MATLAB EXPO

Optimize EV Battery Performance Using Simulation

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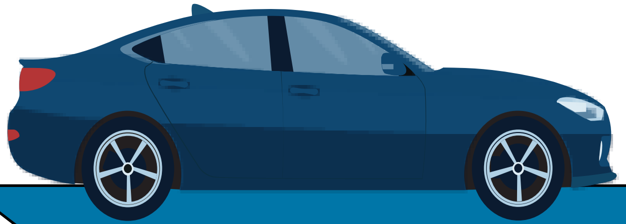
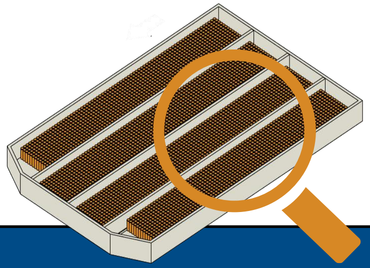
Key takeaways

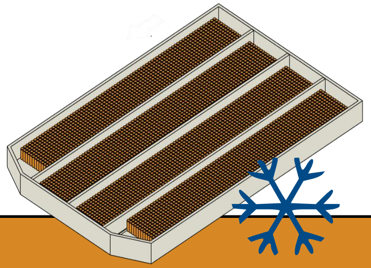
Optimize EV battery performance using simulation



Assess system performance



Find optimal pack size



Design battery pack

Powertrain Blockset	Global Optimization Toolbox Simulink Design Optimization	Simscape Battery
System-level models to quantify vehicle range, battery performance, and costs	Efficiently optimize the design while accounting for competing requirements	Perform detailed battery design studies

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Agenda

Optimize EV battery performance using simulation

- **Problem statement**
- Assess system performance
- Find optimal pack size
- Design battery pack
- Conclusions

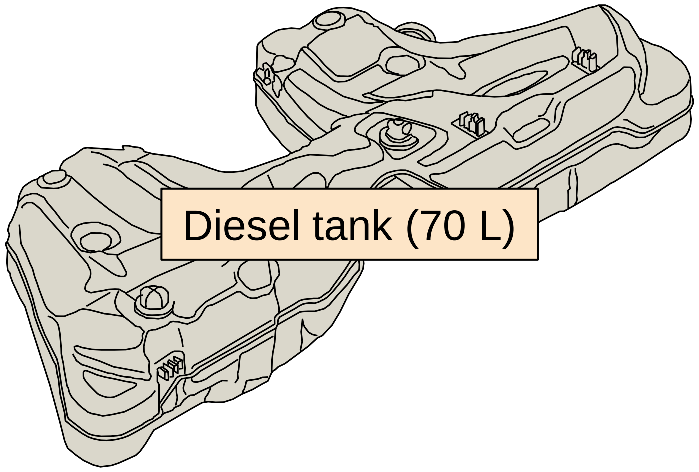
Problem statement: the electrification of the powertrain

Current challenges

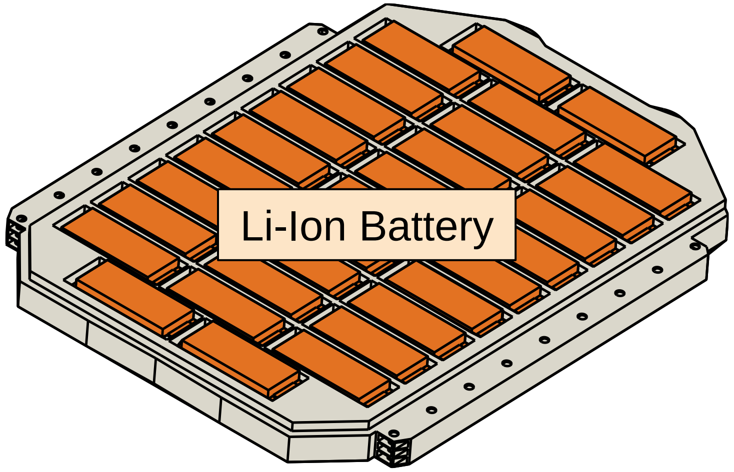
The automotive sector is focusing on reducing CO_2 emissions. For this scope, Battery Electric Vehicles (BEVs) are a promising solution:

- Localize emissions to energy production source
- Can be charged with renewable energy

However, **engineering challenges remain** …



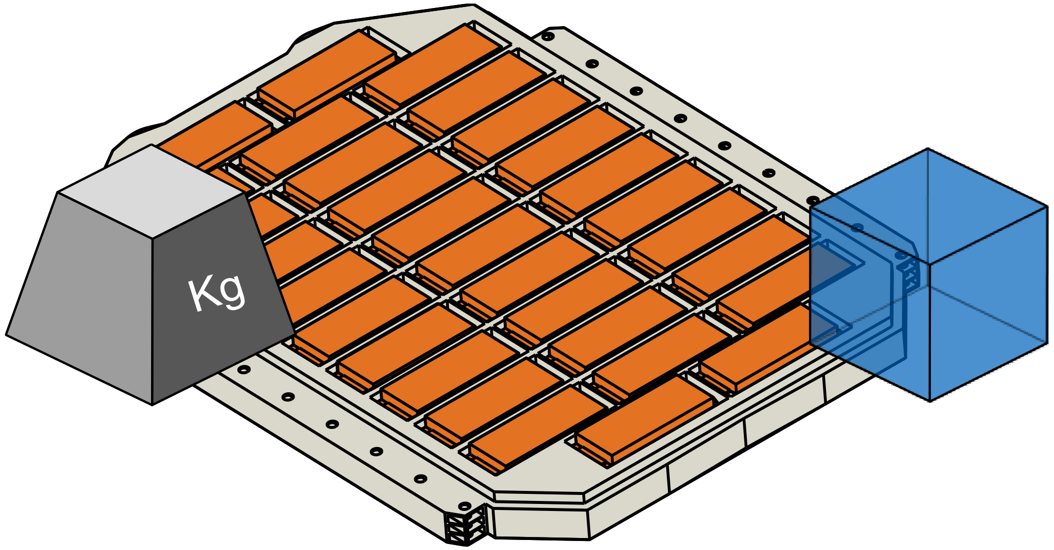
Diesel tank		Li-Ion Battery
700 kWh	Energy	95 kWh
95 kg	Mass	700 kg
85 L	Volume	430 L



Problem statement: the electrification of the powertrain

Current challenges

- The battery impacts the **vehicle mass** and on other crucial system-level specifications
  - **Energy consumption**
  - **Range**
  - **Acceleration**
- The battery's integration represents a major challenge
- Today's goal is to show how you can use MathWorks products to:
  1. Create a BEV model (and assess vehicle performance)
  2. Optimize the battery pack size
  3. Detail the battery pack



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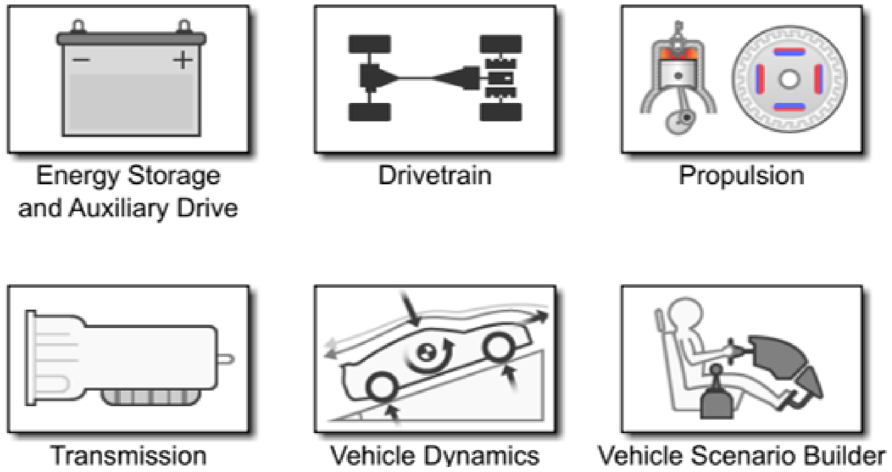
Create a BEV model

Using Powertrain Blockset™

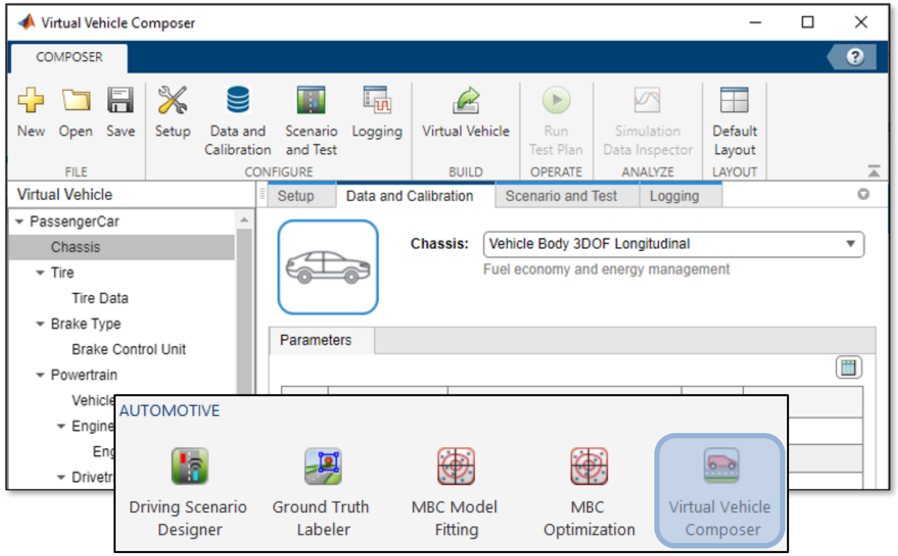
Create a vehicle model with Powertrain Blockset

- Blocks for gasoline, diesel, hybrid, and electric systems
- Provides a standard model architecture that can be reused throughout the development process
- Ideal for trade-off analysis, component sizing, and optimization



