Exceed Your Electrification Goals With Thermal Simulation

TAI Webinar, March 5, 2020

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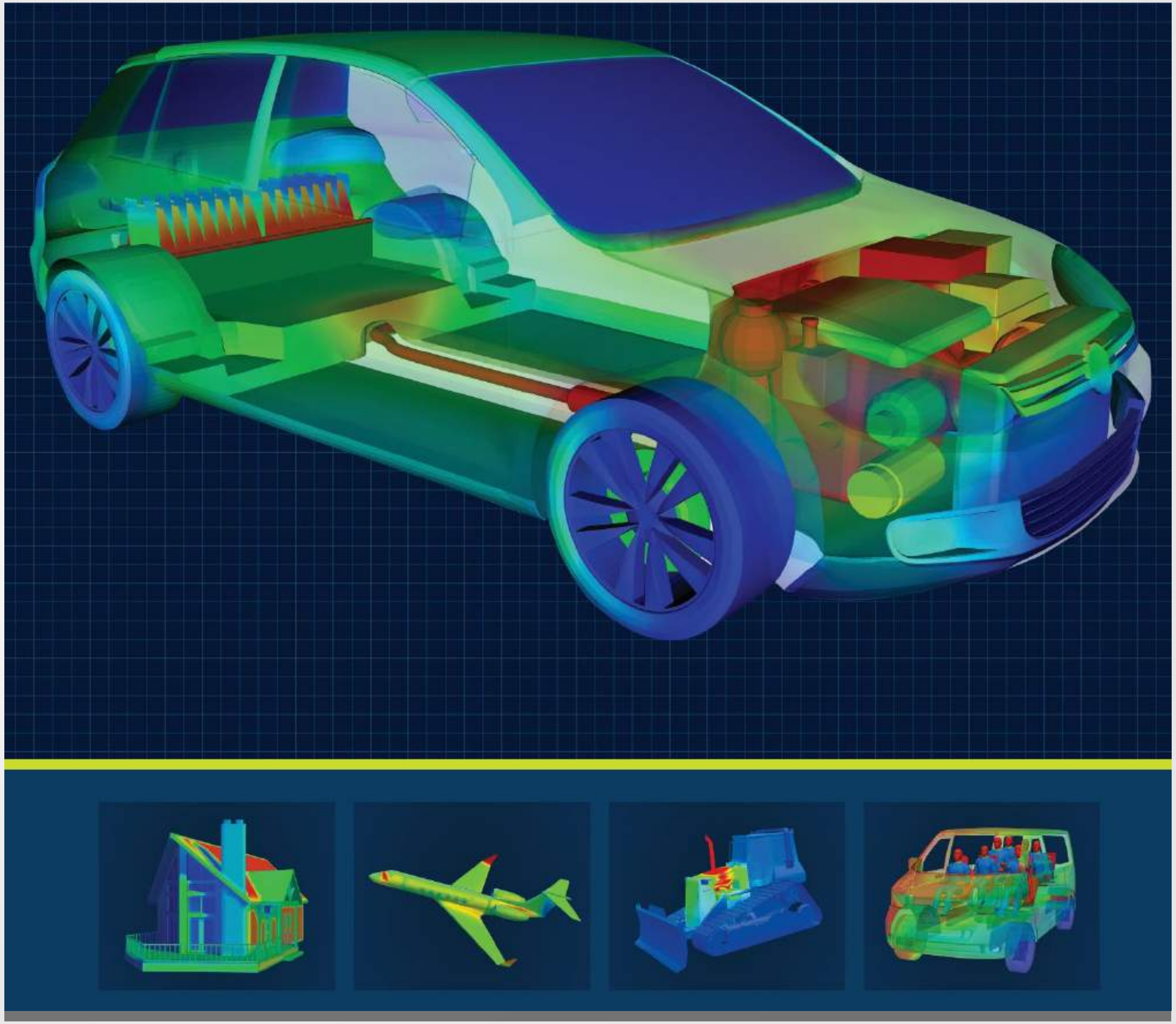
ThermoAnalytics®

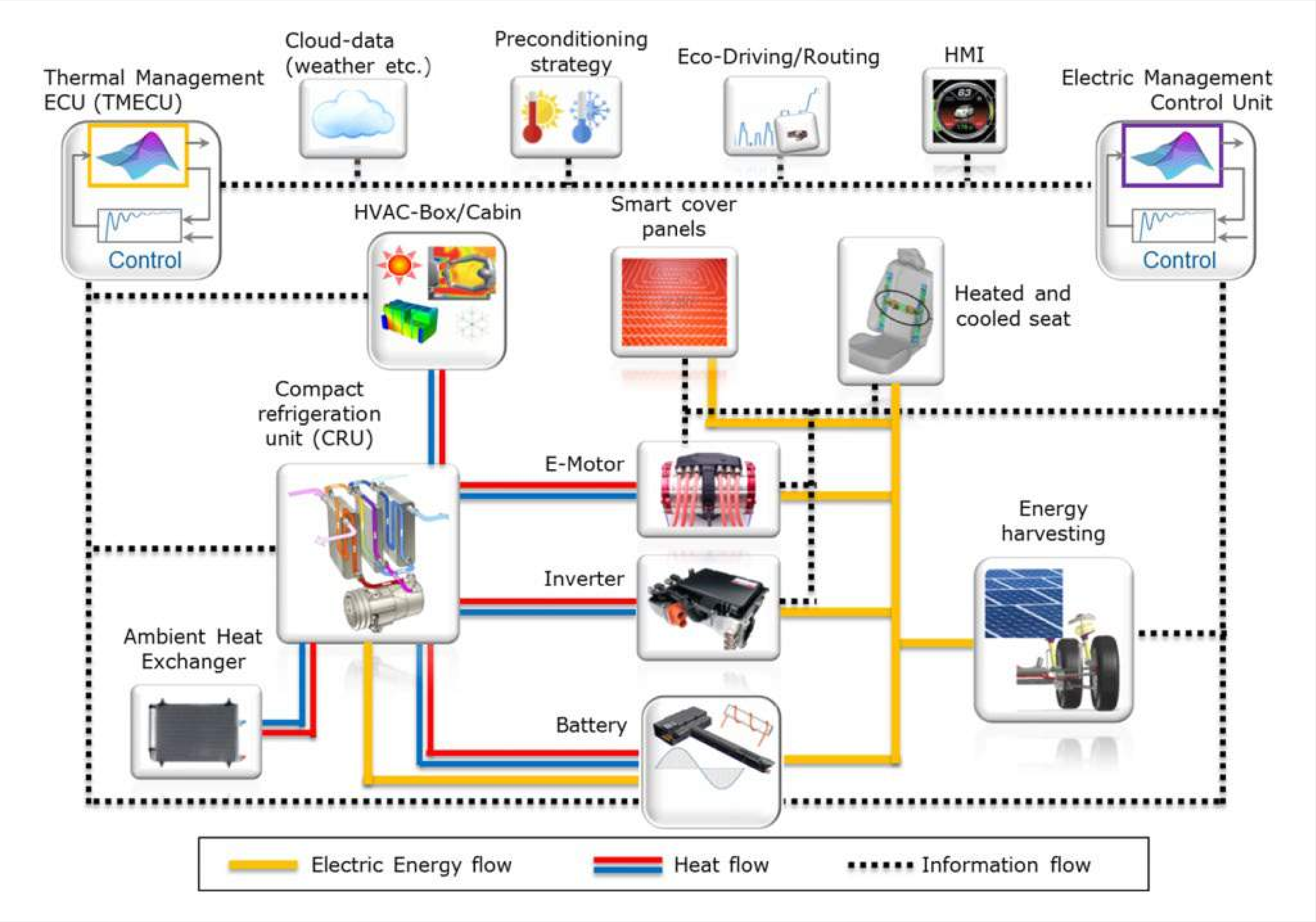
Agenda

- EV/HEV Design
- Battery Modeling
- Drive Cycle Simulation
- Cabin Comfort
- Lifetime and Durability
- Design for Safety
- Multi-Physics Coupling



