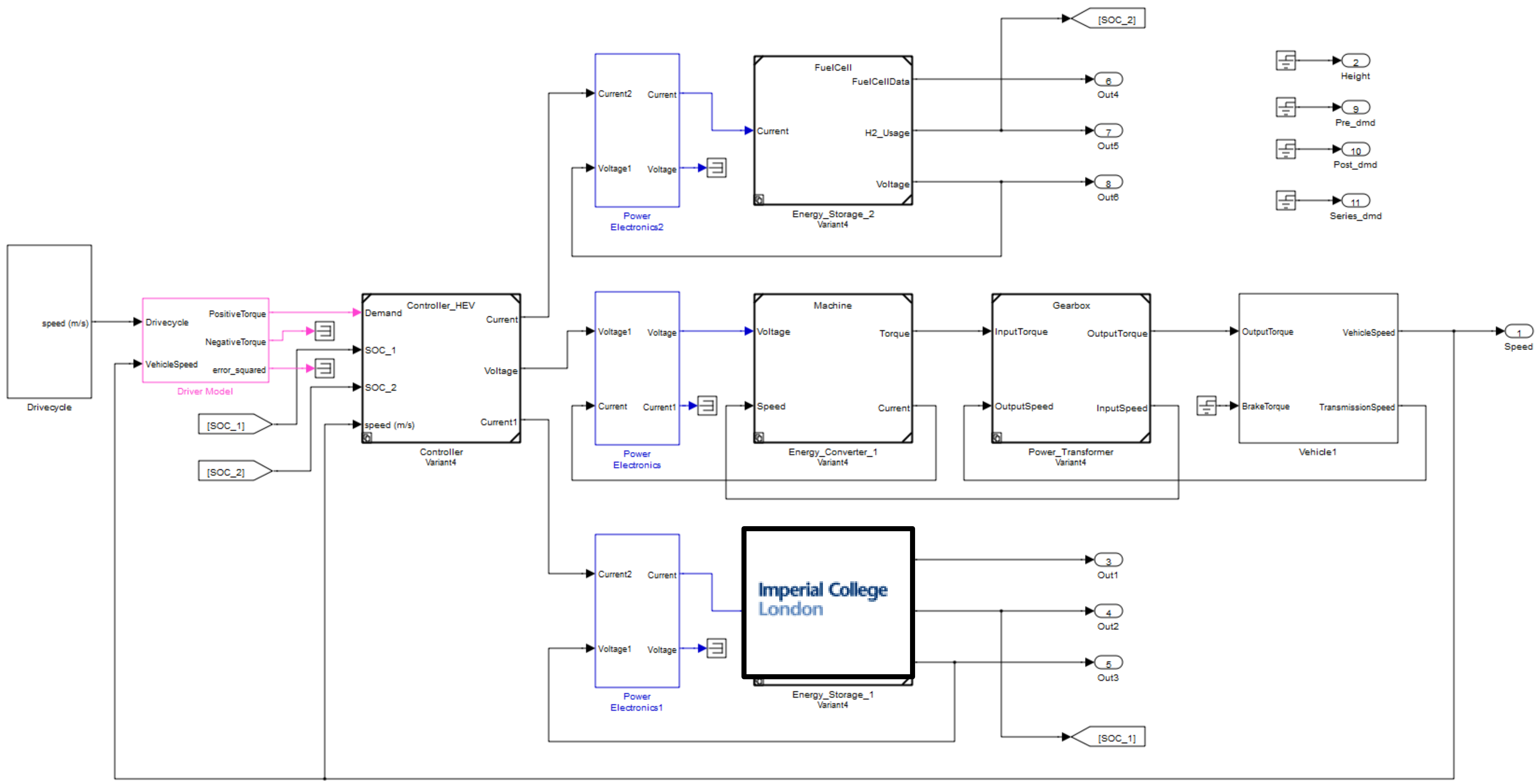
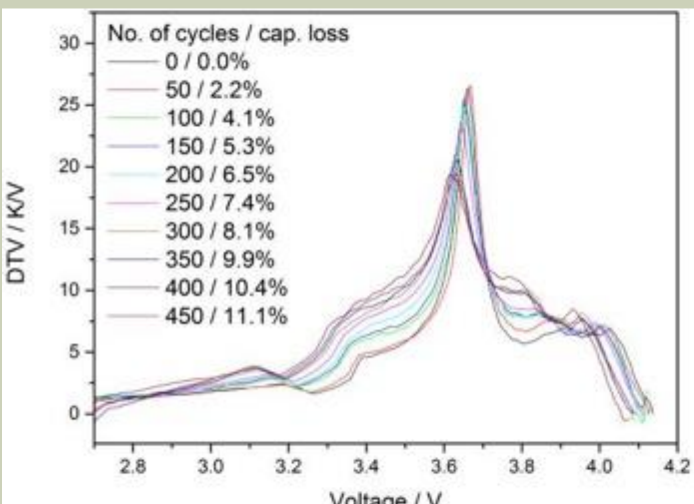
BATTERIES