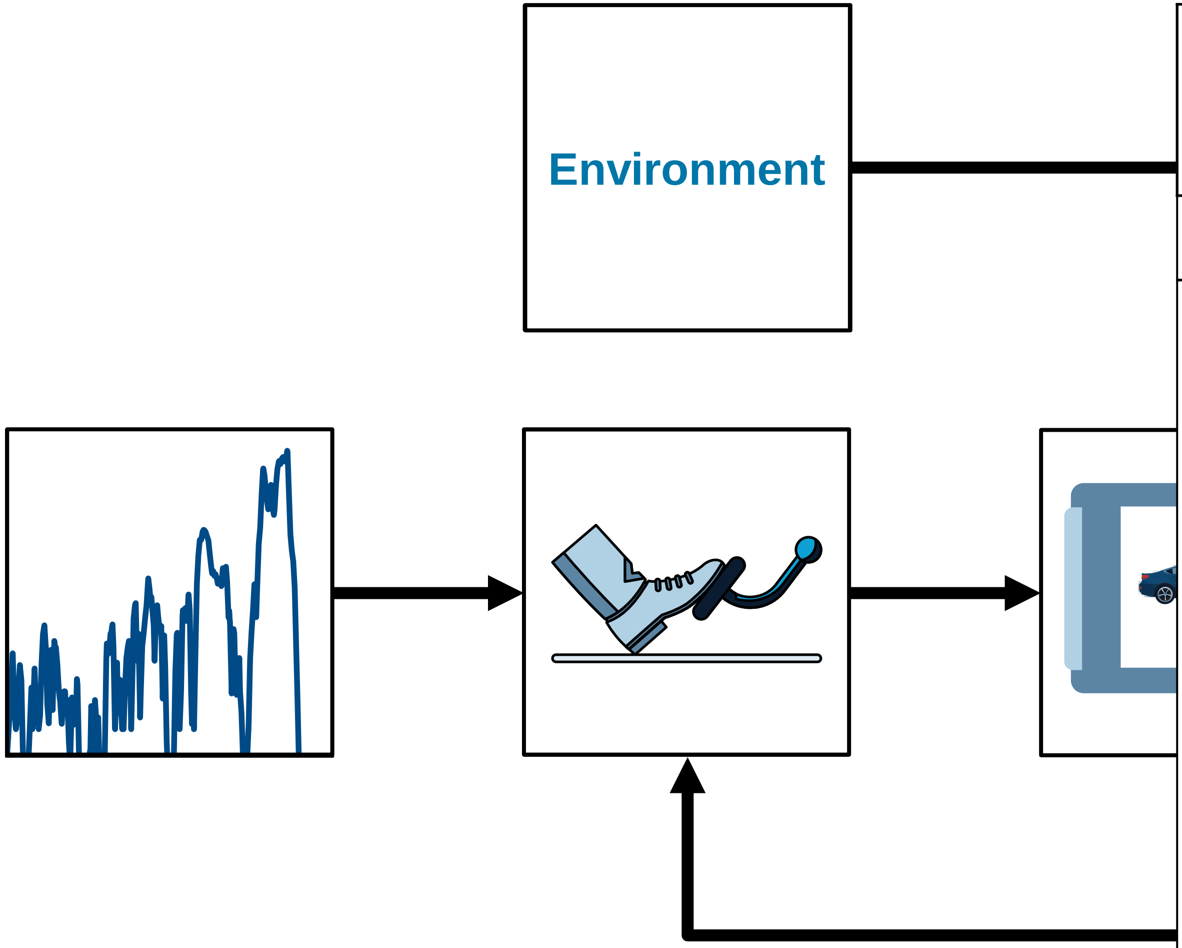
Generate a vehicle model with Virtual Vehicle Composer

- Interactive app
- Several pre-built vehicle templates
- Easy component parametrization
- Generates a full vehicle model



Overview vehicle model

Generated with Virtual Vehicle Composer



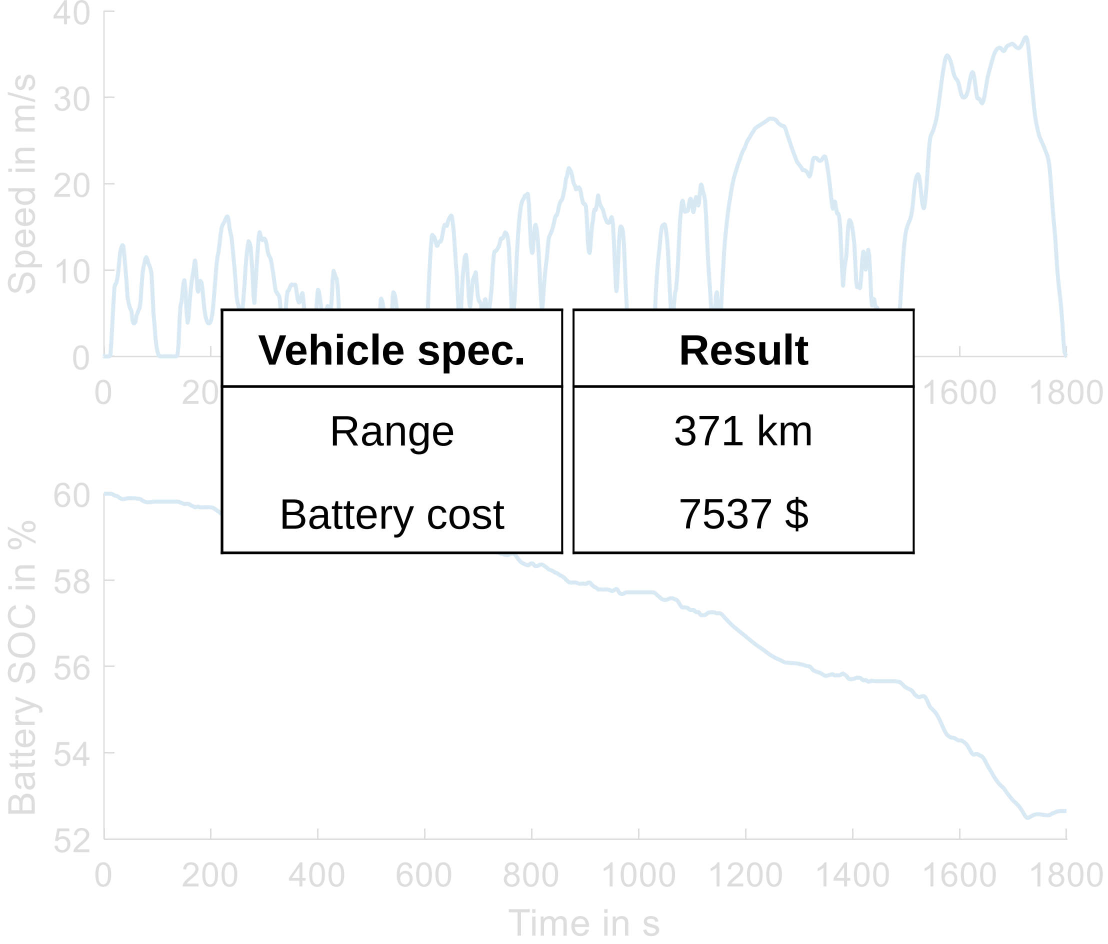
Chosen parametrization set (mid-size passenger car)

Variable	Value
Vehicle mass	1611 kg
L101 / W103 / H100	2.87 m / 1.85 m / 1.44 m
Aerodynamic drag	0.23
Cell configuration	96s31p
Gearbox ratio	9.0
Battery energy density	145 Wh/kg
Battery costs	125 $/kWh

Overview vehicle model

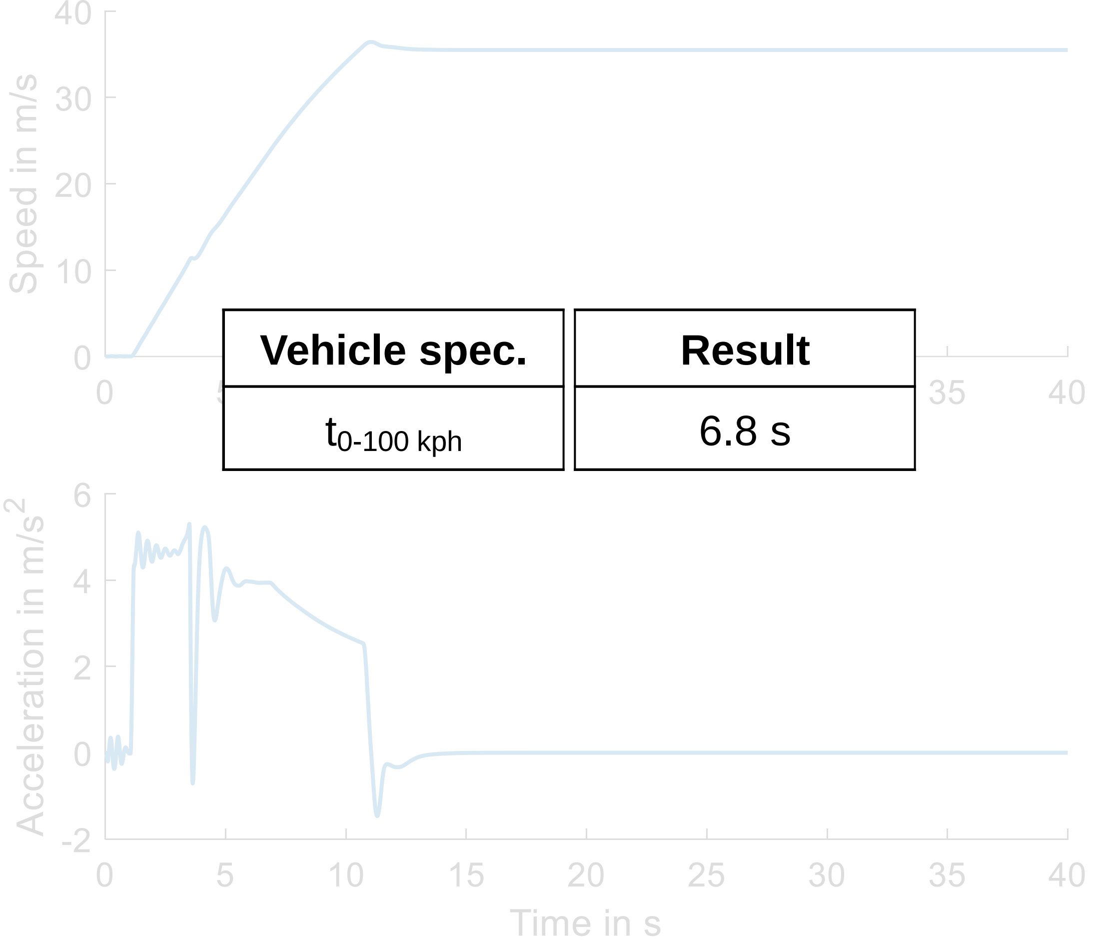
Initial assessment, mid-size electric passenger car

Drive cycle simulation (WLTP)



Vehicle spec.	Result
Range	371 km
Battery cost	7537 $

Acceleration simulation (WOT)



Vehicle spec.	Result
$t_{0\text{-}100\ kph}$	6.8 s

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Problem statement

Objectives, constraints, and design variables

Given the vehicle model, define the optimization problem:

- Objective:

