MathWorks
AUTOMOTIVE CONFERENCE 2024
Europe

Design and Analyze a Battery Electric Vehicle with Thermal Management

Lorenzo Nicoletti, MathWorks

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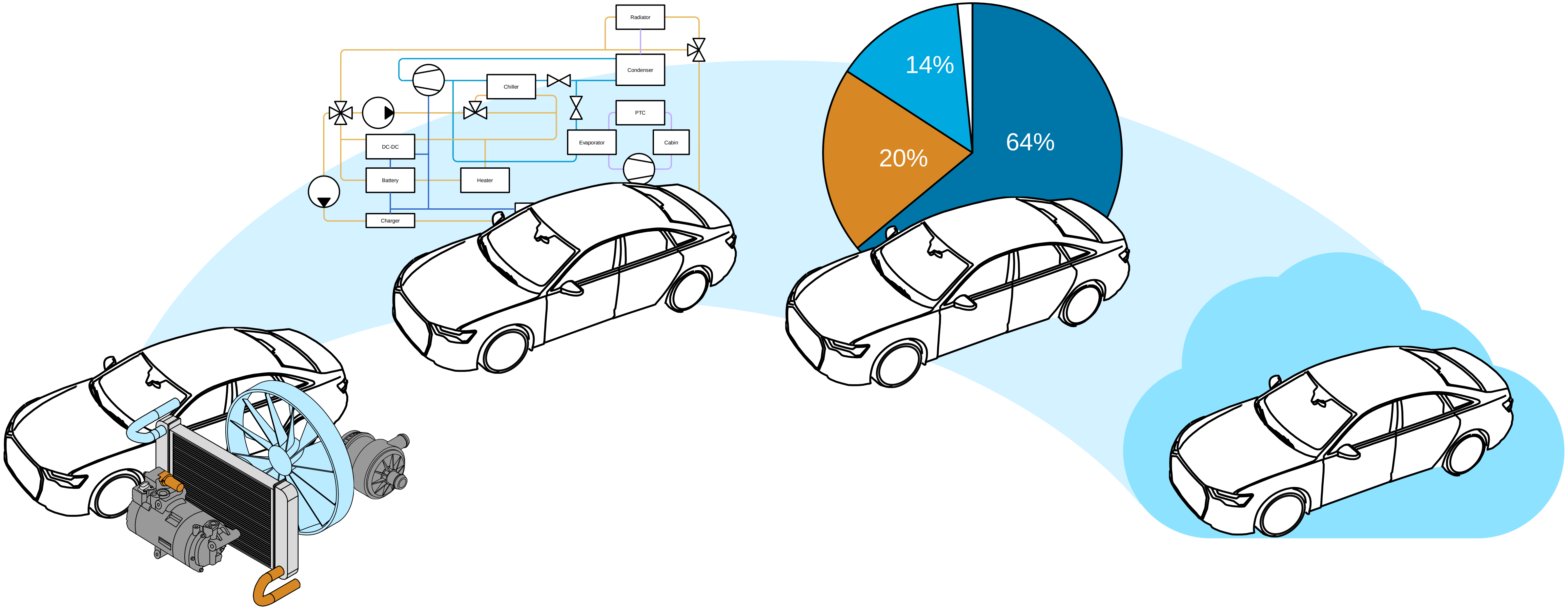
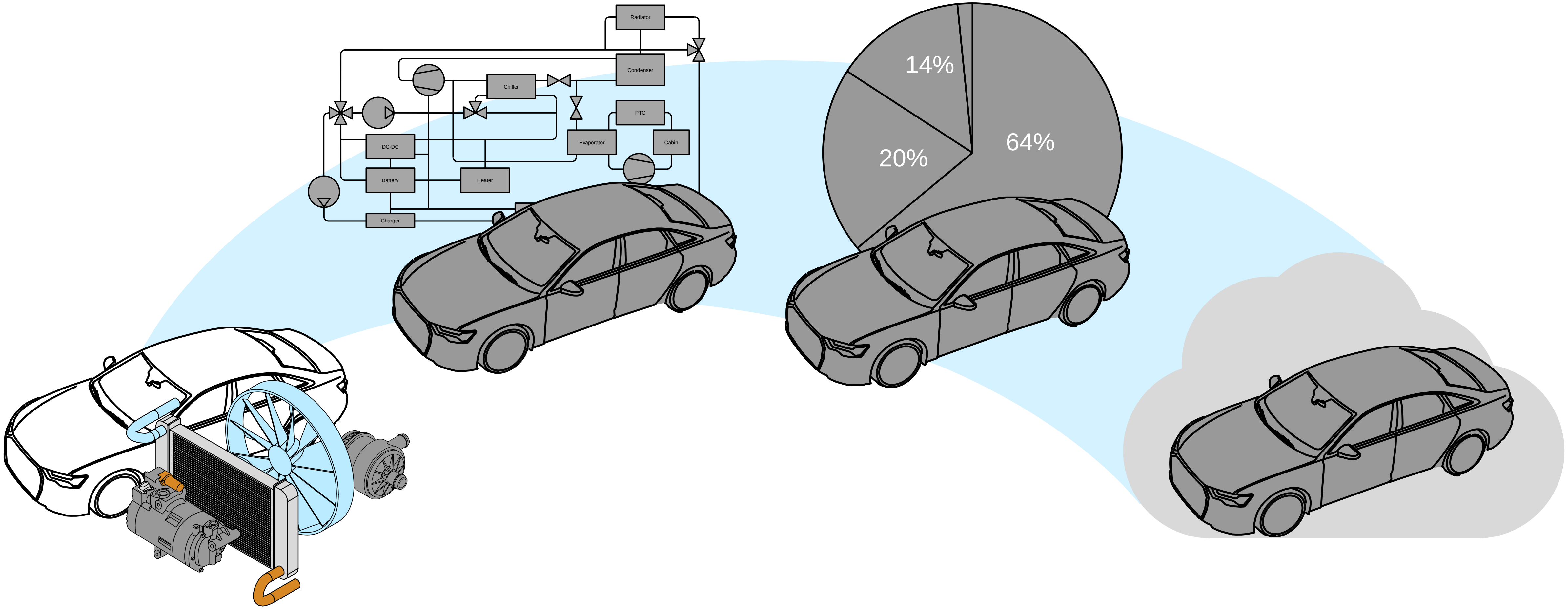
What Will You Learn Today?

Design and Analyze a BEV with Thermal Management



Design and Analyze a BEV with Thermal Management

Why Do We Need a Virtual Vehicle?



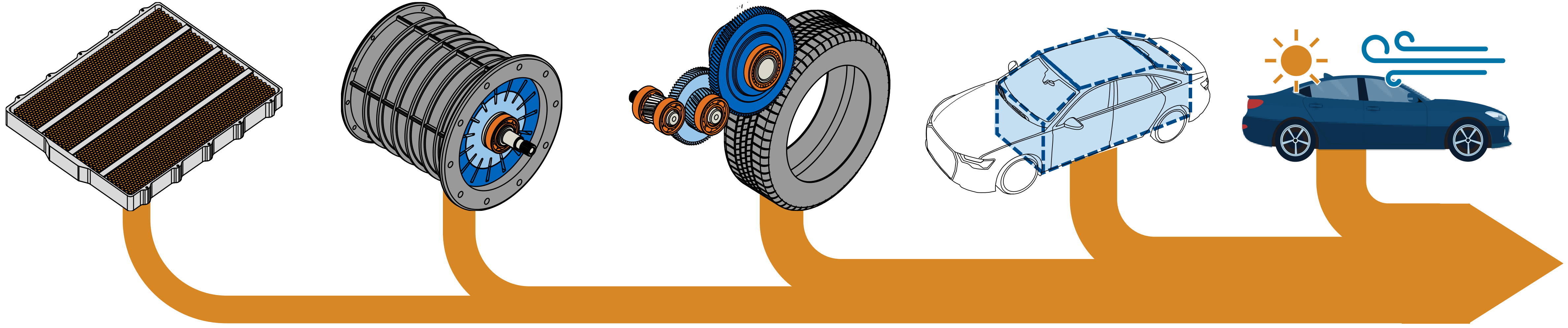
How to Improve BEVs Range?

