National Highway Traffic Safety Administration

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U.S. Proposal on BMS Functionality-In Use

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Objective

- The objective is to evaluate the Battery Management System (BMS) response to a variety of failure and abuse conditions that may be experienced during normal operation of the vehicle and that, if not properly controlled, could lead to hazardous conditions.

GTR vs. US Proposal

GTR

- 6.2.8 Over-Charge Protection (current)
- 6.2.9 Over-Discharge Protection
- 6.2.10 Over Temperature Protection

U.S.

- 1) Over- Charge
  - **Over-voltage**
  - Over-current
- 2) Over-Discharge
  - **Driving mode**
  - **Charging mode**
- 3) Operation under Extreme-Temperature
  - **Low Temperature**
  - High Temperature

1) Over-Charging Protection

Over-Current

- Condition when voltage remains proper, but excessive current
- Fault conditions: external charger, regenerative braking, sensor failure, or voltage reference drift, resulting in Li-ion Cell thermal runaway.

Over-Voltage

- Condition when charge voltage exceeds proper limits, but current remains within the proper bounds
- Fault conditions: external charger, regenerative braking, sensor failure, or voltage reference drift, resulting in Li-Ion Cell thermal runaway.

2) Over-Discharging Protection

Drive Mode

- Protection from undesirable over-discharging, leading to undesirable aging, swelling or violent failure.
- For HEV

Charge Mode

- Protection from undesirable over-discharging, leading to undesirable aging, swelling or violent failure
- For EV & PHEV

3) Operation under Extreme Temperature Conditions

Low Temperature Operation

- Examine BMS functionality at low temperature without heating system
- Aggressive operations at low T, leading to high rate of charging and discharging and temperature imbalance
- -20 C

High Temperature Operation

- Examine BMS functionality at high temperature without cooling system
- Aggressive operations at high T, leading to high rate of charging and discharging and temperature imbalance
- 40 C

Discussions/Next Steps

- Submitted the draft report in Nov 2014
- Discussions made today are preliminary
- Will work with Task Force 4 to address potential proposal criteria:
  - Max SOC or other recommendation
  - Recommend to use a DC Link like connection
  - Rate of over-current and over-voltage input (vehicle specific)
  - Rate of discharge
  - Temperature range tested: -20C to 40C (OEM specific input)

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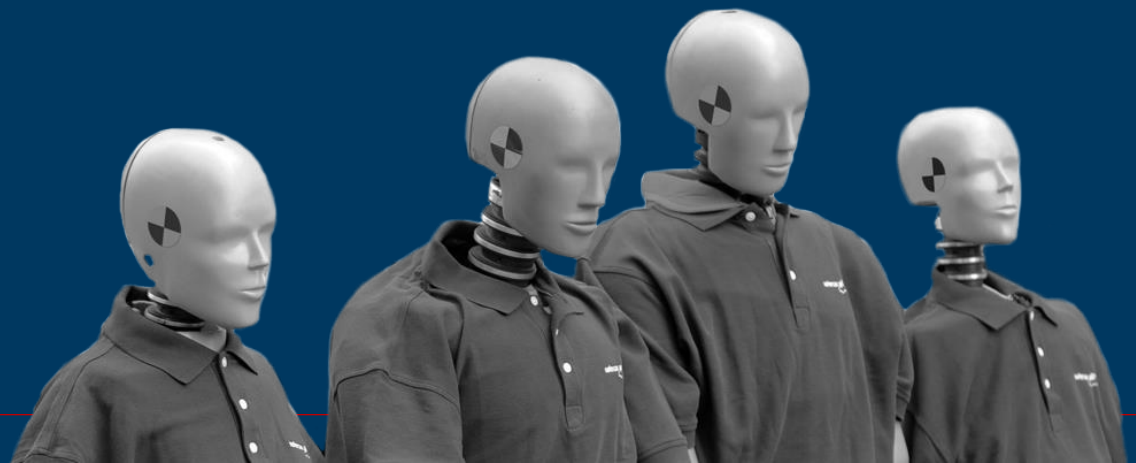


1) Over-Current Overcharge

Prep	Prep/Procedure	Evaluation
• SOC at 95% • Ambient Temperature • Calculate Max theoretical Voltage-OEM to provide • DC Link	• EV and PHEV (L1 charger) • HEV (driving mode) • turn on over current supply • Linearly increasing charging current over 1000 sec from zero to max current	• Collect the data as continue charging • Watch for 2hr to 24 hrs or until SOC reaches 130% • Either BMS will automatically disconnect the RESS or failure occurs

1) Over-Voltage Overcharge

Prep	Procedure	Evaluation
• SOC at 95% (discharge as needed) • HEV (fuel @100%) • Ambient T • Calculate Max theoretical V-OEM to provide • DC Link	• Set current and voltage to prescribed • Set voltage to 10% higher • Place in charging mode (HEV in driving mode) • Once charging begin, turn on the over-voltage supply	• Collect data • Watch for 2hr or until SOC reaches 130% • Either BMS will automatically disconnect the RESS or failure occurs

3) Low Temperature

Prep	Procedure	Procedure/Evaluation

• SOC at 50%
• Disconnect heating system (be minimally invasive)
• EV and PHEV-plug in
• HEV-do UDDS discharge cycle @25C; add only 50% fuel
• Temp chamber with dyno (-20C) for 6hr conditioning.
	• **EV and PHEV**, max allowable charge (allow normal termination or 1 hr after SS reached);
	• **EV**
	  • **Charge** (attempt to charge the vehicle-allow normal termination-rate of SOC change)
	  • **Discharge** (max allowable-speed and rolling resistance)
	  • **Charge** (normal charging)or stop after 24hrs.
		• HEV/PHEV
		  • Discharge (use UDDS &US06)
		  • Charge (max allowable)
		  • Discharge or stop after 24hrs.
		• Evaluate BMS after restore the heating system.