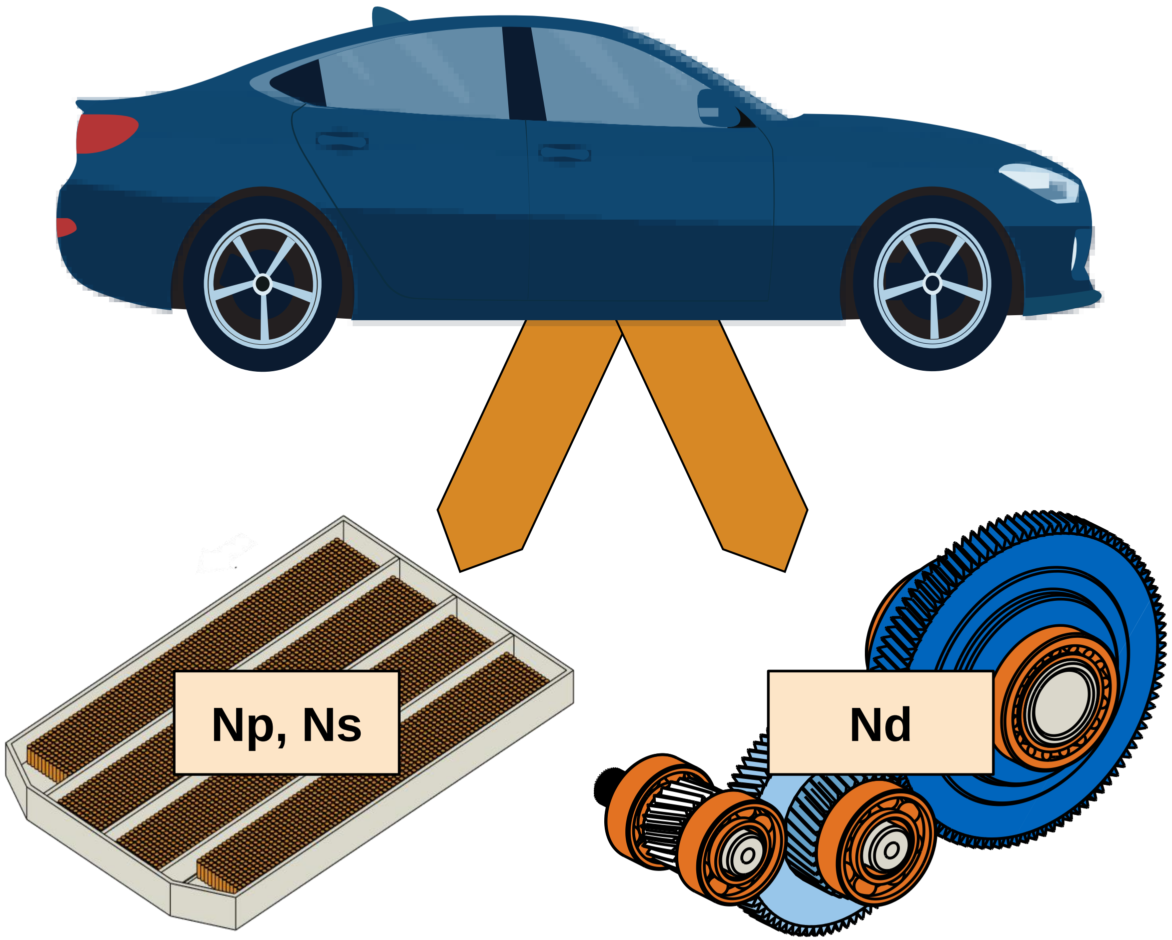
  minimize $f(x) = w_1 * Cost - w_2 * Range$

- Constraints:

  g_1: DriveCycleFault ≤ 0
  g_2: Range ≥ 400 km
  g_3: $t_{0\text{-}100\ kph} \leq 7$ s

- Design variables

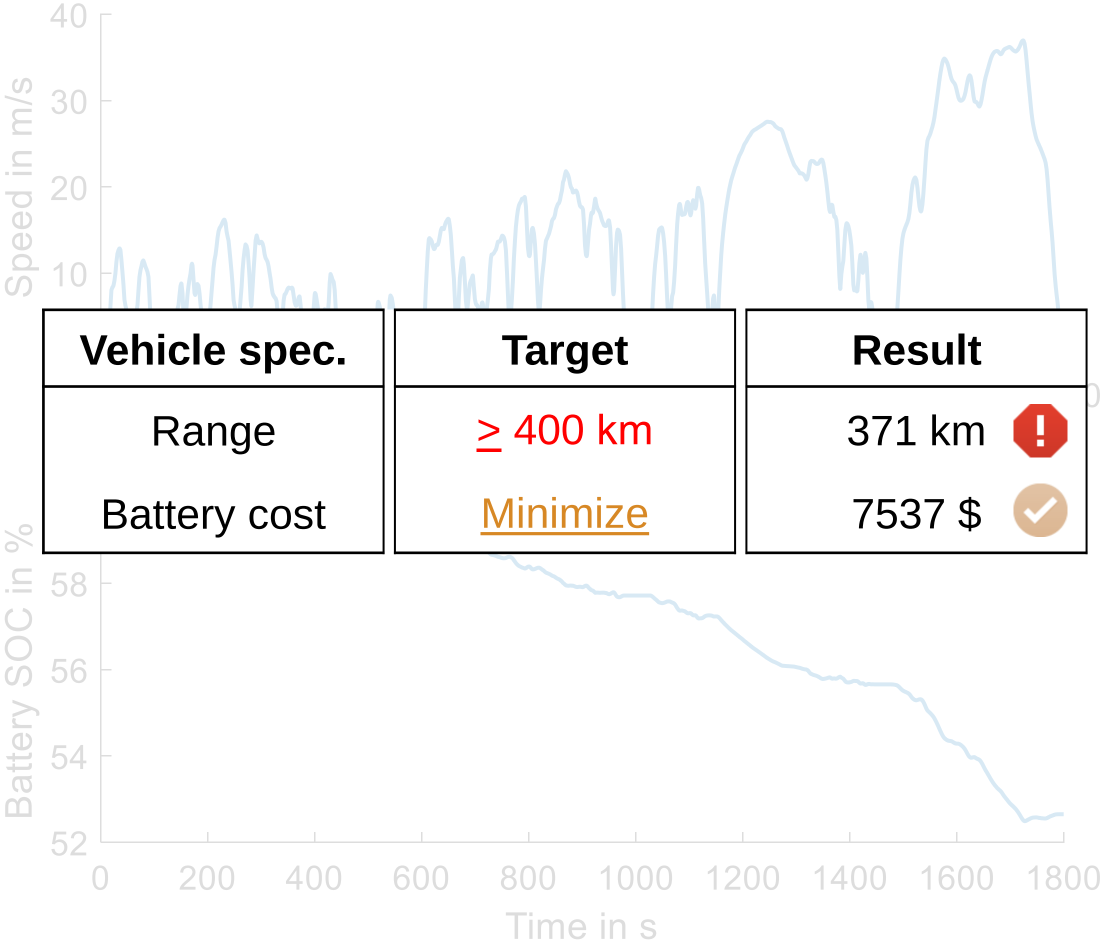
  x_1: $10 \leq Np \leq 50$ (Integer)
  x_2: $80 \leq Ns \leq 140$ (Integer)
  x_3: $7 \leq Nd \leq 10$ (Continuous)



Comparison with initial assessment

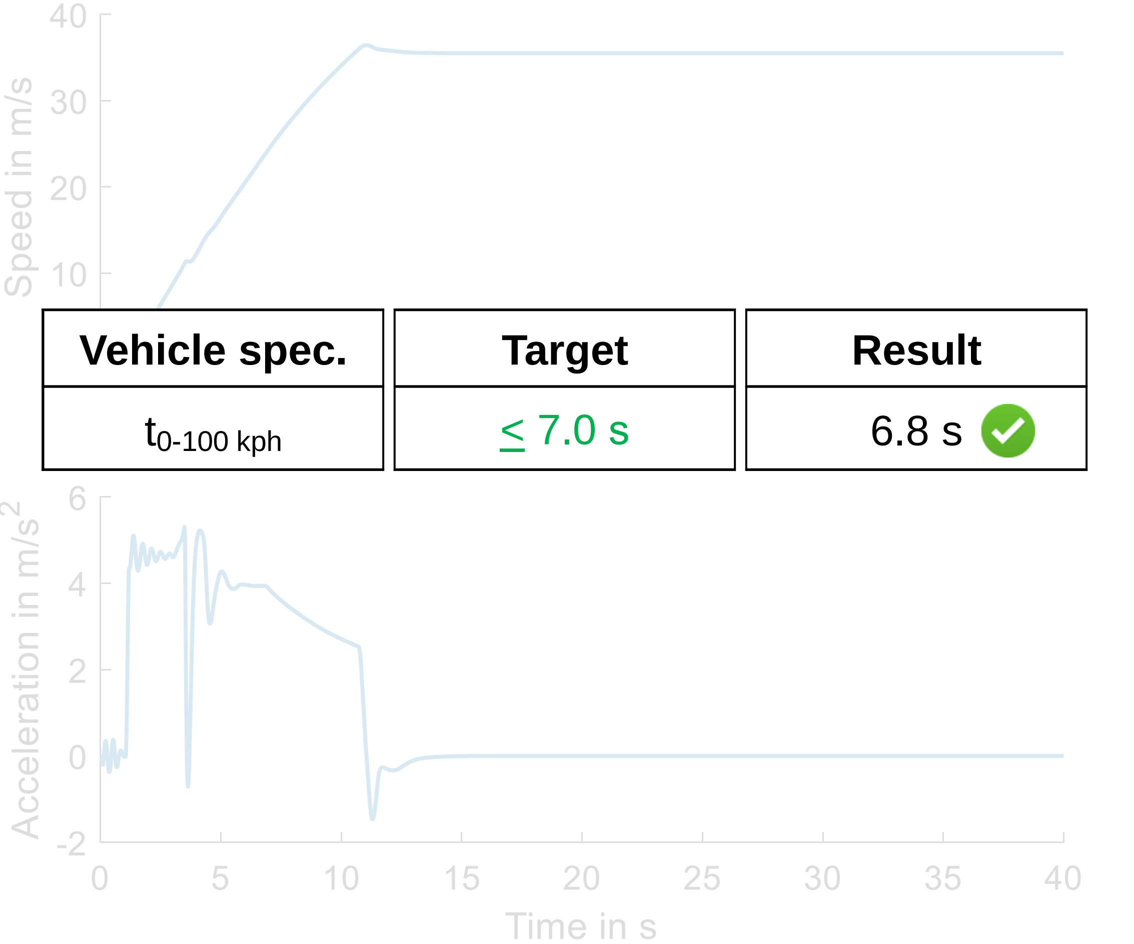
Range constraint is not fulfilled

Drive cycle simulation (WLTP)



Vehicle spec.	Target	Result
Range	≥ 400 km	371 km !
Battery cost	Minimize	7537 $ ✓

Acceleration simulation (WOT)



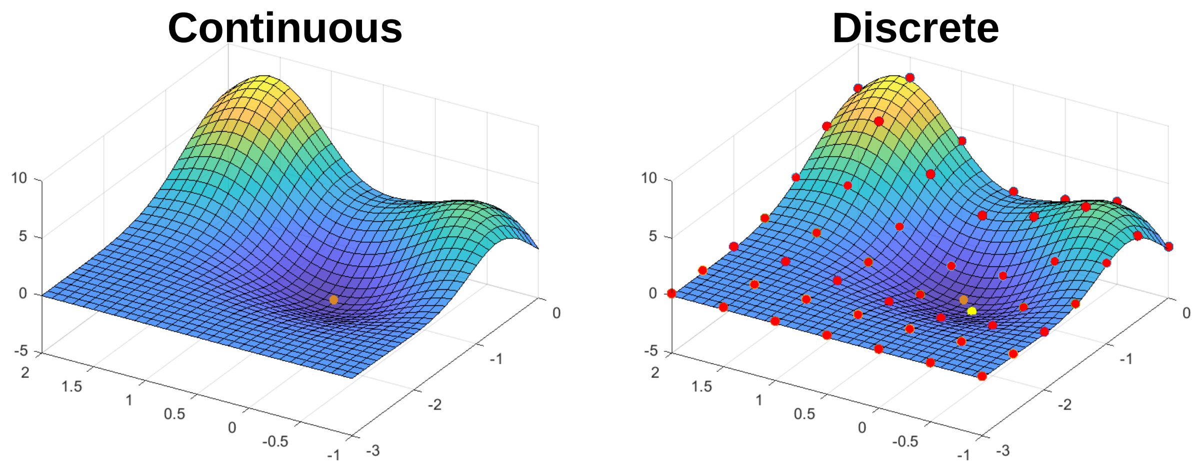
Vehicle spec.	Target	Result
$t_{0\text{-}100\ kph}$	≤ 7.0 s	6.8 s ✓