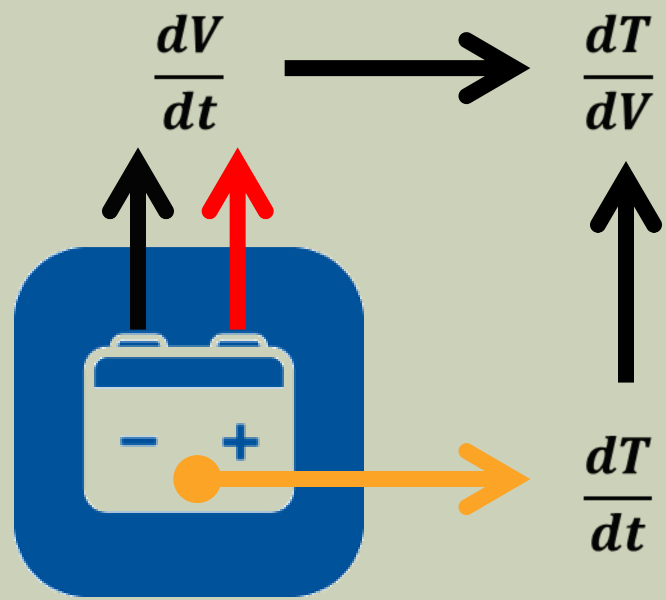

[SOC_2]
FuelCell
FuelCellData
Current2
Current
Voltage1
Voltage
H2_Usage
Out4
Out5
Out6
Height
Pre_dmd
Post_dmd
Series_dmd
Power Electronics2
Energy_Storage_2
Variant4
speed (m/s)
Drivecycle
VehicleSpeed
PositiveTorque
NegativeTorque
error_squared
Driver Model
Demand
Controller_HEV
SOC_1
SOC_2
speed (m/s)
Current1
Controller
Variant4
[SOC_1]
[SOC_2]
Power Electronics
Machine
Torque
Speed
Energy_Converter_1
Variant4
Gearbox
InputTorque
OutputTorque
OutputSpeed
InputSpeed
Power_Transformer
Variant4
OutputTorque
VehicleSpeed
BrakeTorque
TransmissionSpeed
Vehicle1
Speed
Imperial College London
Out1
Out2
Out3
Power Electronics1
Energy_Storage_1
Variant4
[SOC_1]

DIFFERENTIAL THERMAL VOLTAMMETRY

- Novel in-situ battery diagnosis method for tracking degradation
- Uses the temperature profile under constant current discharge to infer the same data as SRCV/IC but in a much reduced time

- Plotted against cell voltage, it may be possible to give an indication of the entropy changes in carefully controlled conditions
- Peaks represent phase transformation