EV Component Modeling

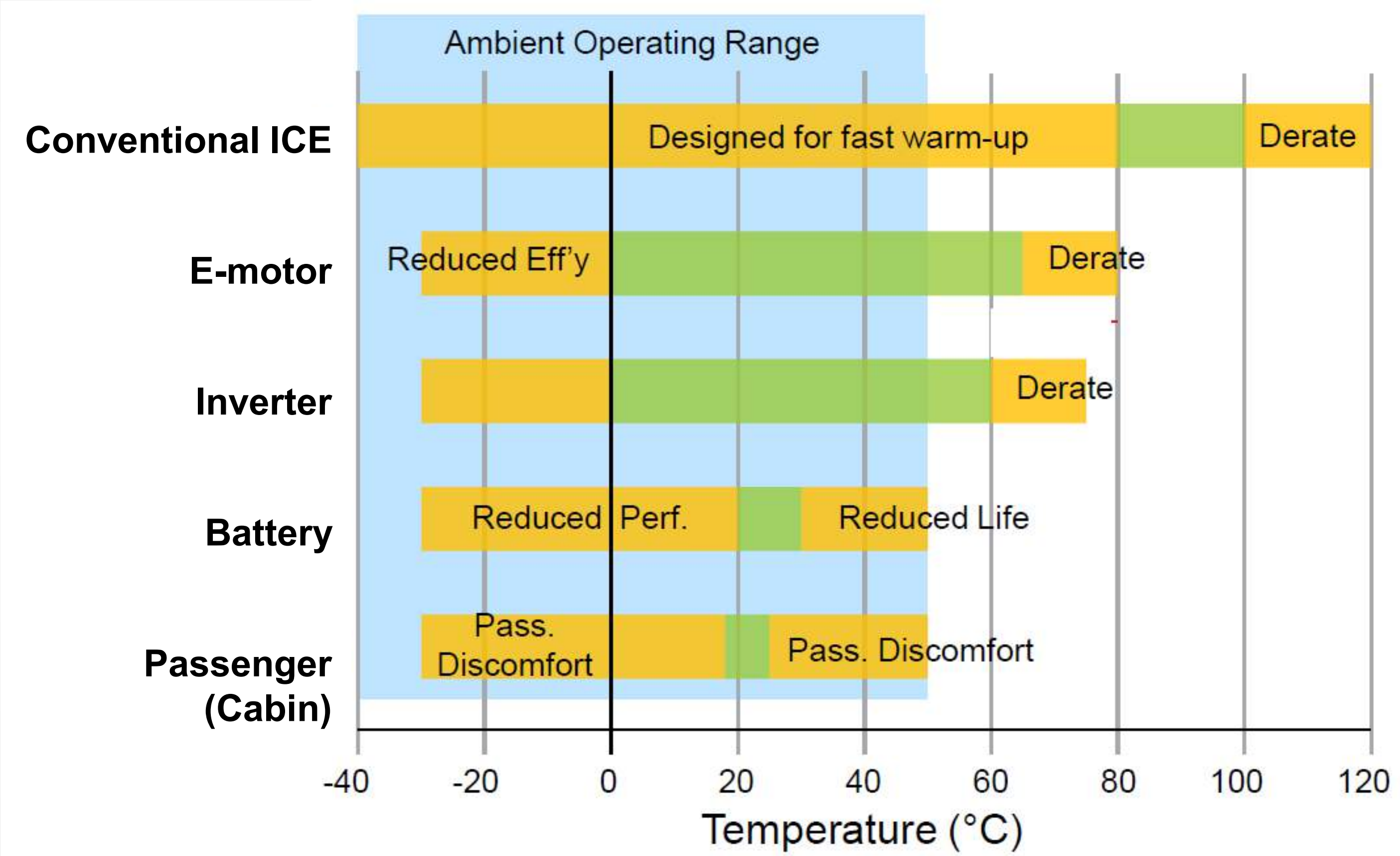
- Electric motors
- Electrical inverters and wiring
- Heat exchangers and cold plates
- Vehicle energy management
- Battery packs
- System Modeling



https://www.compositesworld.com/blog/post/new-composite-material-lowers-temp-of-ev-dashboard

EV Operating Temperature Ranges

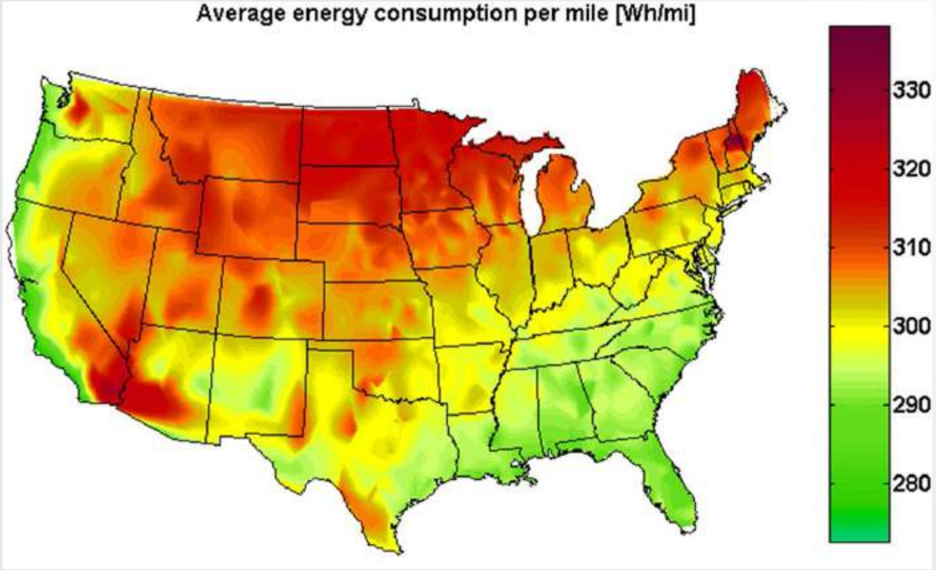
- EV components have vastly different operating ranges than ICE vehicle components
- EV thermal management systems require separate coolant loops that exchange heat with one another



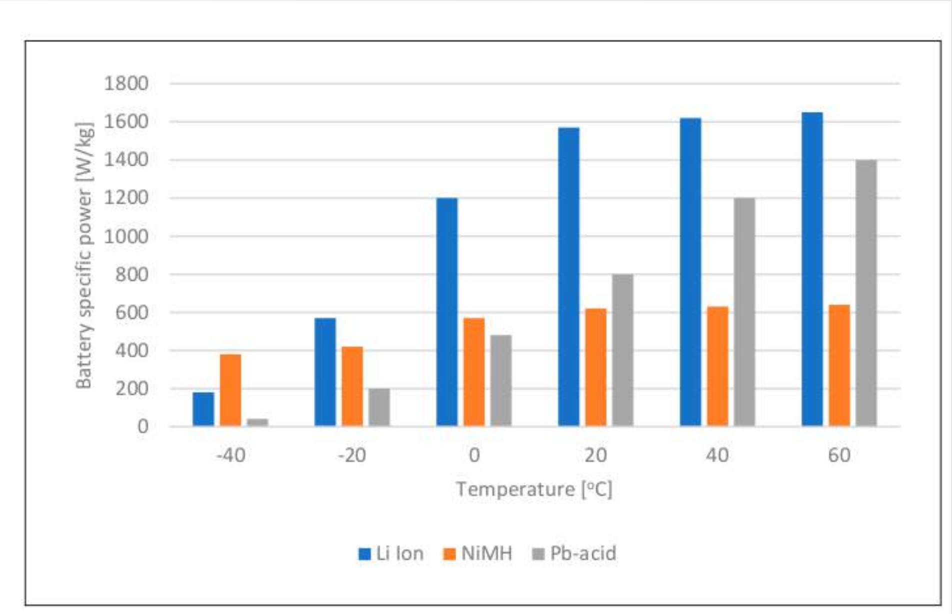
"xEV Thermal Management – Model based development and model predictive control approaches", 3rd annual conference 2020 automotive thermal management, 21 January 2020, Dr. Cedric Rouaud

