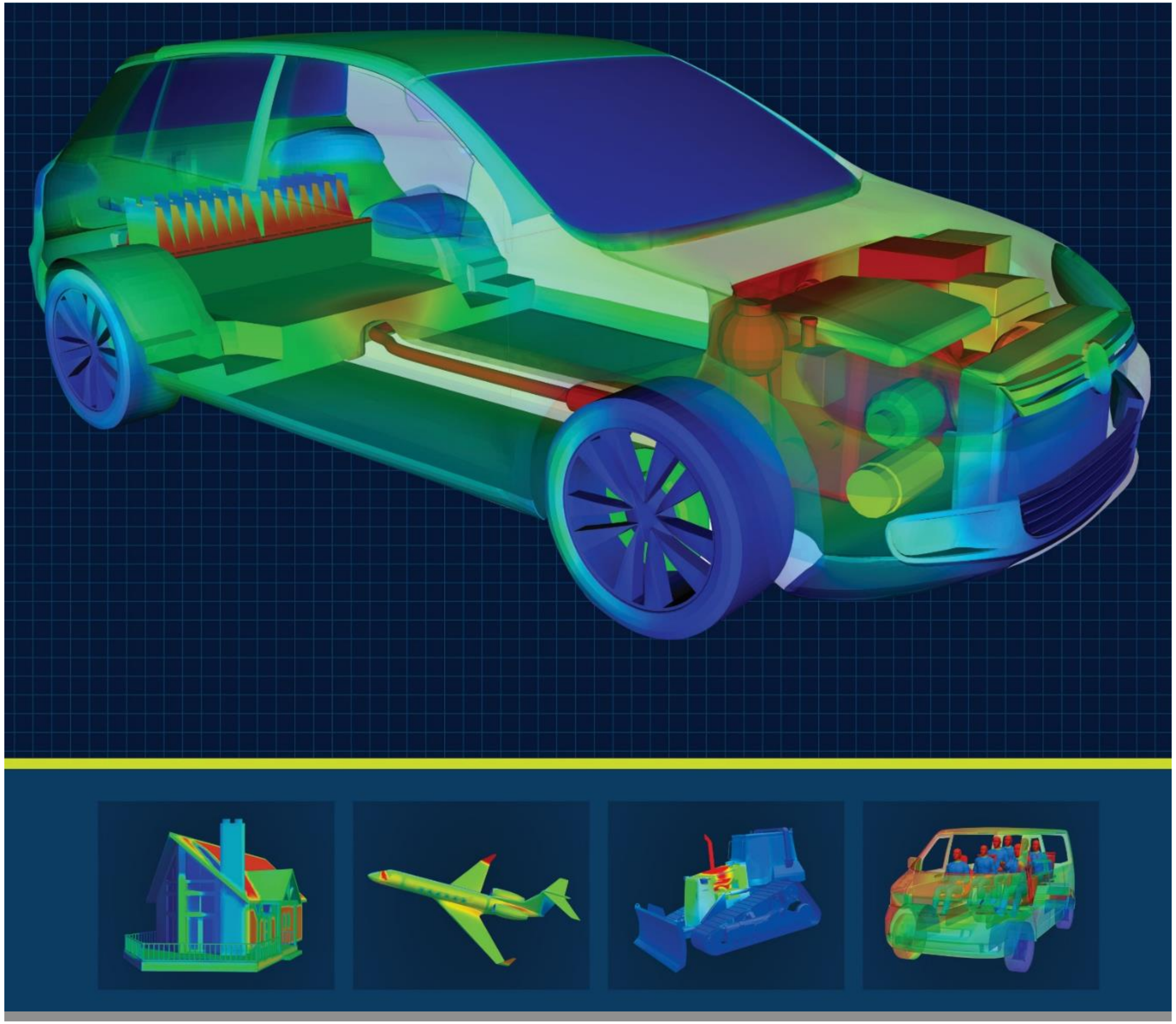
Battery Modeling for Performance, Lifetime, and Safety

Zachary Edel, Ph.D., Senior Research Engineer

THERMO ANALYTICS

Agenda

- Introduction
- TAITherm battery models
- Case studies
  - Hybrid Electric Vehicle
  - Battery Electric Vehicle
  - Thermal Runaway
- New Features



Current Challenges in EV Batteries

- Thermal Management
- Life span: increasing both cycle stability and calendar age
- Performance in harsh environments:
  - Difficult to optimize performance for wide range for temperatures
- Capacity
  - Driving range
- Charging time
- Safety: i.e. avoiding thermal runaway
- Cost
  - Need to be reduced to compete with gasoline vehicles

Battery Models in TAITherm

Battery Models in TAITherm

- Electrical and thermal behaviors are coupled

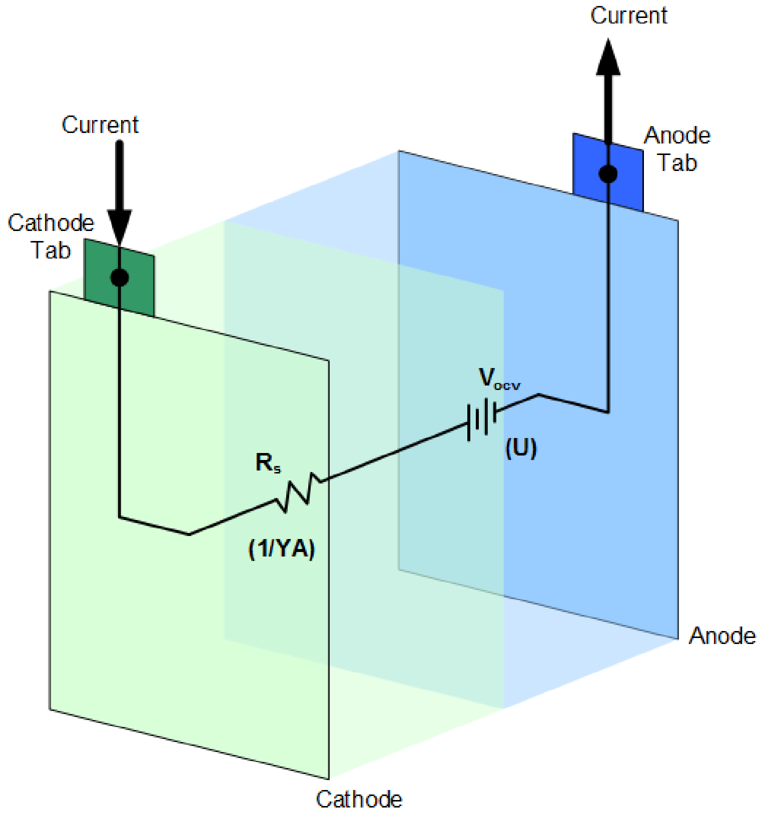
Battery resistance depends on temperature and DoD

T depends on resistive heating and chemical reactions

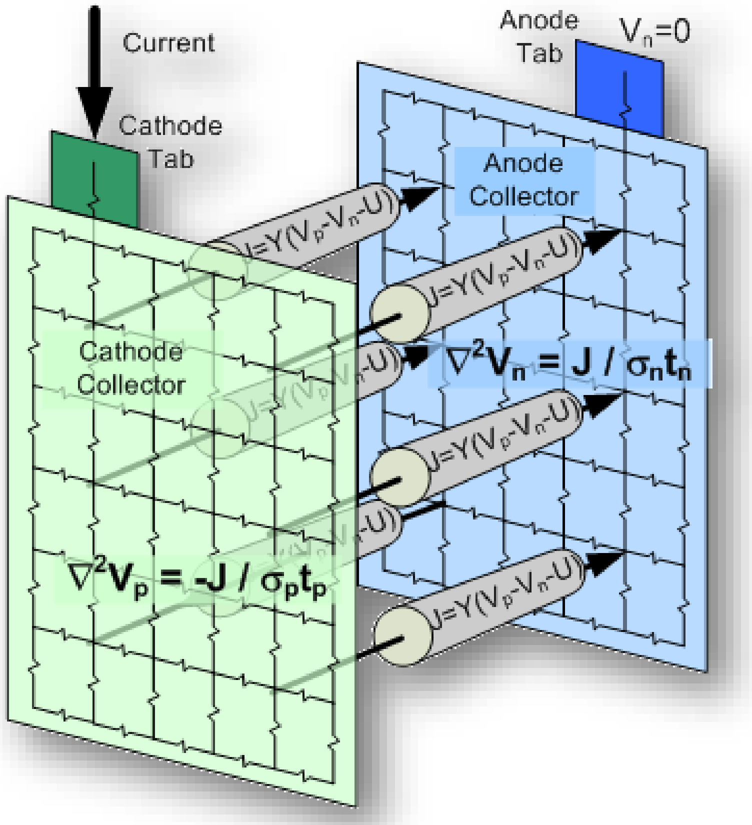
- Battery models compute an imposed heat on the battery geometry
- Imposed heat computed by solving electrical circuit equations

TAITherm Battery Models Overview

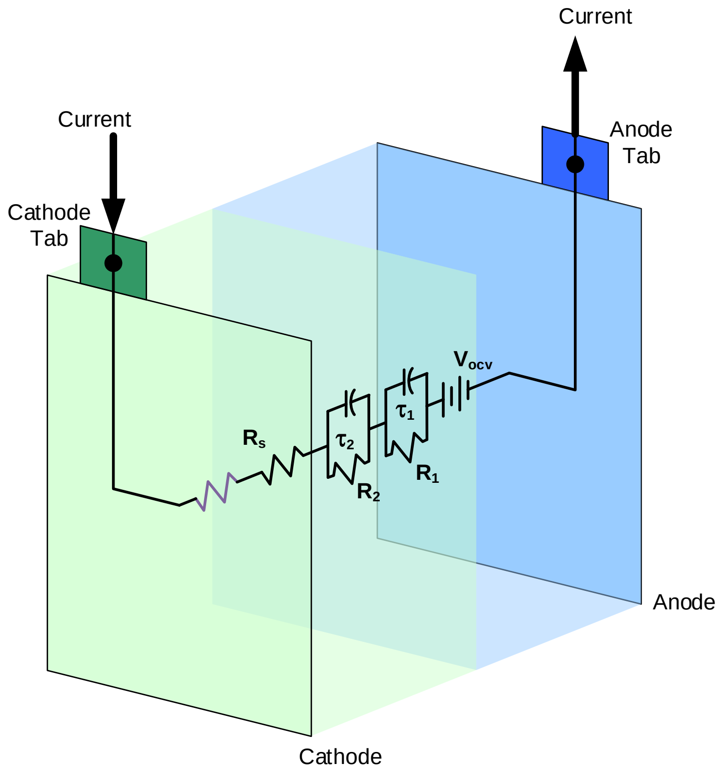
NTG Equivalent Circuit Model



NTG Distributed Model

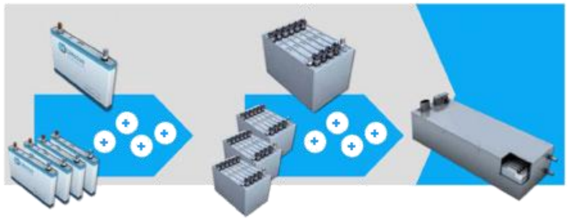


NREL Equivalent Circuit Model

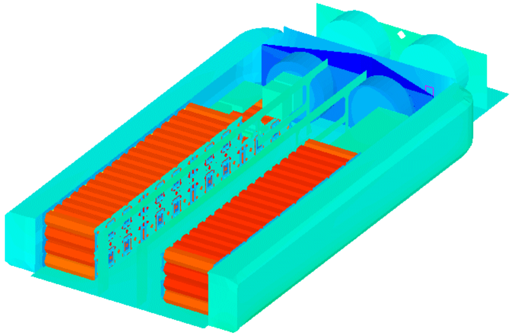


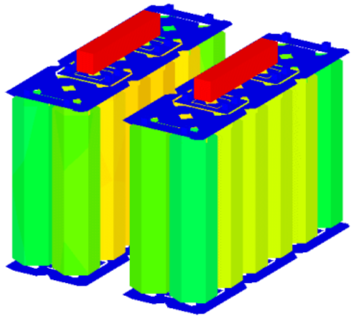
Case Studies: Cooling, Insulation, and Heat Protection

