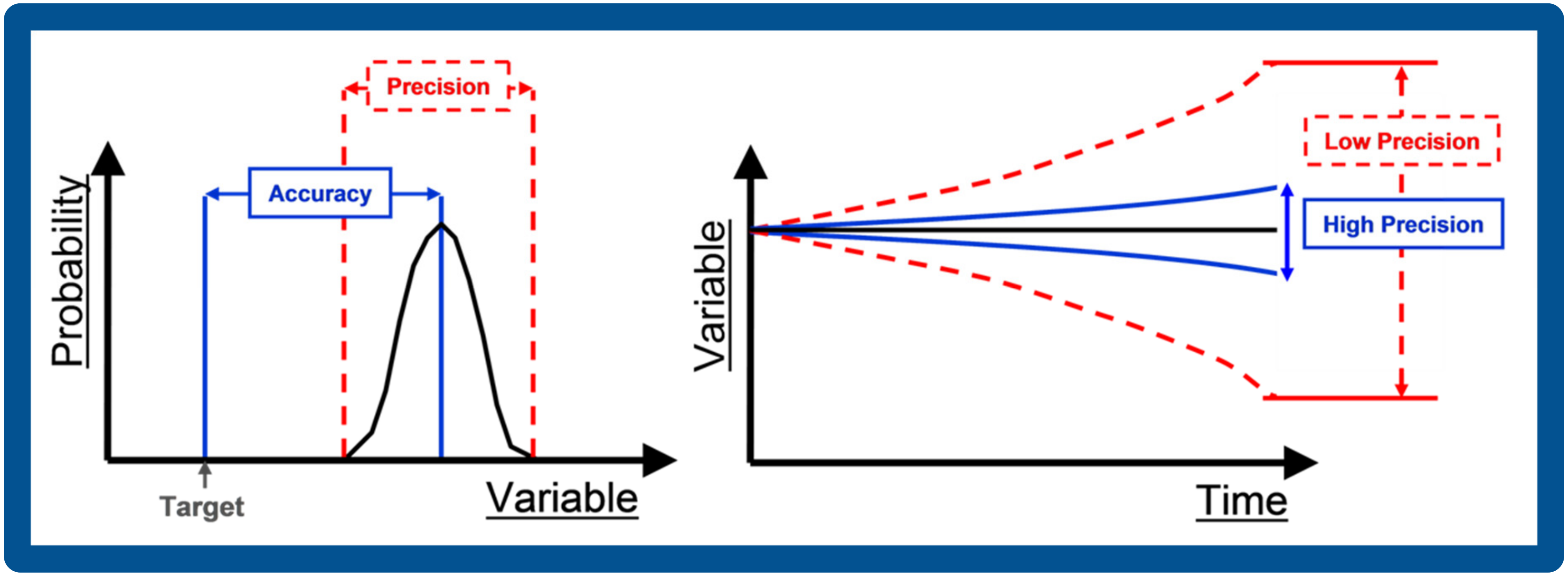
A. Masias and T. Miller, "Automaker Energy Storage Needs for High Energy Application," in *Advanced Automotive Batteries Conference*, Orlando, 2010.

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

- Transportation Battery Needs
- Life Prediction
  - Low Current
  - High Current
- Safety Prediction
  - Mechanical
  - Thermal
  - Electrical
- Future