Optimization algorithm

Selecting the appropriate optimizer

The choice of a suitable optimization algorithm must take into account different requirements

- Design variable space
  - Continuous
  - Integer (discrete)
  - Mixed Integer
- Local / global search space
  - Optimization Toolbox (local)
  - Global Optimization Toolbox



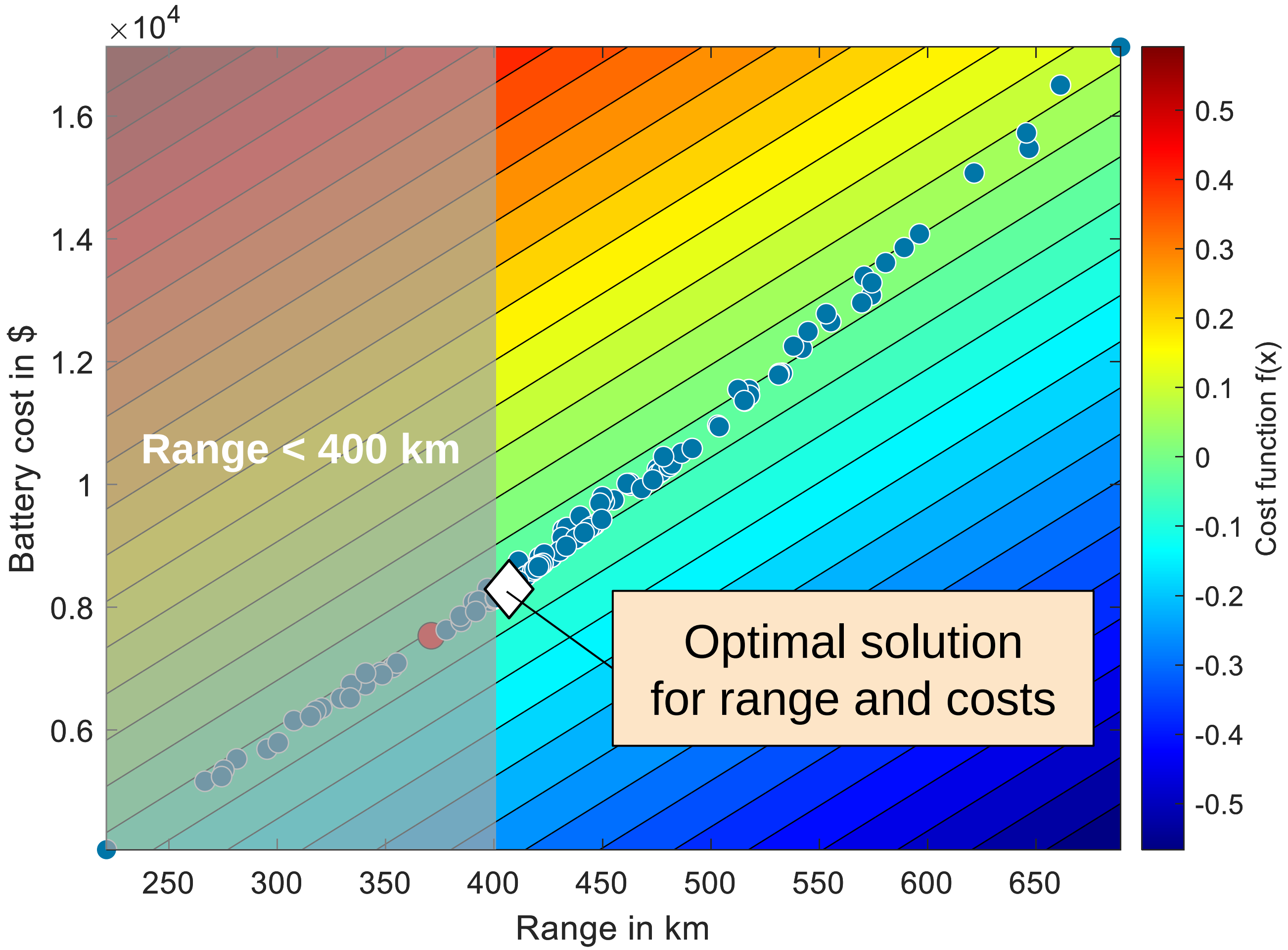
For this problem, the surrogate optimization (surrogateopt) algorithm was selected

- Uses fewer function calls than other global optimization solvers
- Automatically builds up cheap to evaluate surrogate models
- Searches for global solution
- Can work with continuous and integer variables

$$\min f(x) \text{ such that } \begin{cases} LB \leq x \leq UB \\ Ax \leq b \\ Ax_{eq} = b_{eq} \\ c(x) \leq 0 \end{cases}$$

Optimization results

Compare initial assessment and optimal solution



Variable	Initial assessment	Optimal solution
Range	371 km	406 km
Battery cost	7537 $	8279 $
$t_{0\text{-}100\ kph}$	6.8 s	6.8 s
Nd	9	7
Ns, Np	96s31p	91s36p
Bus voltage	357.8 V	339.2 V
Capacity	60.3 kWh	66.3 kWh

The algorithm performed 300 function calls and converged within 2.5 hours (no Parallel Computing)

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Battery design study workflow

Simscape Battery

1. Size battery pack within context of full system operation
2. Create lumped battery pack model and demonstrate equivalence
3. Design battery system in Simscape Battery
4. Select appropriate model fidelity for full system evaluation
5. Evaluate battery design in full system

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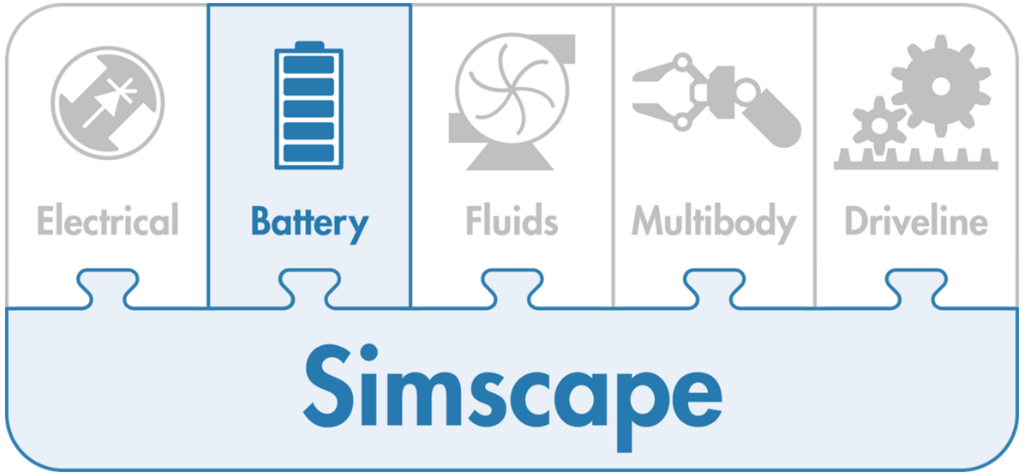
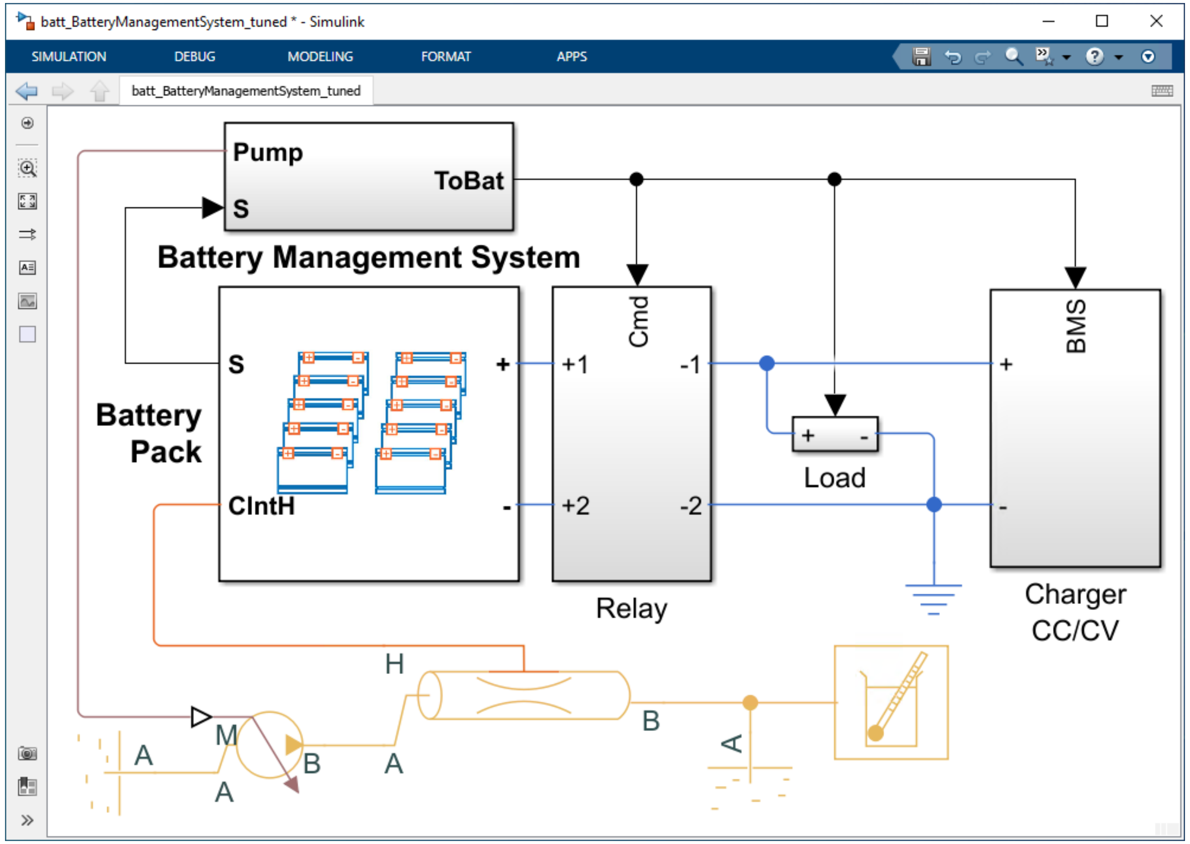
Simscape Battery

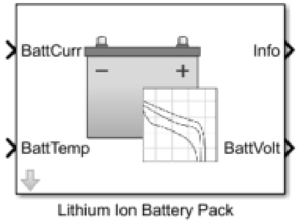
- Design and simulate battery and energy energy storage systems
  - Electrothermal cell behavior
  - Battery pack design
  - Battery management systems (BMS)