Battery Design Considerations



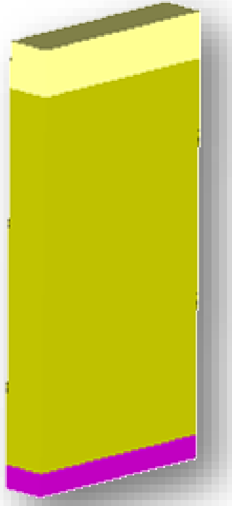
- Battery Cells, Packs & Systems
  - Cells – uniform current distribution, temperature distribution
  - Packs – uniform cooling, environmental effects
  - Systems – Cell balance (battery management), SOC estimation
- Cooling Strategies
  - Air
  - Liquid
  - Heat sink, cooling plates, heat pipe, ….
- Hybrid & Electric Vehicle Batteries
  - Performance (temperature dependent)
  - Lifetime & Durability
  - Safety (thermal runaway)



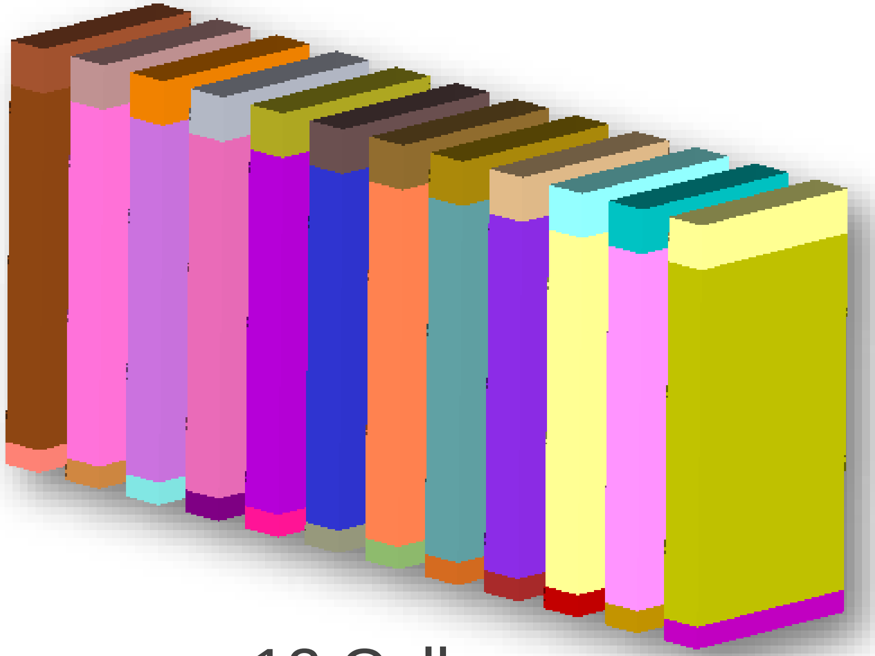


Case Study 1: Plug-in Hybrid

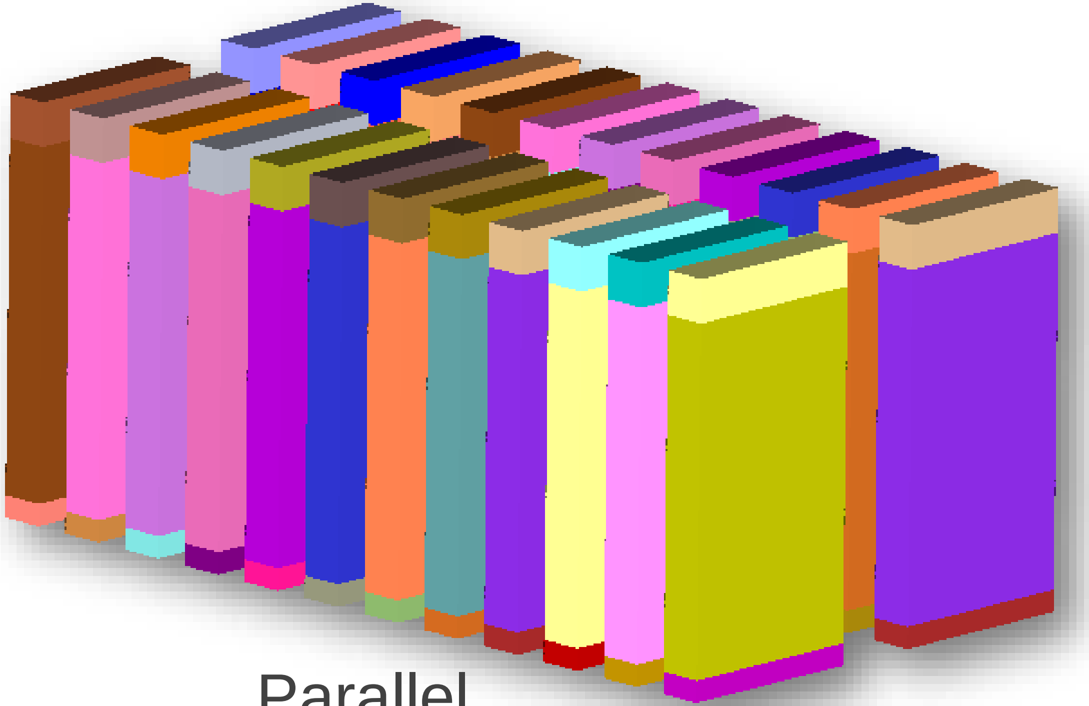
Example 1: Plug-in Hybrid



Nominal
4 Volt Cell

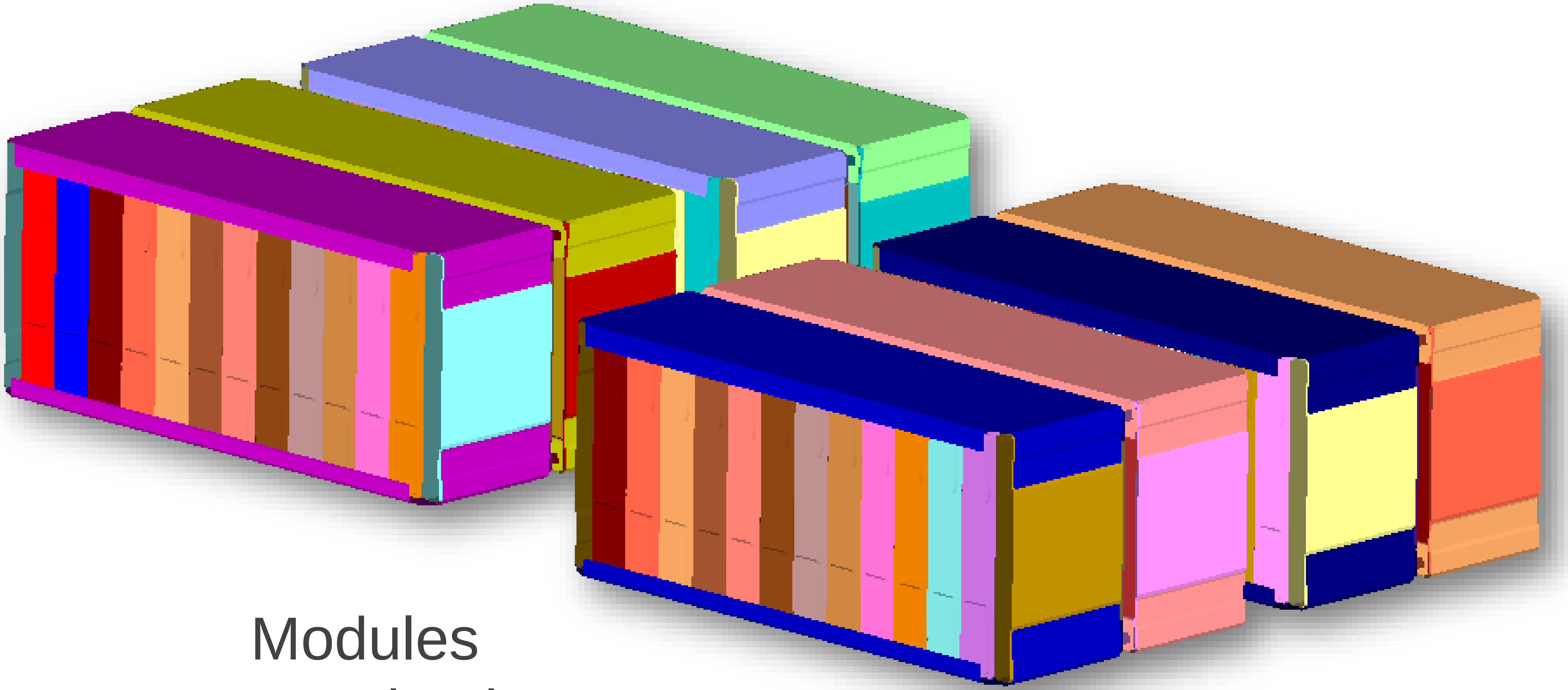


12 Cells
Connected in