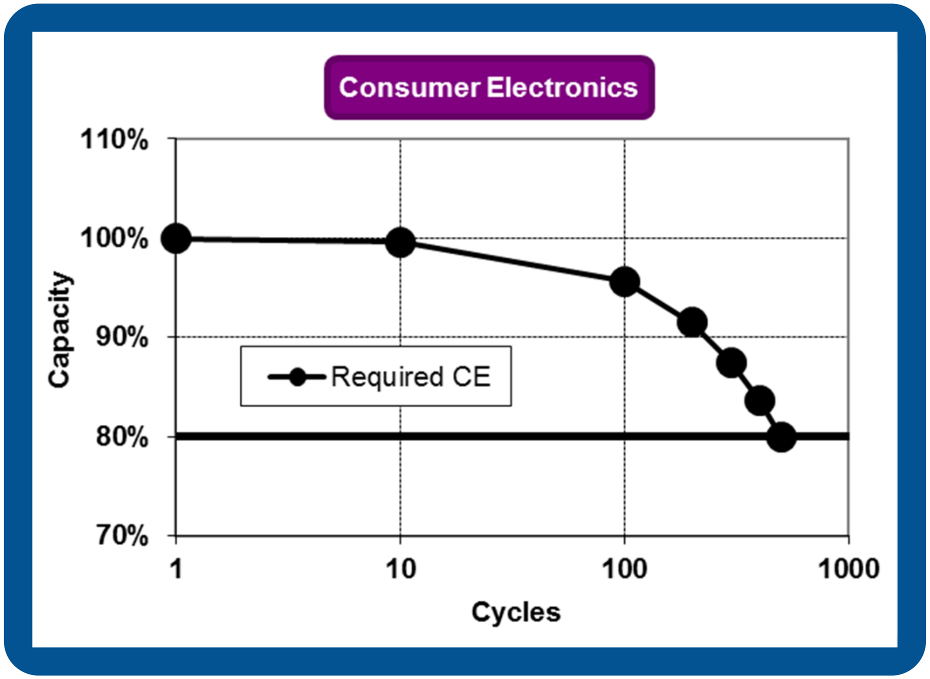
Precision vs. Accuracy

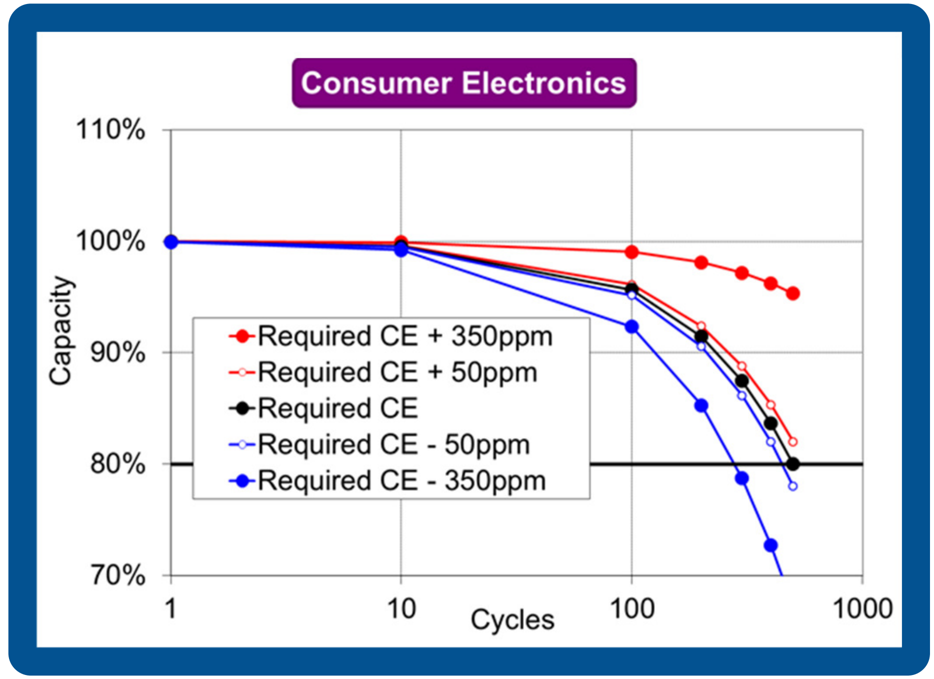
ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL



Capacity Fade Prediction

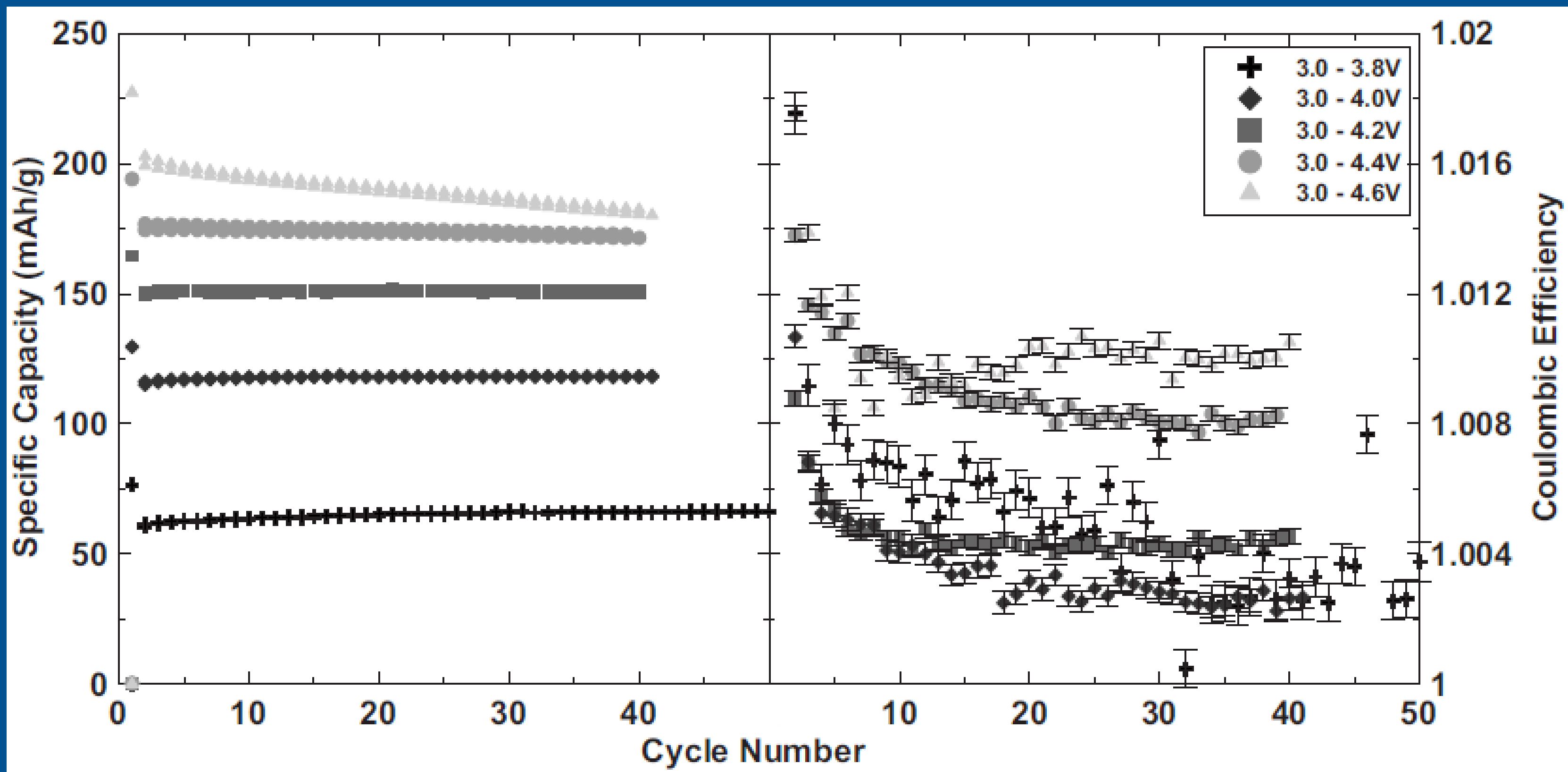
ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL