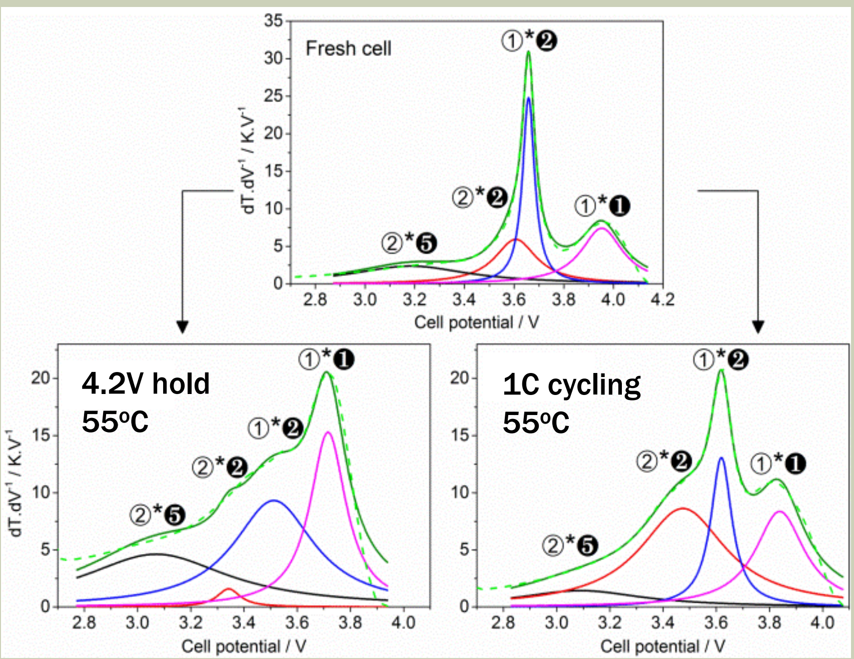




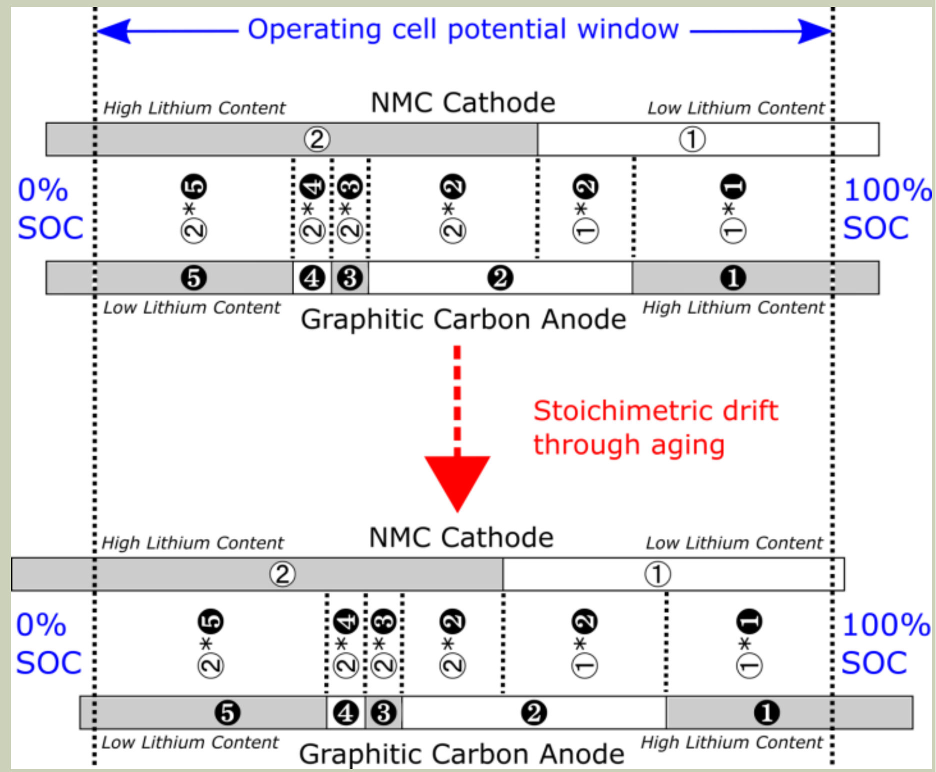
Journal of Power Sources, Vol:273, 2015, Pages:495-501

DIFFERENTIAL THERMAL VOLTAMMETRY

- Temperature possible (i.e. DTV)
- Where current is not (i.e. ICA (dQ/dV))



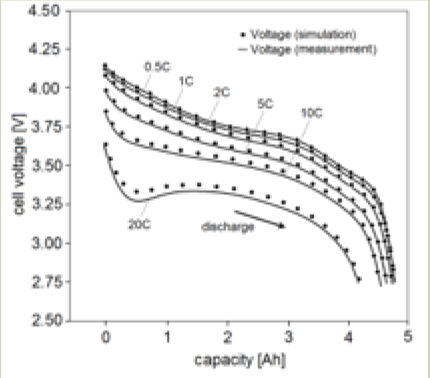
Y. Merla, Journal of Power Sources, Vol:307, 2016, Pages:308-319