Series – 48 Volt



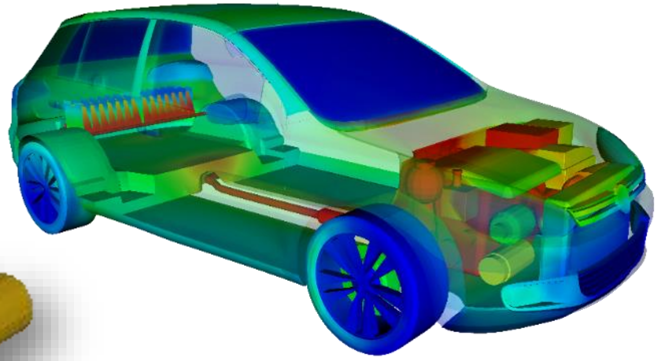
Parallel
connections
increase
capacity

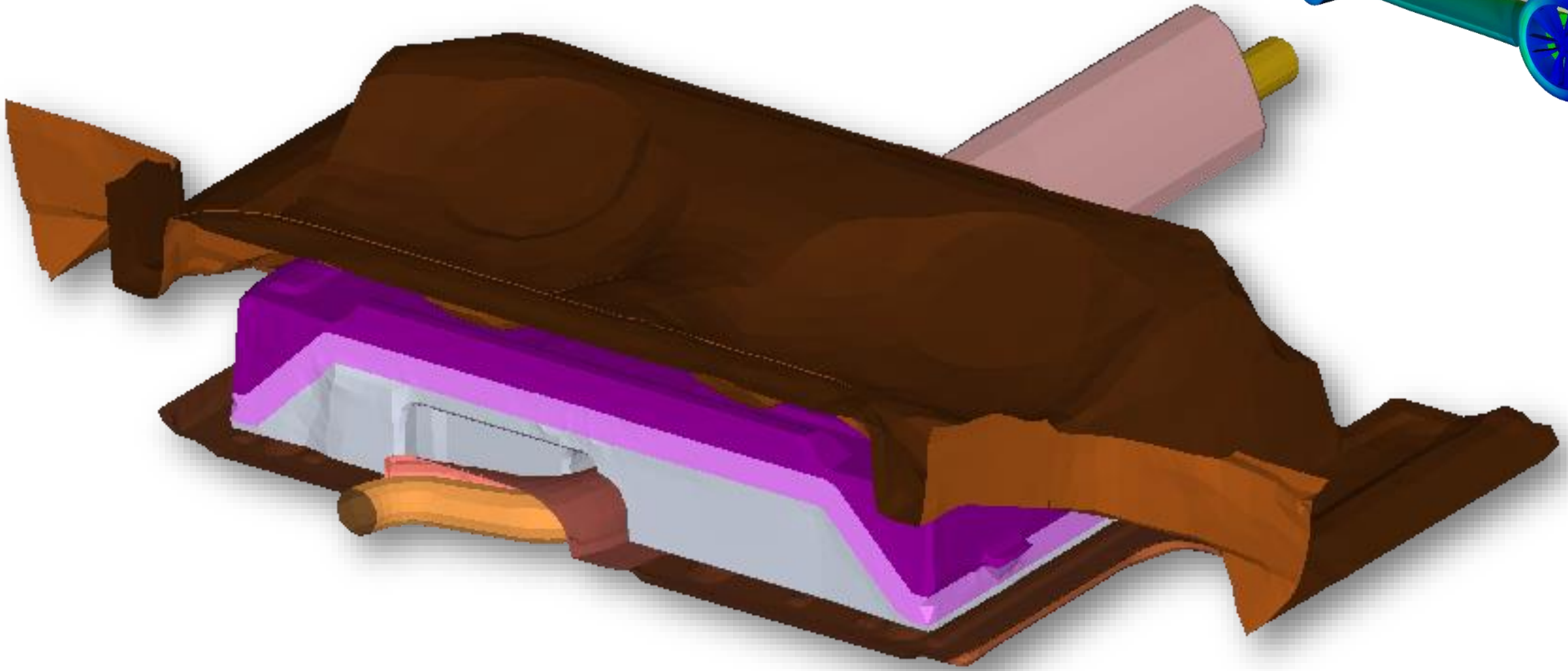
Case Study Geometry



Modules
organized
into a **Pack**

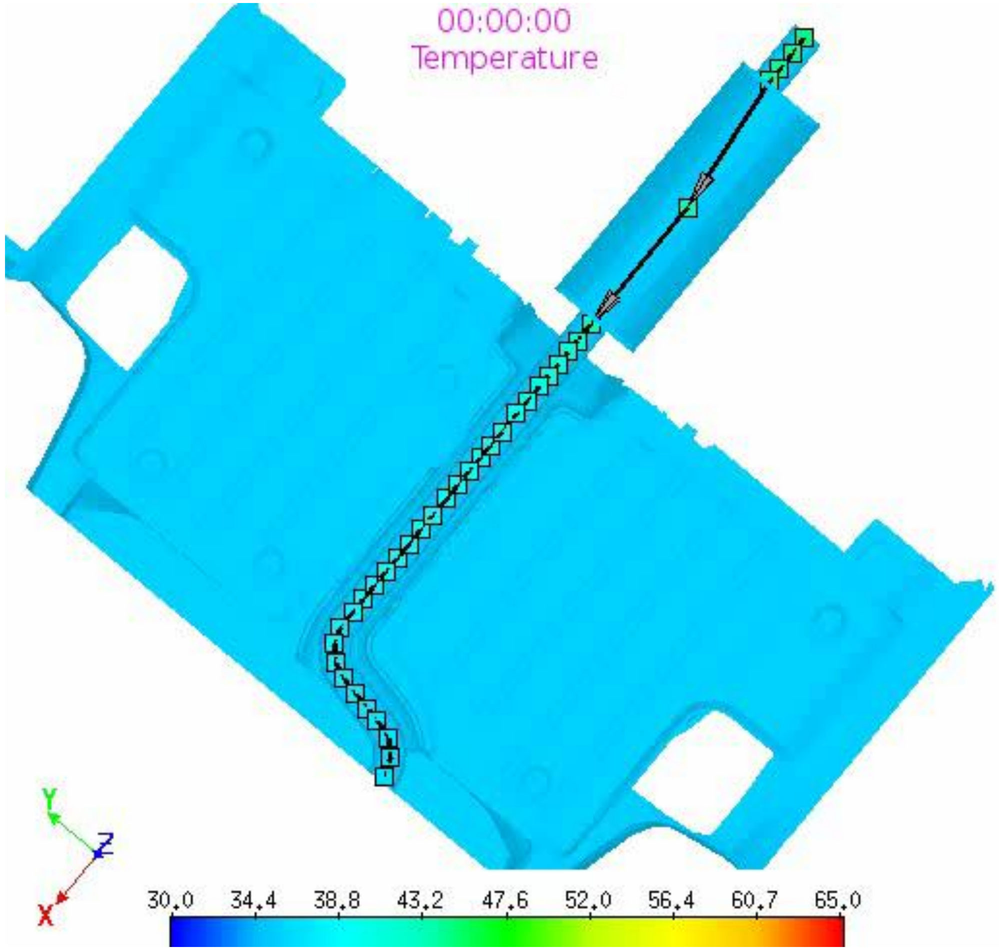
Case Study Geometry

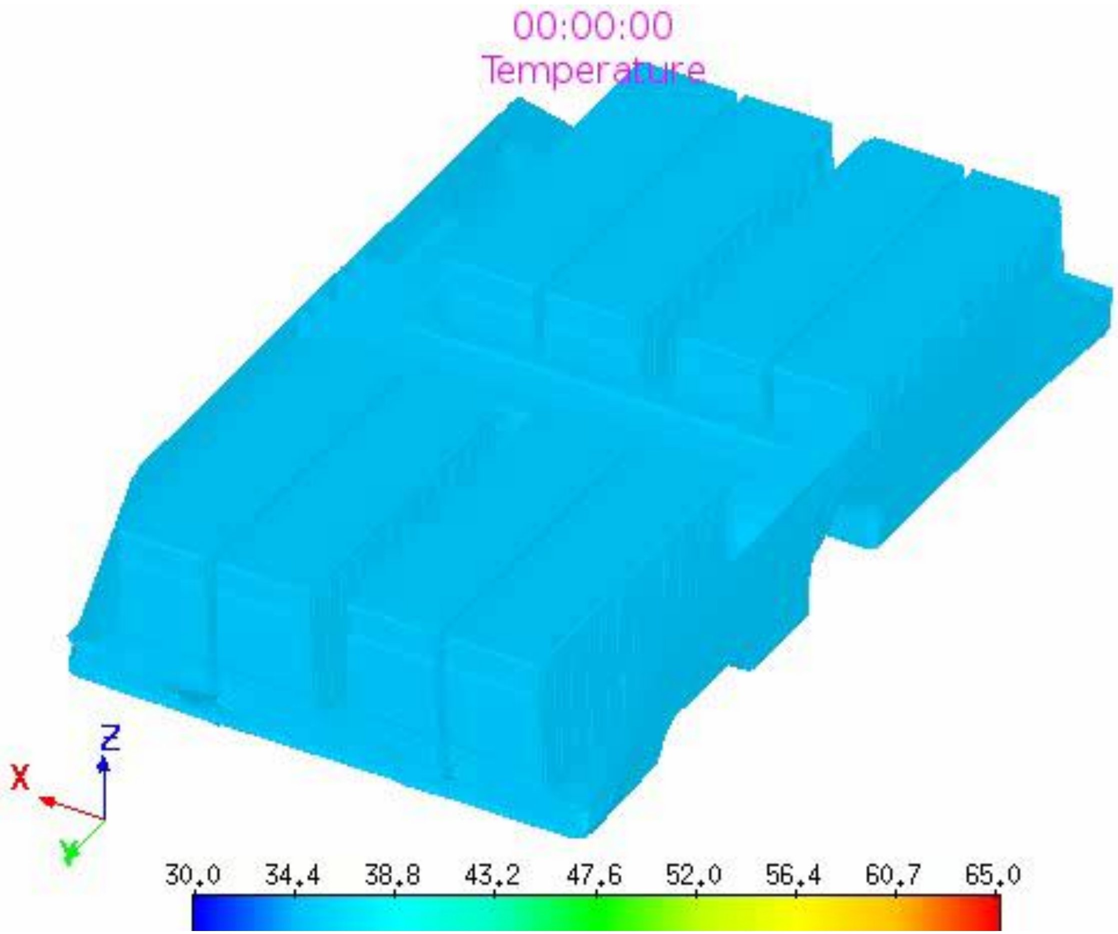




Box packaged in a vehicle underbody

Temperature Results

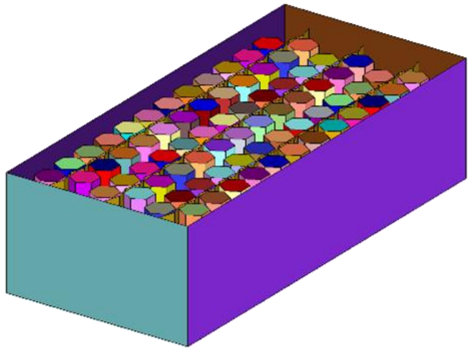
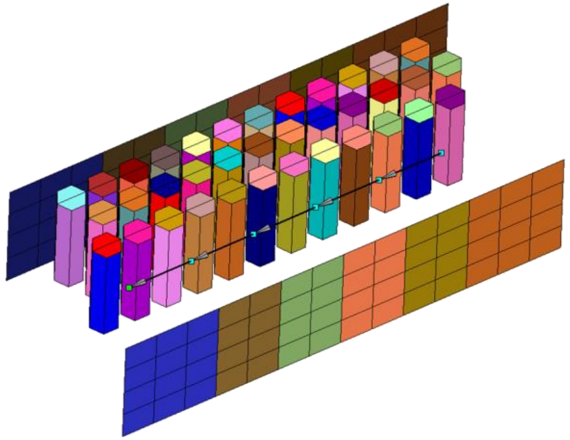
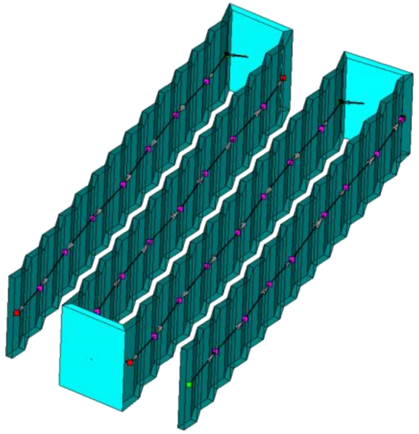




Case Study 2: Tesla Type Battery Pack

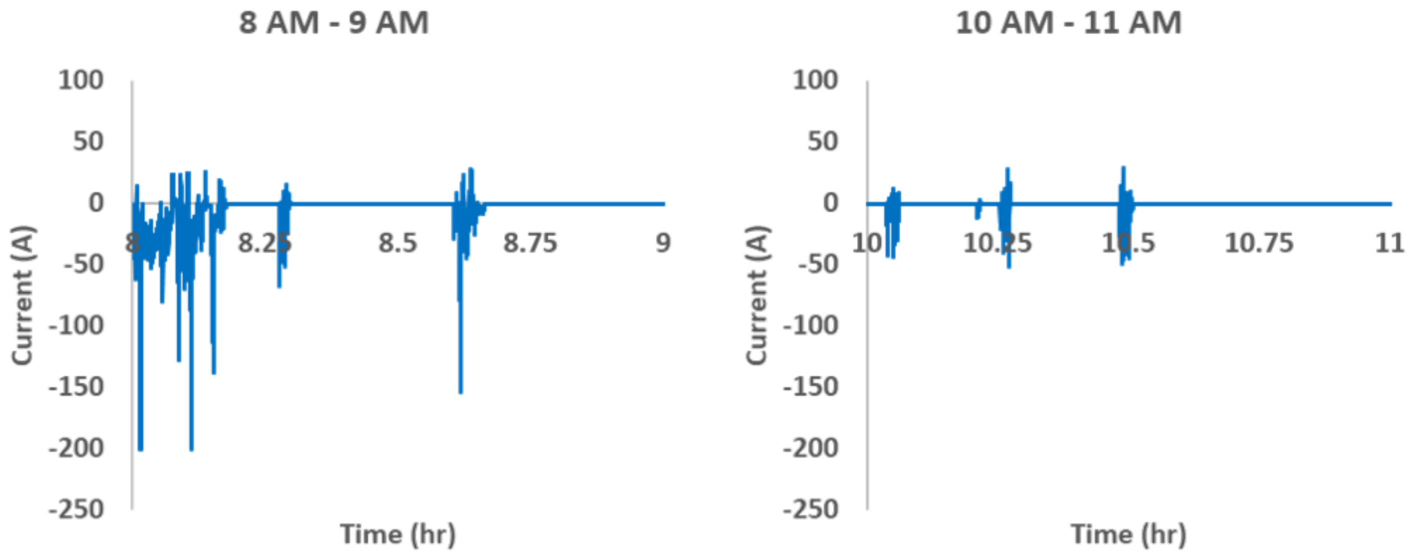
Model Comparison – Cooling Scenarios

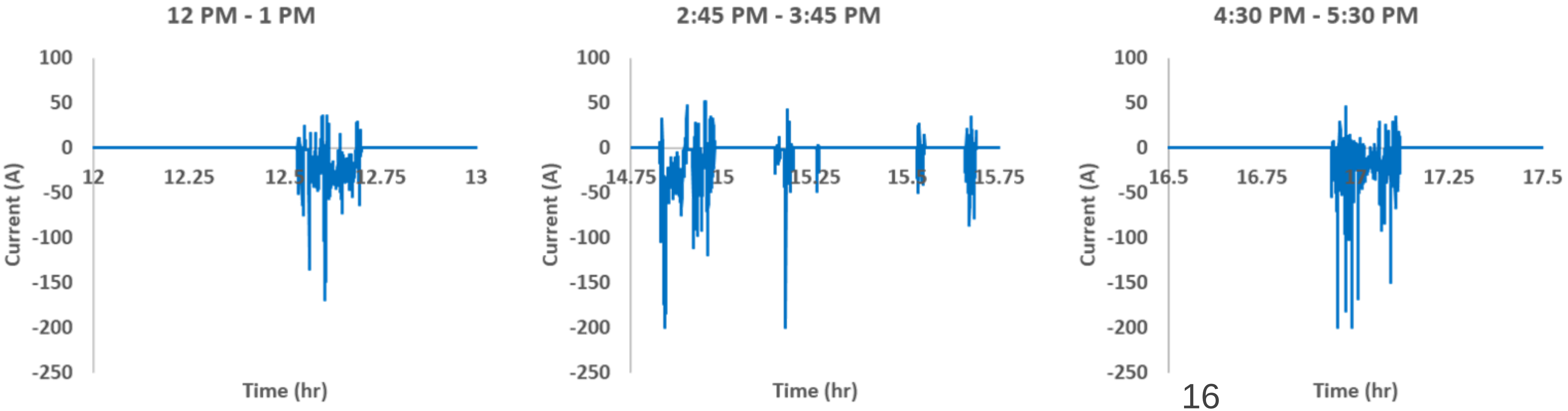
Boundary Conditions
Cabin Temp: Ambient/20°C
Location: Yuma, AZ
Background: Outdoor, Asphalt