Environmental effects on EV Range

- EV range is strongly influenced by temperature
  - Depends on battery type



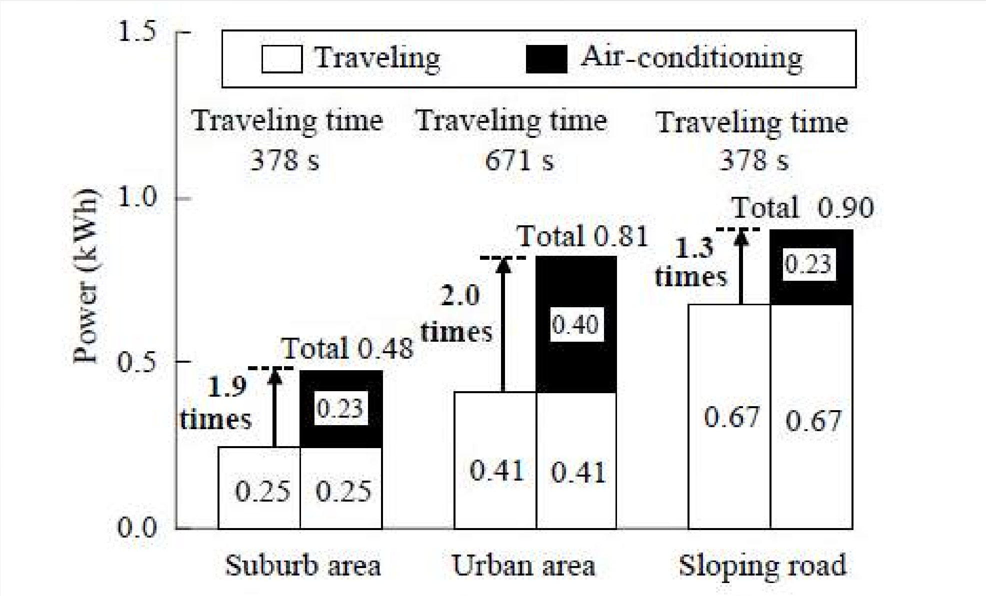
Energy consumption per mile averaged across a fleet of Nissan Leaf EVs over a full year. (Environ. Sci. Technol. 49, 2015.)



Influence of temperature on energy performance of different battery types (Energies 2019, 12, 946)

HVAC Impact

- Climate control loads cause significant range reduction
  - 17-37% in summer*
  - 17-54% in winter*
- Possible design improvements
  - Improved insulation
  - Correlation of BTMS with the HVAC system
  - Thermo-electric generator based heat recovery systems
  - Proper HVAC sizing for cabin comfort



EV Power consumption with operating the air-conditioner in different environments.
Shibata et. al. JEPE 9 (2015)

* Energies 2019, 12, 946

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

TAITherm Battery Thermal-Electric Approach

- Electrical and thermal behaviors are coupled

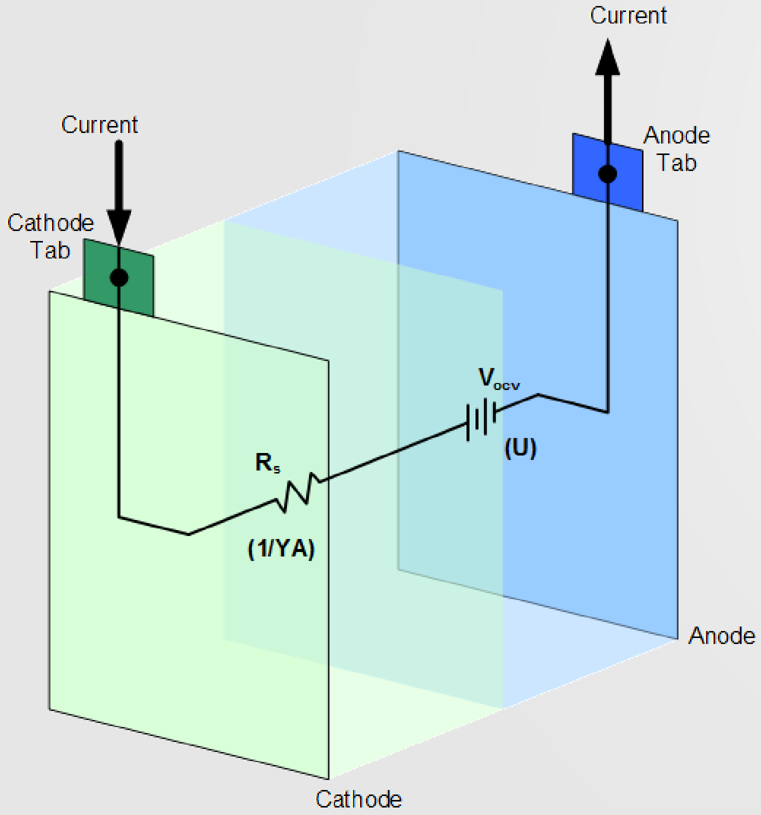
Battery resistance depends on temperature and DoD

T depends on resistive heating and chemical reactions

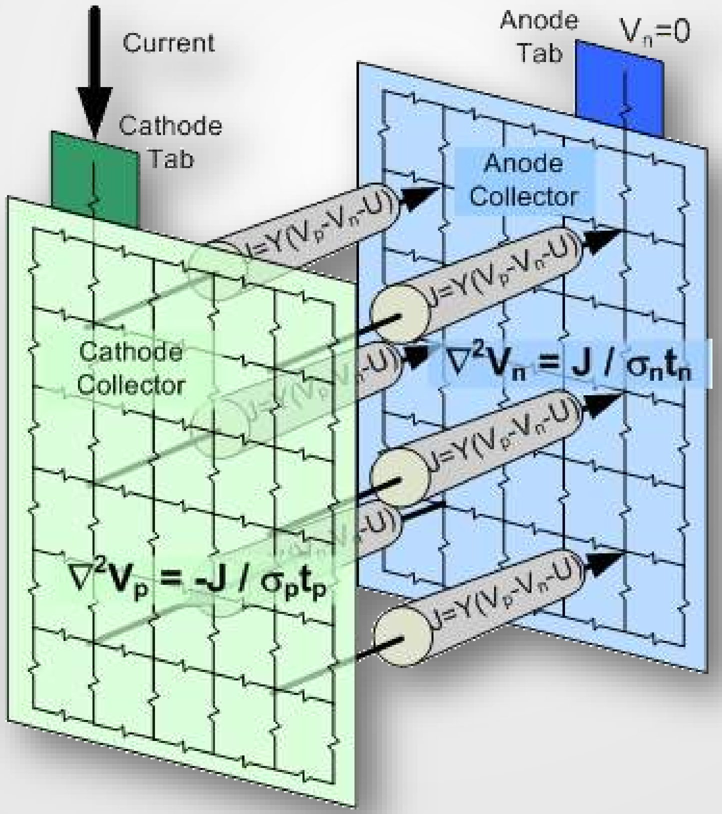
- Battery models compute an imposed heat on the battery geometry
- Imposed heat computed by solving electrical circuit equations