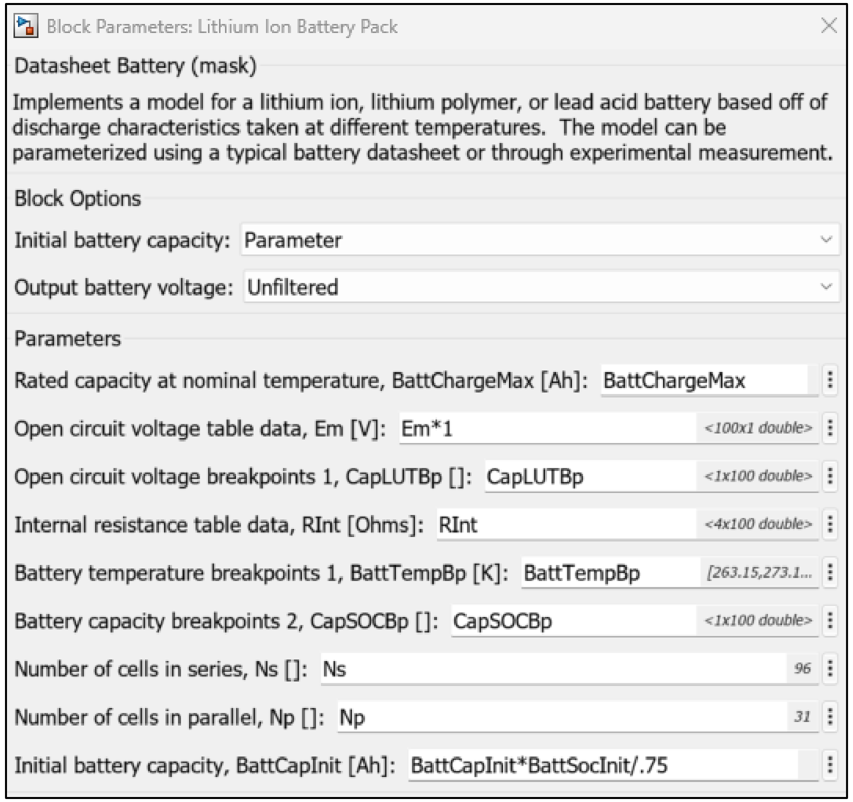
- With Simscape Battery you can
  - Evaluate pack architectures for electrical and thermal requirements
  - Verify robustness of discharge, charge and thermal management algorithms
  - Validate algorithms using HIL testing