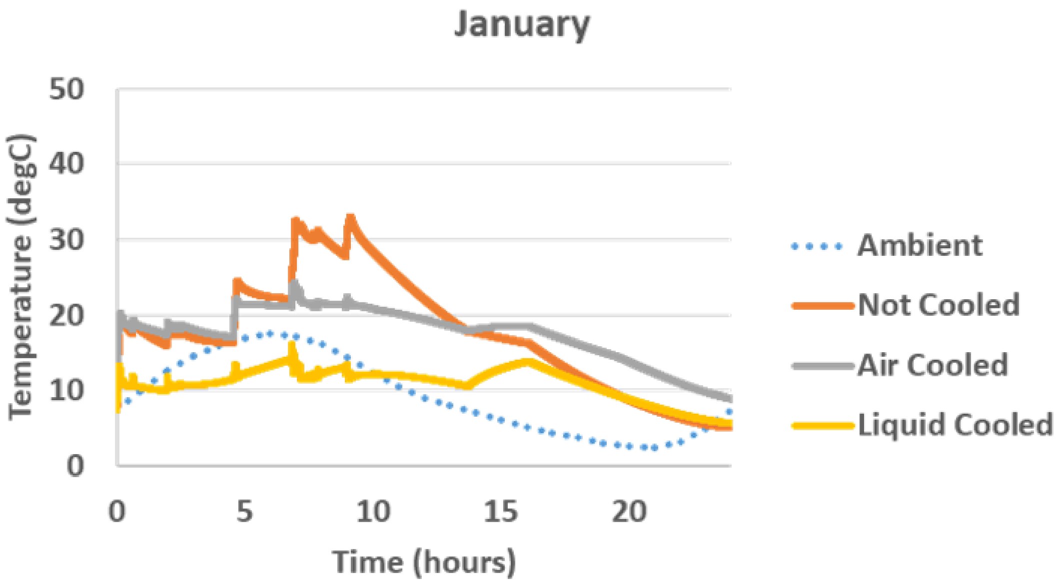
	Passively Cooled	Air Cooled	Liquid Cooled
Coolant Temperature	N/A	20°C	10°C
Cooling Operating Time	N/A	Drive Mode Only	Drive Mode Only
Fluid Model	1 Air Node	6 Air Nodes	20 Coolant Nodes