An Overview

Challenge:

Opportunities for increasing range are woven into every part of the design

Battery	**Motor**	**Driveline**	**Cabin**	**Environment**



Energy Losses

How to Improve BEVs Range?

The Thermal Management Adds an Additional Degree of Complexity

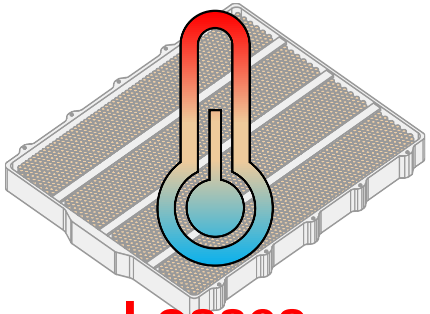
Challenge:

The thermal management influences efficiency and safety of the powertrain

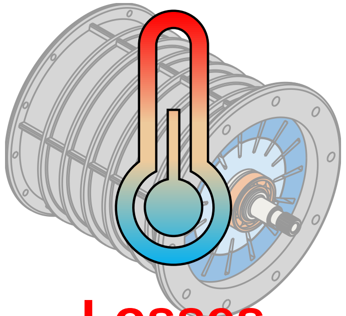
The thermal management is impacted by every subsystem in the vehicle

Solving this multidisciplinary problem requires a virtual vehicle that models all relevant subsystems and their interdependencies

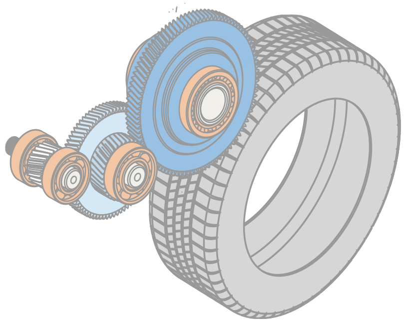
Battery	Motor	Driveline	Cabin	Environment

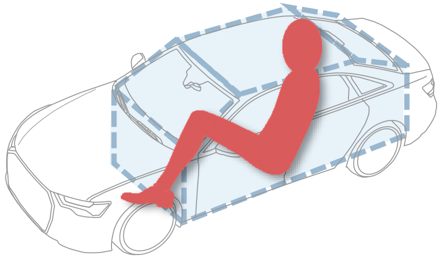


Losses

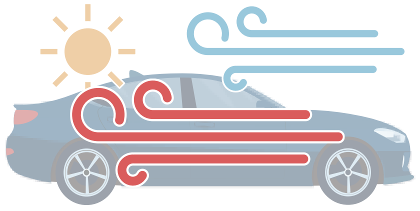


Losses





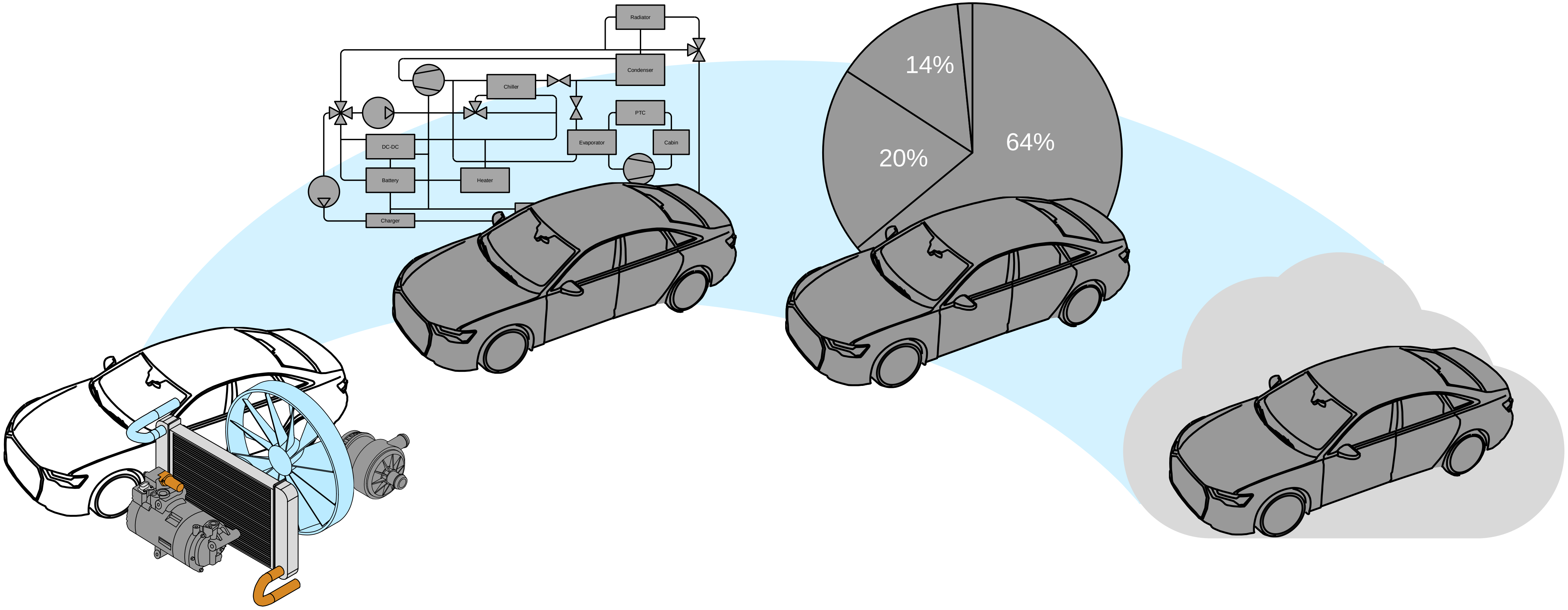
Comfort



Weather

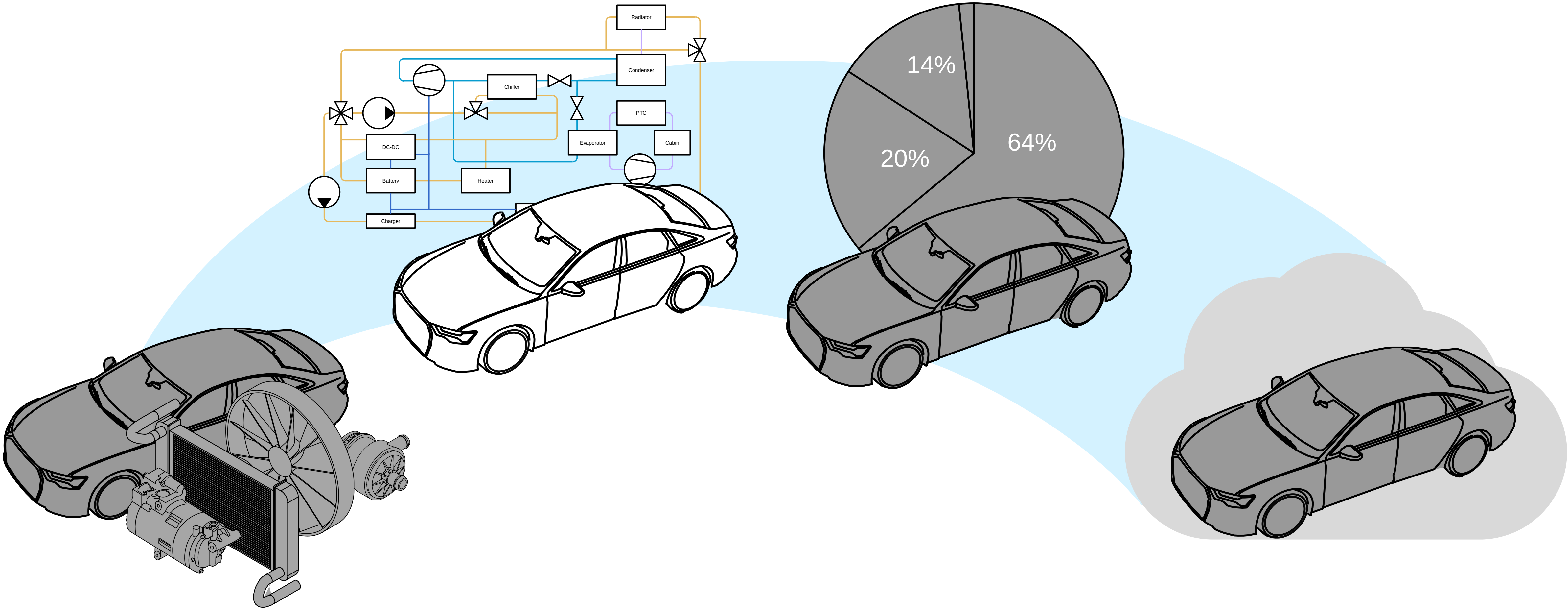
Design and Analyze a BEV with Thermal Management