Low Current, High Precision

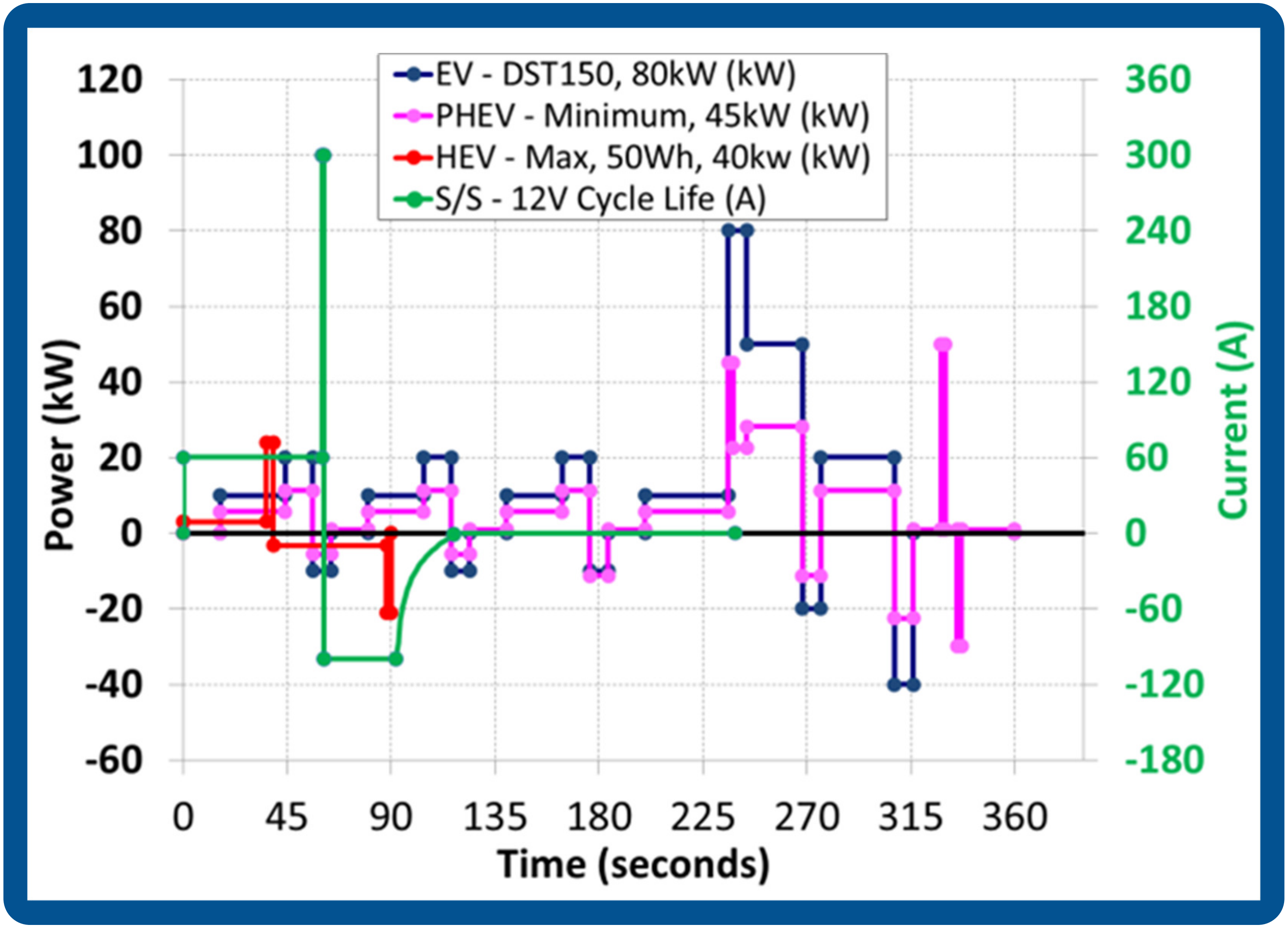
ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL