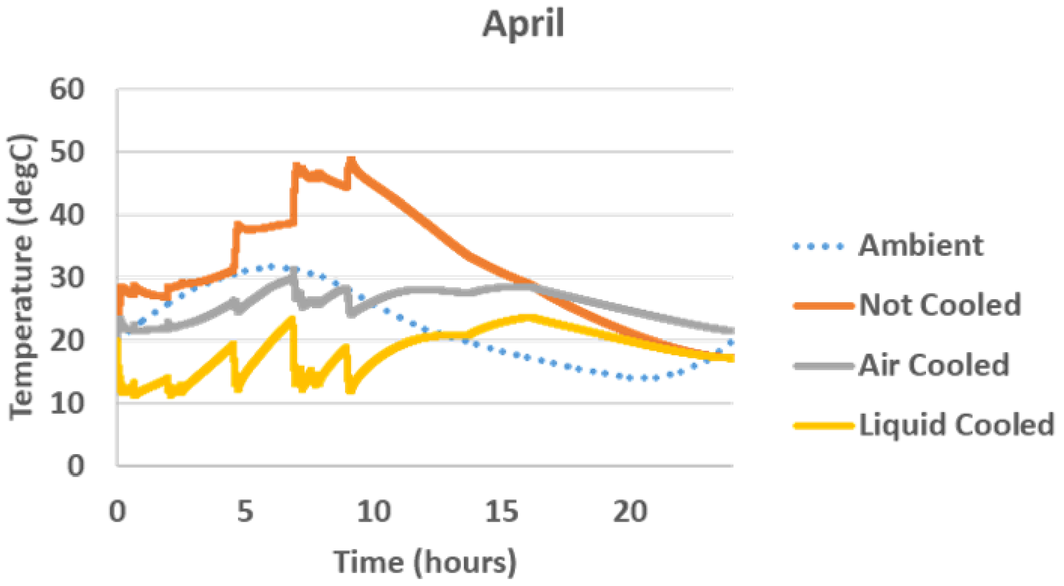
Boundary Conditions: Pack Drive Cycle

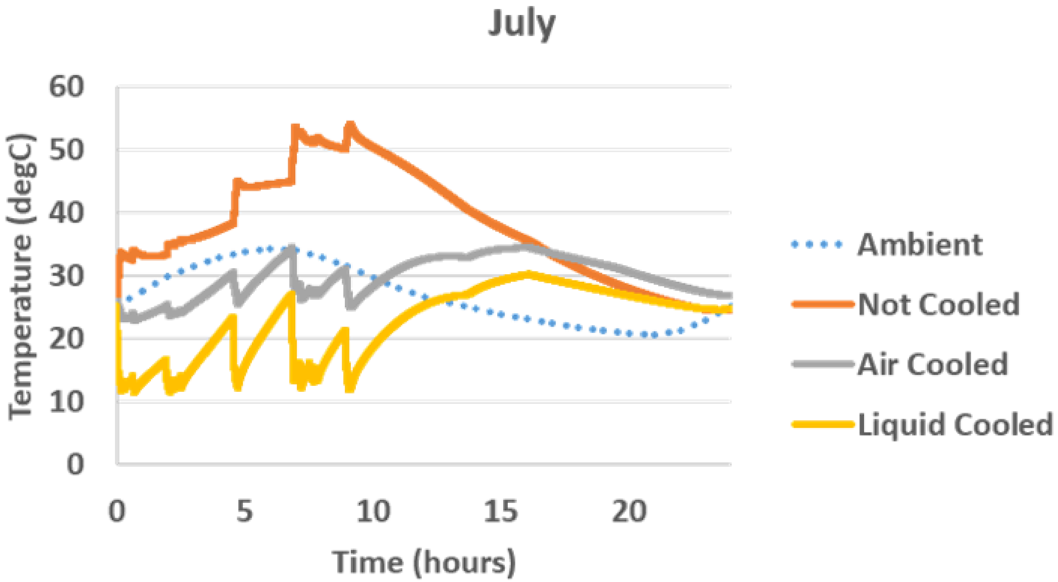


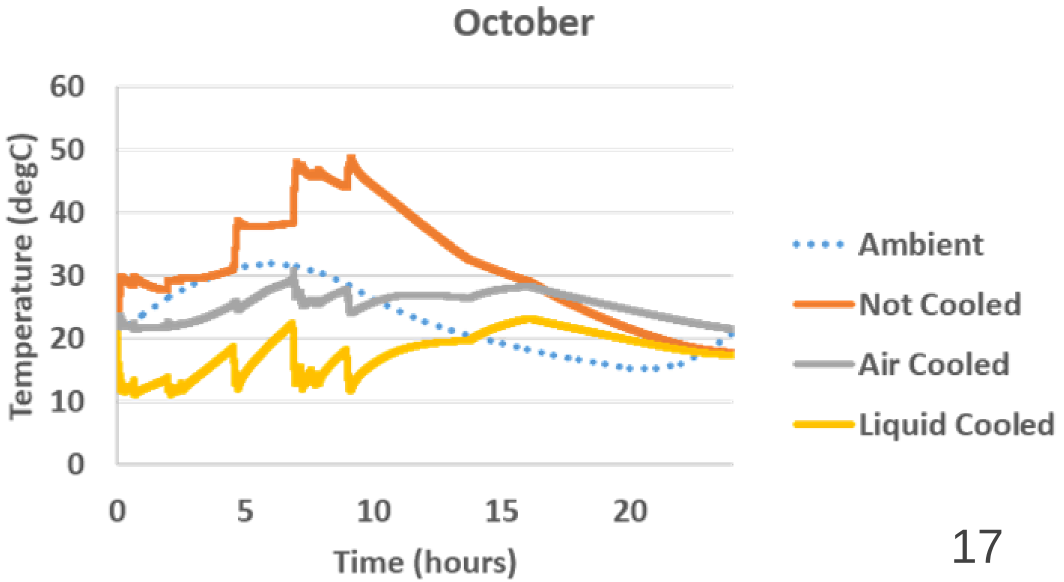


Cell Average Temperatures

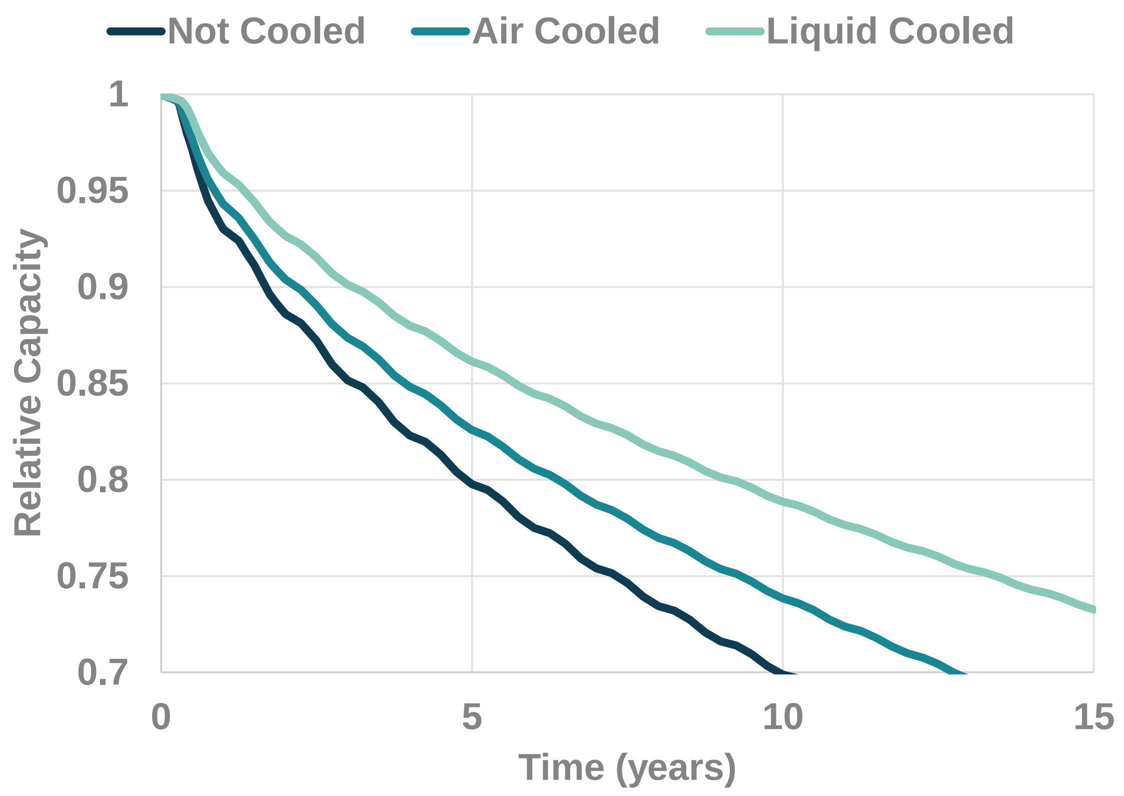


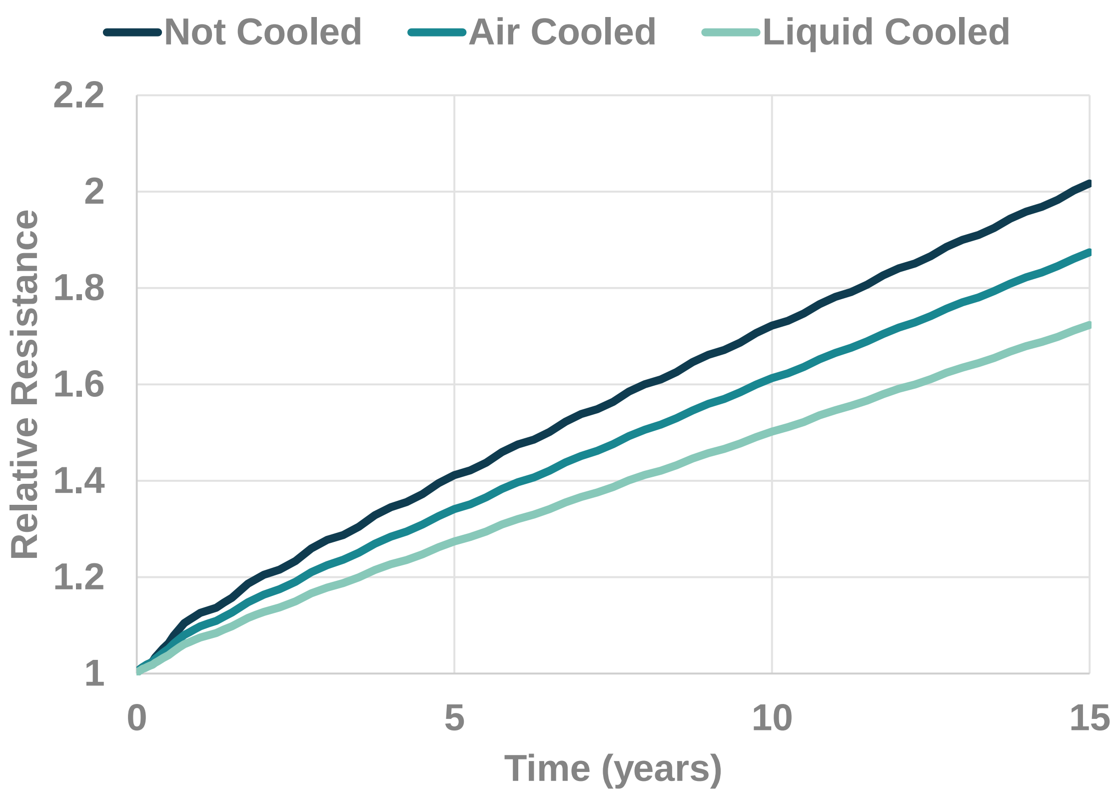






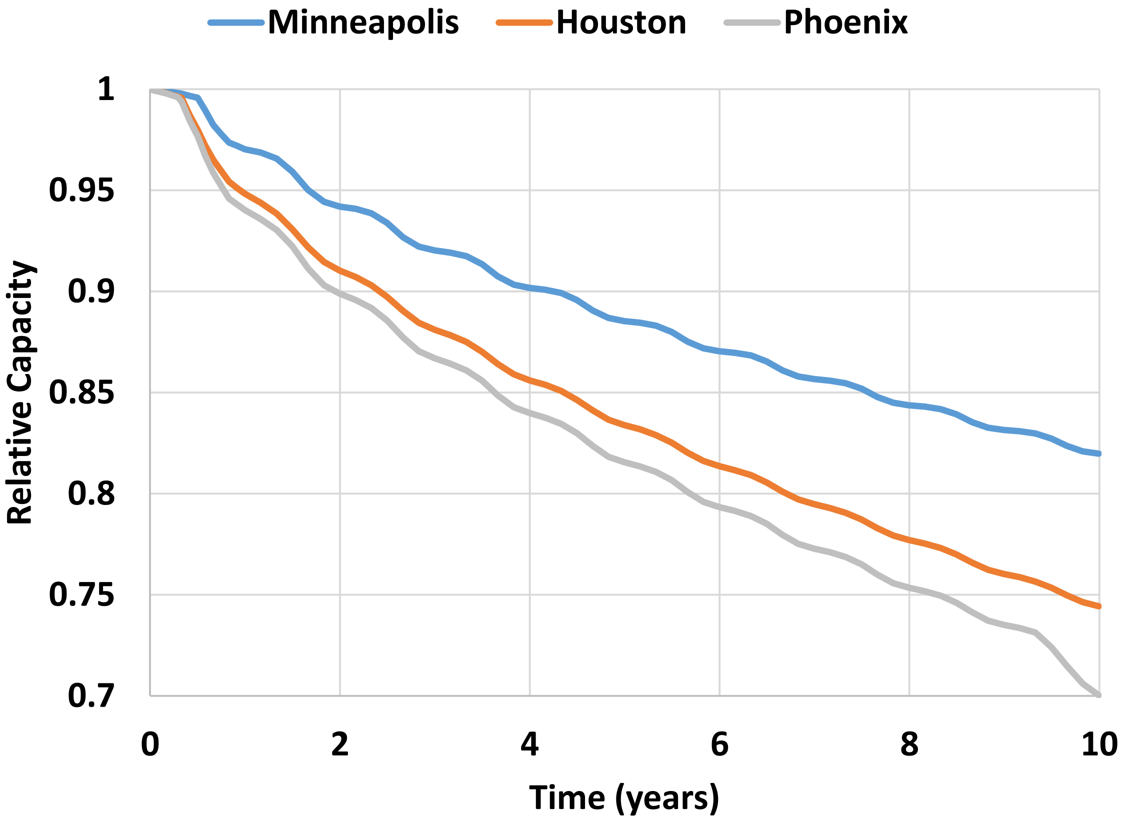
SOH Results – Cooling Scenario

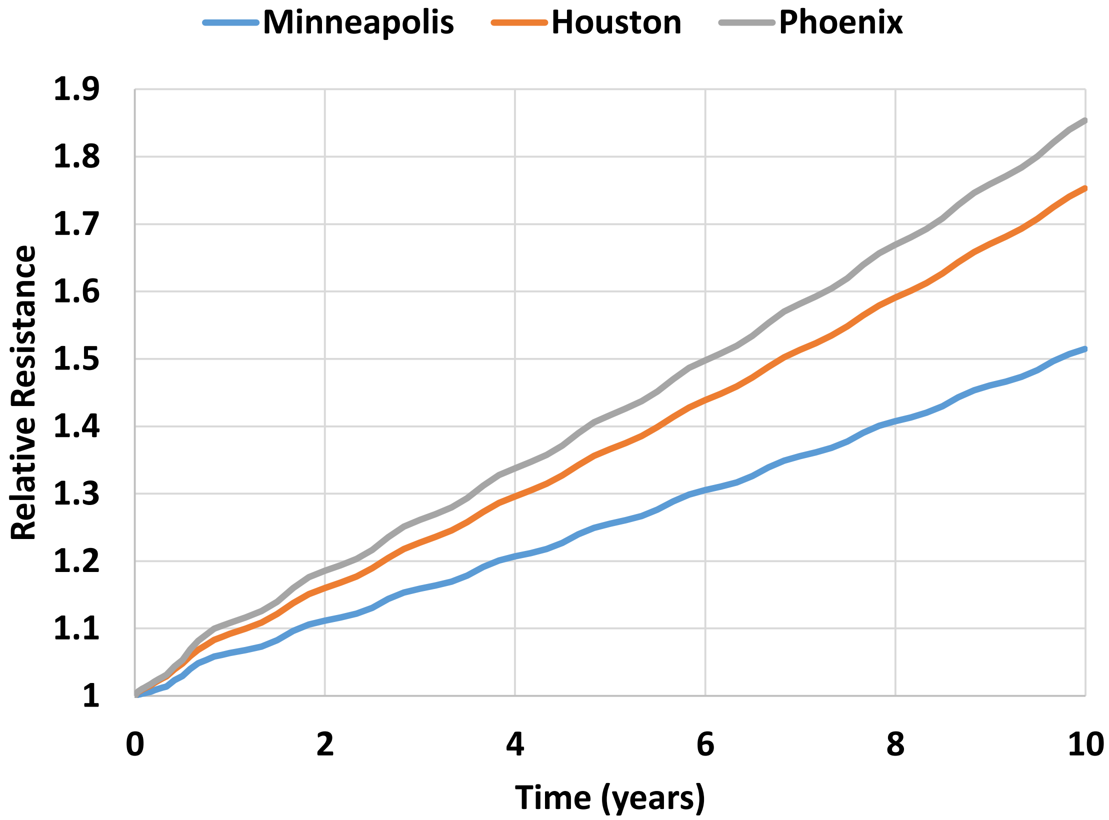




- End of life is generally considered 70-80%
- Air cooling extends life by 2.5 years, while liquid cooling extends life by well over 5 years

SOH Results – Geographic Location



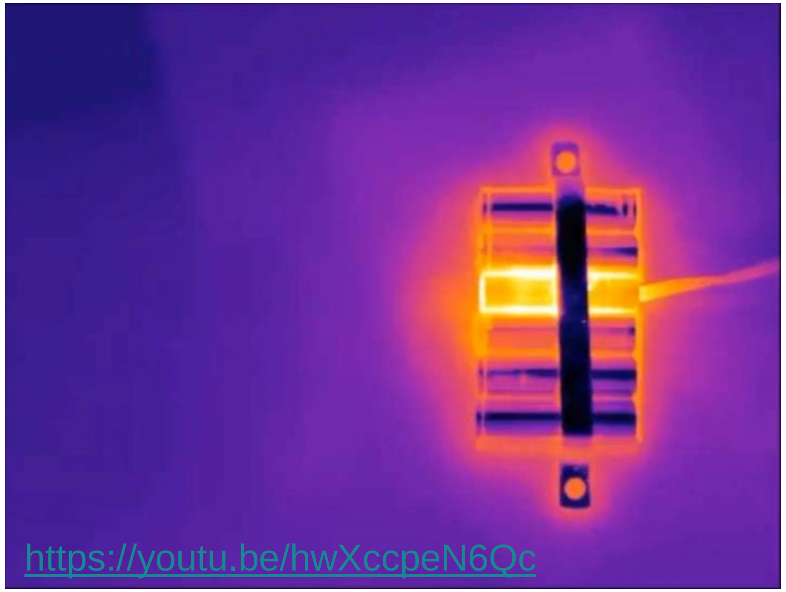


- A vehicle that lasts about 15 years in Houston (Southern USA) will only last 10 years in Phoenix (Desert)
- These are not worst-case driving conditions

Case Study 3: Thermal Runaway

Thermal Runaway

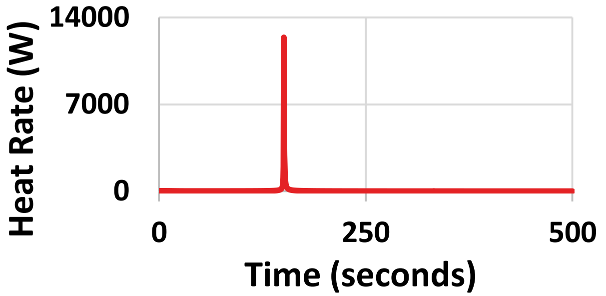
- If the battery temperature gets too high, thermal runaway can happen
  - This can be due to a certain drive cycle on a hot day or a sudden short-circuit
- European law prescribes a mininum time of 5 minutes between the start of thermal run-away and the car to catch fire
- The requires proper management of the heat propagation