TAITherm Battery Models Overview

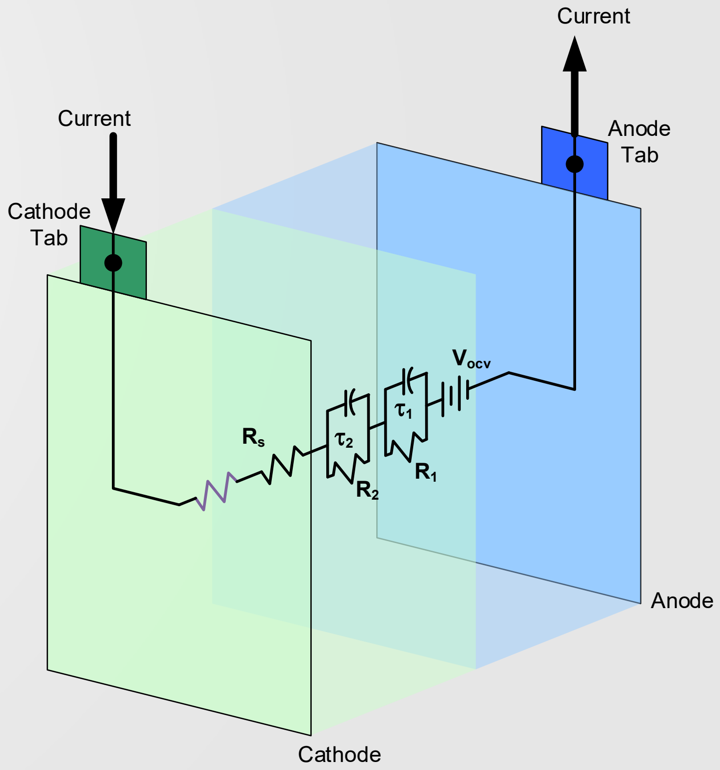
NTG Equivalent Circuit Model



NTG Distributed Model



NREL Equivalent Circuit Model

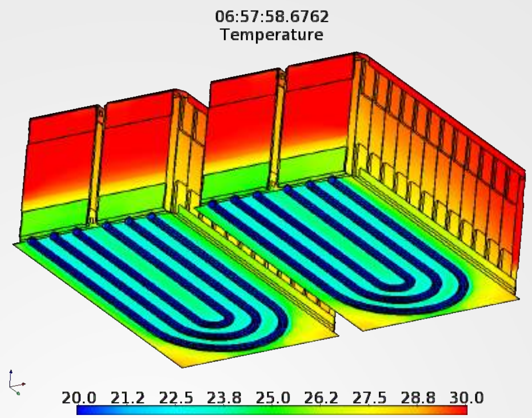


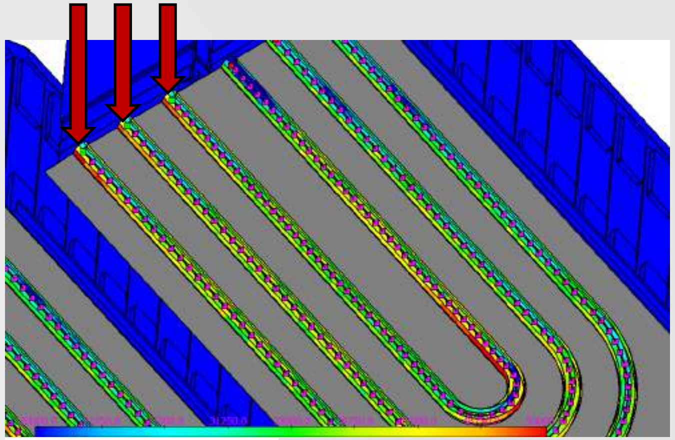
Transient Drive Cycle Simulation

CFD Coupling

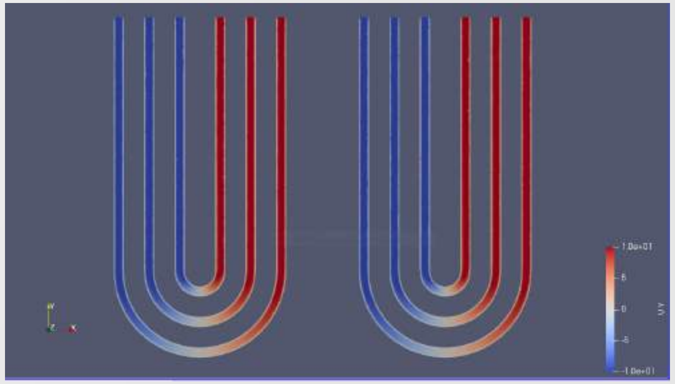
Spatial variance occurs for heat transfer coefficients

- Flow re-direction at bends
- Secondary flow
- Local turbulence
- Heat transfer enhancement structures
- Converging and diverging streams



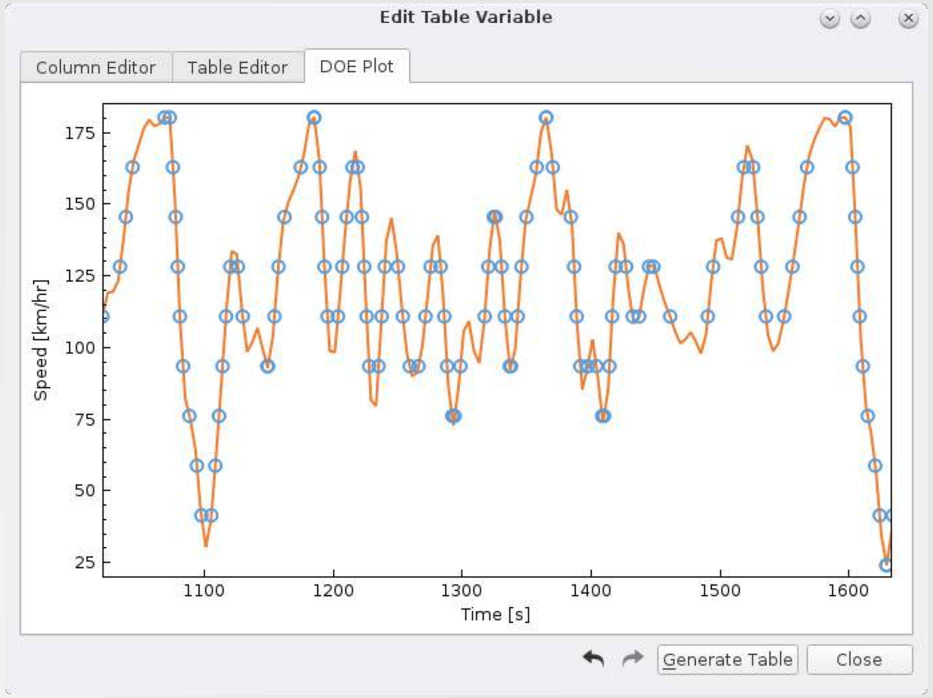


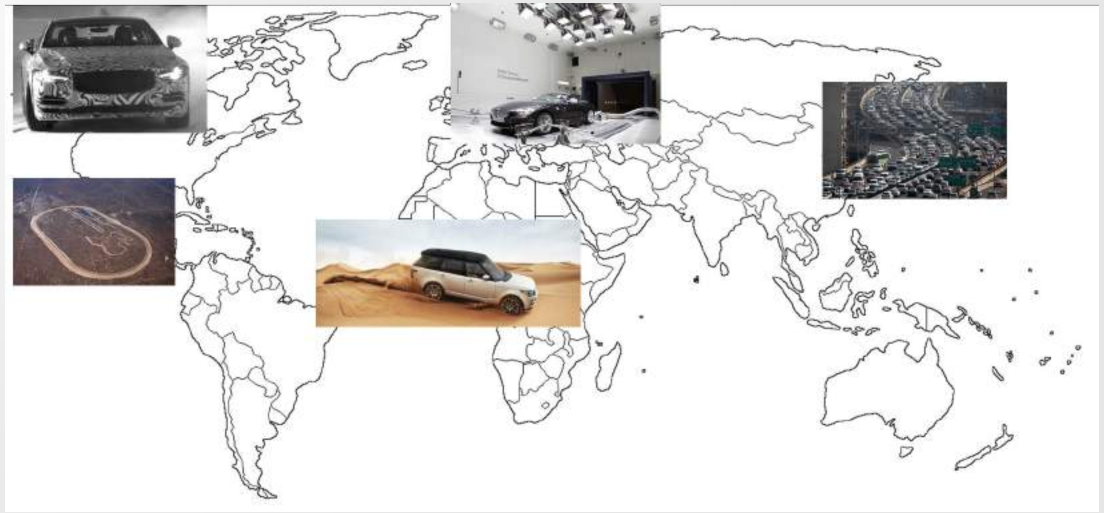
Imported HTC [W/m²K]