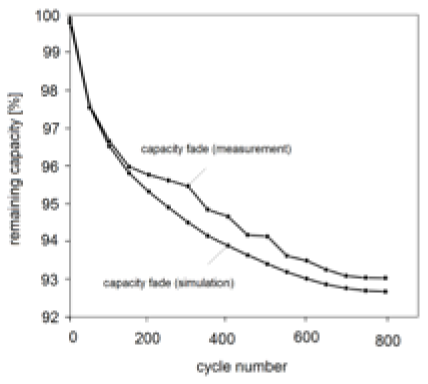


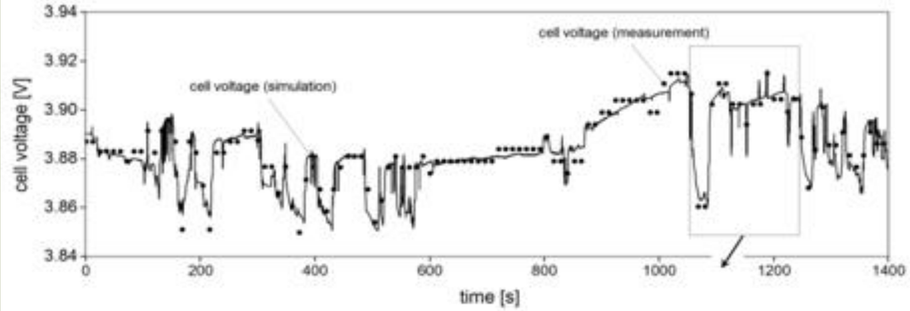
PHYSICS BASED MODELS

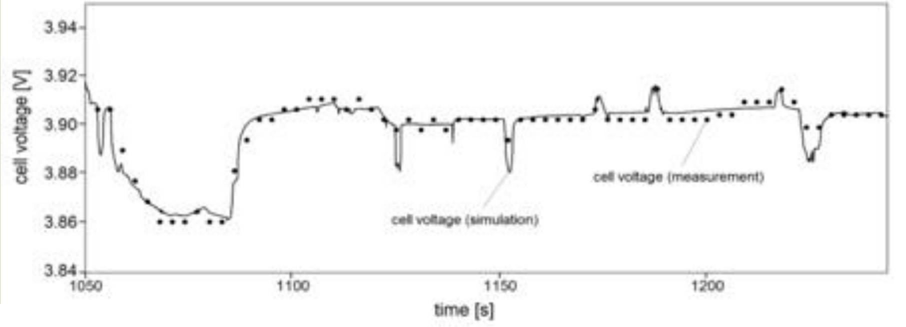
- Physics based electrochemical battery model
  - Variable double layer capacitance
  - Surface concentrations affect current over-potential equations
  - SEI layer growth degradation included
  - Implemented in Simulink for system & control engineers