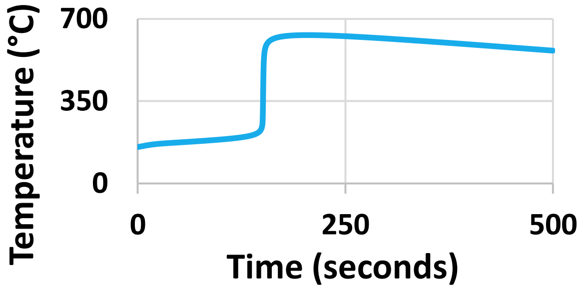


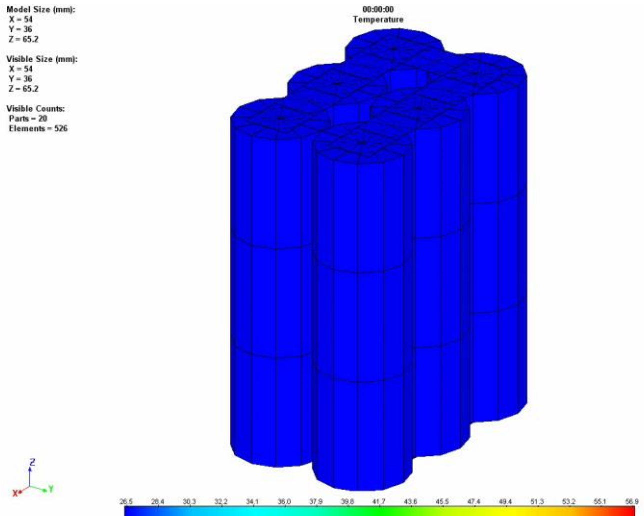
https://youtu.be/hwXccpeN6Qc

NREL Thermal Runaway Model

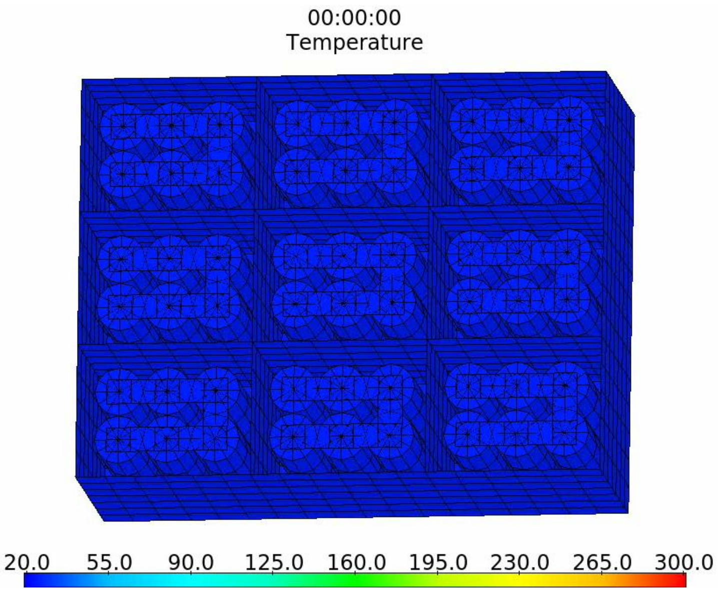
- Describes heating from unwanted chemical reactions at elevated temperatures
  - Elevated temperatures due to hot ambient conditions, I^2R heating at shorts, internal discharge
- Temperature-dependent imposed heating derived from reaction kinetics
  - Predicts heat released by reactions between electrode, separator, and electrolyte materials
  - Uses empirical reaction rate data
- Use to evaluate risk
  - Cell-to-cell propagation of failure
  - Evaluate runaway mitigation strategies





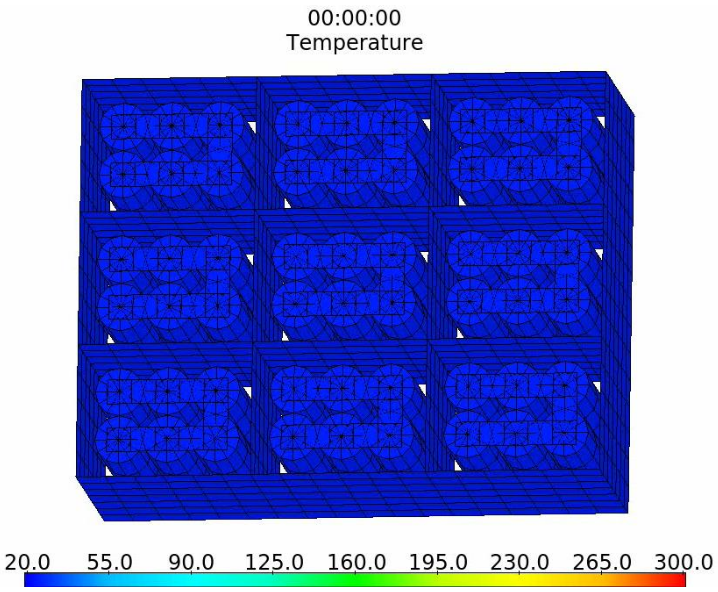


Thermal Runaway



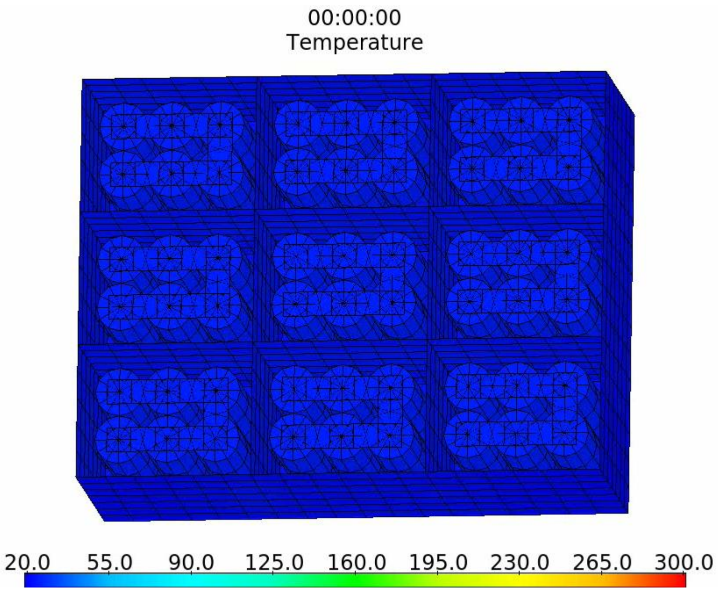
Baseline

5 min



Wall insulation 10mm

12 min



Wall insulation 10mm
+
external cooling

29 min

New Features

Former Interface vs. New Interface

The battery thermal extension was previously all encompassed in an external configuration file

```
(busNodes=packPositiveTerminal,packNegativeTerminal,bus_1,bus_2,bus_3,bus_4,)
(Cells= [name=eqcCell_1, cathodeBus=bus_1, anodeBus=packNegativeTerminal,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_2, cathodeBus=bus_1, anodeBus=packNegativeTerminal,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_3, cathodeBus=bus_1, anodeBus=packNegativeTerminal,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_4, cathodeBus=bus_2, anodeBus=bus_1,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_5, cathodeBus=bus_2, anodeBus=bus_1,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_6, cathodeBus=bus_2, anodeBus=bus_1,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_7, cathodeBus=bus_3, anodeBus=bus_2,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_8, cathodeBus=bus_3, anodeBus=bus_2,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_9, cathodeBus=bus_3, anodeBus=bus_2,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_10, cathodeBus=bus_4, anodeBus=bus_3,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_11, cathodeBus=bus_4, anodeBus=bus_3,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_12, cathodeBus=bus_4, anodeBus=bus_3,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_13, cathodeBus=packPositiveTerminal, anodeBus=bus_4,
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+       [name=eqcCell_14, cathodeBus=packPositiveTerminal, anodeBus=bus_4,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
+       [name=eqcCell_15, cathodeBus=packPositiveTerminal, anodeBus=bus_4,
+        electrodeArea=0.0336, initialDoD=0.0, capacity=19.6, form=pouch, scal
(current=-58.8)
```
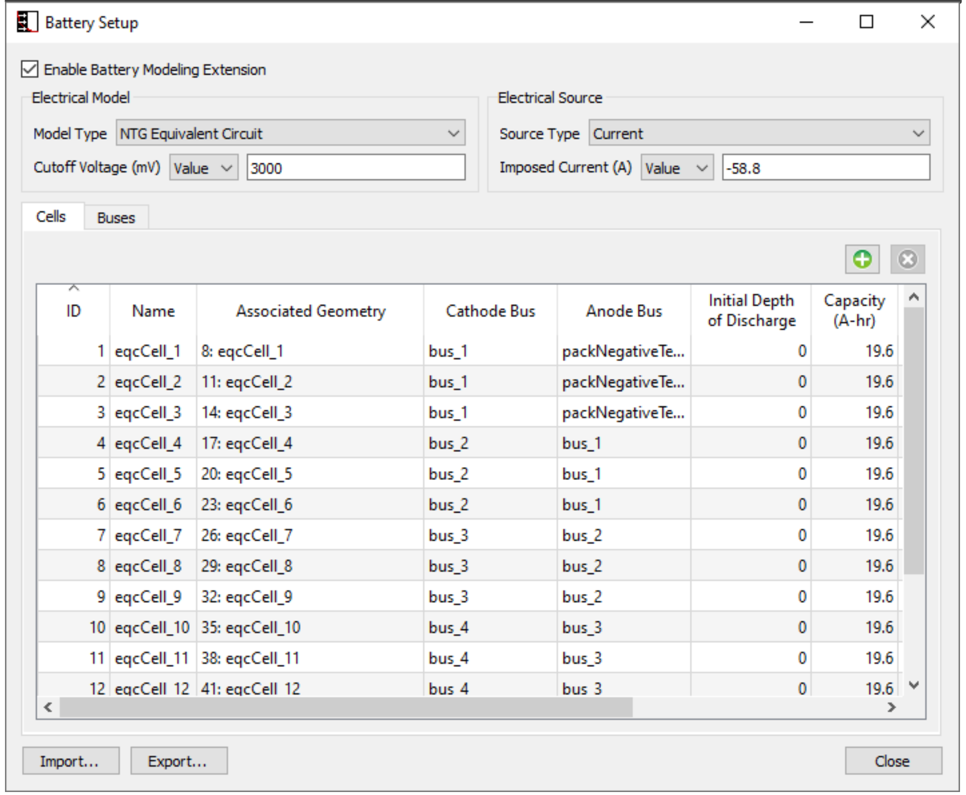
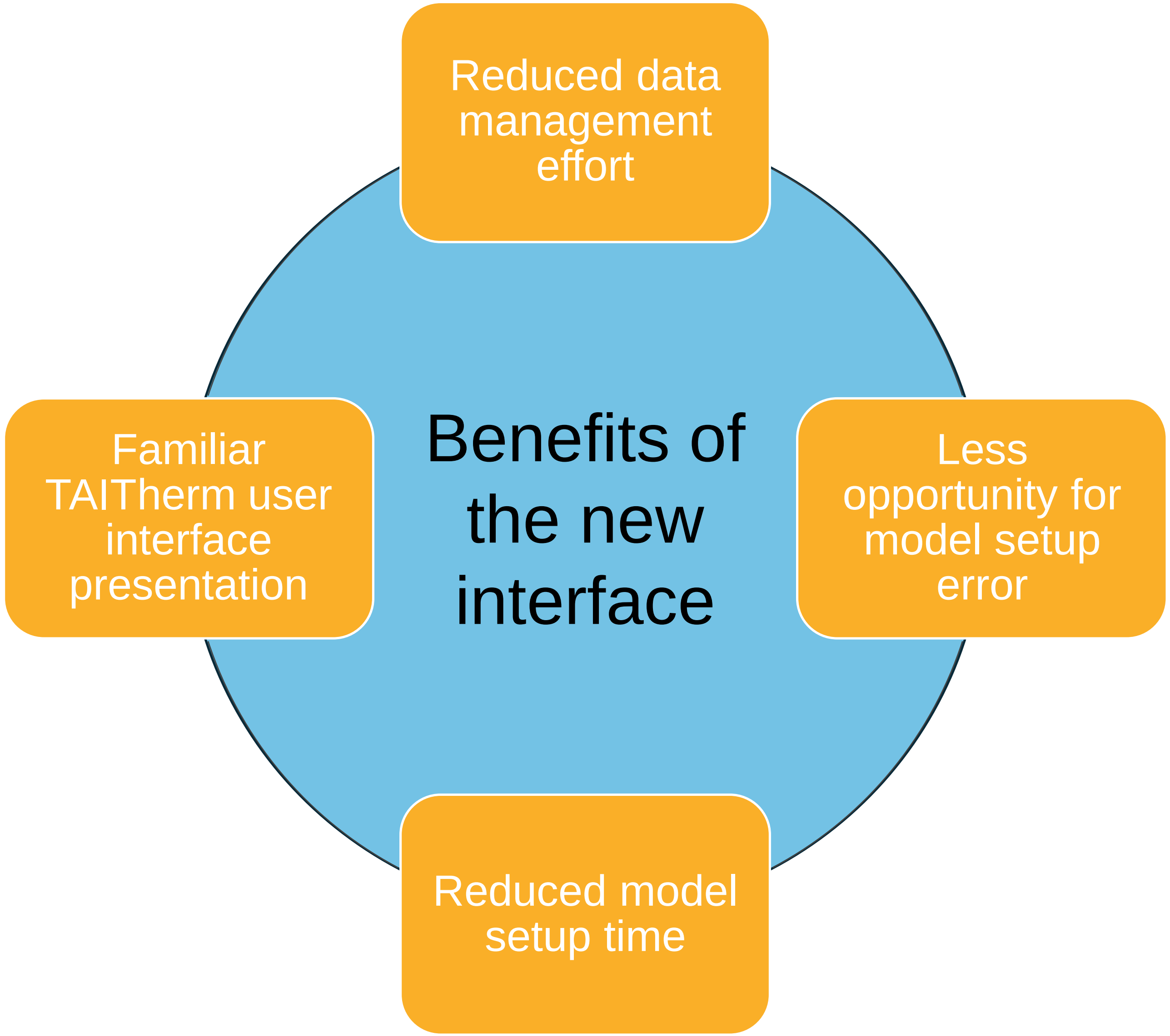