Why Do We Need a Virtual Vehicle?



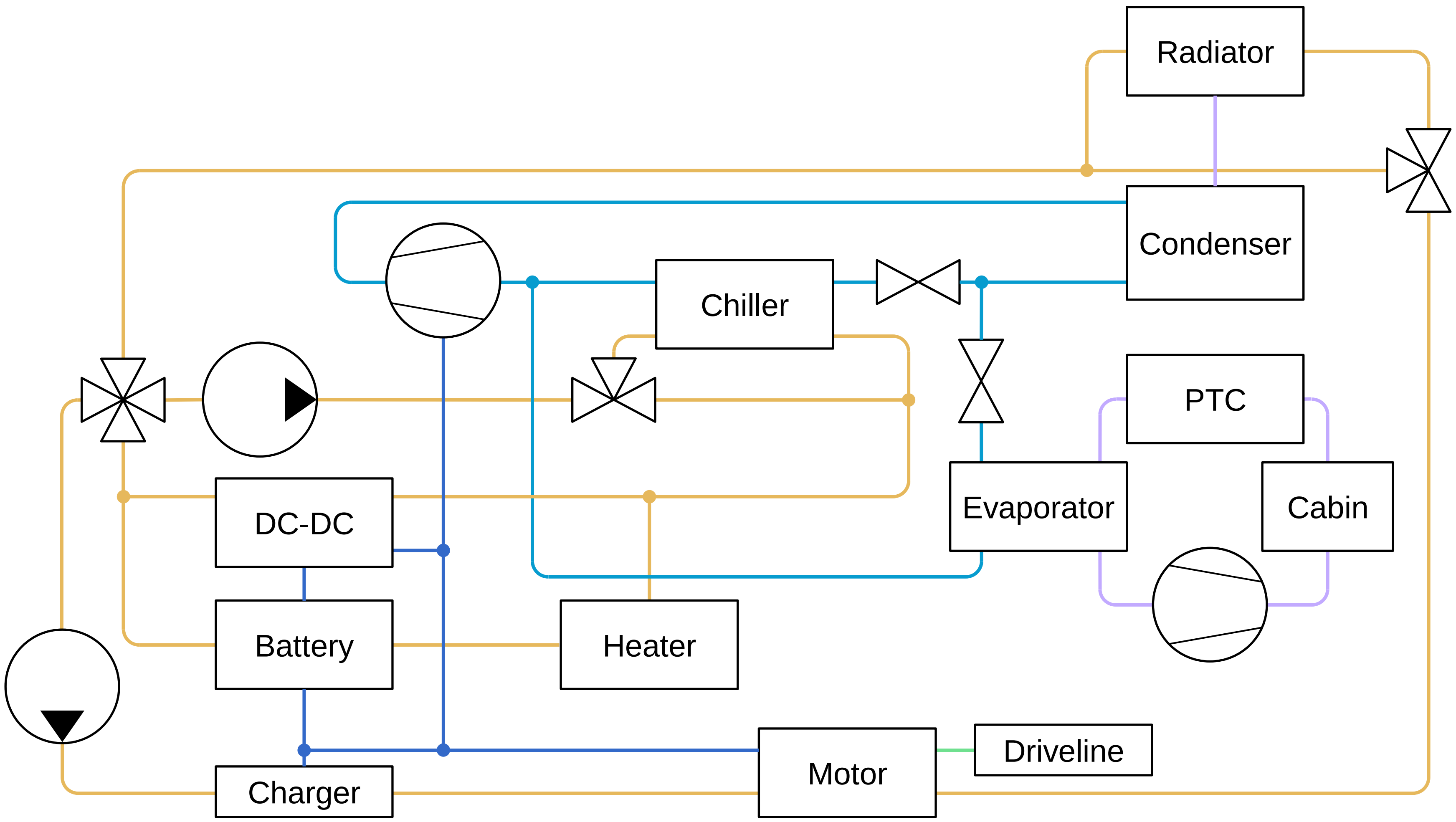
Design and Analyze a BEV with Thermal Management