A. J. Smith, J. C. Burns, S. Trussler and J. R. Dahn, "Precision Measurements of the Coulombic Efficiency of Lithium-Ion Batteries and of Electrode Materials for Lithium-Ion Batteries," *Journal of the Electrochemical Society,* vol. 157, no. 2, pp. A196-A202, 2010.

Automotive Currents

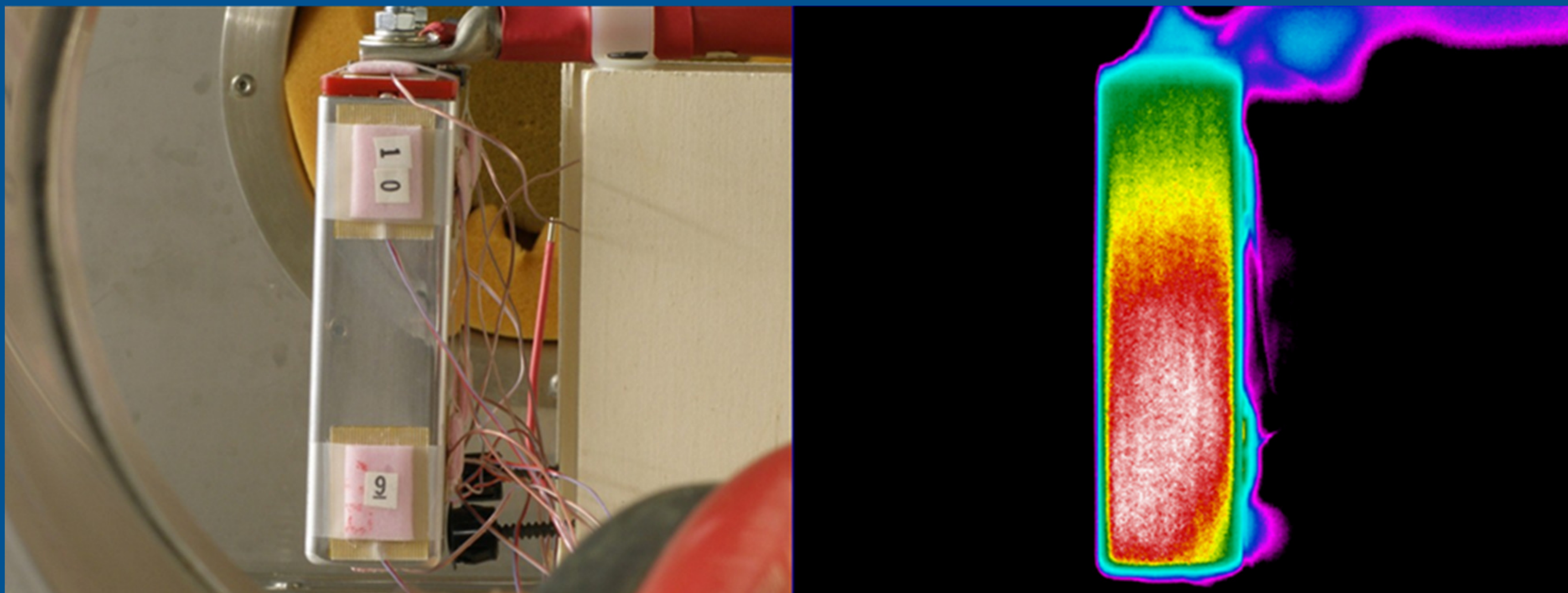
ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL



"United States Advanced Battery Consortium," http://www.uscar.org/guest/teams/12/U-S-Advanced-Battery-Consortium