M-T von Srbik, Paper Under Review, Journal Power Sources



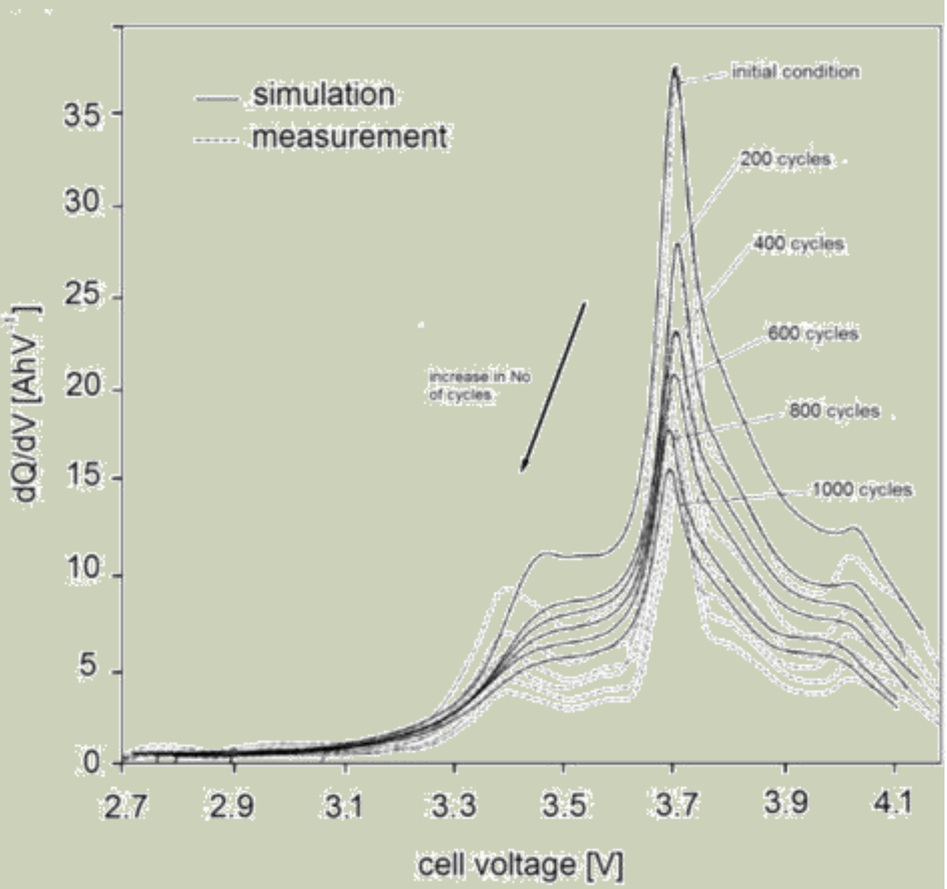






MODELS MATCH DIAGNOSTIC TECHNIQUES

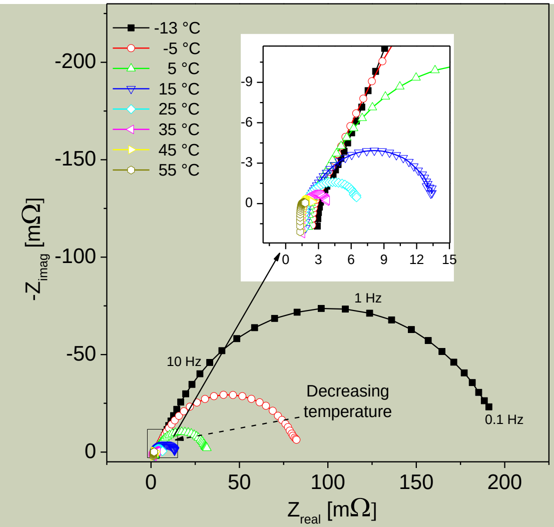
- Model works for highly transient loads and up to 20C
- Model capable of matching diagnostic techniques for degradation

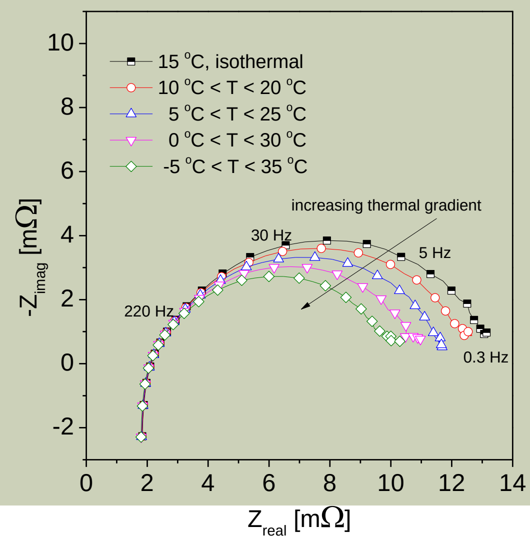


M-T von Srbik, Paper Under Review, Journal Power Sources

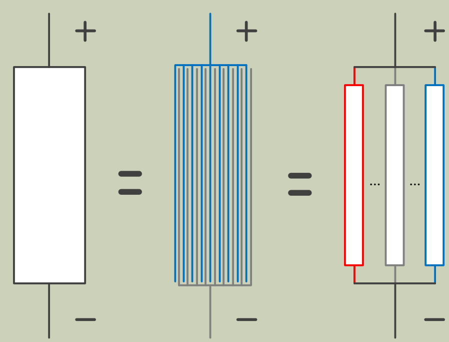
EMERGENT BEHAVIOUR CAUSES FEEDBACK LOOPS

- Temperature affects impedance exponentially
  - Effect is due to non-linear temperature dependence on charge transfer resistance
- Under a thermal gradient a cell behaves like one with a higher average temperature
  - Some layers do more work than others
  - Analogous to cells in parallel