Building a Virtual Vehicle Model to Assess Range



Building a Virtual Vehicle Model to Assess Range

Using Simscape™

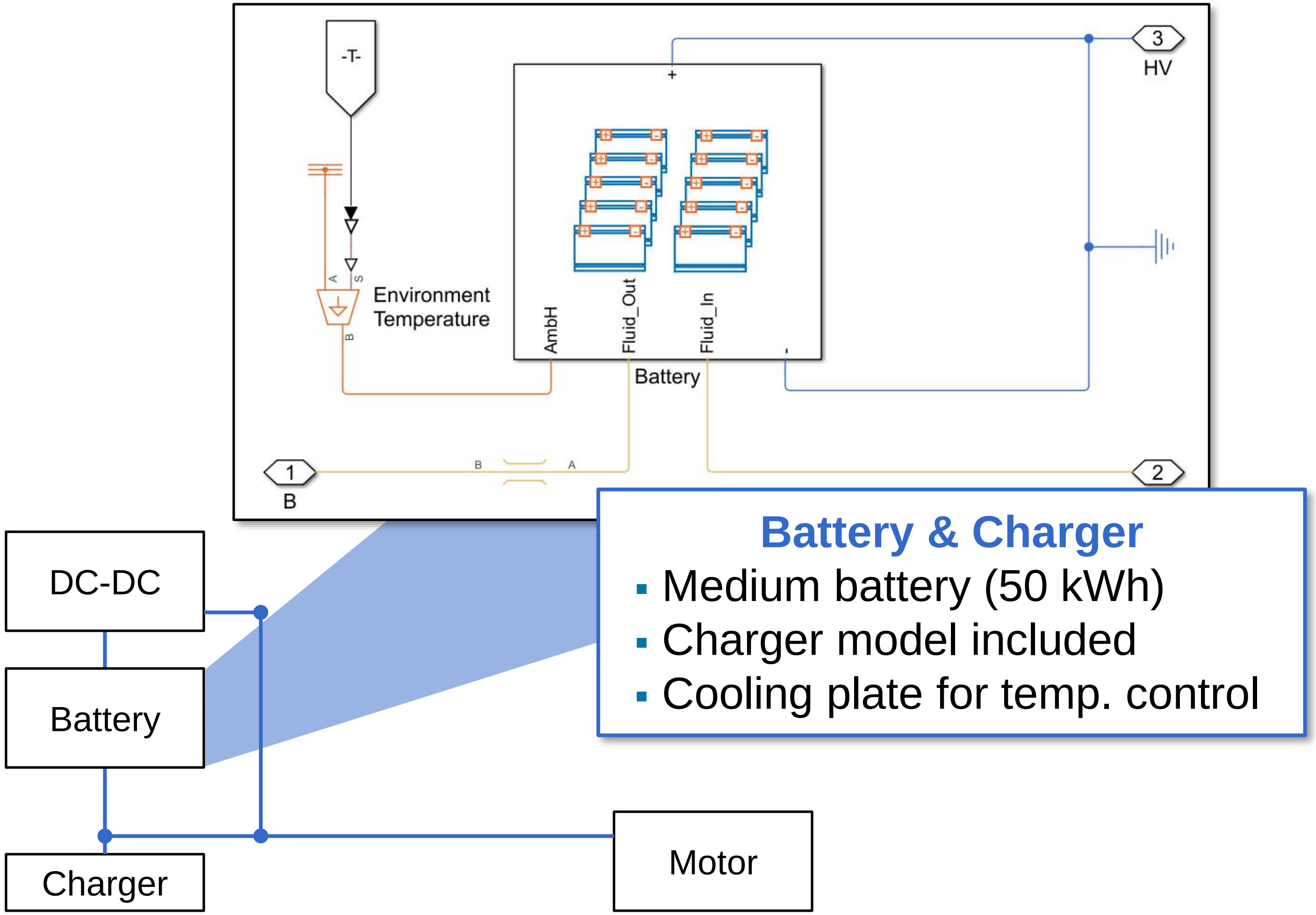


Subsystems

- Battery, Charger
- Powertrain
- Driveline
- Cabin HVAC
- Refrigerant Loop
- Motor Loop
- Battery Loop

Building a Virtual Vehicle Model to Assess Range

Using Simscape™



Battery & Charger

- Medium battery (50 kWh)
- Charger model included
- Cooling plate for temp. control

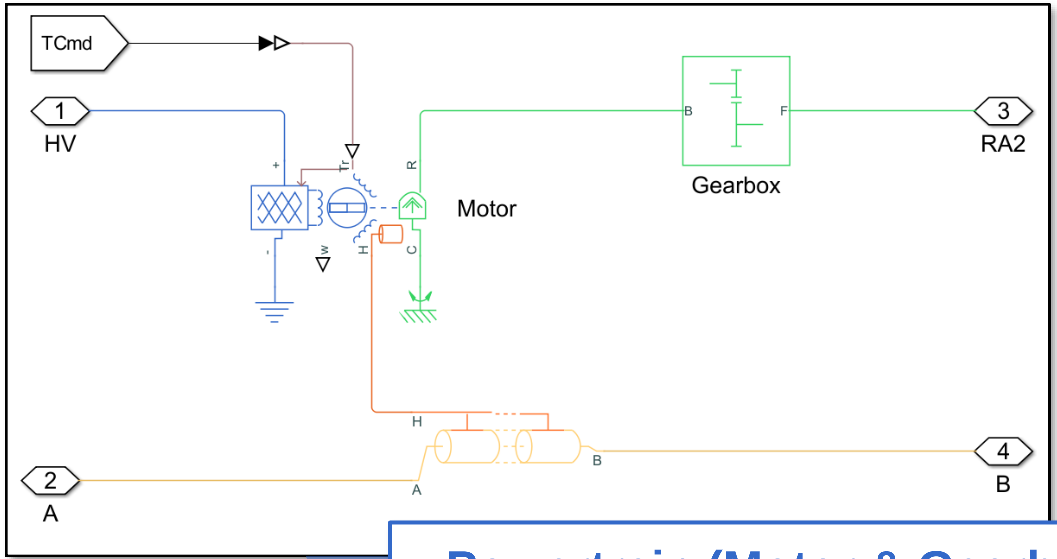
Subsystems

- **Battery, Charger**
- Powertrain
- Driveline
- Cabin HVAC
- Refrigerant Loop
- Motor Loop
- Battery Loop

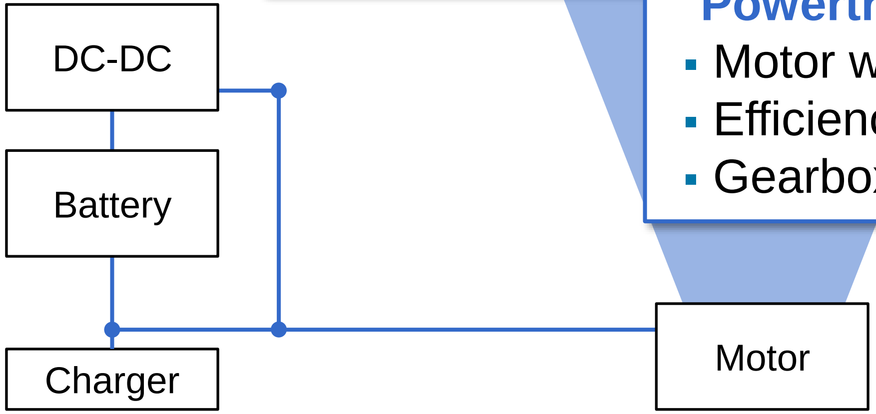
Battery, plate, and charger are modeled with [Simscape Battery™]

Building a Virtual Vehicle Model to Assess Range

Using Simscape™



Powertrain (Motor & Gearbox)
- Motor with torque request
- Efficiency maps for motor losses
- Gearbox with fixed ratio