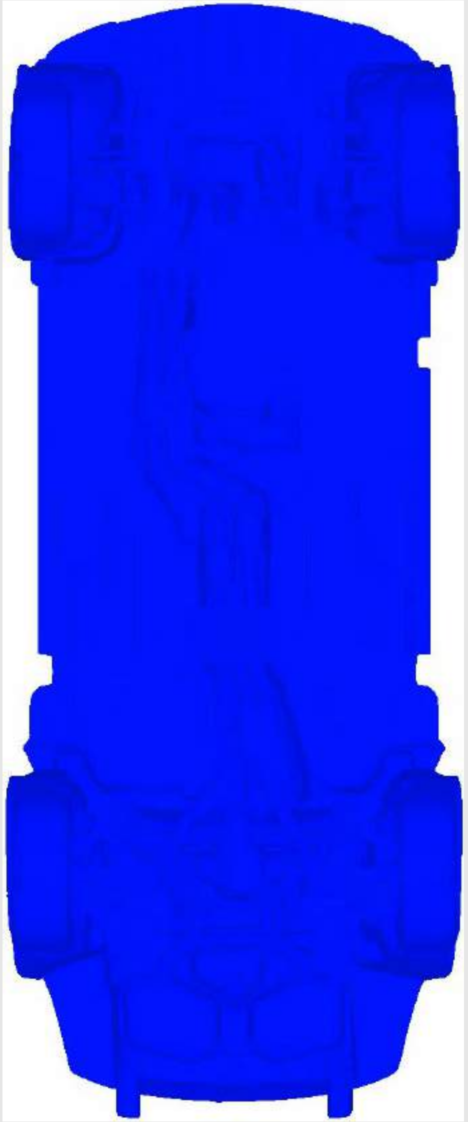
Drive Cycle

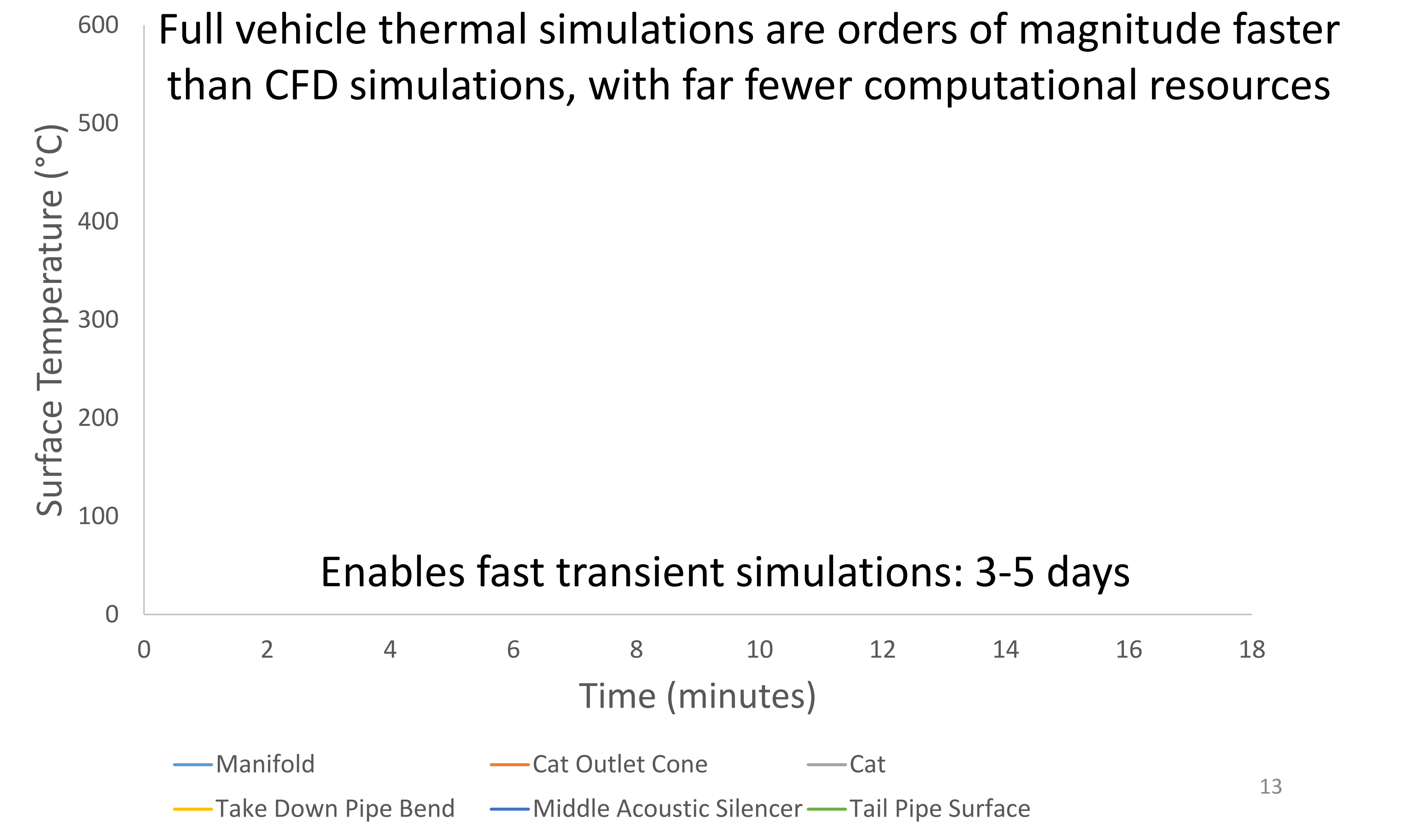
- Enhanced CFD-Coupling CoTherm Template
  - Signal simplification
  - Surrogate Model Creation
  - CFD Recycling
- Simulate any Driving Profile with Added Efficiency
  - Optimized Coupling Methods
  - Minimum Amount of CFD
  - Maximum Time Step Size
- Fully Automated Process
- Fully Customizable Process





Efficient Use of Computational Resources

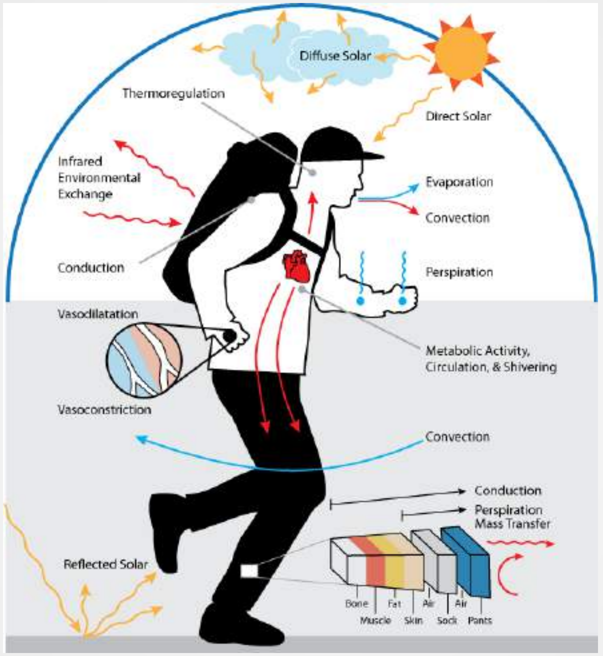


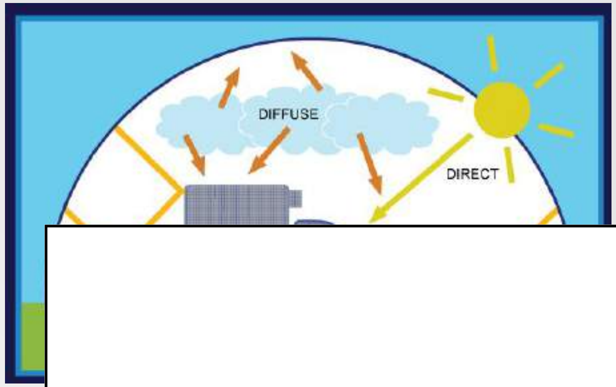


Human Thermal Extension

Human Physiology Model

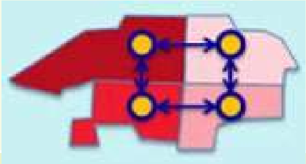
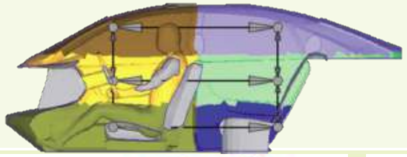
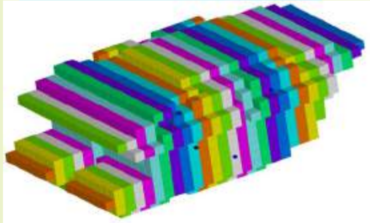
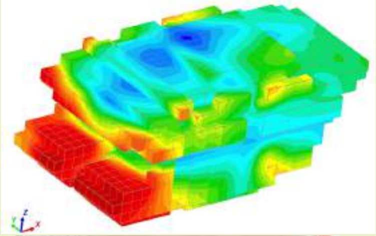
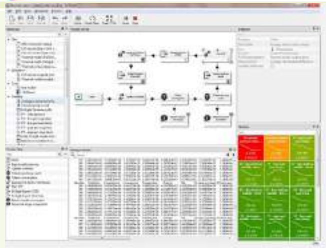
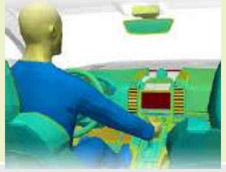
- 20+ body segments
- Thermal Model
  - Metabolic Heating
  - Shivering
  - Respiration
  - Sweating
  - Peripheral Vasomotion





- Predicts Skin Temp, Interior Tissue Temps, Blood Pool Temp, Core Temp
- Berkeley Comfort Modeling: Is the passenger comfortable?