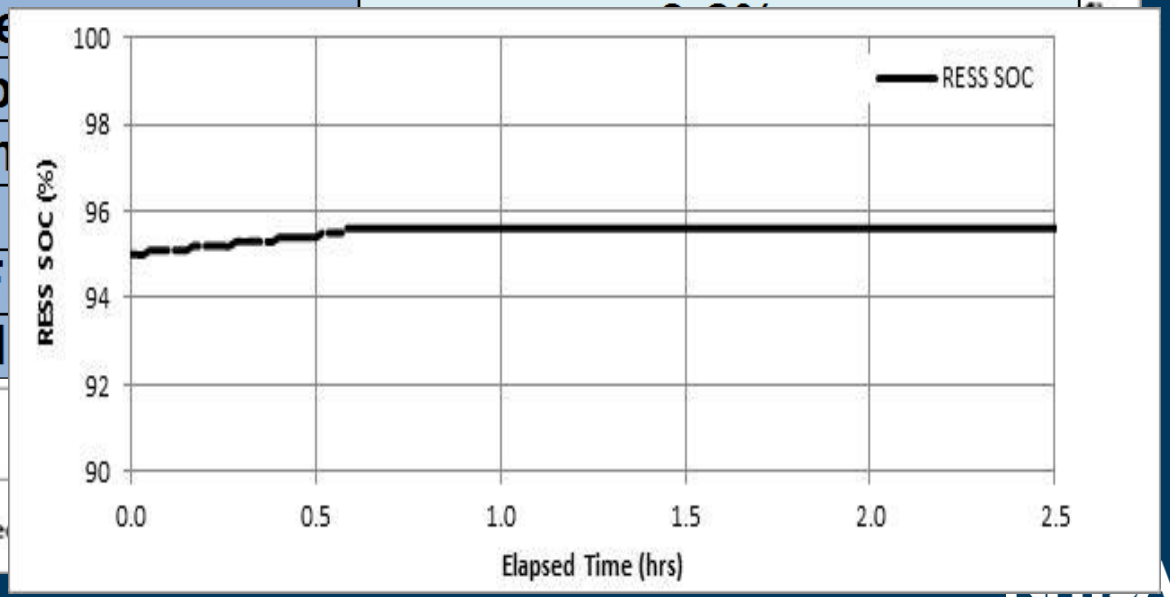
3) High Temperature

Vehicle Prep	Procedure	Procedure/Evaluation

• EV and PHEV: SOC at 100%
• HEV and PHEV: discharge with UDDS cycle & add 100% fuel
• Disconnect cooling system (be minimally invasive)
• Temp chamber with dyno (40C) for 6 hrs.
	• EV and PHEV, max allowable charge (allow normal termination or 1 hr after SS reached);
	• EV
	  • **Discharge** (allow max discharge)
	  • **Charge** (max allowable)
	  • **Discharge** or stop after 24hrs.
		• HEV/PHEV
		  • Discharge (use UDDS &US06)
		  • Charge (max allowable)
		  • Discharge (same method) stop after 24 hrs regardless
		• Evaluate BMS after restoring the heating system.

Over-Current Overcharge

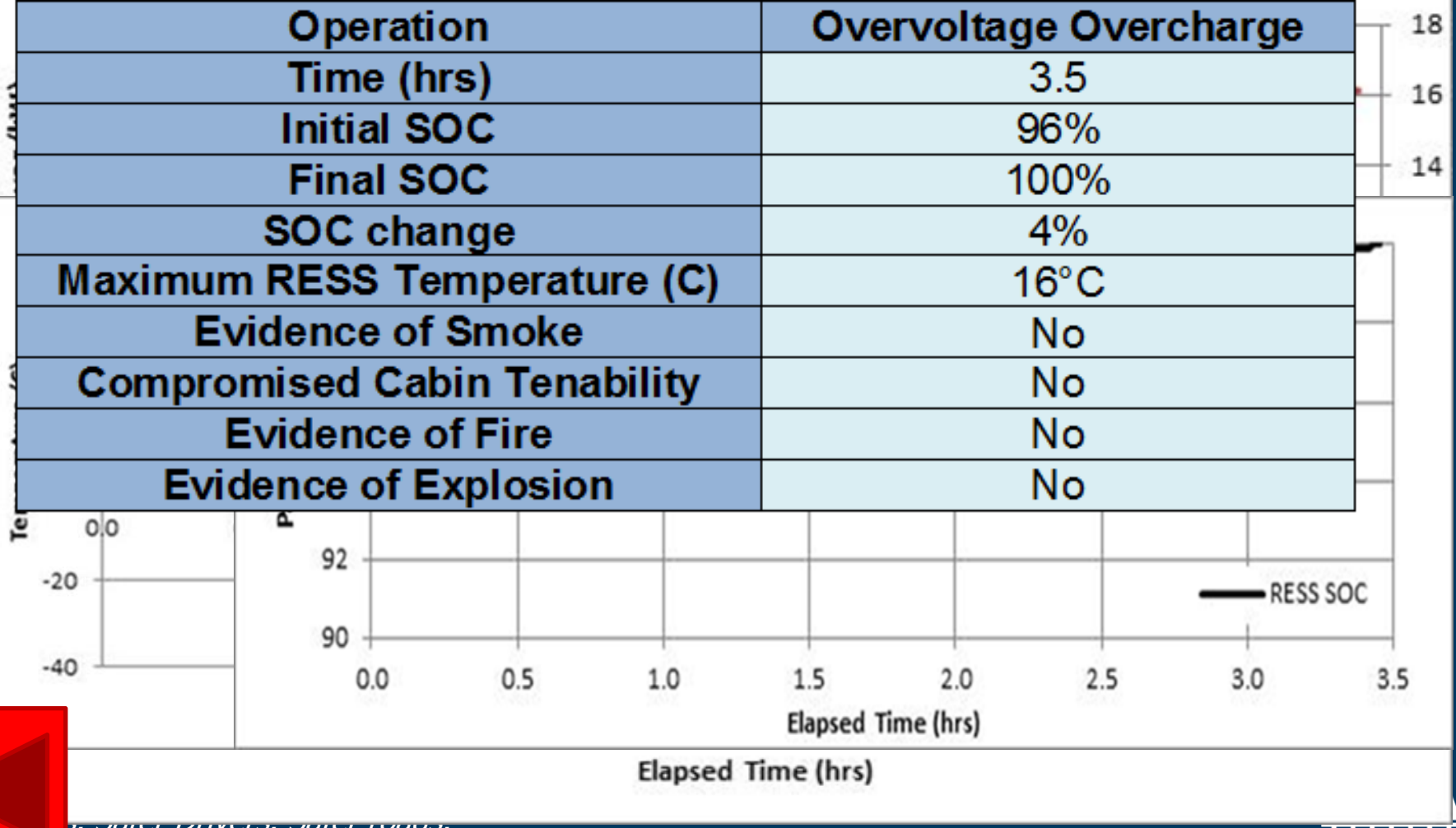
Operation	Over-current overcharge
Time (hrs)	2.5
Initial SOC	95%
Final SOC	95.6%
SOC change	
Maximum RESS Temp	
Evidence of Sm	
Compromised Cabin	
Evidence of F	
Evidence of Expl	



Over-Voltage Overcharge

Manufacturer A Vehicle: Over Voltage Overcharge

Operation	Overvoltage Overcharge
Time (hrs)	3.5
Initial SOC	96%
Final SOC	100%
SOC change	4%
Maximum RESS Temperature (C)	16°C
Evidence of Smoke	No
Compromised Cabin Tenability	No
Evidence of Fire	No
Evidence of Explosion	No