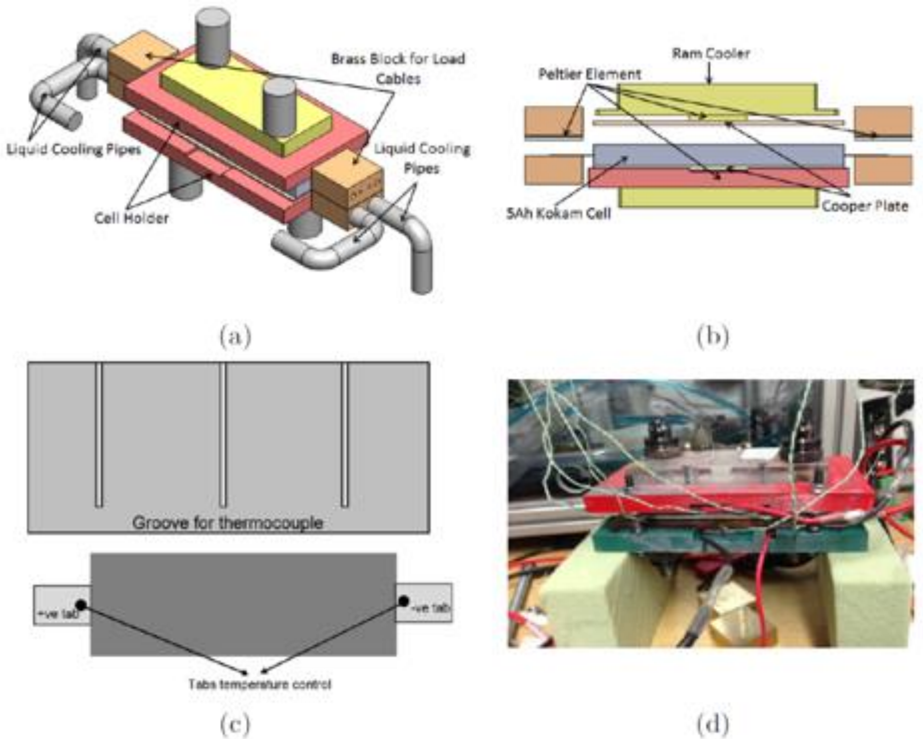


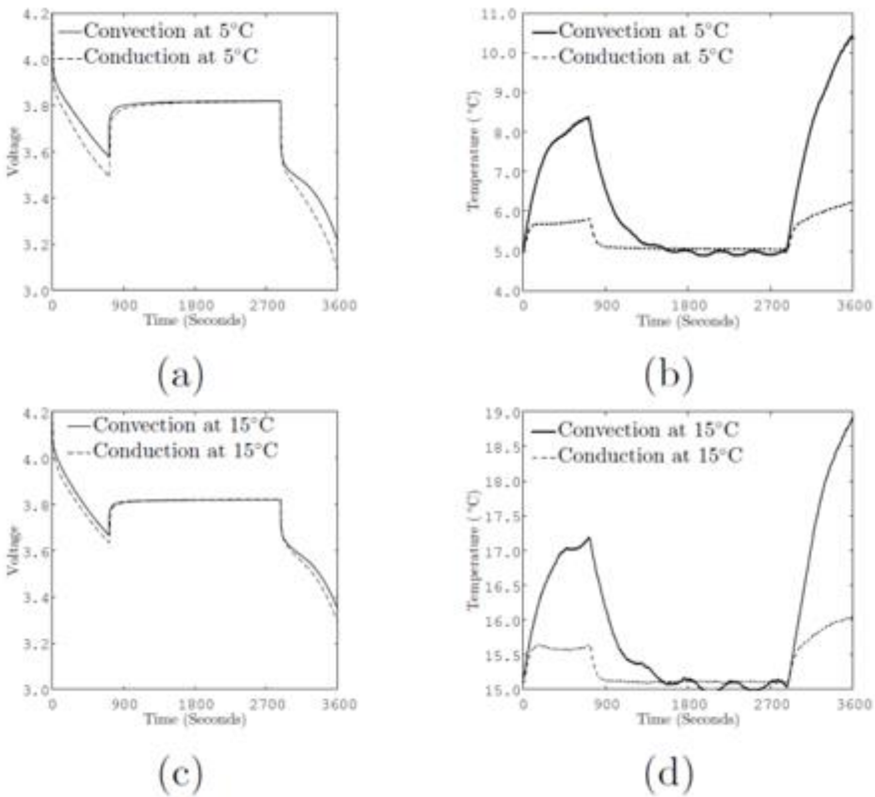
Troxler et al., Journal of Power Sources, Vol:247, 2014, Pages:1018-1025