Methods Available

Method		
TAITherm Standalone Single Fluid Node		
TAITherm Standalone Multiple Fluid Node		
TAITherm 1D Coupling (GT Suite & Amesim) 20-10k Cells		 
TAITherm CFD Coupling Millions of Cells	DASSAULT SYSTEMES	
TAITherm Manikin Coupling		

Accuracy

Reduced Computational effort

Localized heating and cooling

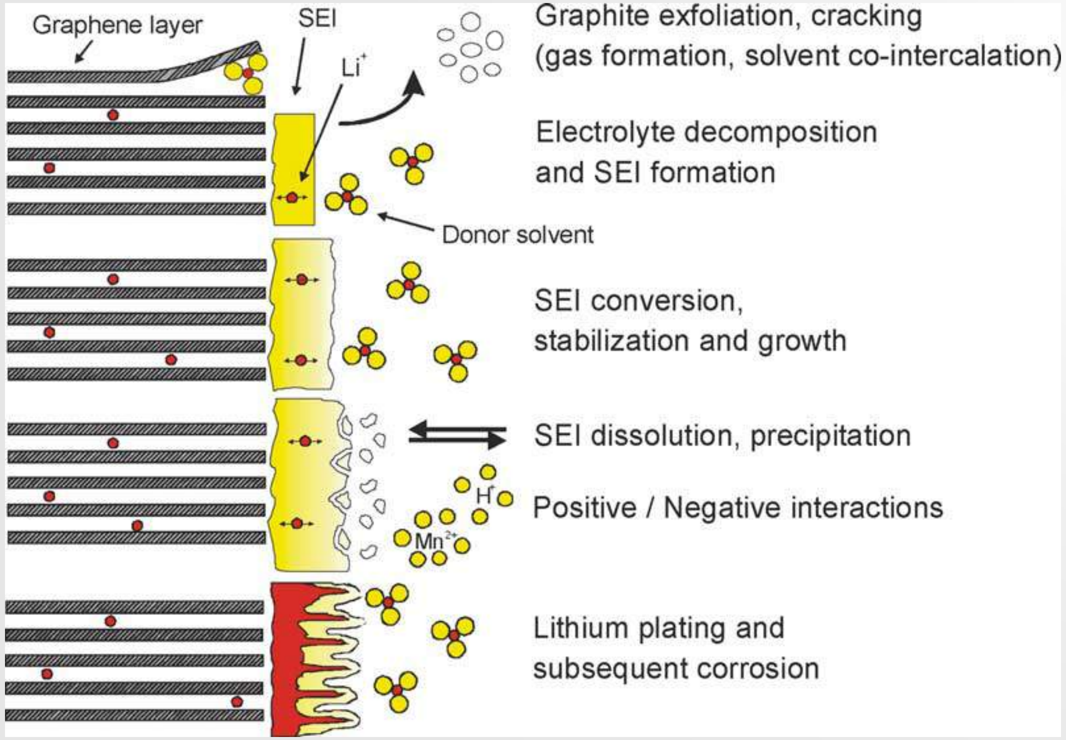
Heated Steering Wheel

Heated Seat

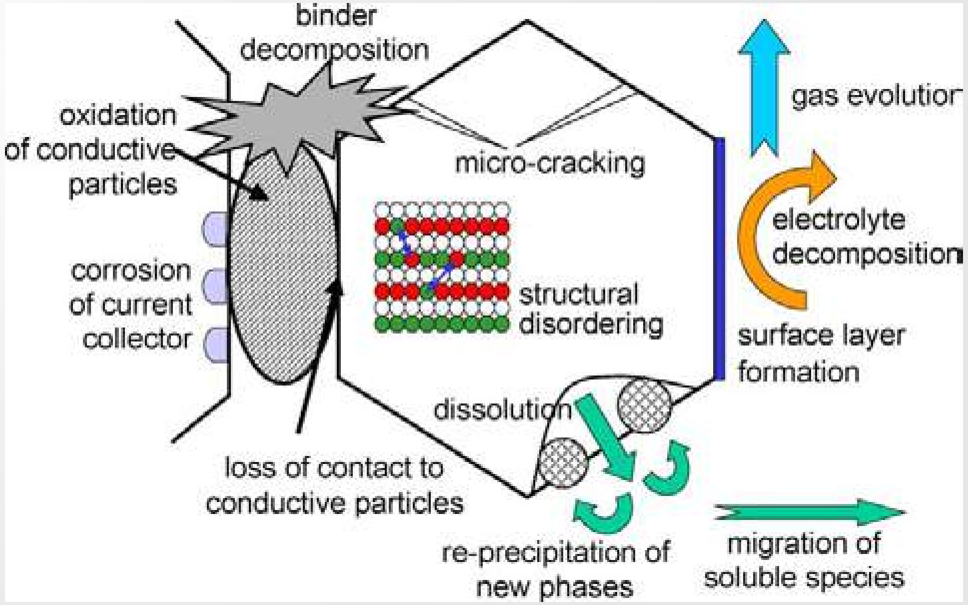
Radiant Panels

Battery Ageing Mechanisms

- Battery ageing is caused by many complex and coupled electrochemical mechanisms
- First principles models exist, but are highly battery chemistry dependent and not yet able to capture all relevant mechanisms.
- A more general semi-empirical model is more practical and can be applied to multiple different batteries by refitting the parameters



Anode



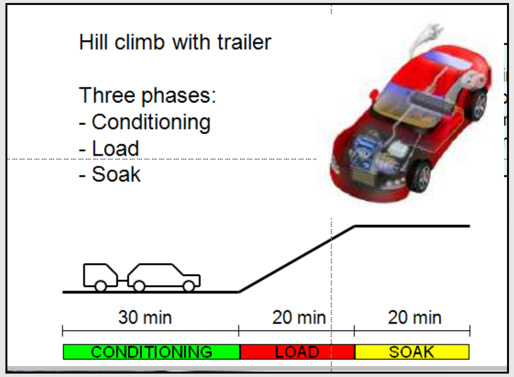
Cathode

Images from: Ageing mechanisms in lithium-ion batteries," *J. Power Sources,* 147 (2005) 269-281

Simulation Approach: NREL Lifetime Outputs

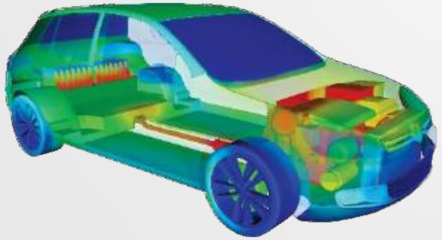
Vehicle Drive cycles
- Speed vs. time traces
- Charging assumptions

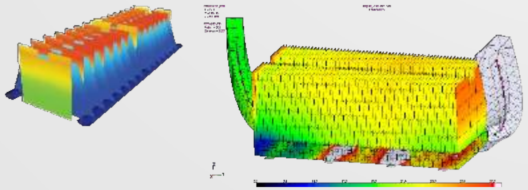
Vehicle (Dyno Test)