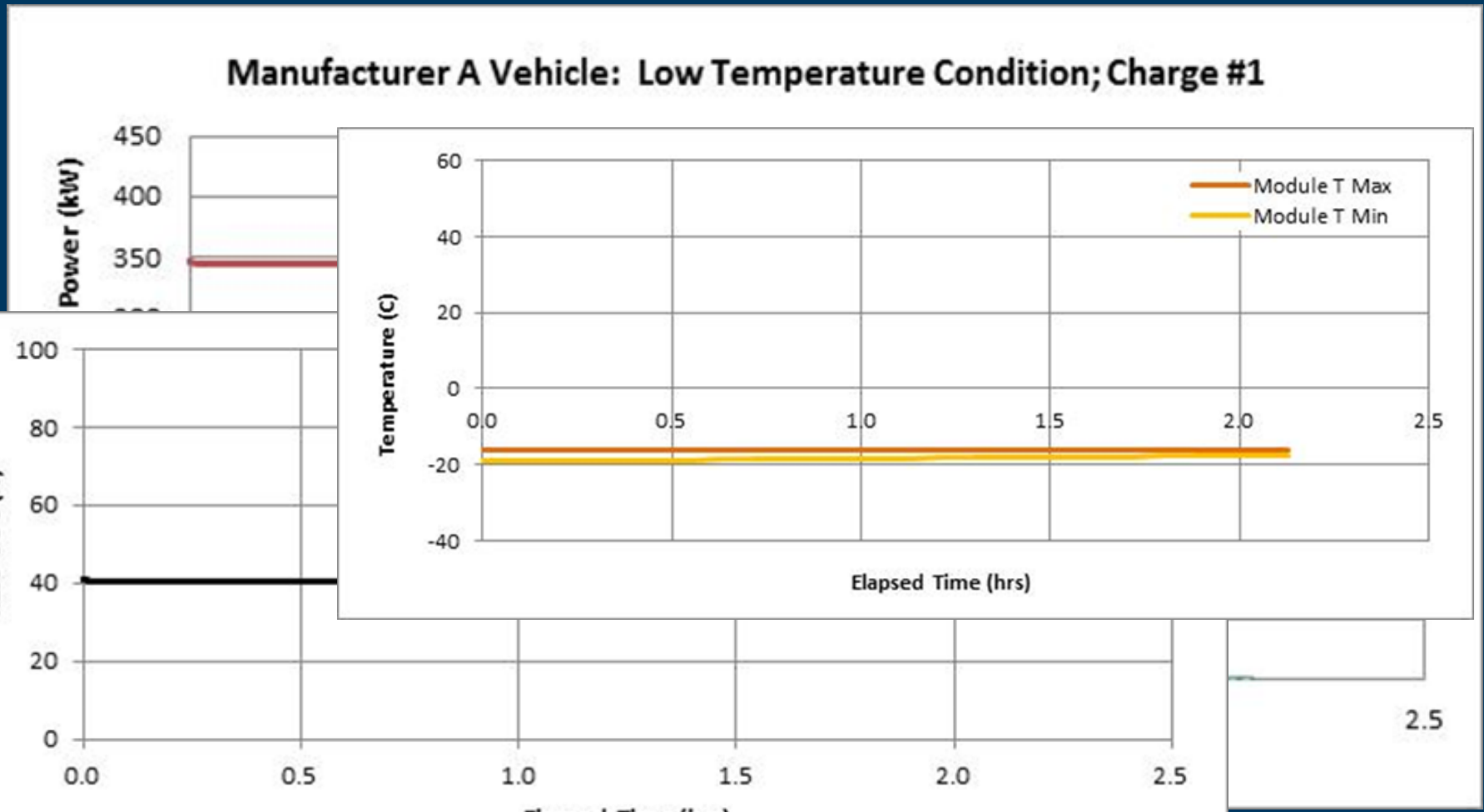


Over-Discharging

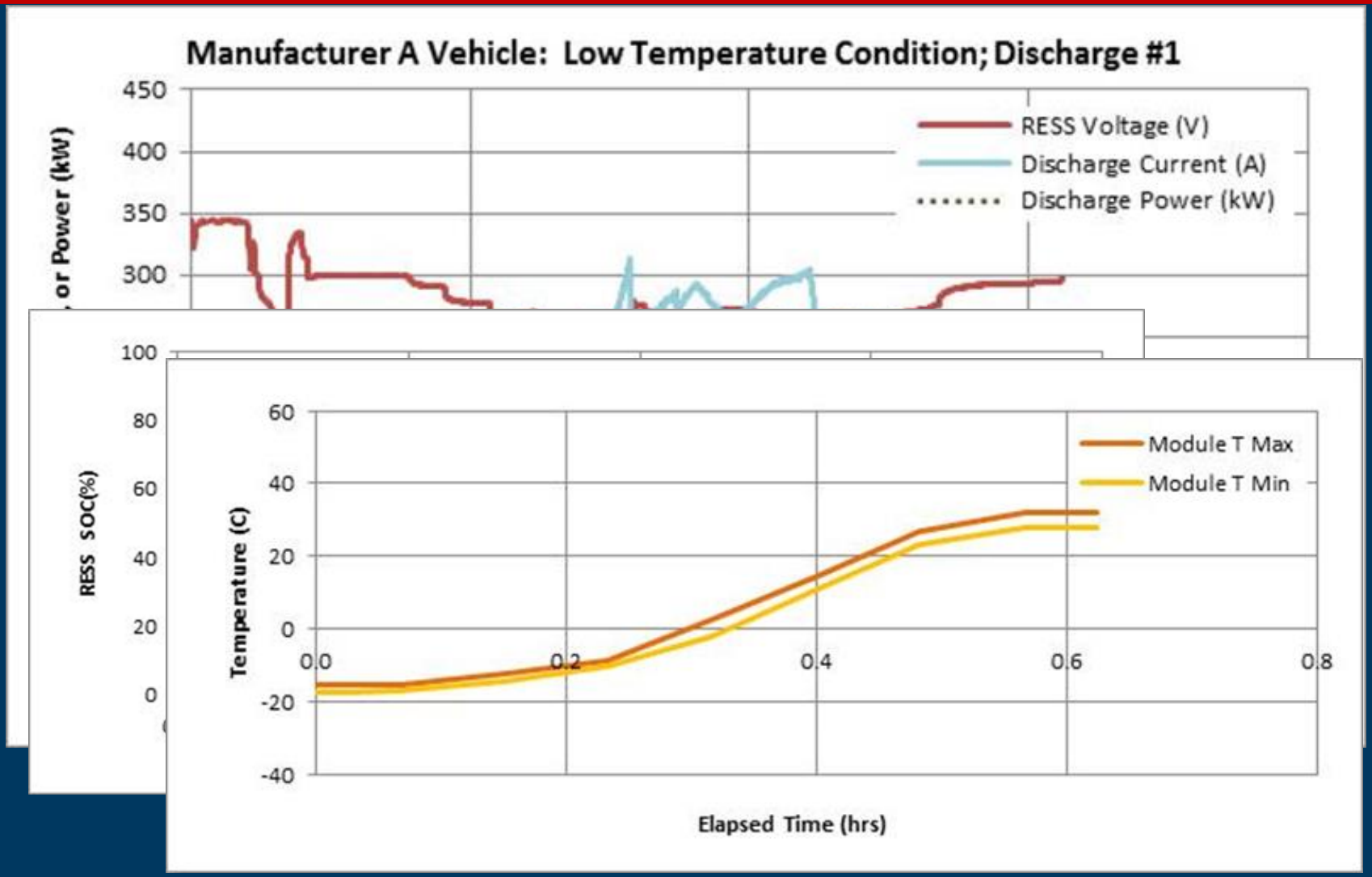
Operation	Drive Mode	Charge Mode
Time (hours)	4.2	
Initial SOC	12%	8%
Final SOC	8%	7%
SOC change	4%	1%
Maximum RESS Temperature (C)	22°C	16°C
Evidence of Smoke	No	No
Compromised Cabin Tenability	No	No
Evidence of Fire	No	No
Evidence of Explosion	No	No