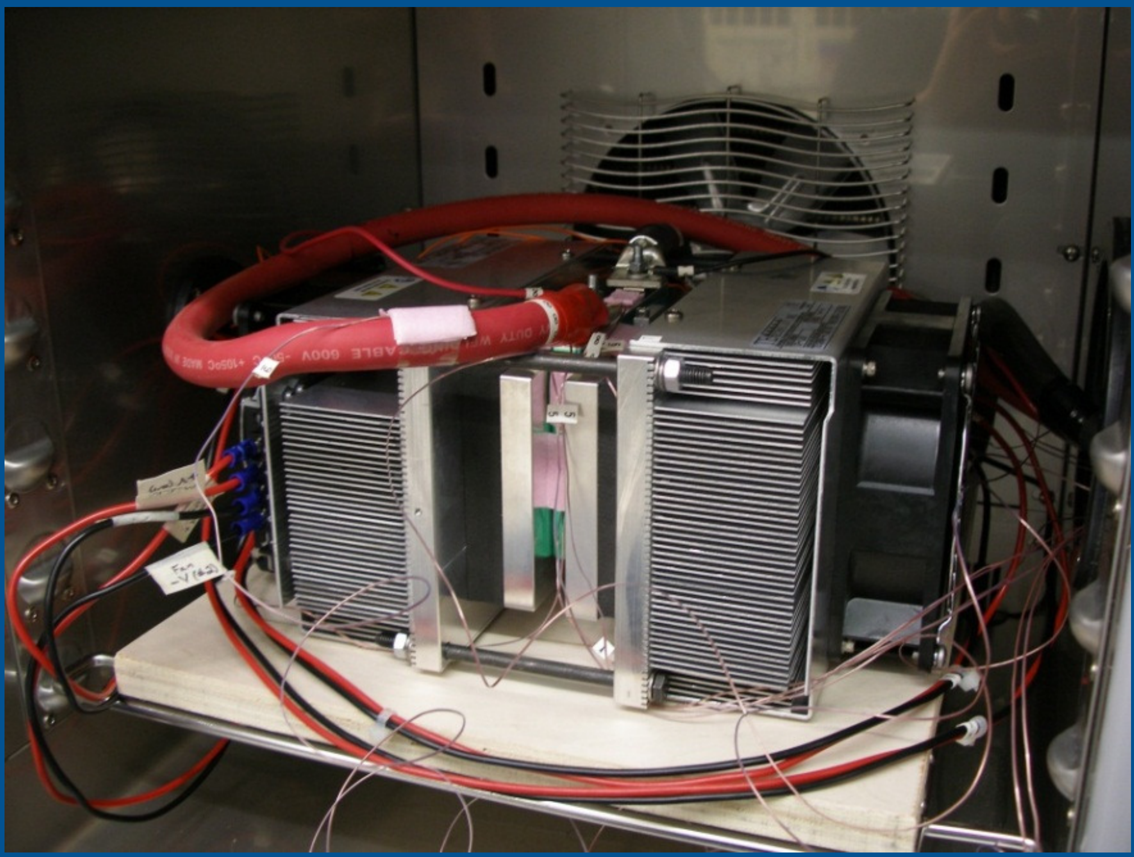
Cell Thermals

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL



Thermal Management Research

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL



ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

- Transportation Battery Needs
- Life Prediction
  - Low Current
  - High Current
- Safety Prediction
  - Mechanical
  - Thermal
  - Electrical
- Future

FMVSS 305

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

Section		Requirement
S5.1	Electrolyte Spillage from Propulsion Batteries	<5L Spillage Total, 0 into Passenger Cabin 30 minutes after barrier test
S5.2	Electrical Energy Storage / Conversion Device Retention	Energy Device shall remain attached to vehicle and out of passenger cabin
S5.3	Electrical Safety	Maintain Isolation >100ohm/volt with monitoring or >500 ohm/volt without monitoring

FMVSS 305, Chapter V NHTSA ed., Vols. Title 49 - Transportation, 2011, p. Part 571.305.

EUCAR Rating System

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

Score	Title	Description
0	No Effect	No Effect. No loss of functionality
1	Passive Protection Activated	No defect; no leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Cell reversibly damaged. Repair of protection device needed.
2	Defect / Damage	No leakage: no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Cell irreversibly damaged. Repair needed.
3	Leakage (Δ mass < 50%)	No venting, fire or flame*; no rupture; no explosion. Weight loss <50% of electrolyte weight (electrolyte = solvent +salt).
4	Venting (Δ mass > 50%)	No fire or flame*; no rupture; no explosion. Weight loss of ≥50% of electrolyte weight (electrolyte= solvent + salt).
5	Fire or Flame	No rupture; no explosion (i.e., no flying parts).
6	Rupture	No explosion, but flying parts of the active mass.
7	Explosion	Explosion (i.e., disintegration of the cell).

UNECE, "Electric Vehicle Safety (EVS) - Transport - Vehicle Regulations - UNECE Wiki," https://www2.unece.org/wiki/pages/viewpage.action?pageId=3178628