Battery power profile
- $I(t)$, $T_{amb}(t)$, h_{conv}

TAITherm Battery Model





Battery stress statistics
- $T(t)$, $V(t)$, $\Delta SOC(t)$, …

NREL Battery Life Model

$$Capacity = \min\left(b_0 - b_1 t^{1/2}, c_0 - c_1 N\right)$$

$$Resistance = a_0 + a_1 t^{1/2} + a_2 N$$

Solution is Coupled at Each Life Time Step

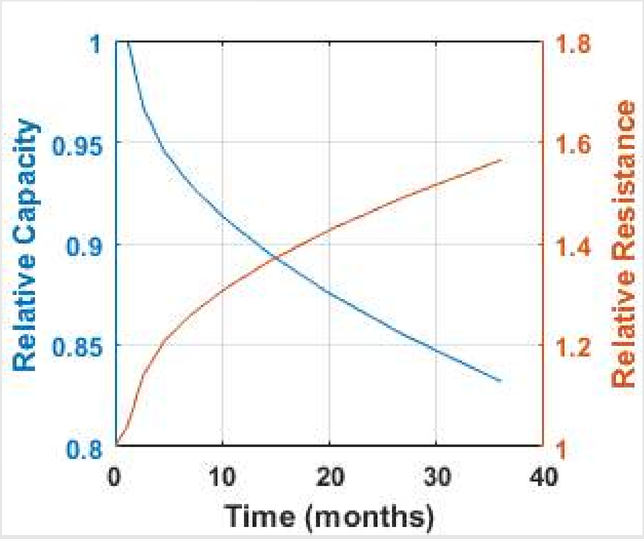
TAITherm Battery Model

NREL Battery Life Model

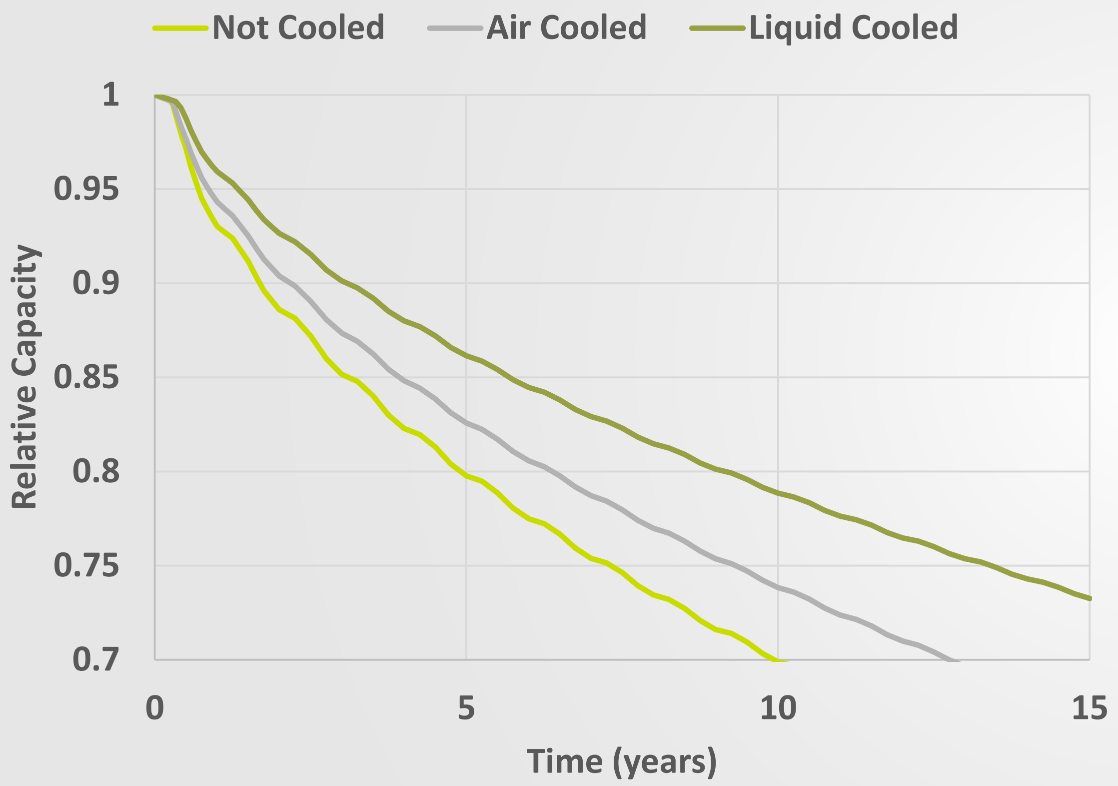
T & SOC

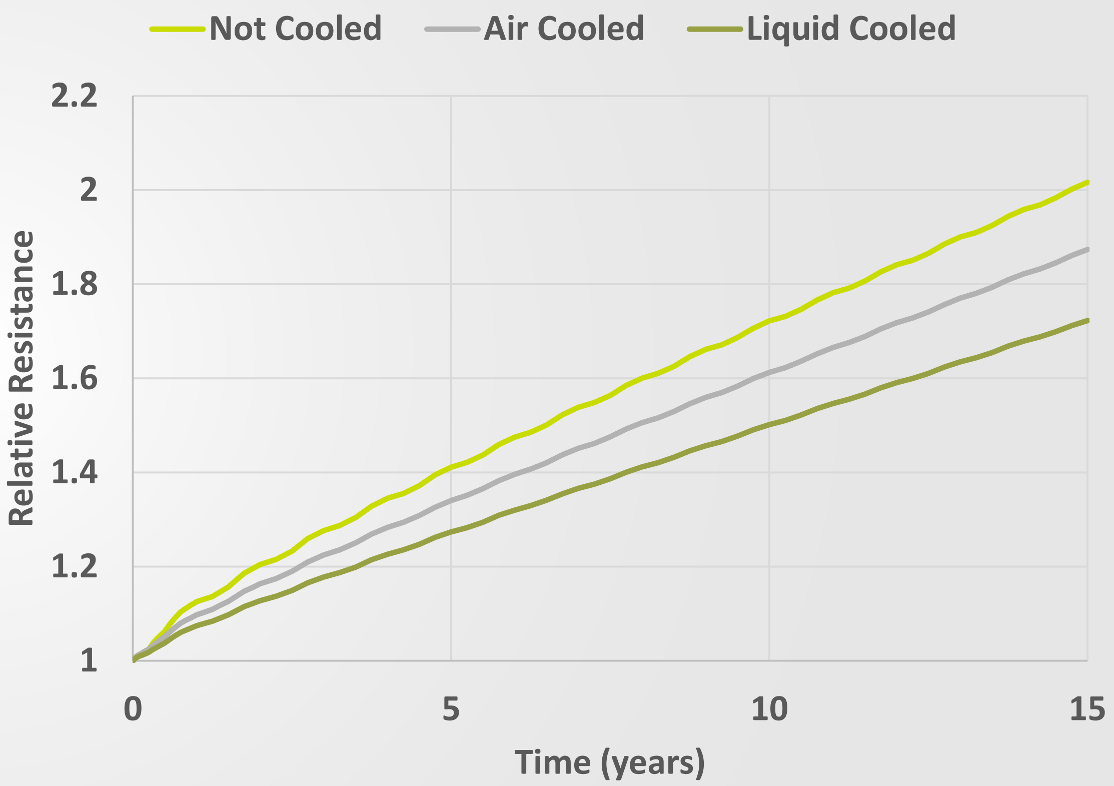
R & Cap.

Lifetime statistics
- Relative Capacity
- Relative Resistance



State-Of-Health (SOH) Results



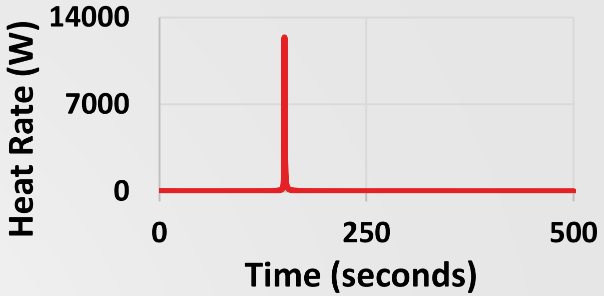


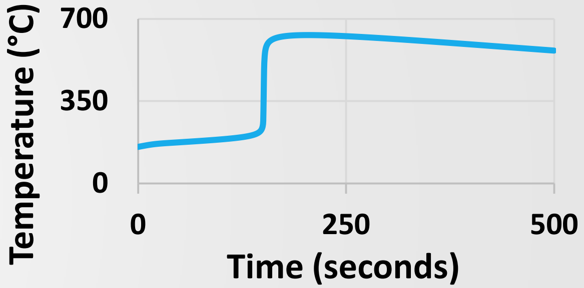
Thermal Runaway

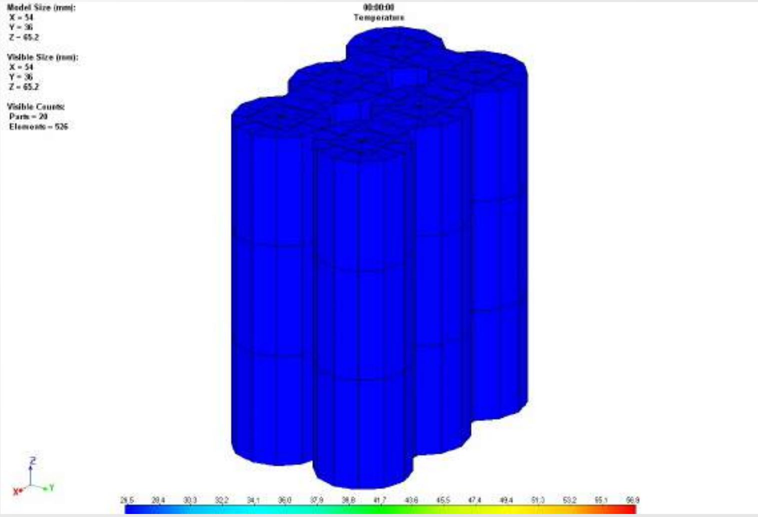
- If the battery temperature gets too high, thermal runaway can happen
  - This can be due to a certain drive cycle on a hot day or a sudden short-circuit
- European law prescribes a mininum time of 5 minutes between the start of thermal run-away and the car to catch fire
- The requires proper management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