Operation under Extreme Temperature Conditions

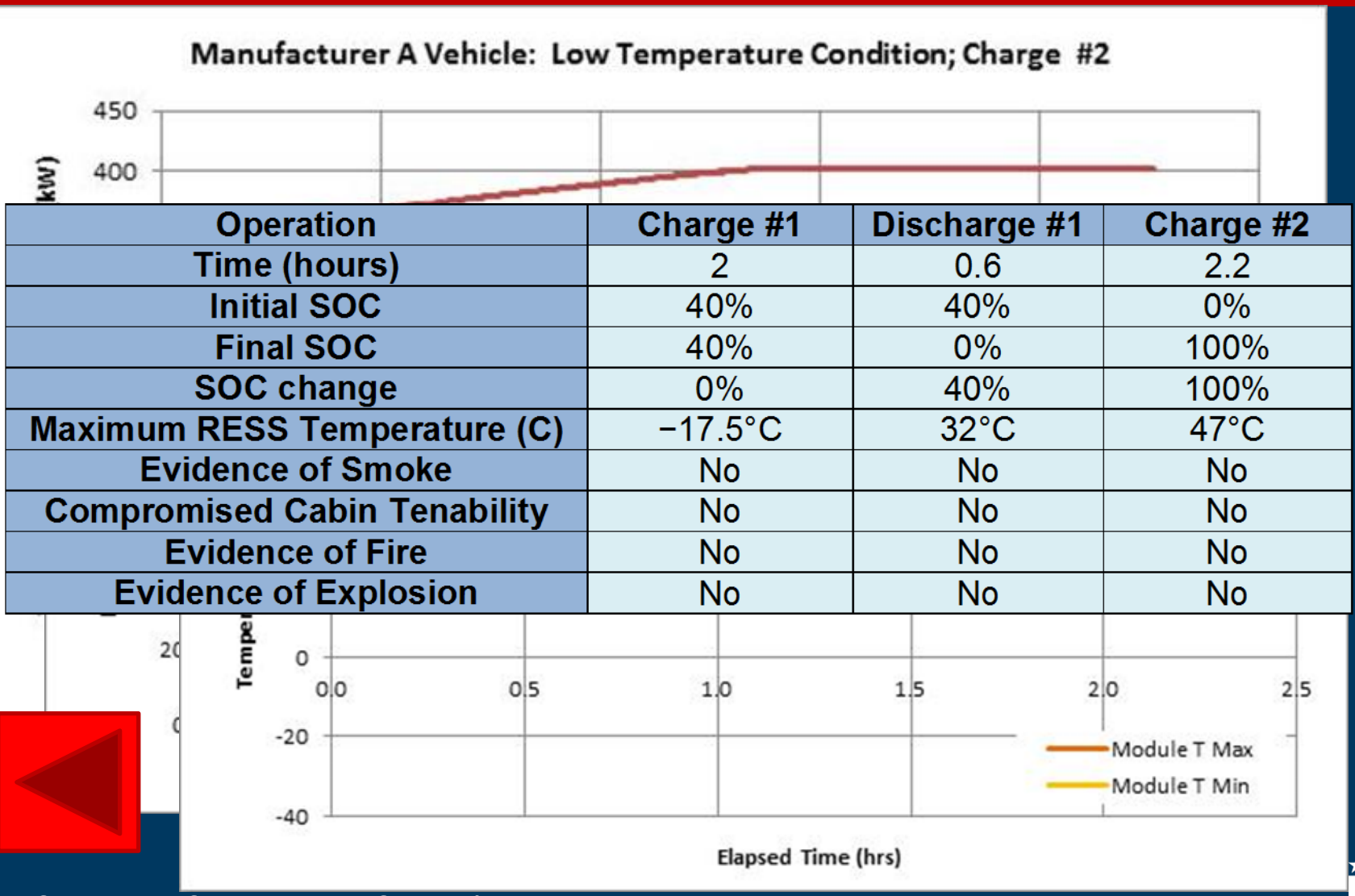
Charge #1 @ Low Temp



Discharge #1 @Low Temp

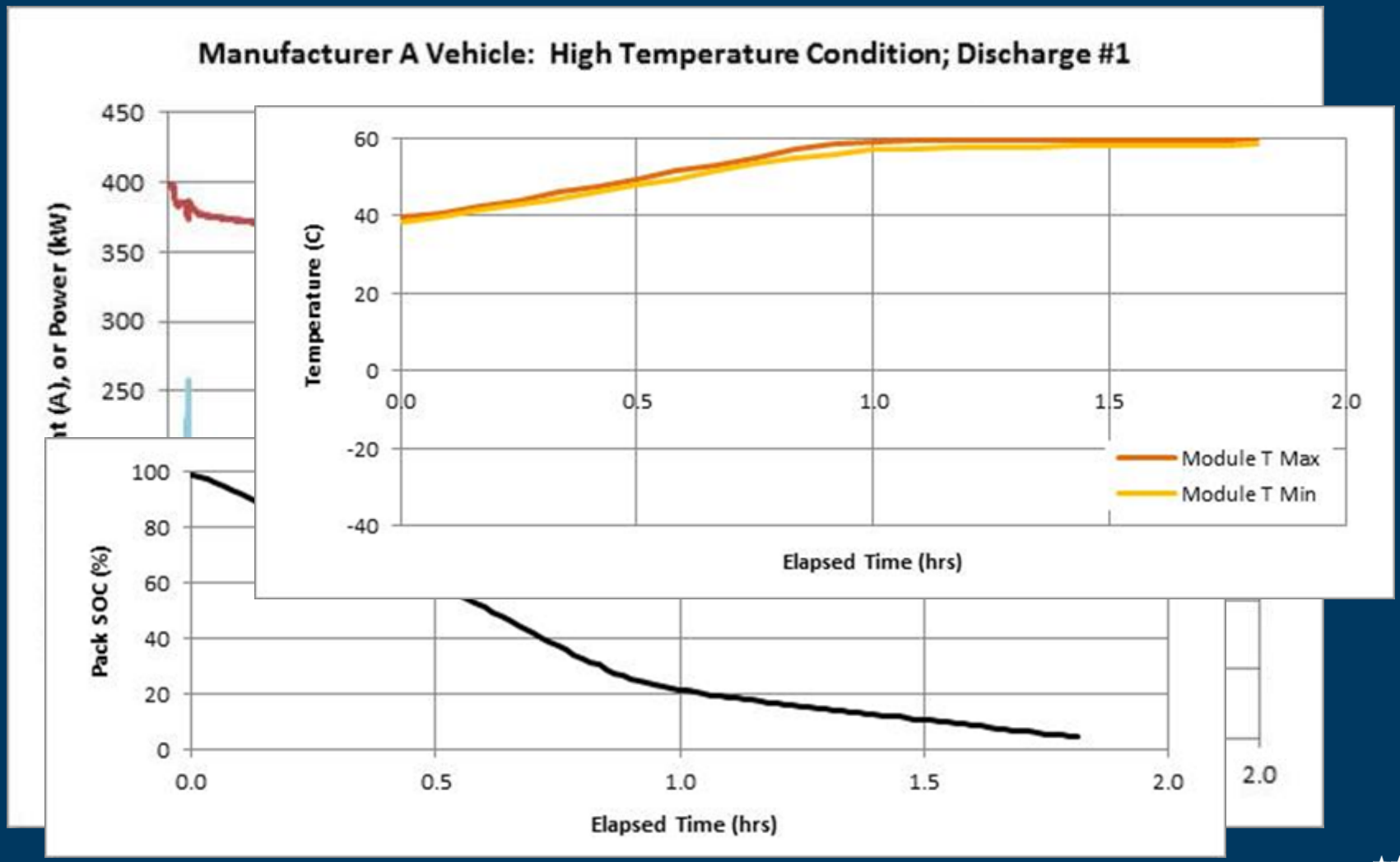


Charge #2 @Low Temp

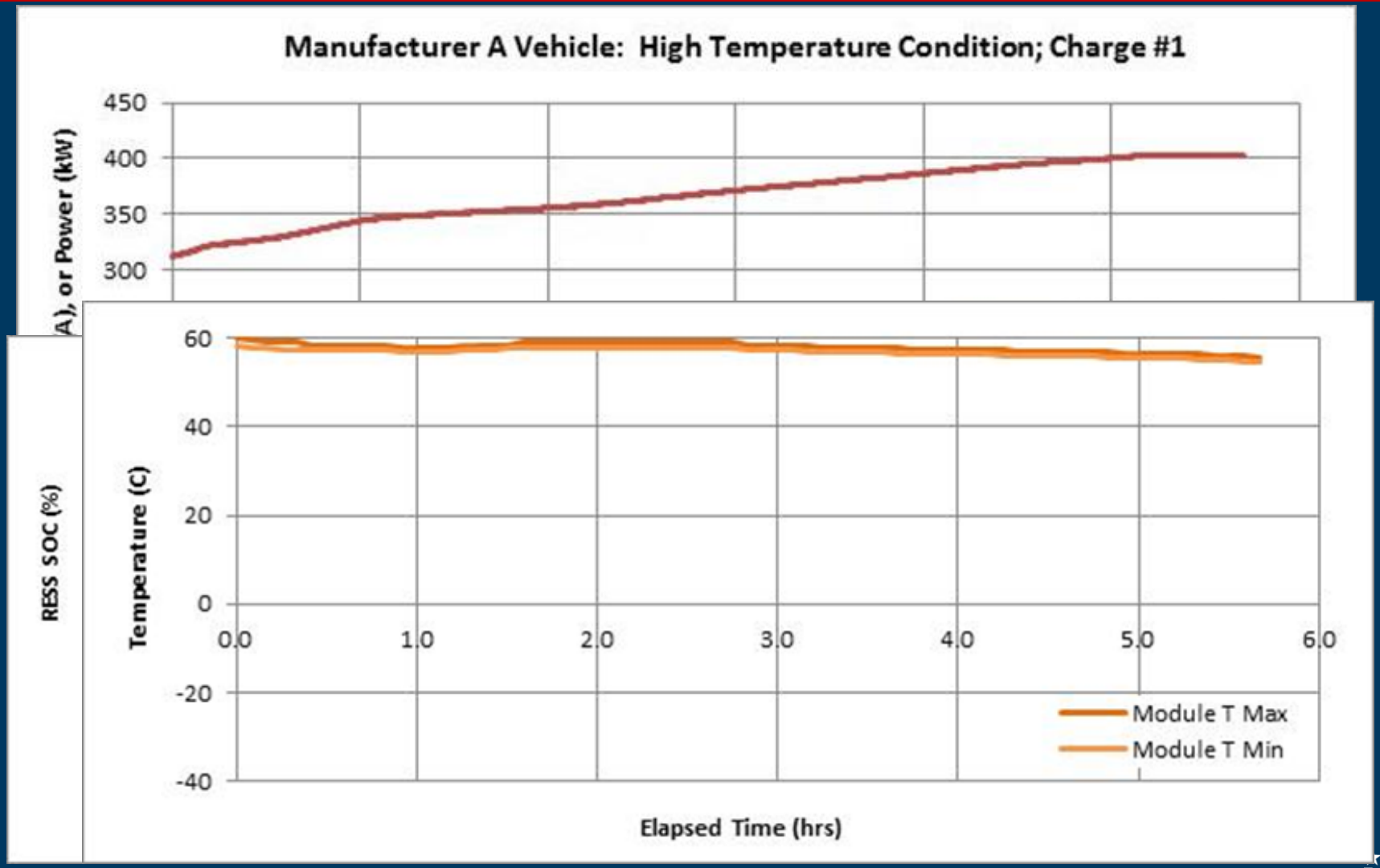


Operation	Charge #1	Discharge #1	Charge #2
Time (hours)	2	0.6	2.2
Initial SOC	40%	40%	0%
Final SOC	40%	0%	100%
SOC change	0%	40%	100%
Maximum RESS Temperature (C)	−17.5°C	32°C	47°C
Evidence of Smoke	No	No	No
Compromised Cabin Tenability	No	No	No
Evidence of Fire	No	No	No
Evidence of Explosion	No	No	No