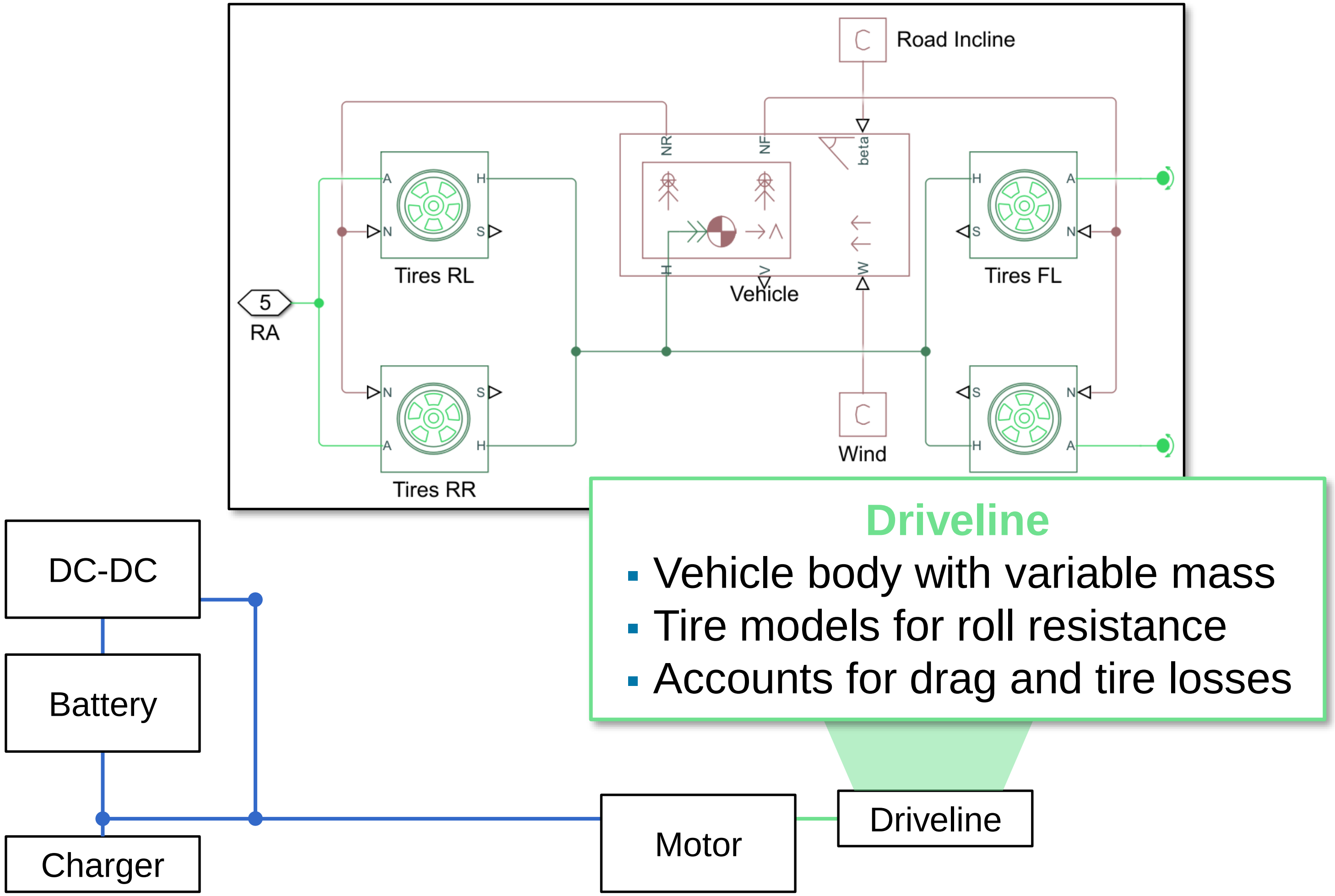


Subsystems
- Battery, Charger
- **Powertrain**
- Driveline
- Cabin HVAC
- Refrigerant Loop
- Motor Loop
- Battery Loop

Motor and gearbox are modeled with [Simscape Driveline™]

Building a Virtual Vehicle Model to Assess Range

Using Simscape™



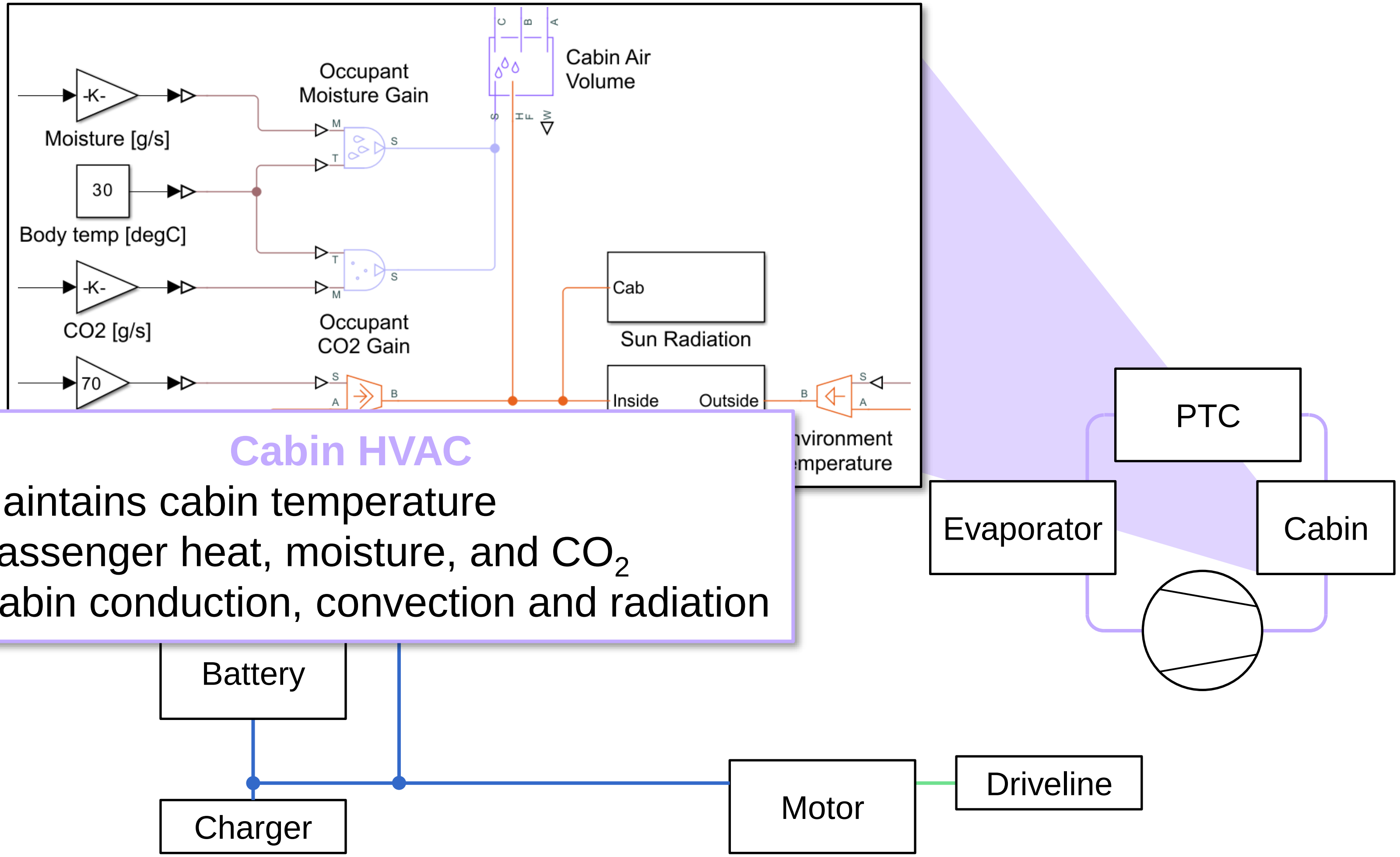
Subsystems

- Battery, Charger
- Powertrain
- **Driveline**
- Cabin HVAC
- Refrigerant Loop
- Motor Loop
- Battery Loop

Tires and vehicle body are modeled with [Simscape Driveline™]

Building a Virtual Vehicle Model to Assess Range

Using Simscape™



Cabin HVAC

- Maintains cabin temperature
- Passenger heat, moisture, and CO_2
- Cabin conduction, convection and radiation