Version 13.1.0 release

The battery thermal extension is integrated into the main TAITherm interface!



Former Interface vs. New Interface



New Interface

Battery Setup GUI

Battery Setup

☑ Enable Battery Modeling Extension

Electrical Model

Model Type: NTG Equivalent Circuit

Cutoff Voltage (mV): Value | 3000

Electrical Source

Source Type: Current

Imposed Current (A): Curve | Current: driveCycleLoad

Cells | Buses

ID	Name	Associated Geometry	Cathode Bus	Anode Bus	Initial Depth of Discharge	Capacity (A-hr)	Resistance Scale Factor	Electrode Area (mm^2)	Heating Distribution
1	Cell_1	8: eqcCell_1	Pack Positive Terminal	Connector_1	0.2	19.6	1	Value: 33600	Pouch (Legacy)
2	Cell_2	11: eqcCell_2	Pack Positive Terminal	Connector_1	0.2	19.6	1	Value: 33600	Pouch (Legacy)
3	Cell_3	14: eqcCell_3	Pack Positive Terminal	Connector_1	0.2	19.6	1	Value: 33600	Pouch (Legacy)
4	Cell_4	17: eqcCell_4	Connector_1	Connector_2	0.2	19.6	1	Value: 33600	Pouch (Legacy)
5	Cell_5	20: eqcCell_5	Connector_1	Connector_2	0.2	19.6	1	Value: 33600	Pouch (Legacy)
6	Cell_6	23: eqcCell_6	Connector_1	Connector_2	0.2	19.6	1	Value: 33600	Pouch (Legacy)
7	Cell_7	26: eqcCell_7	Connector_2	Connector_3	0.2	19.6	1	Value: 33600	Pouch (Legacy)
8	Cell_8	29: eqcCell_8	Connector_2	Connector_3	0.2	19.6	1	Value: 33600	Pouch (Legacy)
9	Cell_9	32: eqcCell_9	Connector_2	Connector_3	0.2	19.6	1	Value: 33600	Pouch (Legacy)
10	Cell_10	35: eqcCell_10	Connector_3	Connector_4	0.2	19.6	1	Value: 33600	Pouch (Legacy)
11	Cell_11	38: eqcCell_11	Connector_3	Connector_4	0.2	19.6	1	Value: 33600	Pouch (Legacy)
12	Cell_12	41: eqcCell_12	Connector_3	Connector_4	0.2	19.6	1	Value: 33600	Pouch (Legacy)
13	Cell_13	44: eqcCell_13	Connector_4	Pack Negative Ter...	0.2	19.6	1	Value: 33600	Pouch (Legacy)
14	Cell_14	47: eqcCell_14	Connector_4	Pack Negative Ter...	0.2	19.6	1	Value: 33600	Pouch (Legacy)
15	Cell_15	50: eqcCell_15	Connector_4	Pack Negative Ter...	0.2	19.6	1	Value: 33600	Pouch (Legacy)

Import... | Export... | Close

Battery Setup File CSV

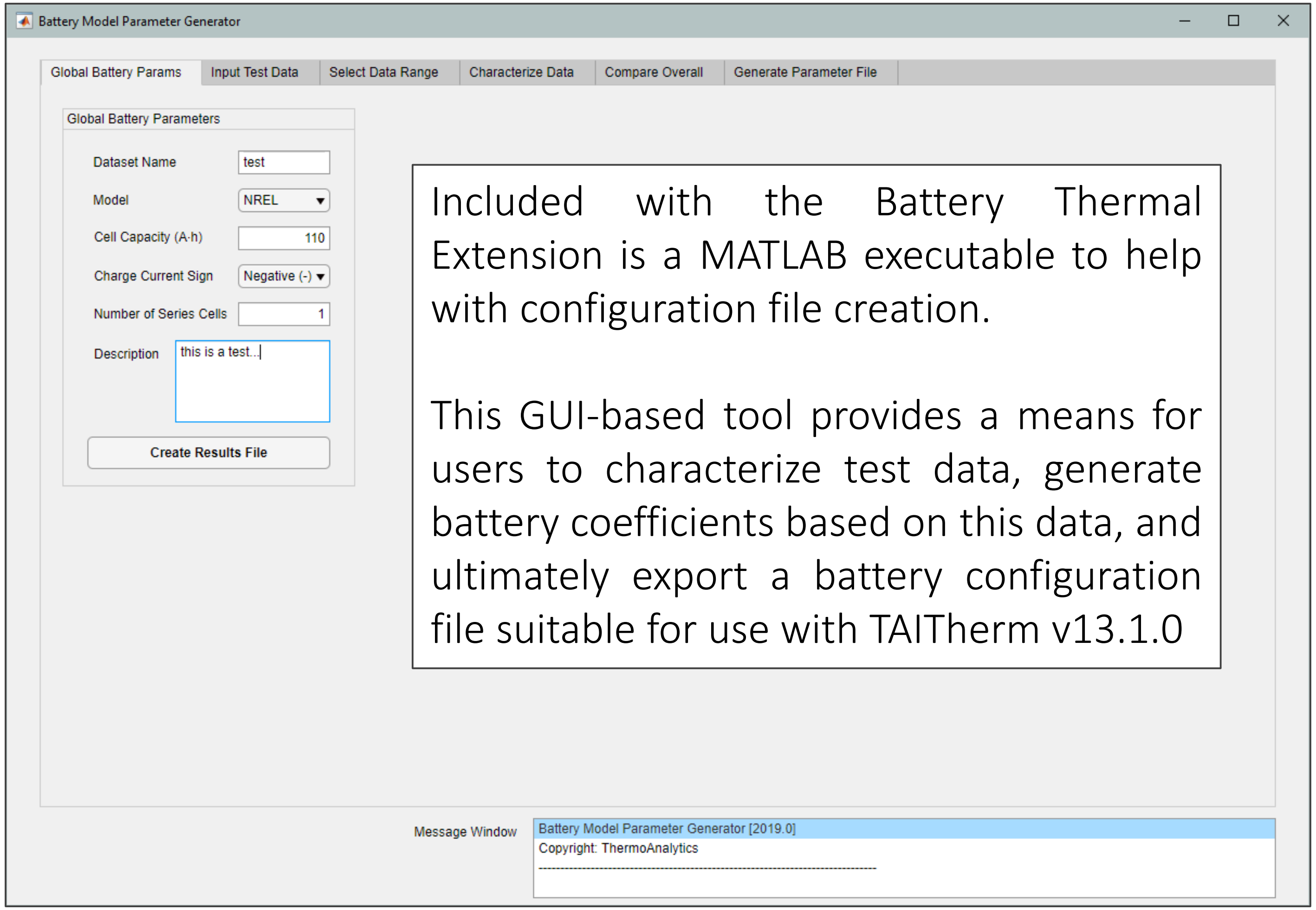
NTG Equivalent Pack Example

	A	B	C	D	E	F	G	H	I	J	K
1	Section Start: Battery Pack Parameters										
2											
3	Electrical Mode	Cutoff Voltage (	Electrical Sourc	Electrical Source (A or mV)							
4	NTG Equivalent	3000	Current	-58.8							
5											
6	Section Start: Battery Buses										
7											
8	Bus Type	Bus Name	Associated Part	Associated Part Name							
9	Positive Termin	packPositiveTe	None	None							
10	Negative Termi	packNegativeTe	None	None							
11	Connector	bus_1	None	None							
12	Connector	bus_2	None	None							
13	Connector	bus_3	None	None							
14	Connector	bus_4	None	None							
15											
16	Section Start: Battery Cells										
17											
18	Cell ID	Cell Name	Associated Geo	Associated Geo	Cathode Bus	Anode Bus	Initial Depth of	Capacity (A-hr)	Resistance Scal	Electrode Area	Heating Distribution
19	1	eqcCell_1	8	eqcCell_1	bus_1	packNegativeTe	0	19.6	1	0.0336	Pouch (Legacy)
20	2	eqcCell_2	11	eqcCell_2	bus_1	packNegativeTe	0	19.6	1	0.0336	Pouch (Legacy)
21	3	eqcCell_3	14	eqcCell_3	bus_1	packNegativeTe	0	19.6	1	0.0336	Pouch (Legacy)
22	4	eqcCell_4	17	eqcCell_4	bus_2	bus_1	0	19.6	1	0.0336	Pouch (Legacy)
23	5	eqcCell_5	20	eqcCell_5	bus_2	bus_1	0	19.6	1	0.0336	Pouch (Legacy)
24	6	eqcCell_6	23	eqcCell_6	bus_2	bus_1	0	19.6	1	0.0336	Pouch (Legacy)
25	7	eqcCell_7	26	eqcCell_7	bus_3	bus_2	0	19.6	1	0.0336	Pouch (Legacy)
26	8	eqcCell_8	29	eqcCell_8	bus_3	bus_2	0	19.6	1	0.0336	Pouch (Legacy)
27	9	eqcCell_9	32	eqcCell_9	bus_3	bus_2	0	19.6	1	0.0336	Pouch (Legacy)
28	10	eqcCell_10	35	eqcCell_10	bus_4	bus_3	0	19.6	1	0.0336	Pouch (Legacy)
29	11	eqcCell_11	38	eqcCell_11	bus_4	bus_3	0	19.6	1	0.0336	Pouch (Legacy)
30	12	eqcCell_12	41	eqcCell_12	bus_4	bus_3	0	19.6	1	0.0336	Pouch (Legacy)
31	13	eqcCell_13	44	eqcCell_13	packPositiveTe	bus_4	0	19.6	1	0.0336	Pouch (Legacy)
32	14	eqcCell_14	47	eqcCell_14	packPositiveTe	bus_4	0	19.6	1	0.0336	Pouch (Legacy)
33	15	eqcCell_15	50	eqcCell_15	packPositiveTe	bus_4	0	19.6	1	0.0336	Pouch (Legacy)

- Includes three sections
  - Battery Pack Parameters
  - Battery Buses
  - Battery Cells
- Imports specified rows/columns only
  - Can be partial changes
- Can import by ID or Name
- Cells/buses automatically created when new rows exist