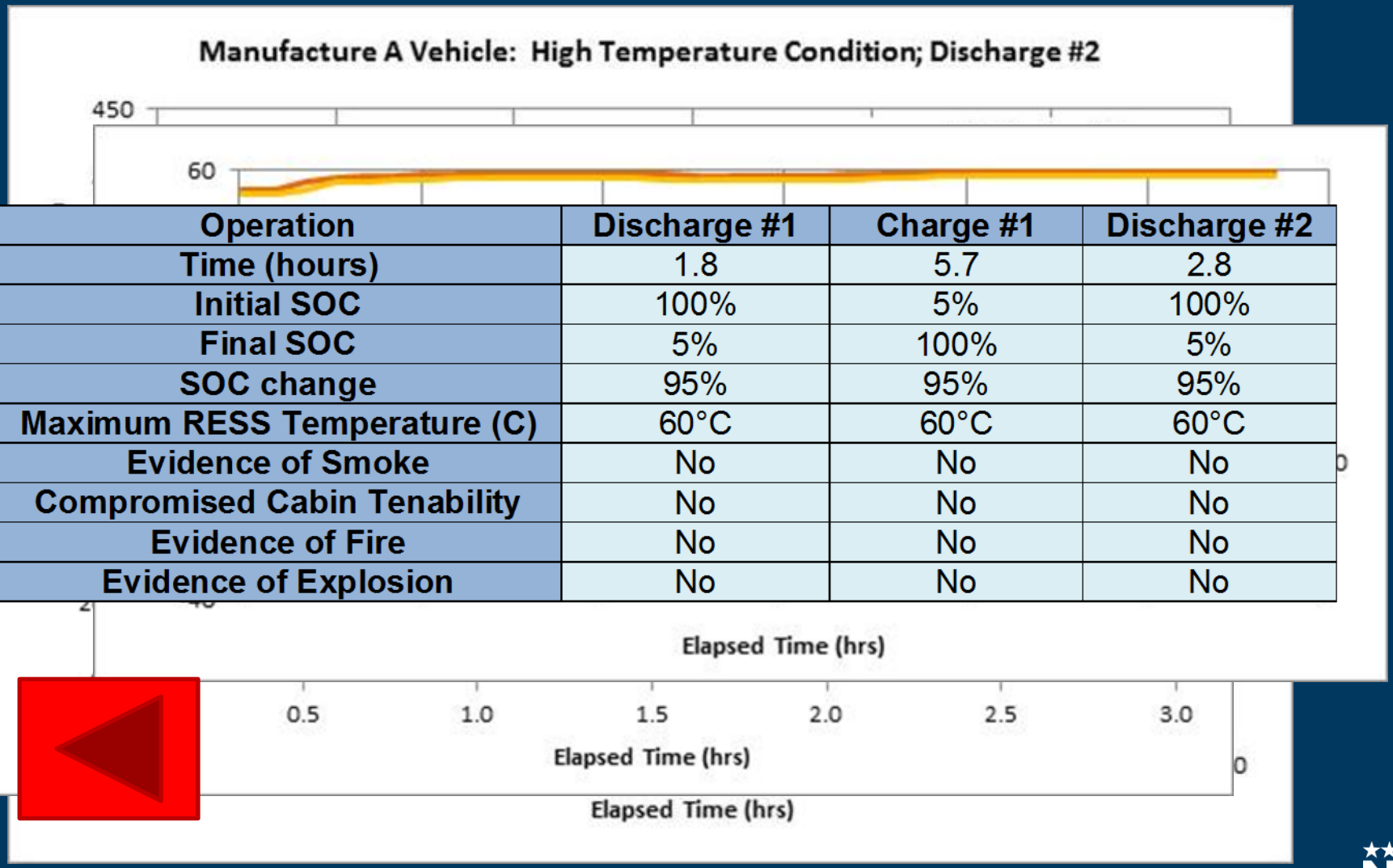
Discharge #1 @High-Temp



Charge #1 @High-Temp



Discharge #2 @ High-Temp

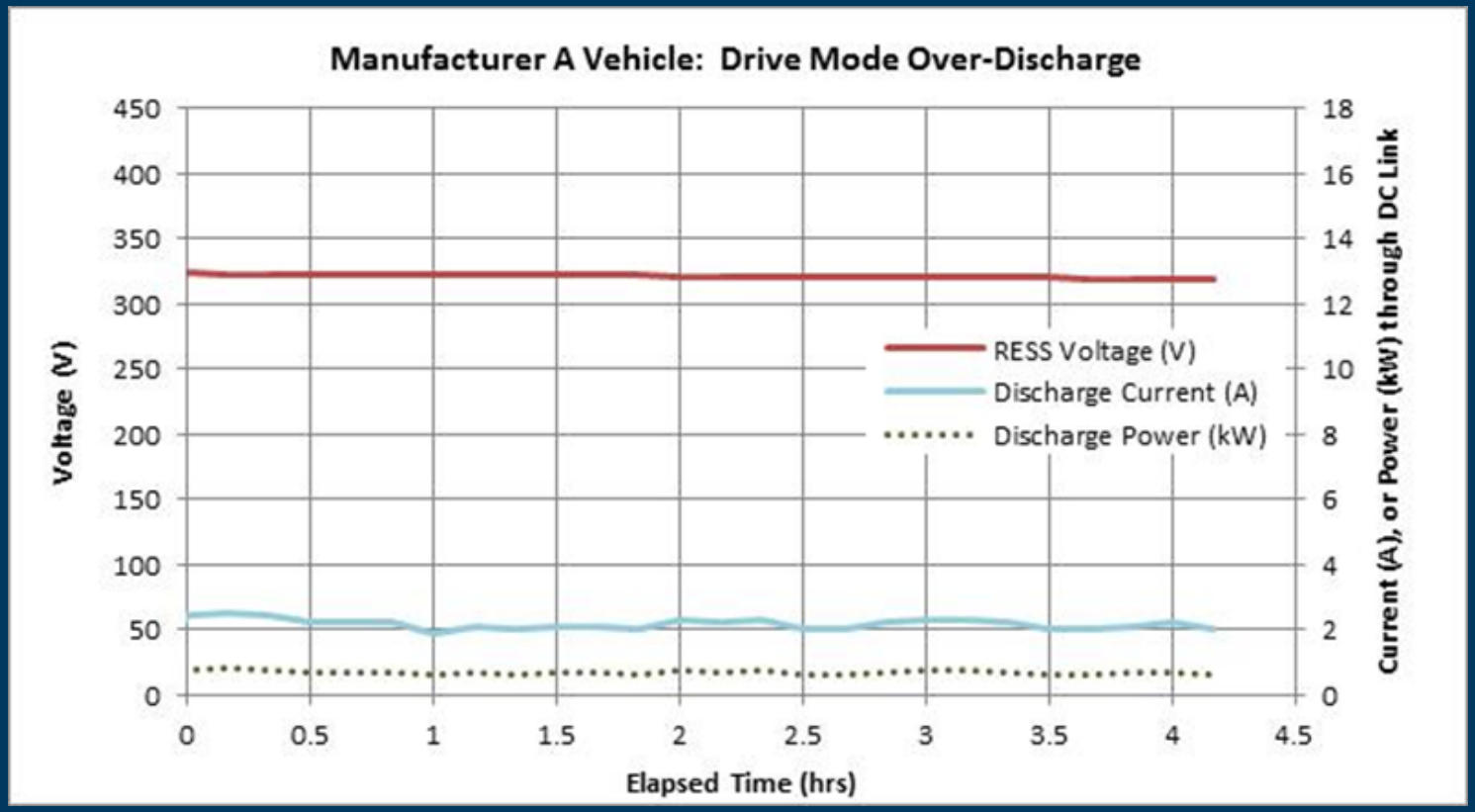


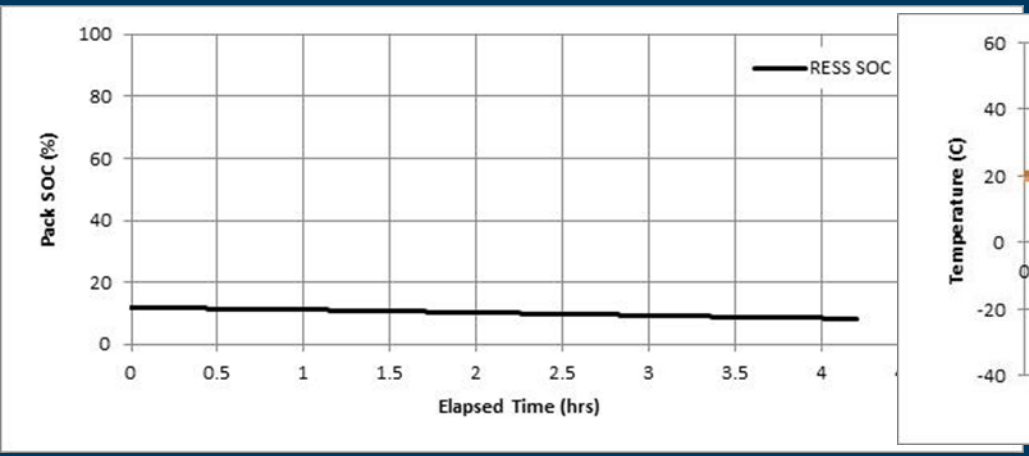
Operation	Discharge #1	Charge #1	Discharge #2
Time (hours)	1.8	5.7	2.8
Initial SOC	100%	5%	100%
Final SOC	5%	100%	5%
SOC change	95%	95%	95%
Maximum RESS Temperature (C)	60°C	60°C	60°C
Evidence of Smoke	No	No	No
Compromised Cabin Tenability	No	No	No
Evidence of Fire	No	No	No
Evidence of Explosion	No	No	No