THERMAL CHAMBERS ARE OFTEN UNSUITABLE

- We can simulate any battery pack thermal management system at a single cell

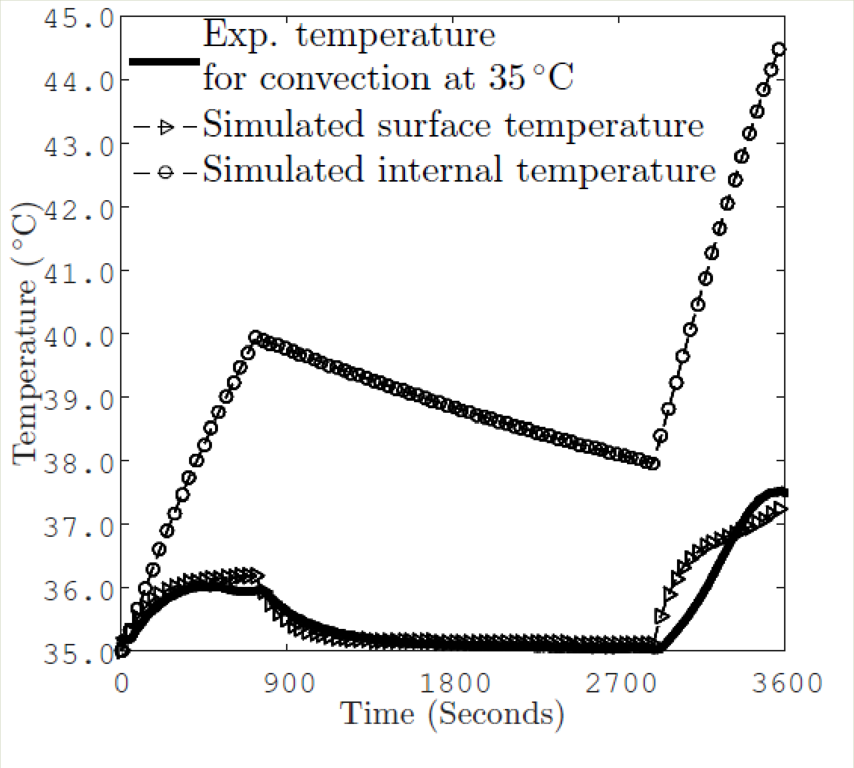




M. I. Ardani, Paper Submitted

HOW BIG CAN THERMAL GRADIENTS GET?

- Even at high temperatures
  - when impedance is low
- Under discharge, internal temperature can be substantially different from surface