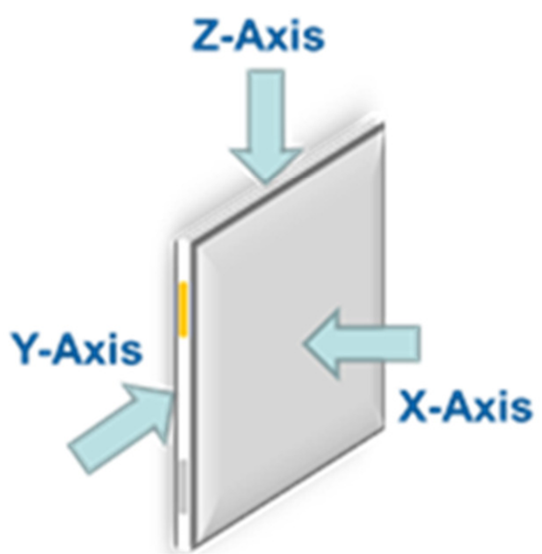
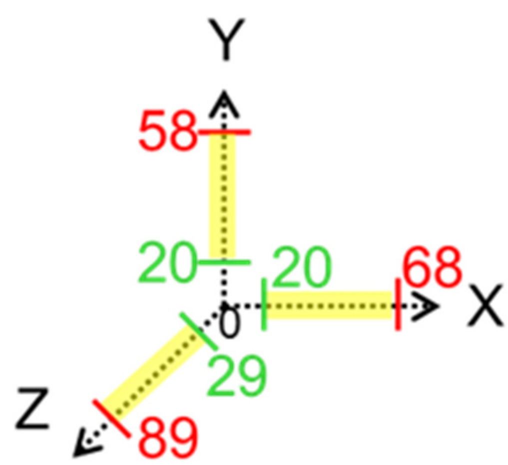
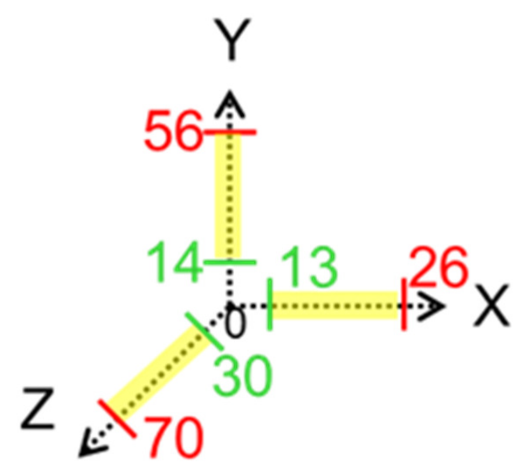
ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

Mechanical Safety Testing

Test Type		Industry Standard					Government Regulation			
		Freedom Car	SAE J2929	SAE J2464	ISO 12405-1	ISO 12405-3	UN 38.3	ECE R100	Q/C-T 743	KMVSS 1.48
Mechanical	Mechanical Integrity	●	●	●		●		●	●	
	Penetration	●		●					●	
	Immersion	●	●	●		●				●
	Roll-Over	●		●						
	Drop	●	●	●		●	●		●	●
	Mechanical Shock	●	●	●	●	●	●	●		
	Vibration		●		●	●	●	●	●	

Mechanical Response

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

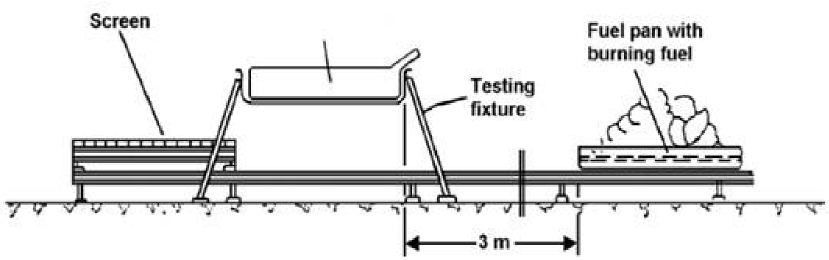
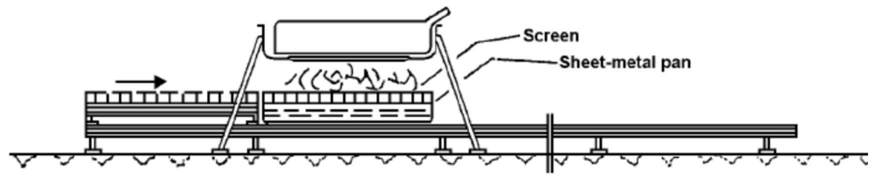
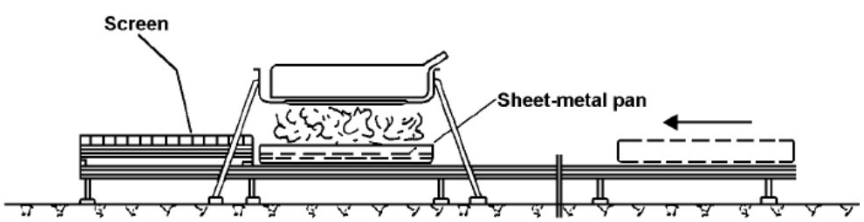
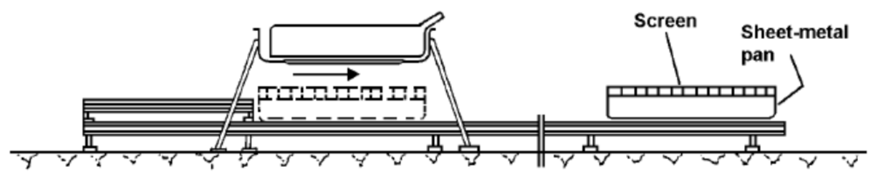
<table>
<tr><th rowspan="2">Cell Orientation</th><th colspan="2">EUCAR 5 vs. Displacement (%)</th></tr>
<tr><th>1 Step</th><th>20 Step</th></tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</table>