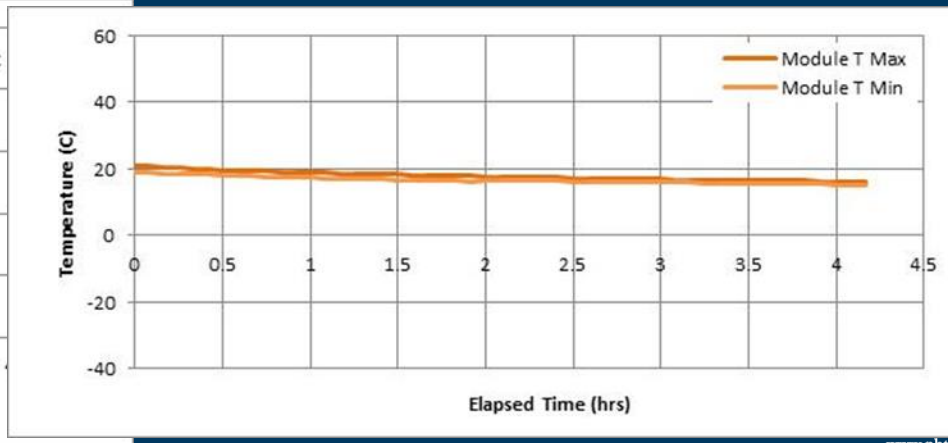
Additional slides

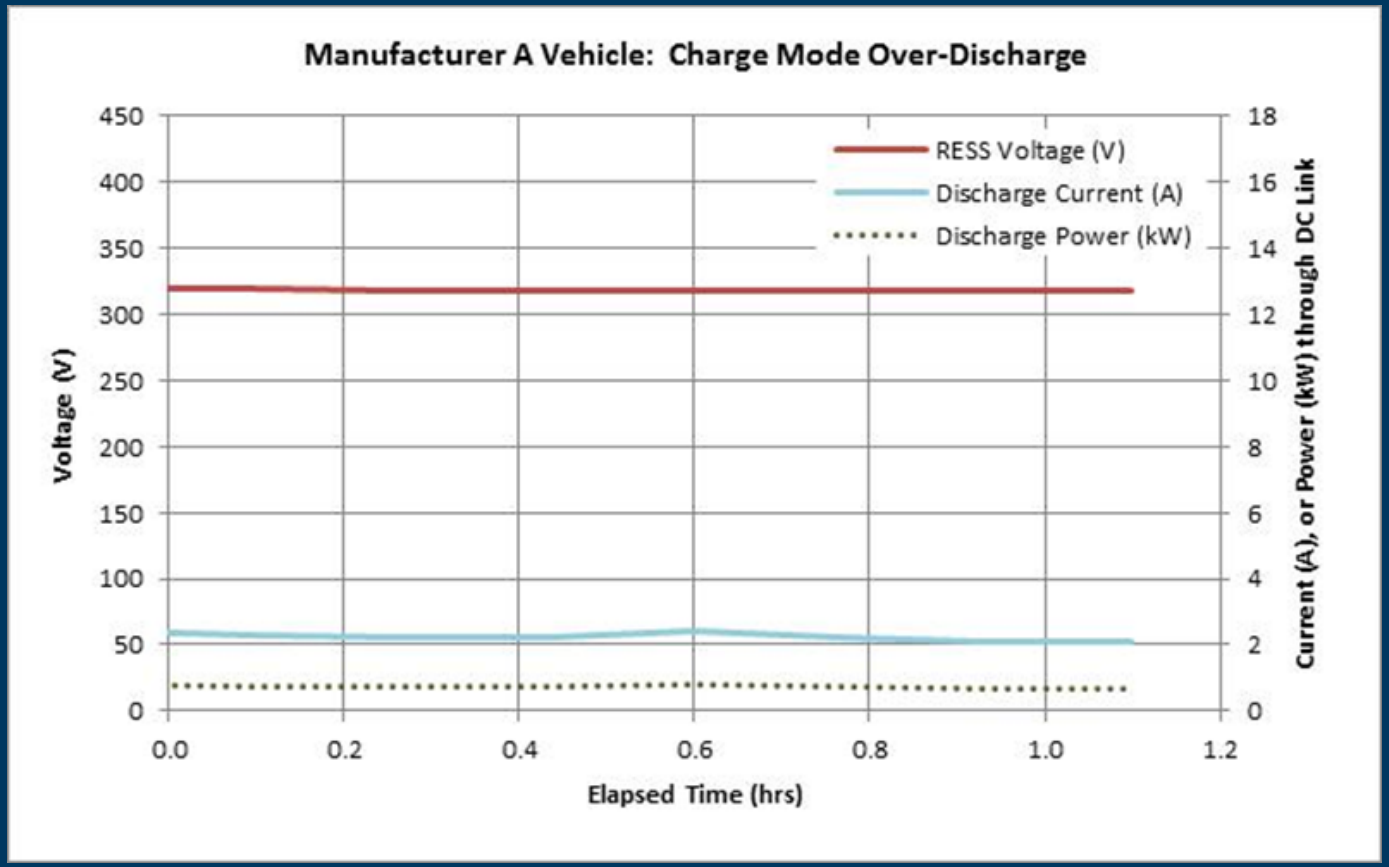
2) Over-Discharge

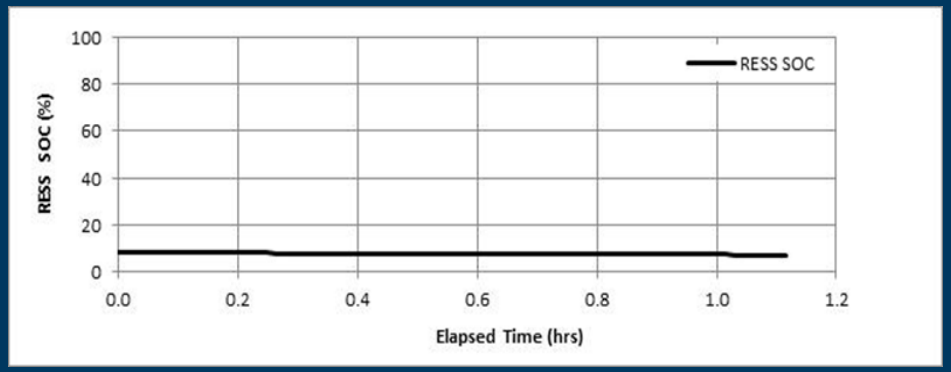
Prep	Procedure	Evaluation
• SOC at 10% • HEV and PHEV- remove fuel (5% full) • Prevent rolling or creep • Ambient T • DC Link	• HEV (**drive mode**) • No accel; over-discharge resistor; discharge @ less than 1kW; • EV/PHEV (**charge mode**)- use L1 charger	• Collect the data • Run till Voltage reaches 0V (terminates) or up to 8hrs (DM) and up to 5 hours (CM) elapse

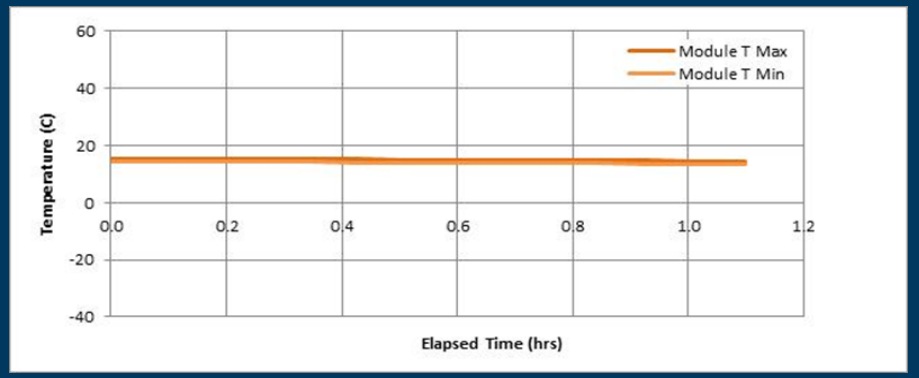

Manufacturer A Vehicle: Drive Mode Over-Discharge
Voltage (V)
Current (A), or Power (kW) through DC Link
Elapsed Time (hrs)
RESS Voltage (V)
Discharge Current (A)
Discharge Power (kW)
450
400
350
300
250
200
150
100
50
0
18
16
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5


Pack SOC (%)
Elapsed Time (hrs)
RESS SOC
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4


Temperature (C)
Elapsed Time (hrs)
Module T Max
Module T Min
60
40
20
0
-20
-40
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5


Manufacturer A Vehicle: Charge Mode Over-Discharge
RESS Voltage (V)
Discharge Current (A)
Discharge Power (kW)
Voltage (V)
Current (A), or Power (kW) through DC Link
Elapsed Time (hrs)
450
400
350
300
250
200
150
100
50
0
18
16
14
12
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2


RESS SOC
RESS SOC (%)
Elapsed Time (hrs)
100
80
60
40
20
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2


Module T Max
Module T Min
Temperature (C)
Elapsed Time (hrs)
60
40
20
0
-20
-40
0.0
0.2
0.4
0.6
0.8
1.0
1.2

Risk Areas/Safety Needs

- In hybrid and electric vehicles, the BMS is perhaps the most critical component next to the battery as the BMS is involved in monitoring and controlling every major aspect of the system. Charging of these vehicles occurs daily and any mismanagement of such system from over-current and over-voltage overcharging, over temperature and over discharging conditions could lead into dangerous situations. Overcharging is generally considered one of the most hazardous failure modes for lithium-ion cell where significant overcharging can result in lithium-ion cell thermal runaway, while a minor overcharging can result in lithium plating that comprises cell safety characteristics. Charging in high temperature could initiate a temperature imbalance which can occur during operation, and if appropriate steps are not taken by the BMS, may lead to thermal runaway of cells. In addition, it has been recognized that over-discharging could lead to undesirable again , electrolyte leakage, and swelling or even violent failure if not well managed. Therefore, it is paramount to ensure that the BMS is up to the task of performing properly even under extreme conditions like over-current and over-voltage overcharging, over temperature and over discharge conditions to ensure that the battery and the system itself is protected from damage that could be detrimental to both the vehicle and the end user.