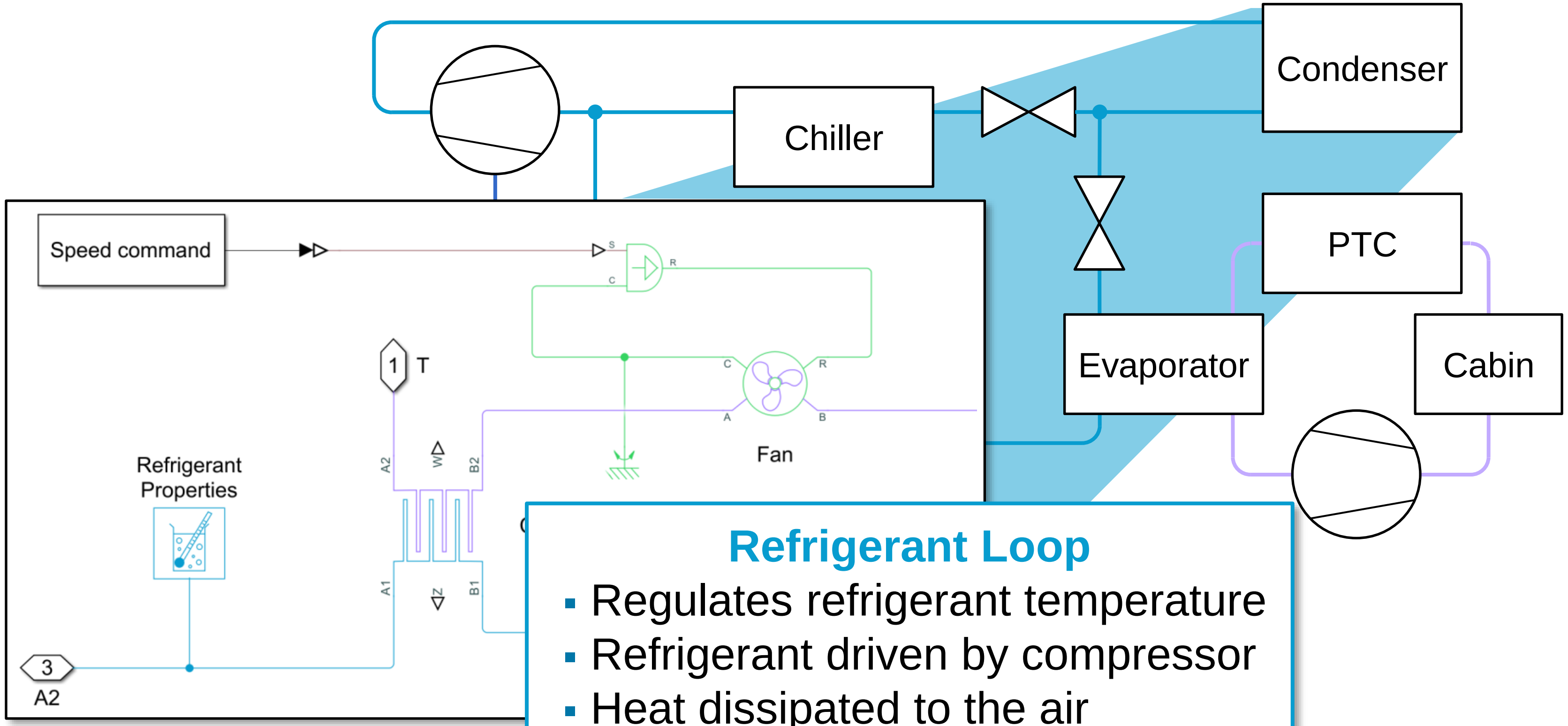
Subsystems

- Battery, Charger
- Powertrain
- Driveline
- **Cabin HVAC**
- Refrigerant Loop
- Motor Loop
- Battery Loop

The cabin components are modeled with the Moist Air domain of Simscape Fluids™

Building a Virtual Vehicle Model to Assess Range

Using Simscape™



Refrigerant Loop

- Regulates refrigerant temperature
- Refrigerant driven by compressor
- Heat dissipated to the air

Subsystems

- Battery, Charger
- Powertrain
- Driveline
- Cabin HVAC
- **Refrigerant Loop**
- Motor Loop
- Battery Loop

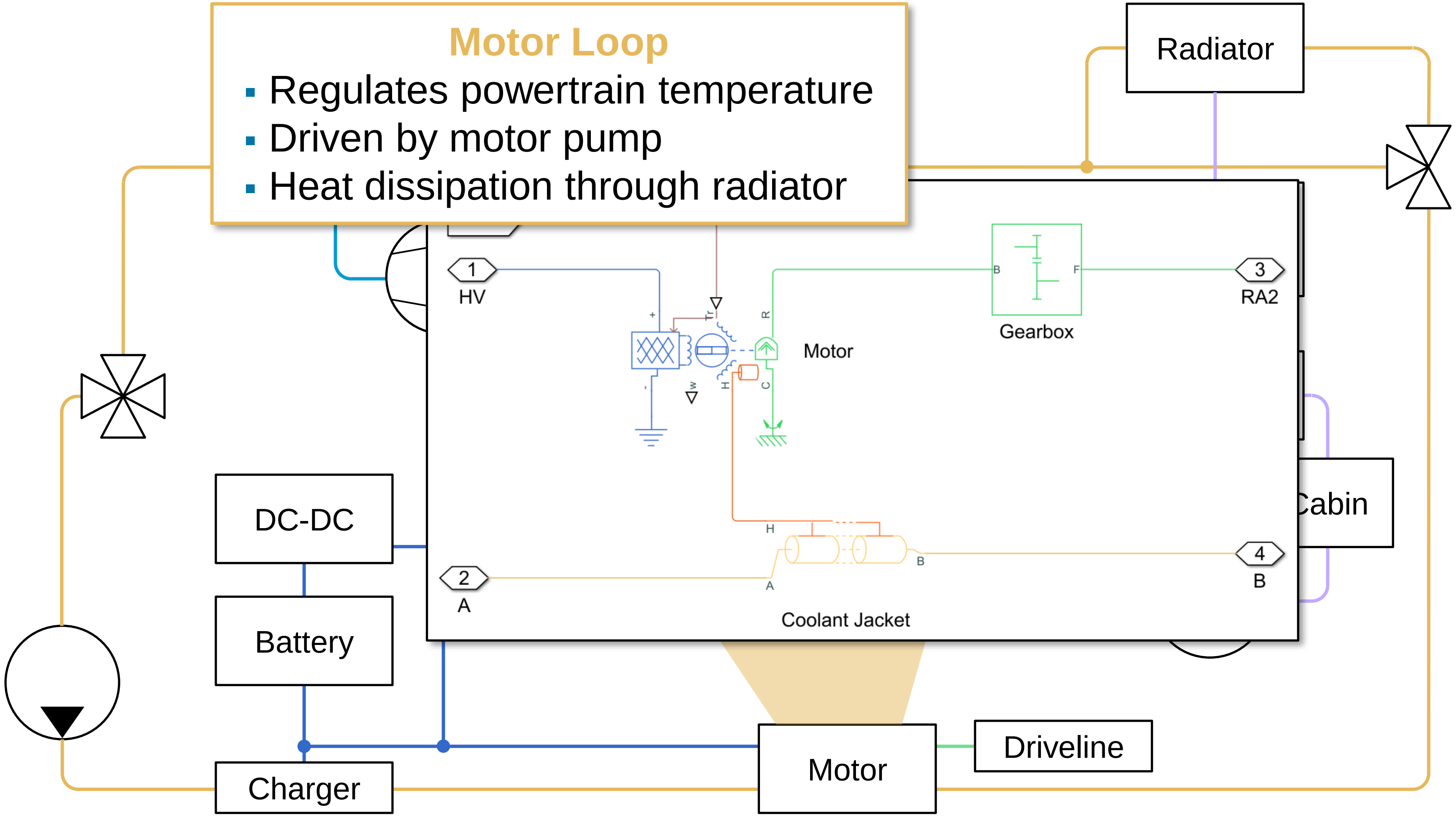
The refrigerant loop is modeled with the Two-Phase Fluid domain of [Simscape Fluids™](#)

Building a Virtual Vehicle Model to Assess Range

Using Simscape™

Motor Loop

- Regulates powertrain temperature
- Driven by motor pump
- Heat dissipation through radiator