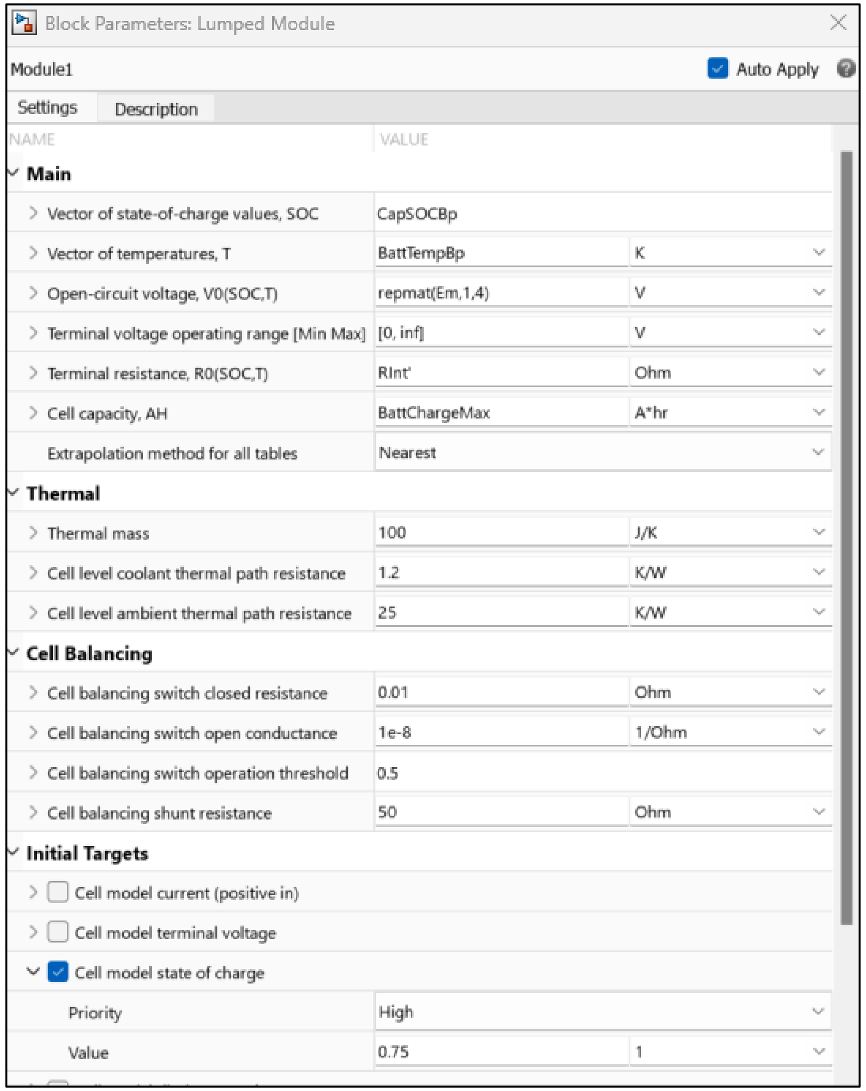


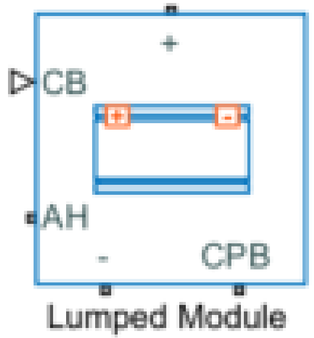


Create lumped battery pack model in Simscape Battery

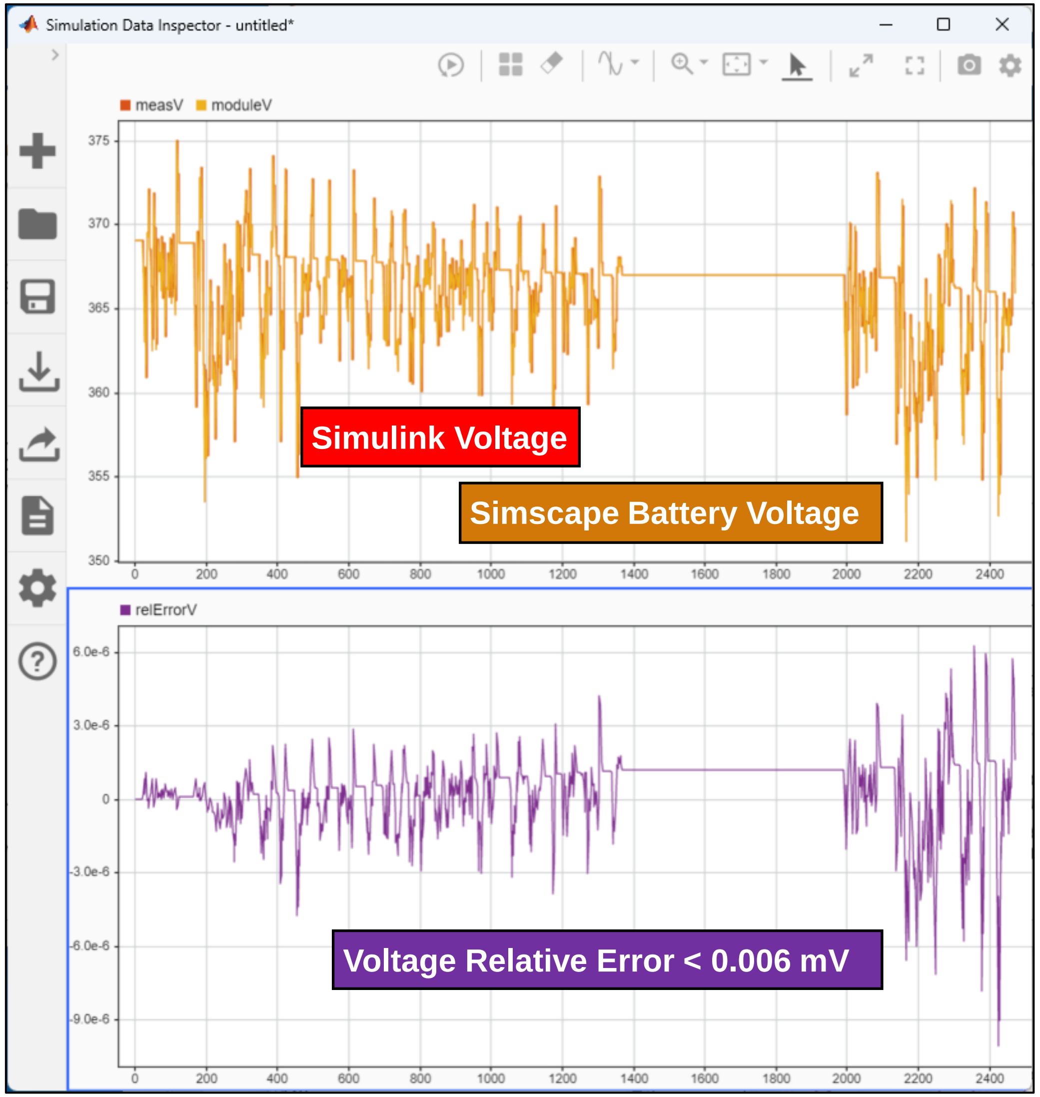


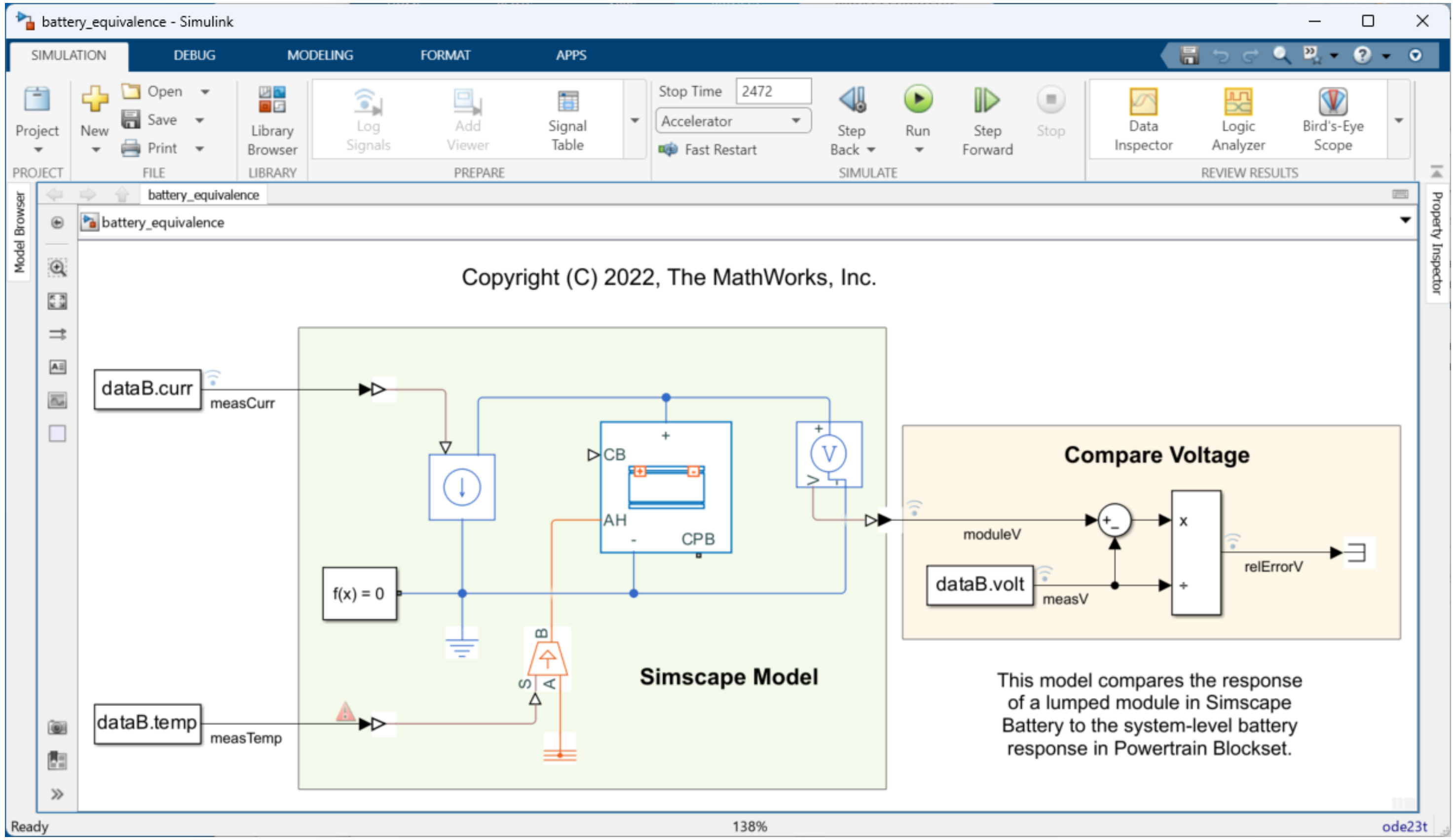






Demonstrate equivalence with unit test

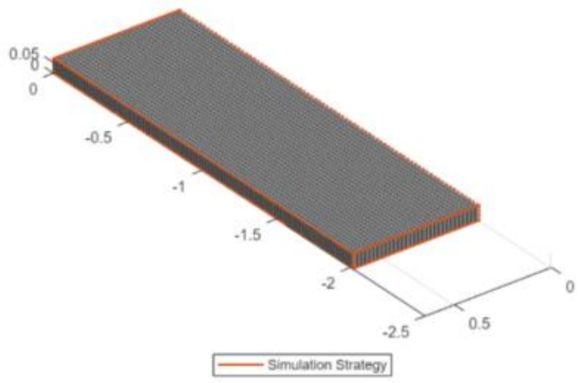




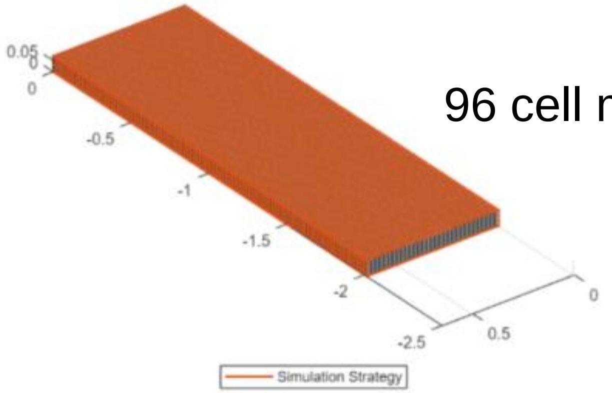
Design battery systems in Simscape Battery

- Create battery pack with higher resolution

Lumped (1 cell model for entire pack)



Grouped (1 cell model for each parallel assembly)



96 cell models

Define module

```
Ns = 96; % number of parallel assemblies in series
batteryModule = Module(ParallelAssembly = batteryParallelAssembly, numSeriesAssemblies = Ns);
```

Define simulation strategy

```
batteryModule.ModelResolution = "Lumped";
```

Define module

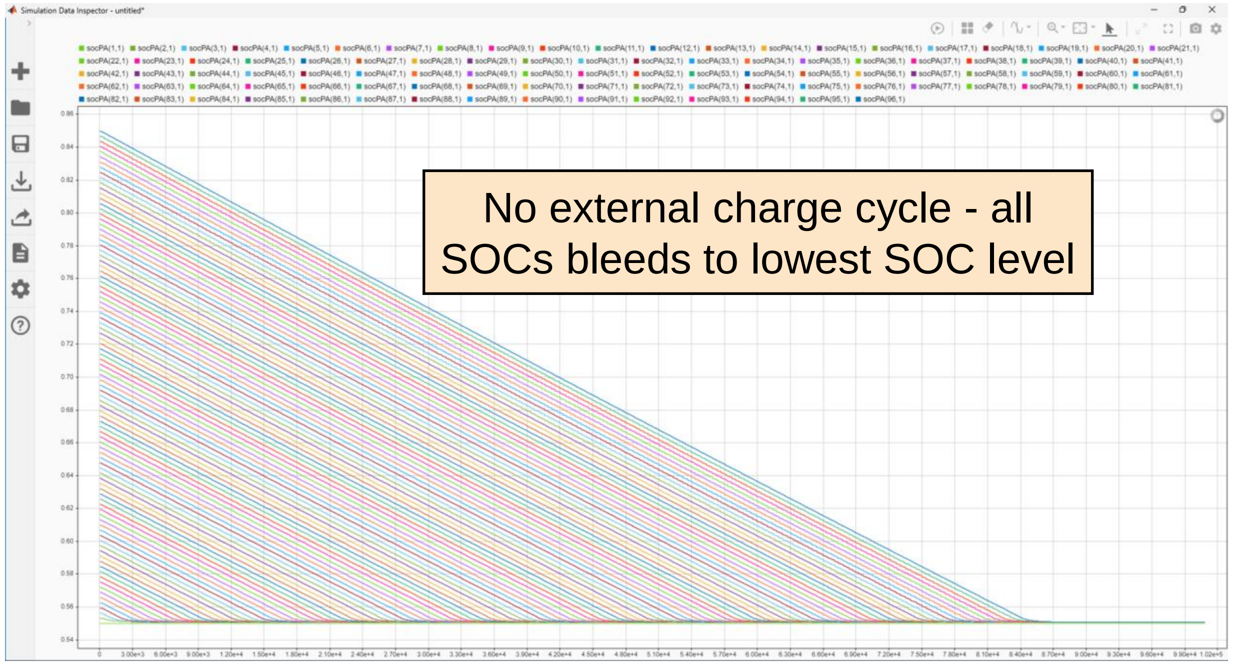
```
Ns = 96; % number of parallel assemblies in series
batteryModule = Module(ParallelAssembly = batteryParallelAssembly, numSeriesAssemblies = Ns);
```

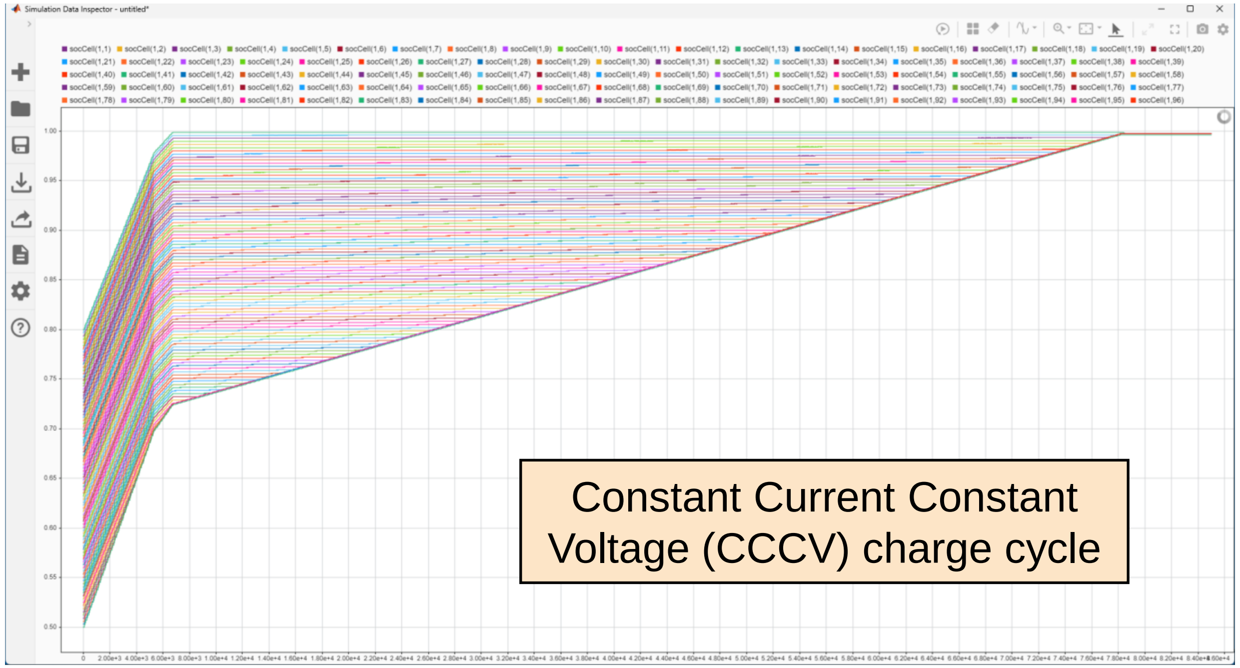
Define simulation strategy

```
batteryModule.ModelResolution = "Grouped";
batteryModule.SeriesGrouping = ones(1,Ns);
```

Passive cell balancing

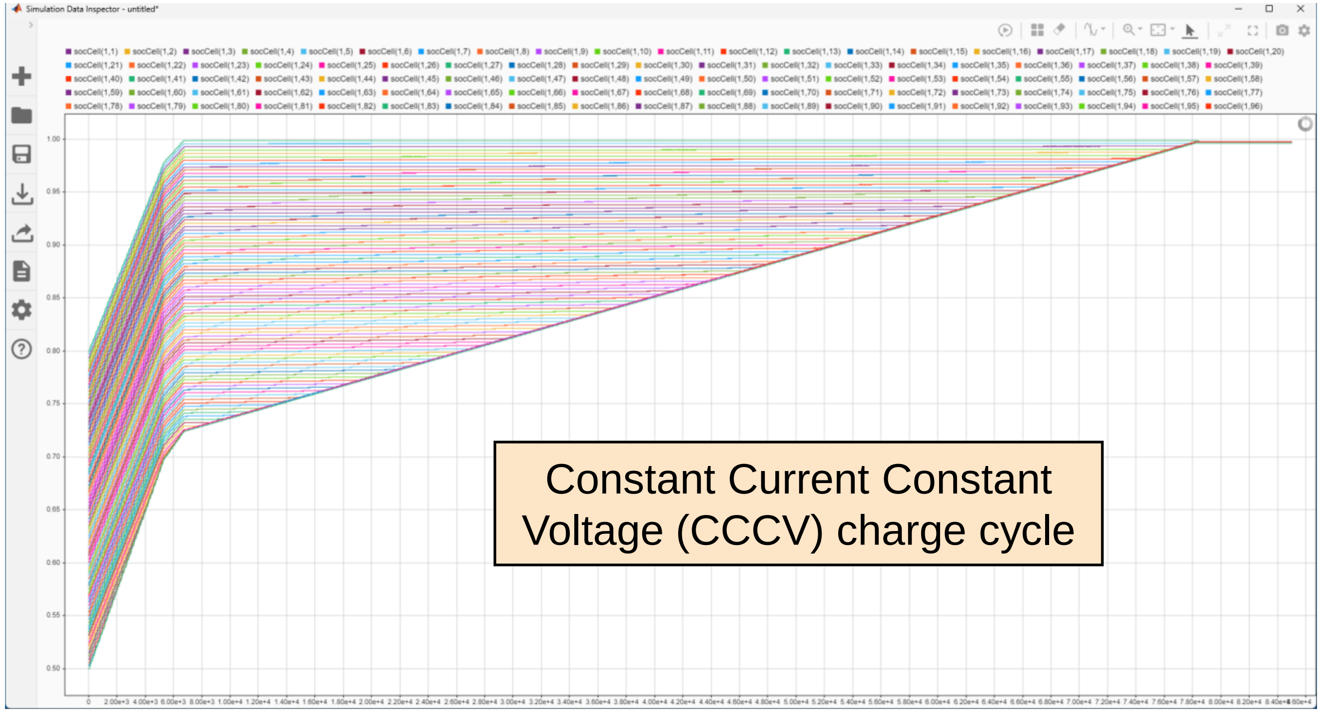
- Cells within a parallel assembly will naturally balance
- One cell balancing circuit for each series-connected parallel assembly