NREL Thermal Runaway Model

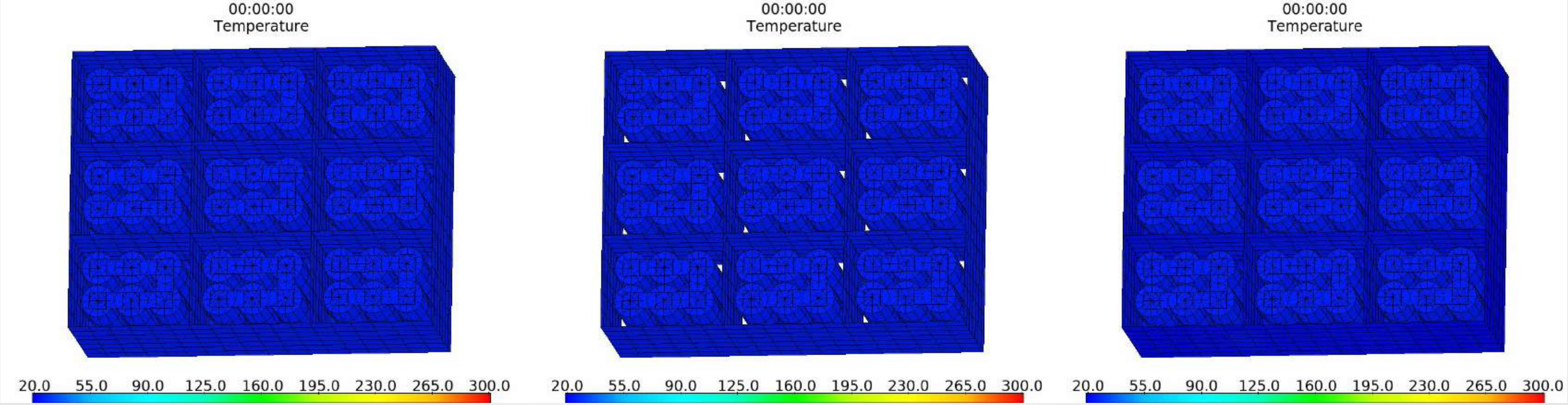
- Describes heating from unwanted chemical reactions at elevated temperatures
  - Elevated temperatures due to hot ambient conditions, I^2R heating at shorts, internal discharge
- Temperature-dependent imposed heating derived from reaction kinetics
  - Predicts heat released by reactions between electrode, 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	Wall insulation 10mm	Wall insulation 10mm + external cooling
5 min	**12 min**	**29 min**

Multi-Physics, Scripting, and Automation

- CAE often requires complex processes
  - Coupling different physics
  - Simplified analysis
    - Drive cycle / dynamic driving
    - Lifecycle modeling
  - Multi-simulation tasks
    - Sensitivity studies / DoE
    - Optimization
- These processes may involve multiple pieces of software, customized scripts, and other domain-specific ‘glue’ to automate
- CoTherm intends to provide an efficient, versatile, and intuitive way of implementing these processes

Process Automation and CAE Coupling

TAITherm by ThermoAnalytics

ANSYS FLUENT

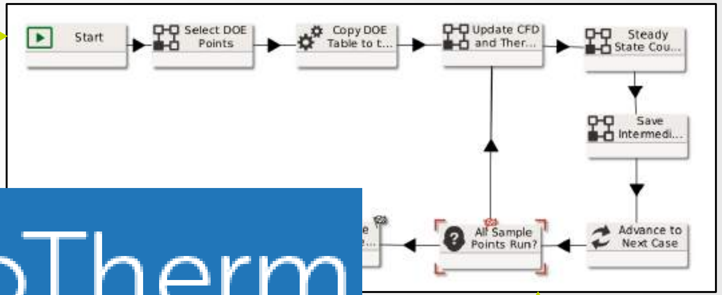
ABAQUS

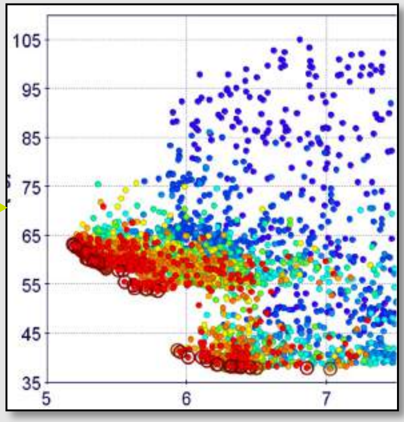
STAR-CCM+

GT

Optimizer

- Improve designs with an integrated optimizer

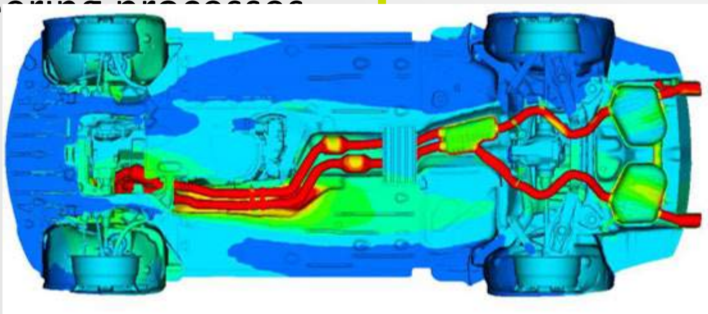




CoTherm by ThermoAnalytics

Process Automation and CAE Coupling

- Link numerous CAE tools to build large automated processes
- Increase productivity and reduce variability by automating engineering processes

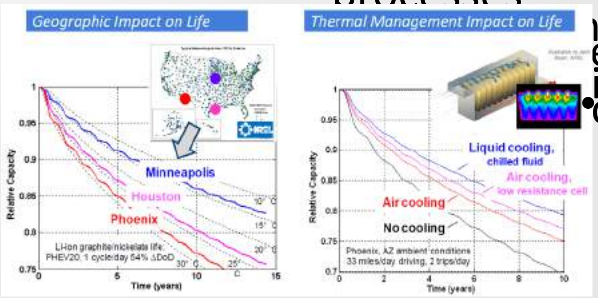


CAE Coupling and process automation tool

- Implement highly automated multi-tool CAE processes

Drive Cycle Tool

...namic drive ...esses while running ...icient and ...on with HPC's



Battery Life Cycle Modeling

- Predict the performance of a ... over its entire life cycle
- ... predictions

Co-Simulation Approach Comparison

Approach	Advantages	Disadvantages
3D – 3D	Highly accurate	Slow, difficult to integrate
1D/2D – 3D	Moderately accurate	Moderately slow, difficult to integrate
1D/2D/3D – Nodal Net	Easy to integrate, moderately fast	Requires thermal calibration
TAITherm Empirical	No integration required, easy to calibrate, fast	Limited by number of models available, requires some calibration
Reduced Order Modeling	Very fast, able to integrate models of varying complexity	Limited range of applicability, requires a lot of data to calibrate

Conclusions

- EV/HEV design affects vehicle range, performance, lifetime, safety, and driver comfort
- Environmental loading is important when considering HVAC loading, BTMS performance, and BMS performance limiting capabilities for safety and reliability
- Using simulation saves money on testing, improves overall performance, allows the modeler to consider use cases which are difficult to test, and allows rapid evaluation of design alternatives
- Co-simulation and multi-physics modeling techniques provide an efficient way to ensure robust, safe, and durable designs that will meet customer expectations for the entire life of the vehicle

Questions?