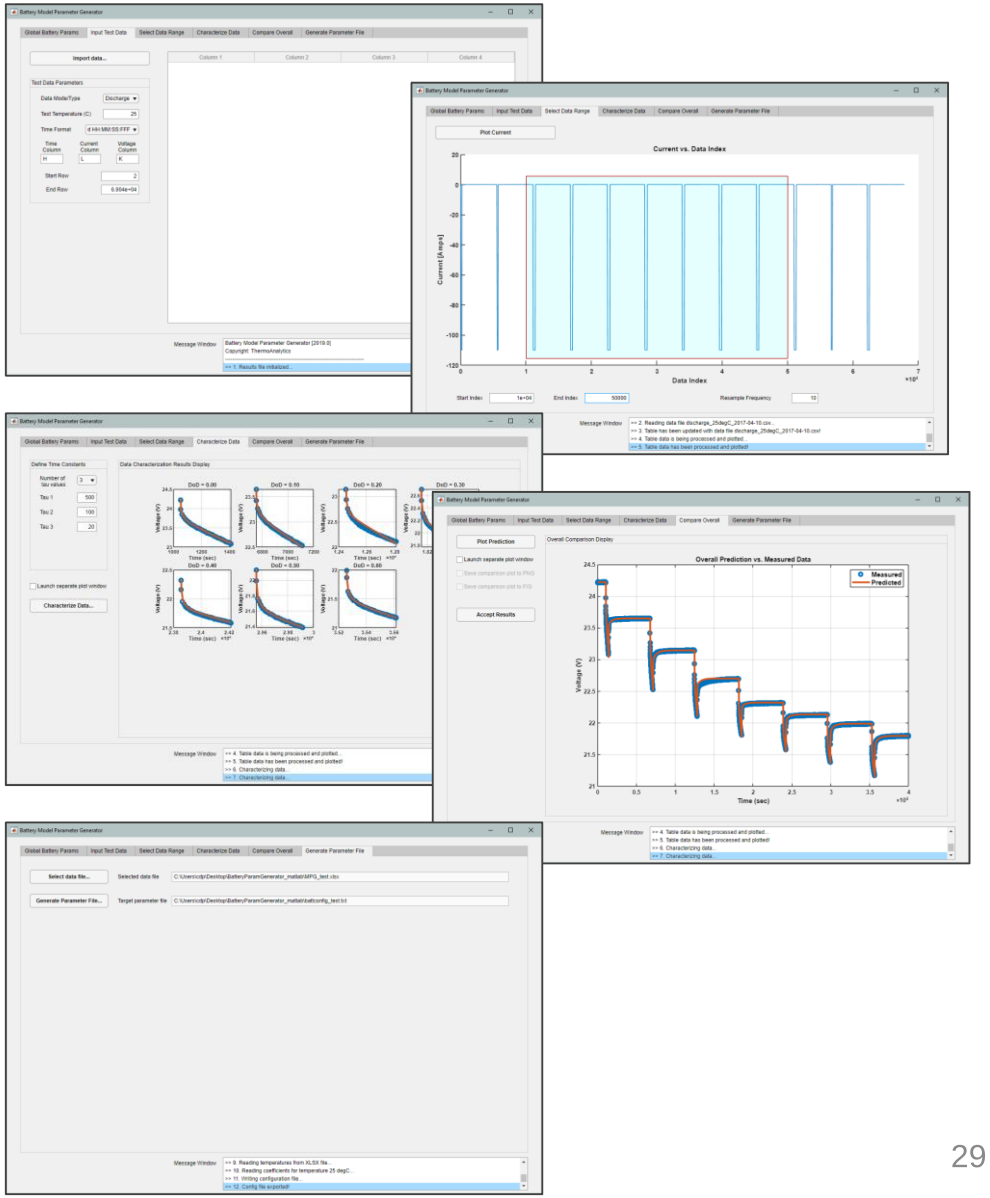
Generating the Battery Configuration File

Battery Model Parameter Generator

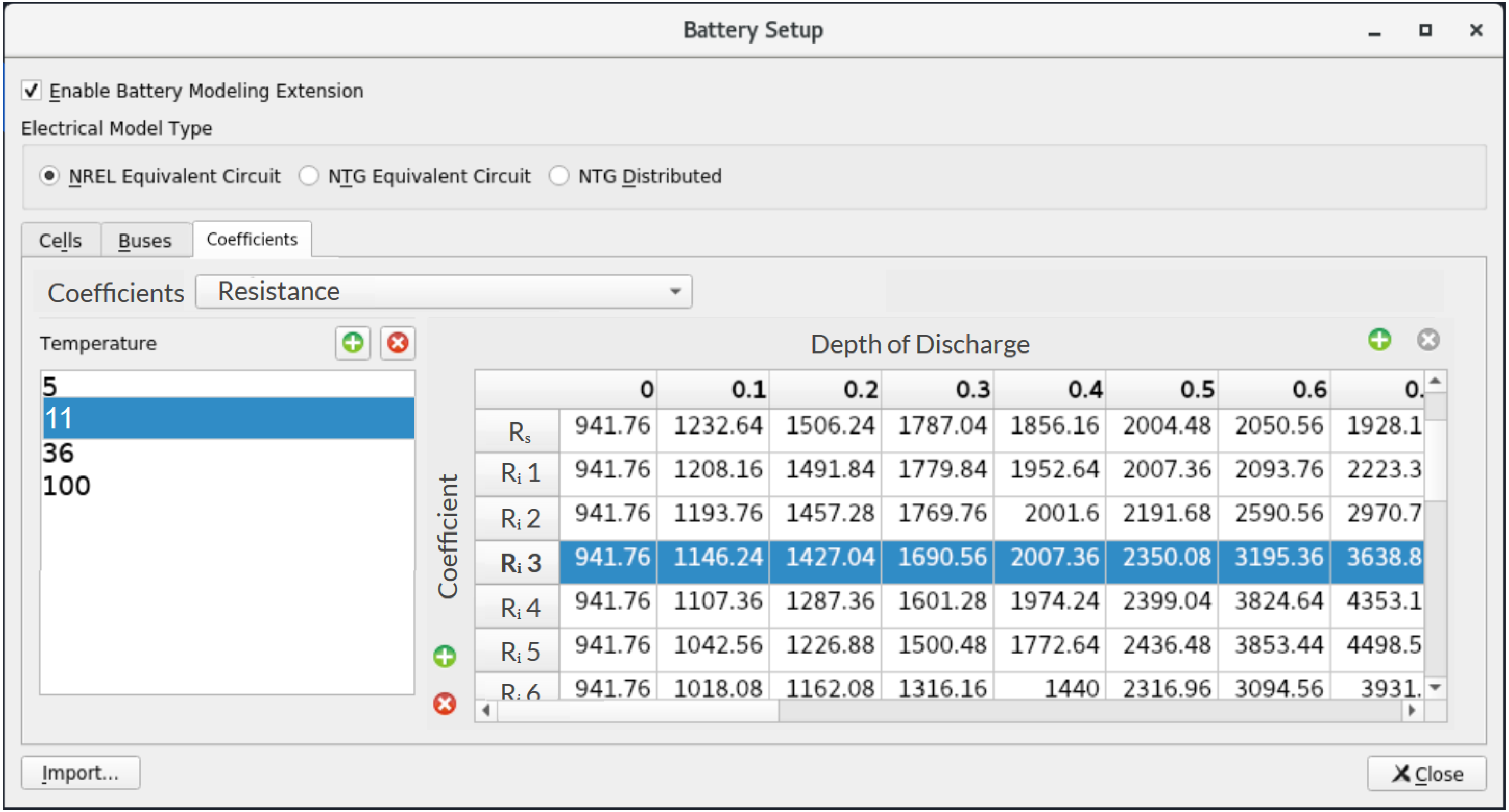


Included with the Battery Thermal Extension is a MATLAB executable to help with configuration file creation.

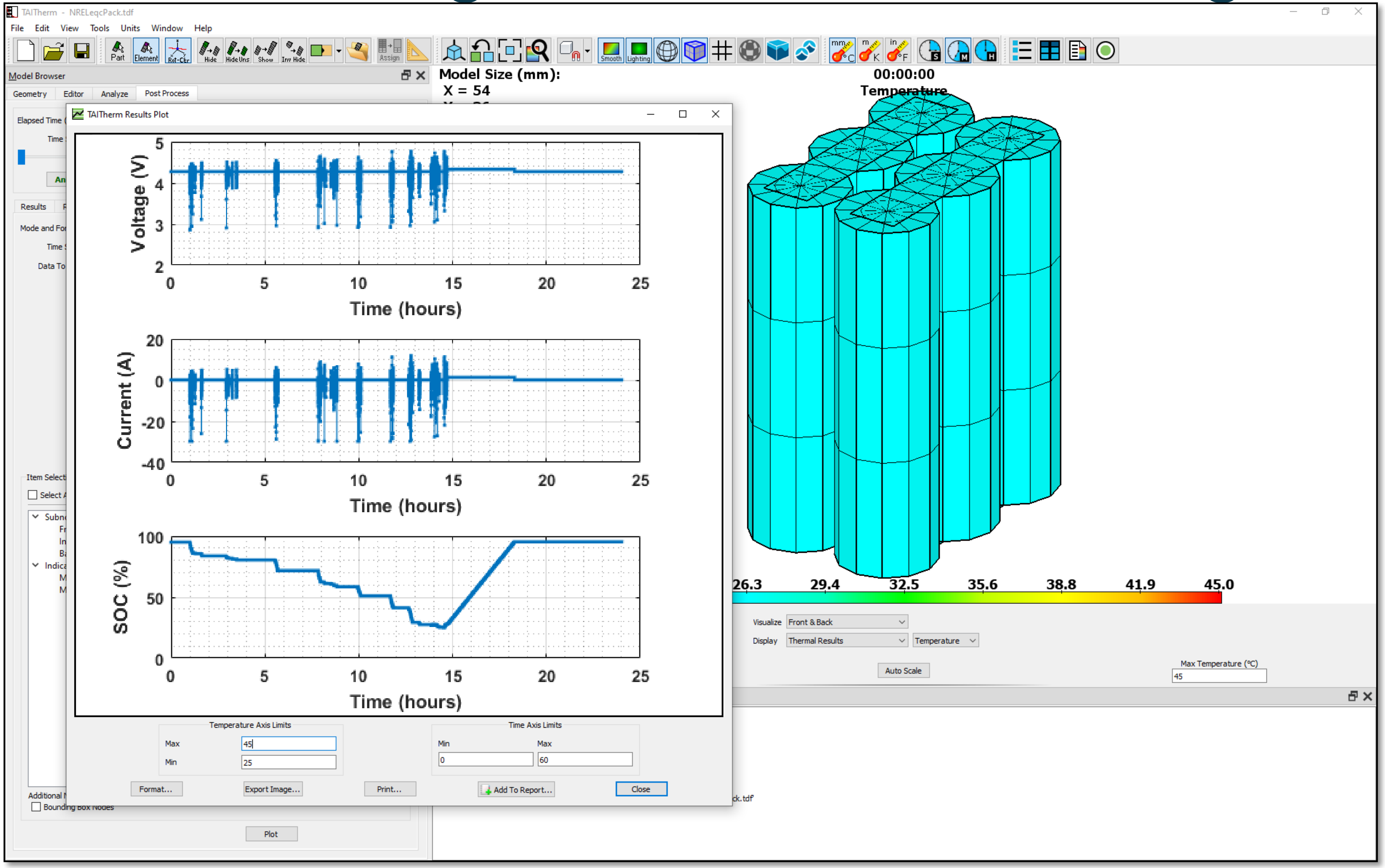
This GUI-based tool provides a means for users to characterize test data, generate battery coefficients based on this data, and ultimately export a battery configuration file suitable for use with TAITherm v13.1.0



Future Work: Integrated Battery Coefficients



Future Work: Integrated Post Processing



Future Work: Integration with EV components

- Power Electronics
  - Battery
  - Motor
  - Inverter
  - Harnesses
  - Connectors
- Entertainment Units
- Cooling Loop
  - Chiller
  - E-pump
  - PTC
  - Heat Exchanger
  - Air/liquid ducts

Thank you

US Location

ThermoAnalytics HQ
23440 Airpark Blvd.
Calumet, MI 49913

Zachary Edel, Ph.D.

Office: +1 (906) 482-9560 x138
zje@thermoanalytics.com
www.thermoanalytics.com