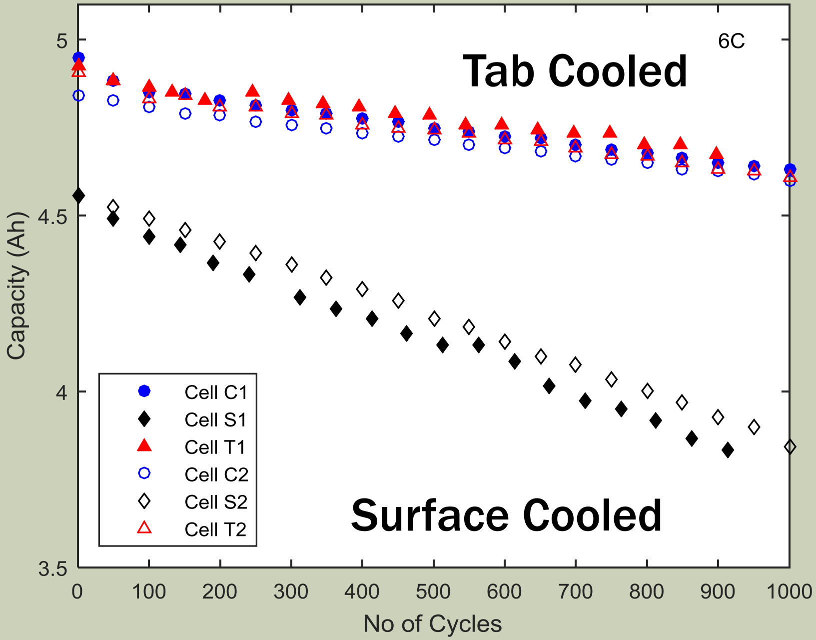


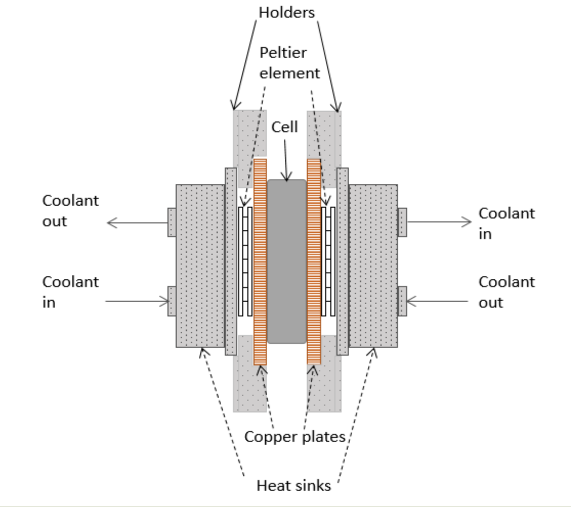
2C discharge of 5Ah Kokam NCM cell

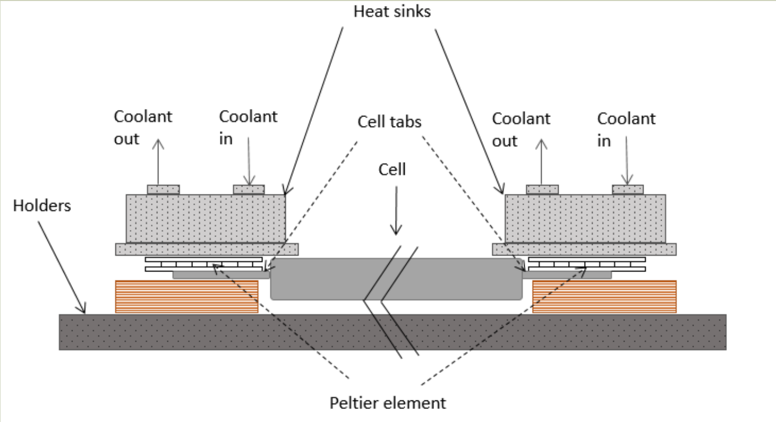
M. I. Ardani, Paper Submitted

THERE ARE GOOD AND BAD THERMAL GRADIENTS

Critical for good pack design





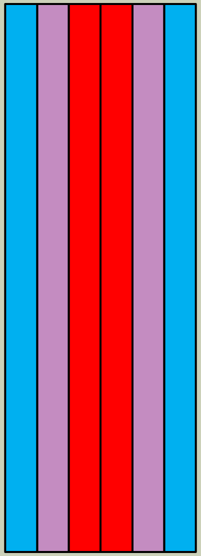


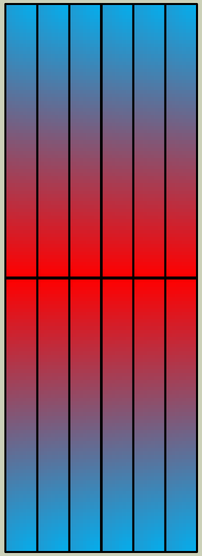
I. Hunt, Paper Under Review, Journal Electrochemical Society

THERE ARE GOOD AND BAD THERMAL GRADIENTS

- Surface cooling
  - Layers different impedance
  - Layers behave differently
  - Positive feedback

- Tab cooling
  - Within layers different impedance
  - Each layer behaves same
  - Minimal feedback





I. Hunt, Paper Under Review, Journal Electrochemical Society

ROOT CAUSE TRIGGERS POSITIVE FEEDBACK

- Initial formation of thermal gradients (inhomogeneity)
  - is a significant root cause of accelerated degradation
- Other root causes of inhomogeneity could similarly start this cycle of detrimental positive feedback by affecting the R term