Thermal Safety Testing

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

	Test Type	Industry Standard					Government Regulation			
		Freedom Car	SAE J2929	SAE J2464	ISO 12405-1	ISO 12405-3	UN 38.3	ECE R100	Q/C-T 743	KMVSS 1.48
Thermal	Thermal Stability	●								
	Fire Exposure	●	●	●		●		●		●
	High Temperature Storage	●							●	●
	Cycle w/o Thermal Control	●	●	●		●		●		
	Thermal Shock	●	●	●	●	●	●	●		
	Humidity Exposure		●		●	●				
	Passive Propagation			●						

Thermal Exposure Test

Phase A: Pre-heating 60 seconds	Phase B: Direct Exposure to Flame 70 seconds
	
Phase C: Indirect Exposure to Flame 60 seconds	**Phase D: End of Test 3 hours**
	

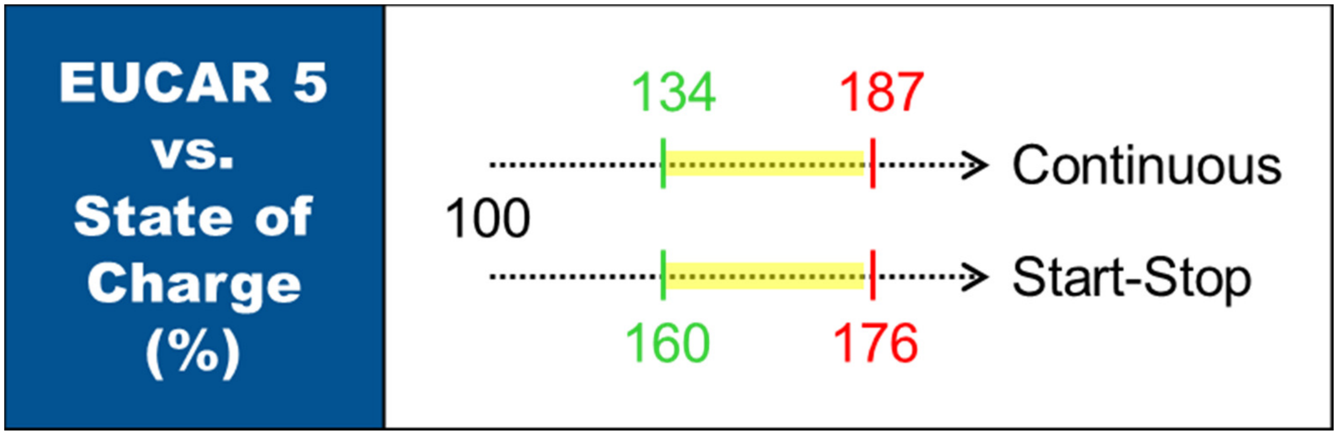
"Electric power trained vehicles. Regulation No. 100 – Rev.2," United Nations Economic Commission for Europe, 2013.

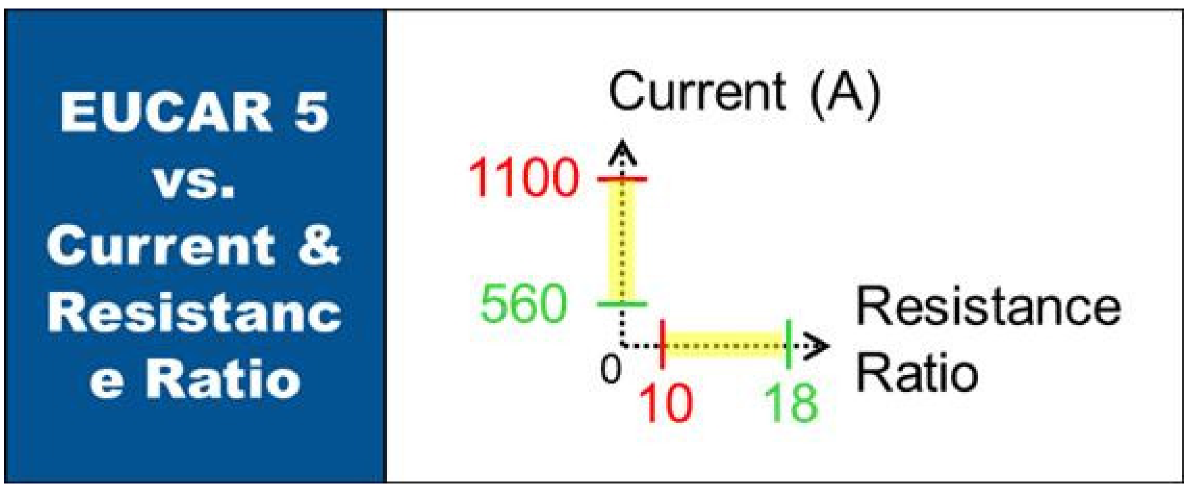
Electrical Safety Tests

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

Test Type		Industry Standard					Government Regulation			
		Freedom Car	SAE J2929	SAE J2464	ISO 12405-1	ISO 12405-3	UN 38.3	ECE R100	Q/C-T 743	KMVSS 1.48
Electrical	Overcharge	●	●	●	●	●	●	●	●	●
	Short Circuit	●	●	●	●	●	●	●	●	●
	Over Discharge	●	●	●	●	●	●	●	●	●
	High Voltage Exposure		●							
	Partial Short Circuit	●								
	Separator Shutdown			●						