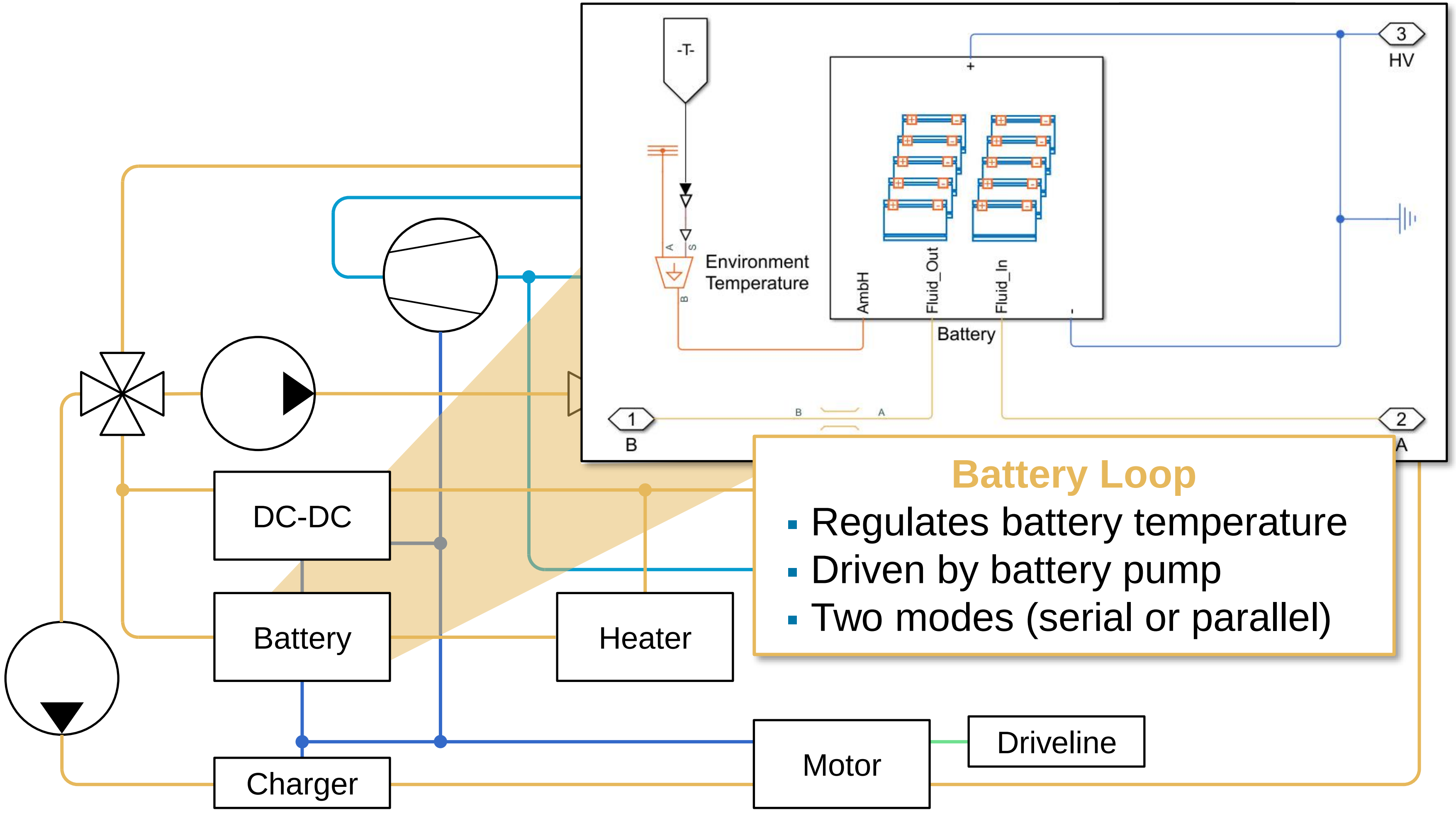
Subsystems

- Battery, Charger
- Powertrain
- Driveline
- Cabin HVAC
- Refrigerant Loop
- **Motor Loop**
- Battery Loop

The motor coolant loop is modeled with the Thermal Liquid domain of [Simscape Fluids™]

Building a Virtual Vehicle Model to Assess Range

Using Simscape™



Battery Loop

- Regulates battery temperature
- Driven by battery pump
- Two modes (serial or parallel)

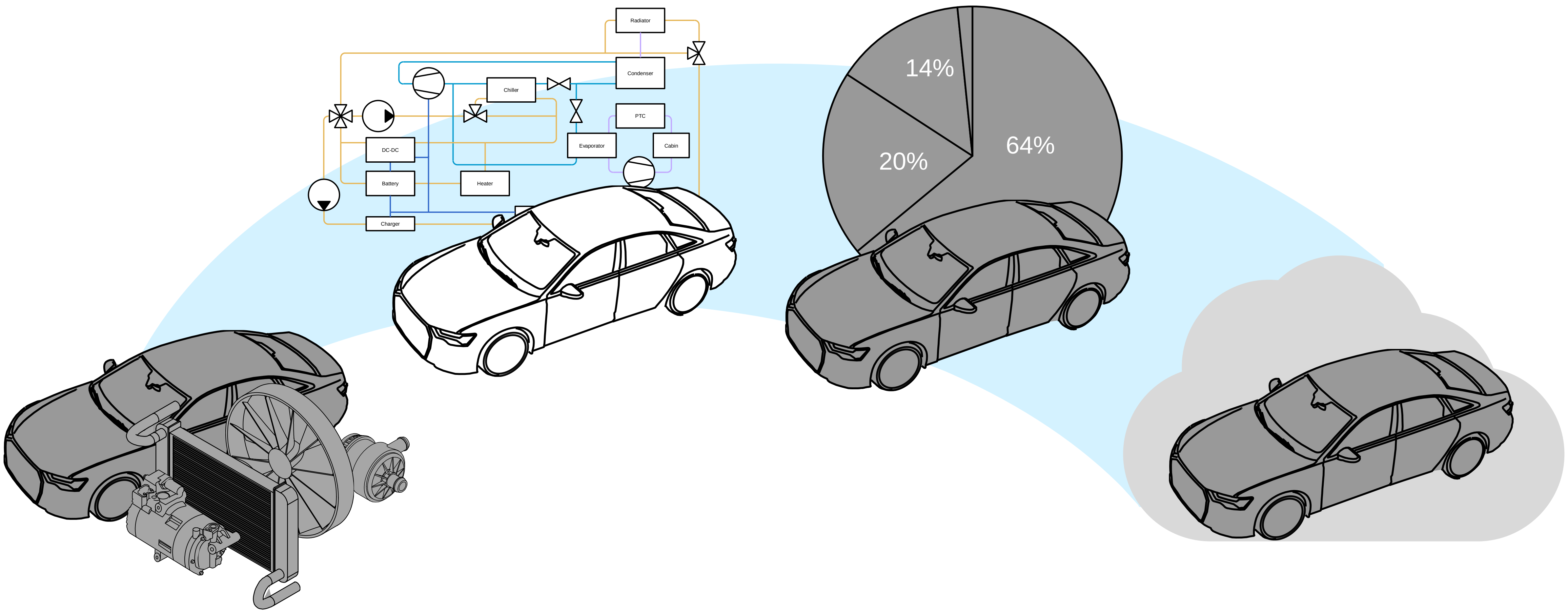
Subsystems

- Battery, Charger
- Powertrain
- Driveline
- Cabin HVAC
- Refrigerant Loop
- Motor Loop
- **Battery Loop**

The battery coolant loop is modeled with the Thermal Liquid domain of [Simscape Fluids™]