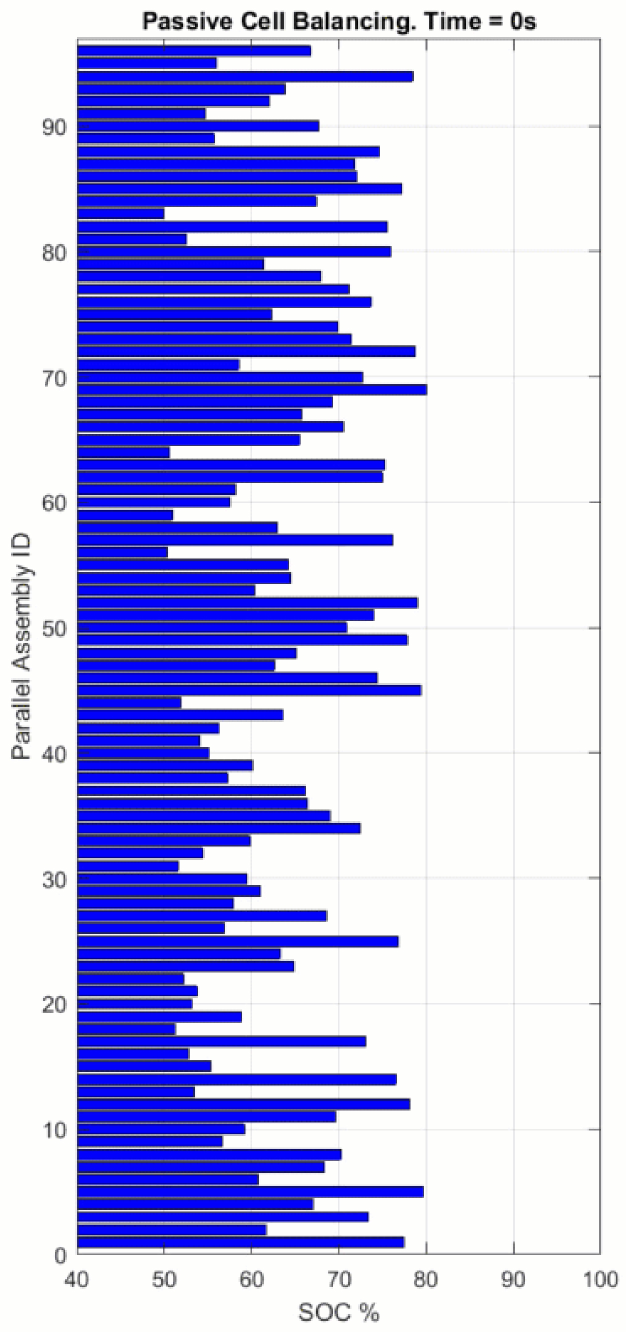




Passive cell balancing

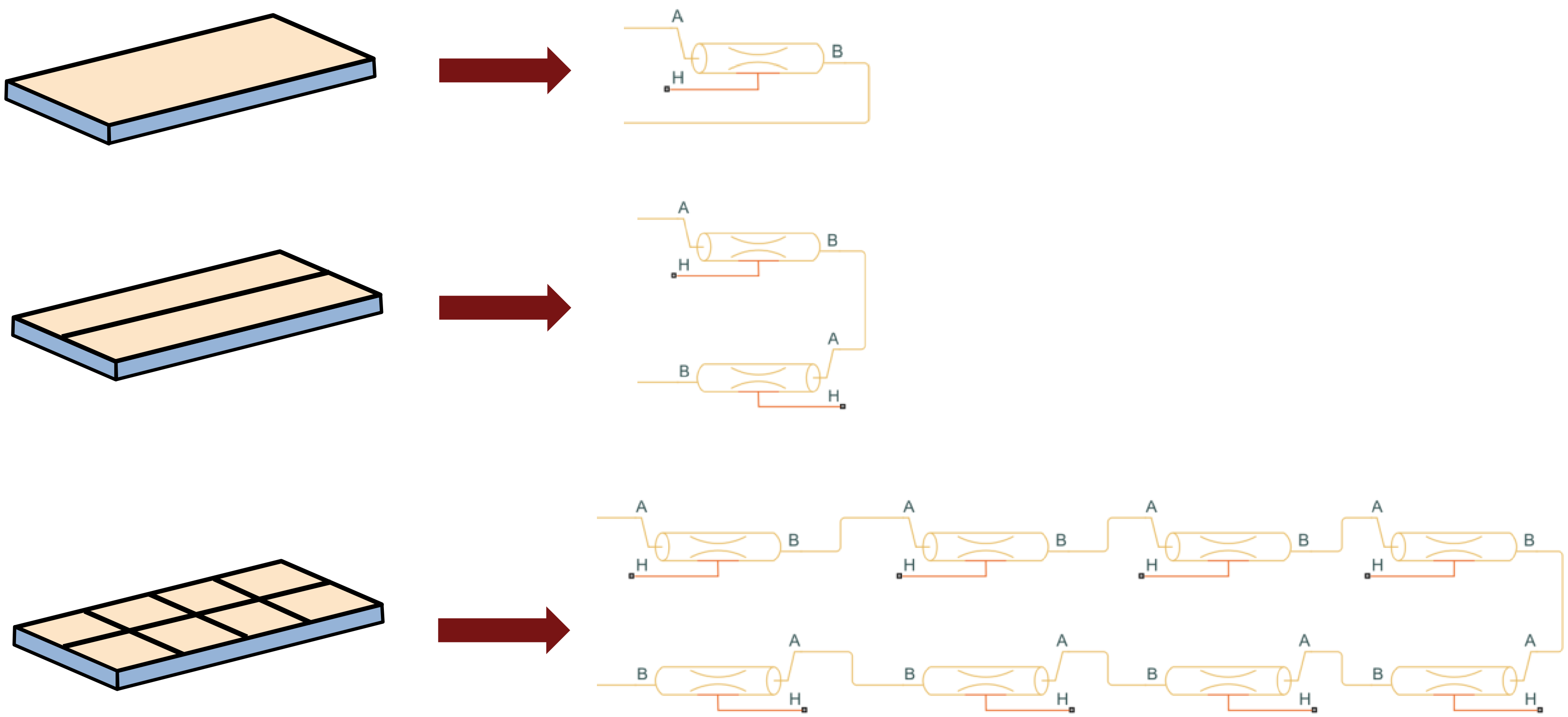
- Animation can bring further clarity to a large number of time-series responses

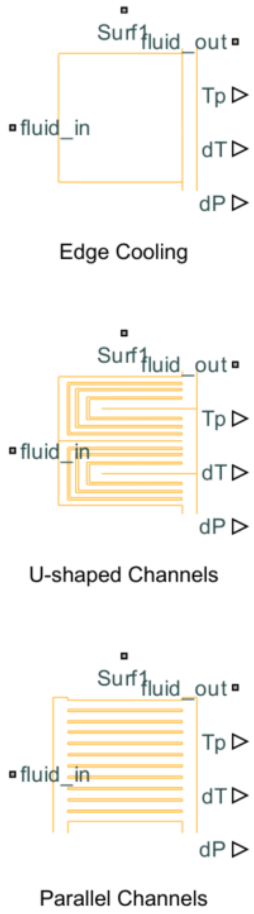




Thermal management

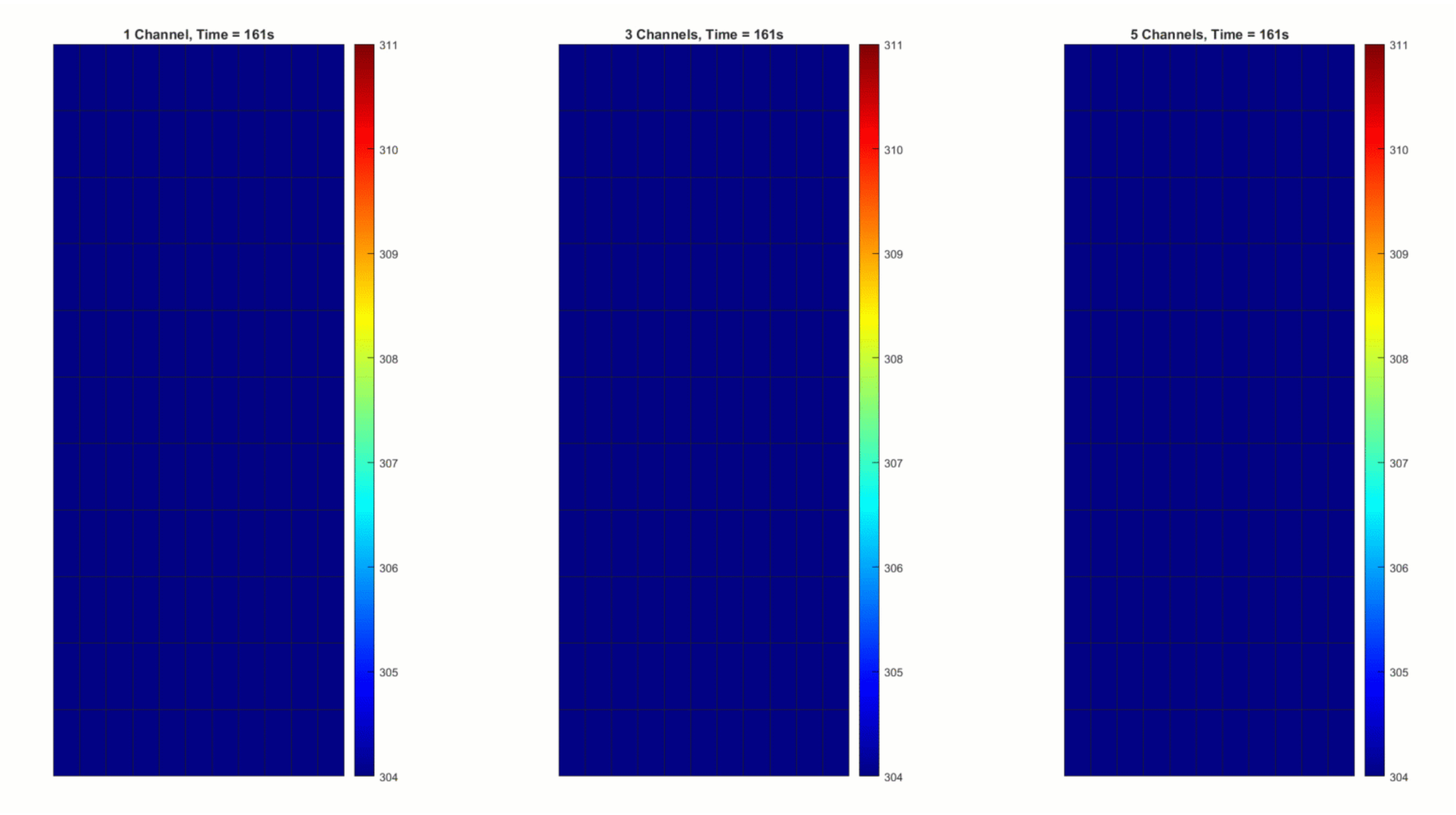
- Change the simulation strategy of cooling plates to meet your model resolution needs
- Connections dependent on cooling plate architecture