Electrical Response





ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

- Transportation Battery Needs
- Life Prediction
  - Low Current
  - High Current
- Safety Prediction
  - Mechanical
  - Thermal
  - Electrical
- Future

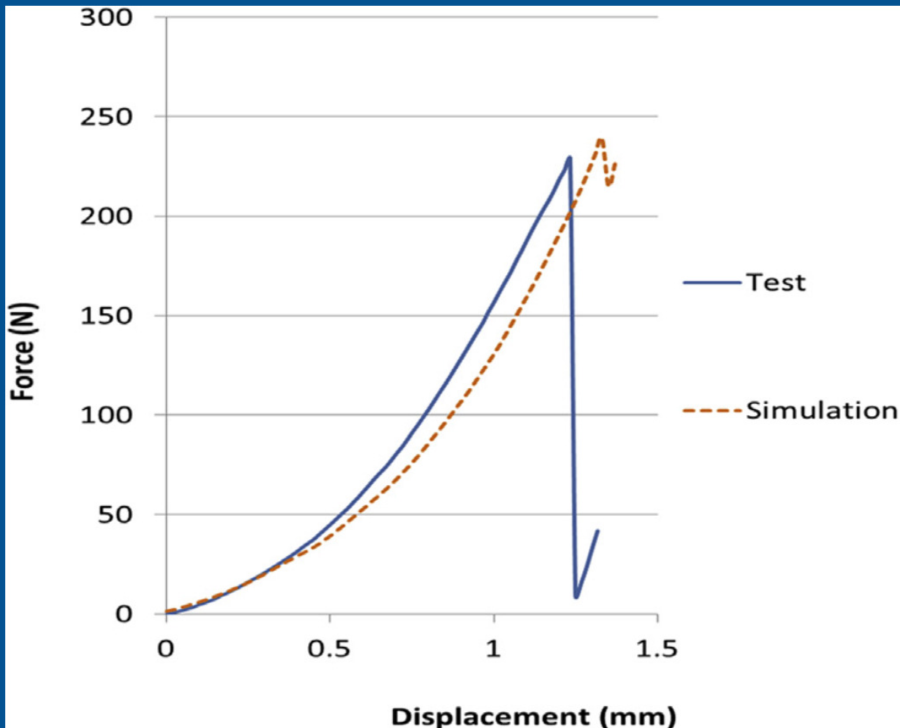
Future Life – High Precision

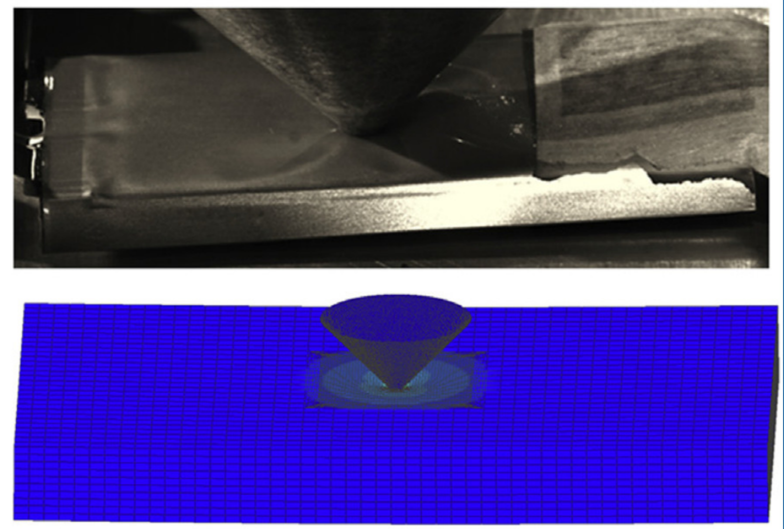
ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL

	Current (A)	Precision (ppm)	Machine	
Academia	<10	10	Dalhousie University UHPC	
Industry	200	50	Arbin Instruments HP2	

Future Safety - Modeling

ONE FORD
ONE TEAM • ONE PLAN • ONE GOAL





E. Sahraei, J. Meier and T. Wierzbicki, "Characterizing and modeling mechanical properties and onset of short," *Journal of Power Sources,* vol. 247, pp. 503-516, 2014.

Acknowledgements

This Work is supported by:

- US Department of Transportation National High Traffic Safety Administration (NHTSA) [DTNH22-11-C-00214]
- US Department of Energy Advanced Projects Agency-Energy (ARPA-E) [DE-AR000267]