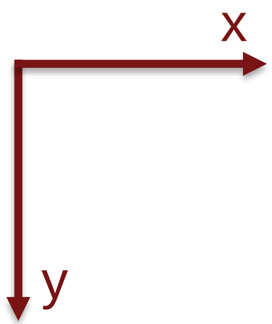




Thermal management

Parallel cooling channels oriented along the x-axis

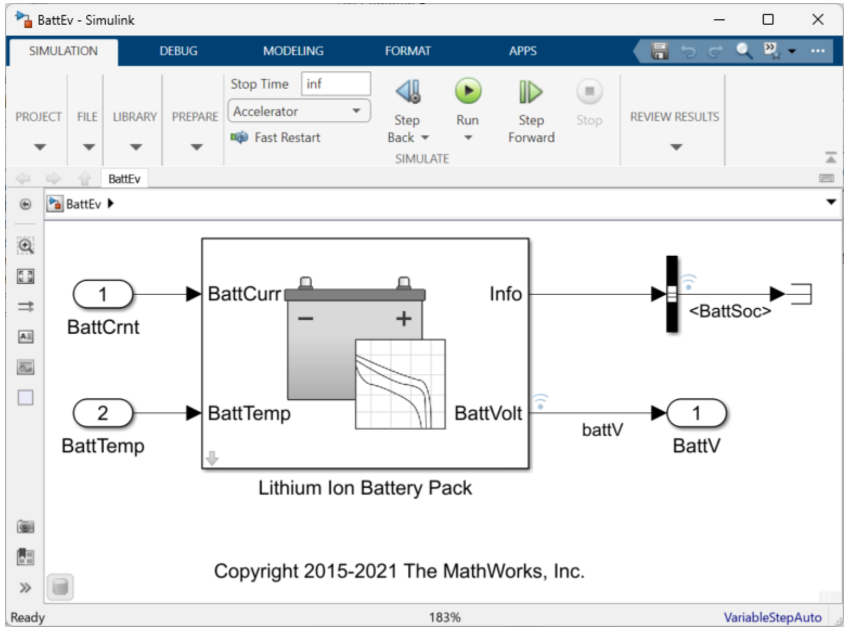


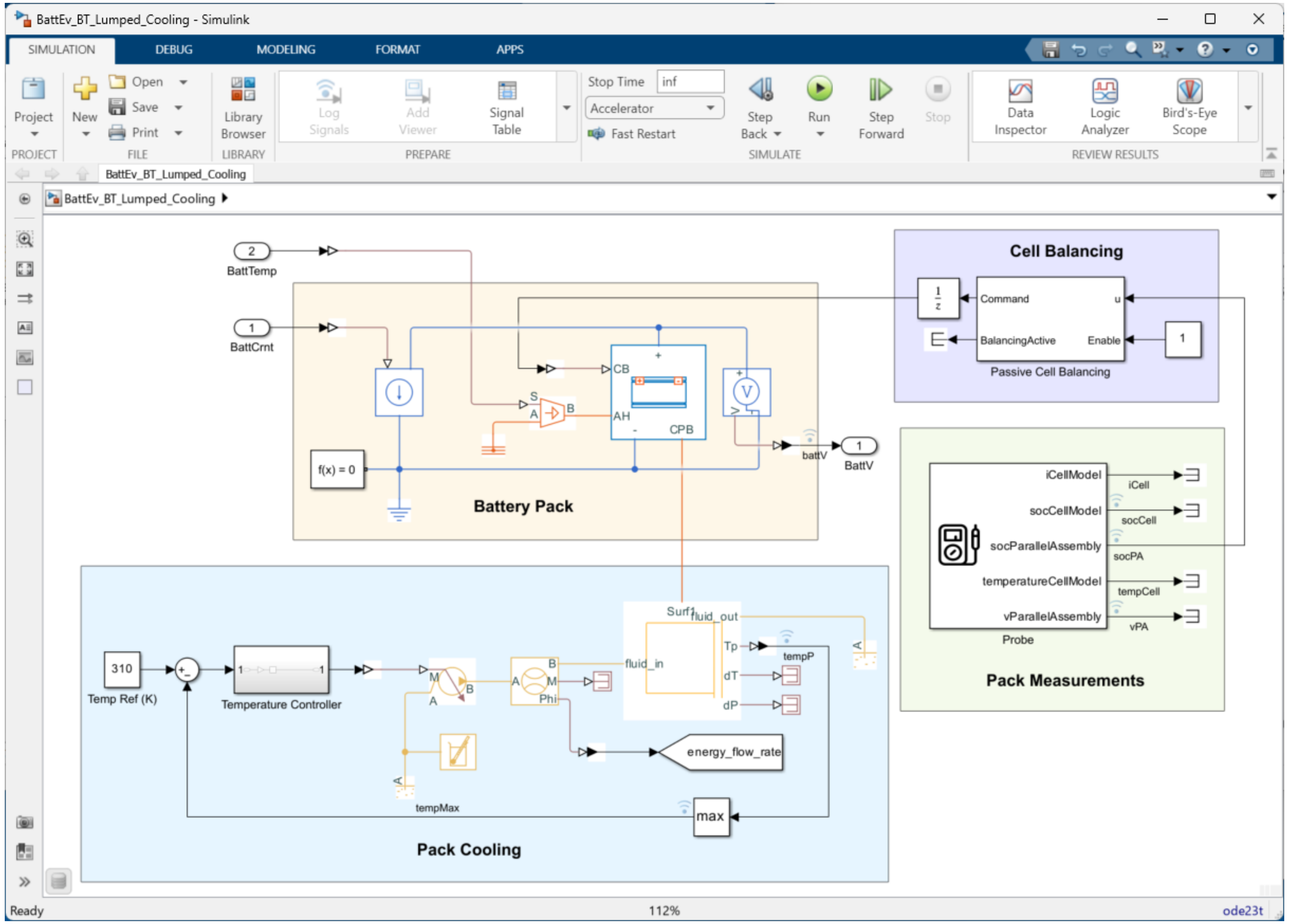


Select appropriate model fidelity for full system evaluation

- For many scenarios, lumped battery model is sufficient for system integration

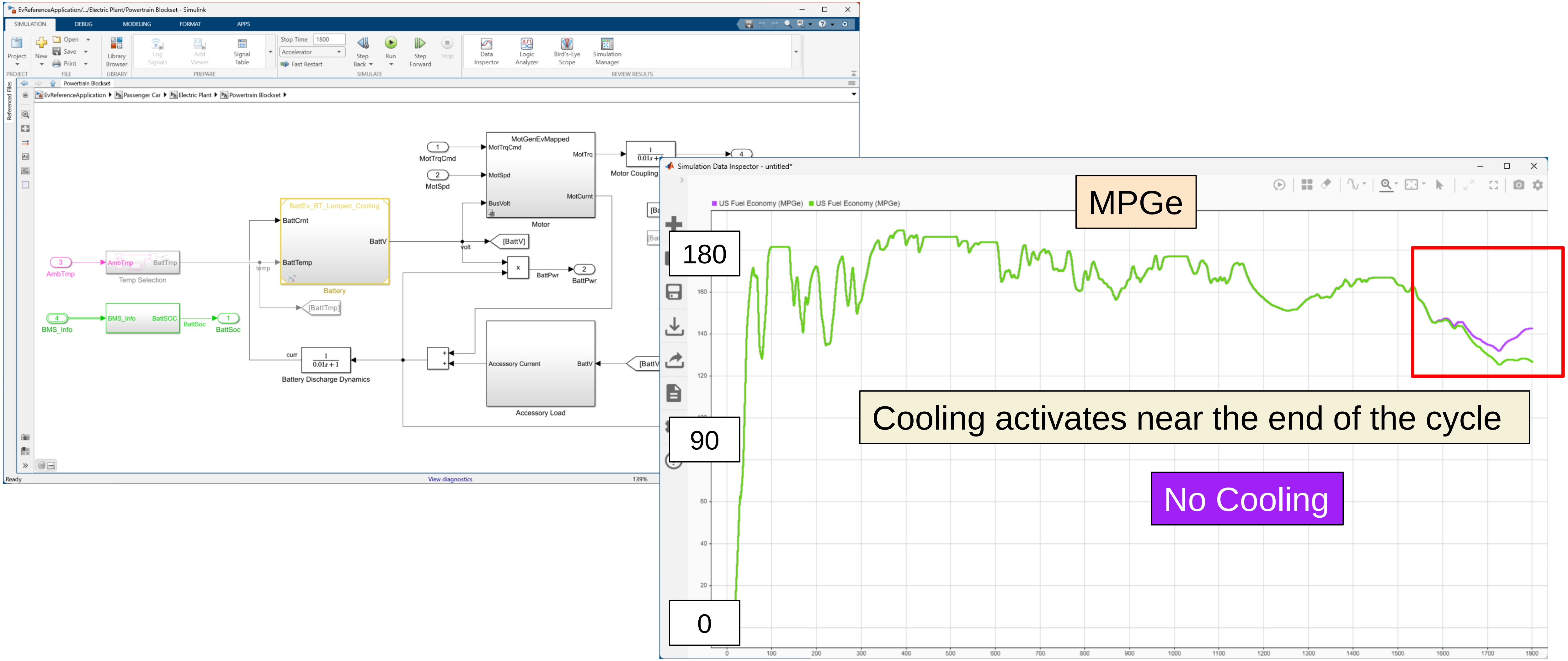
- Other fidelities can be incorporated as needed





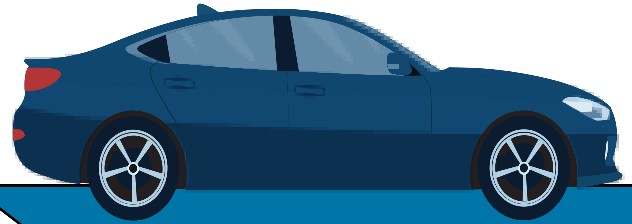
Evaluate battery design in full system

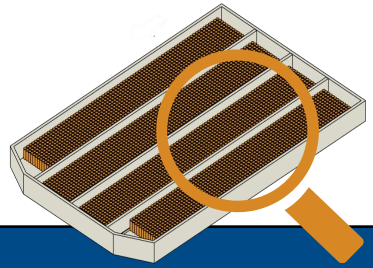
WLTP (Class 3) drive cycle (MPGe)

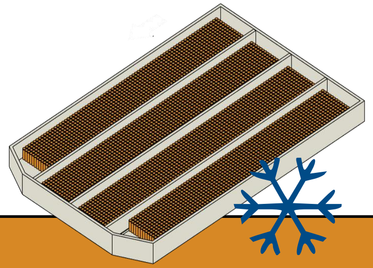


Key takeaways

Optimize EV battery performance using simulation







Assess system performance	Find optimal pack size	Design battery pack
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System-level models to quantify vehicle range, battery performance, and costs	Efficiently optimize the design while accounting for competing requirements	Perform detailed battery design studies

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