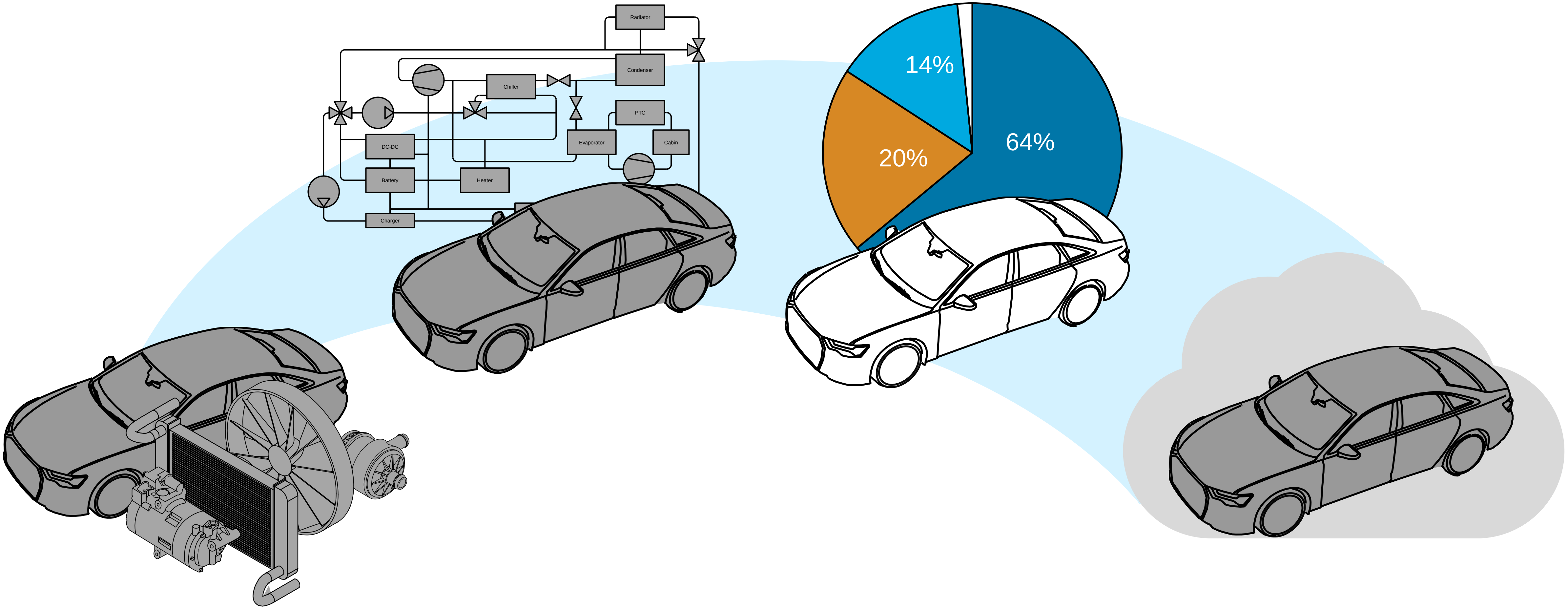
Design and Analyze a BEV with Thermal Management

Building a Virtual Vehicle Model to Assess Range



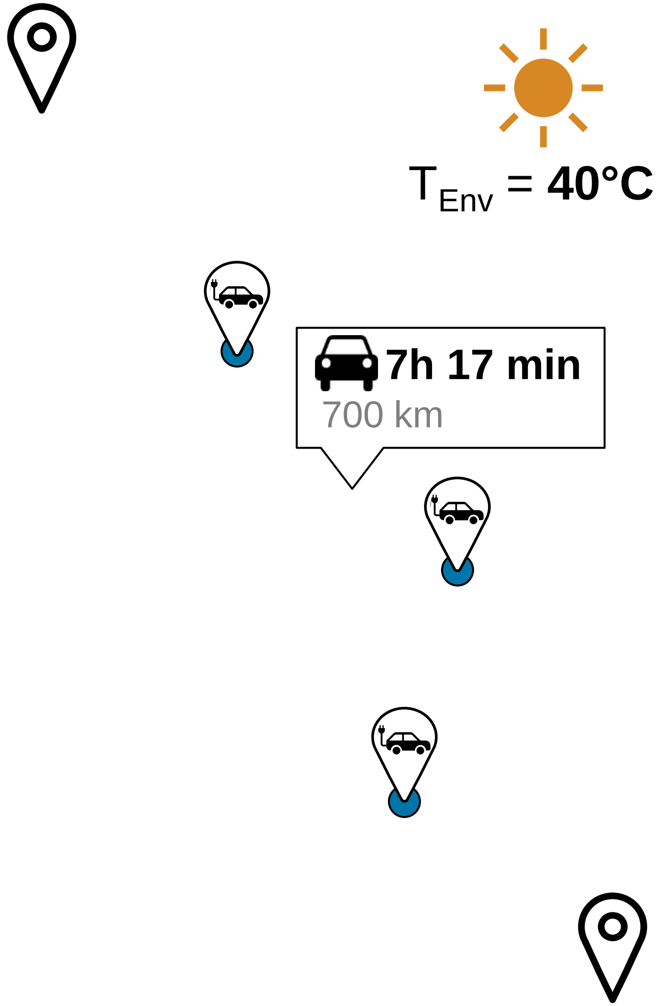
Design and Analyze a BEV with Thermal Management

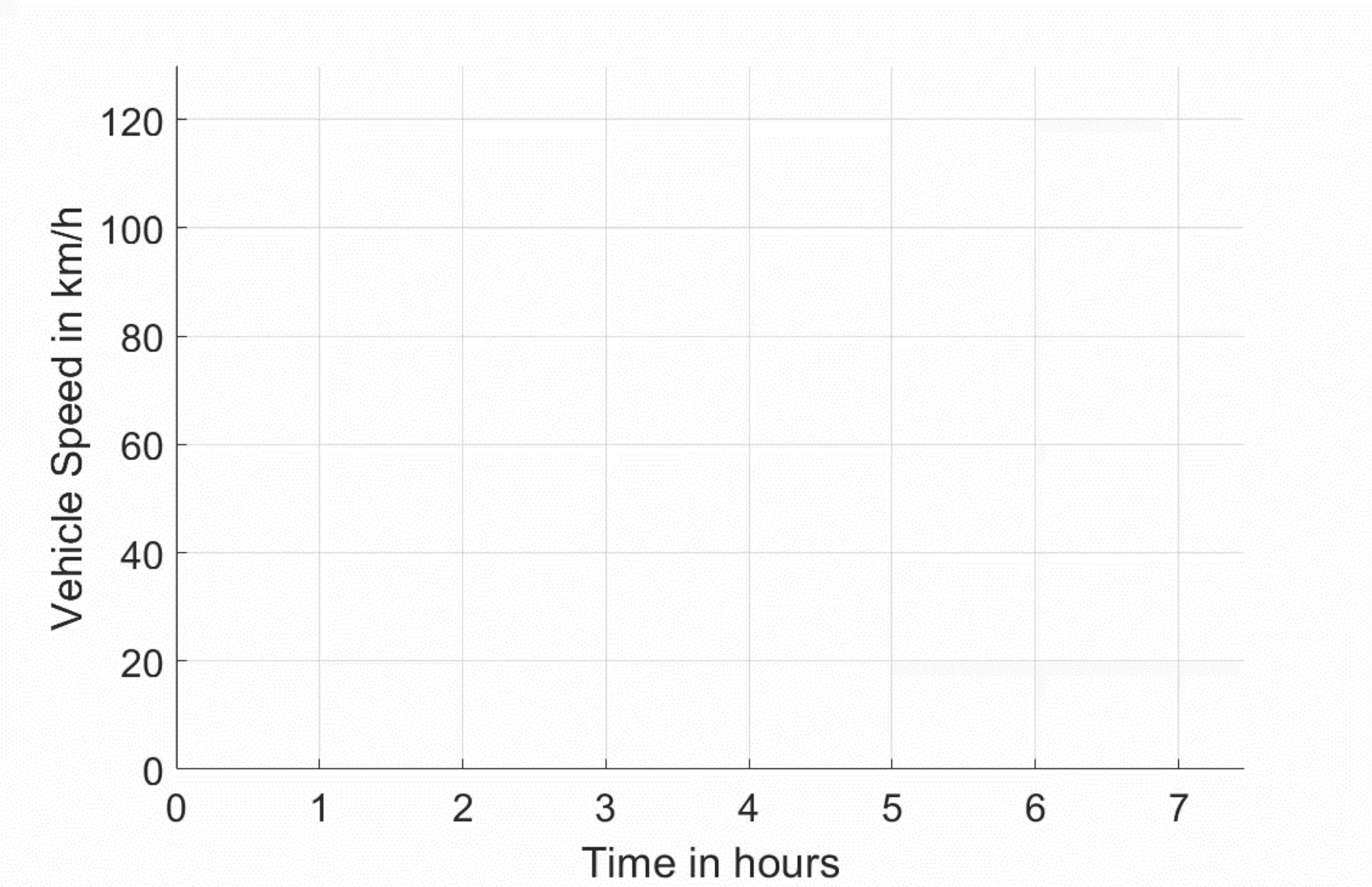
Simulating a Drive Cycle with the Virtual Vehicle Model



Analyze Losses over Drive and Charge Scenario

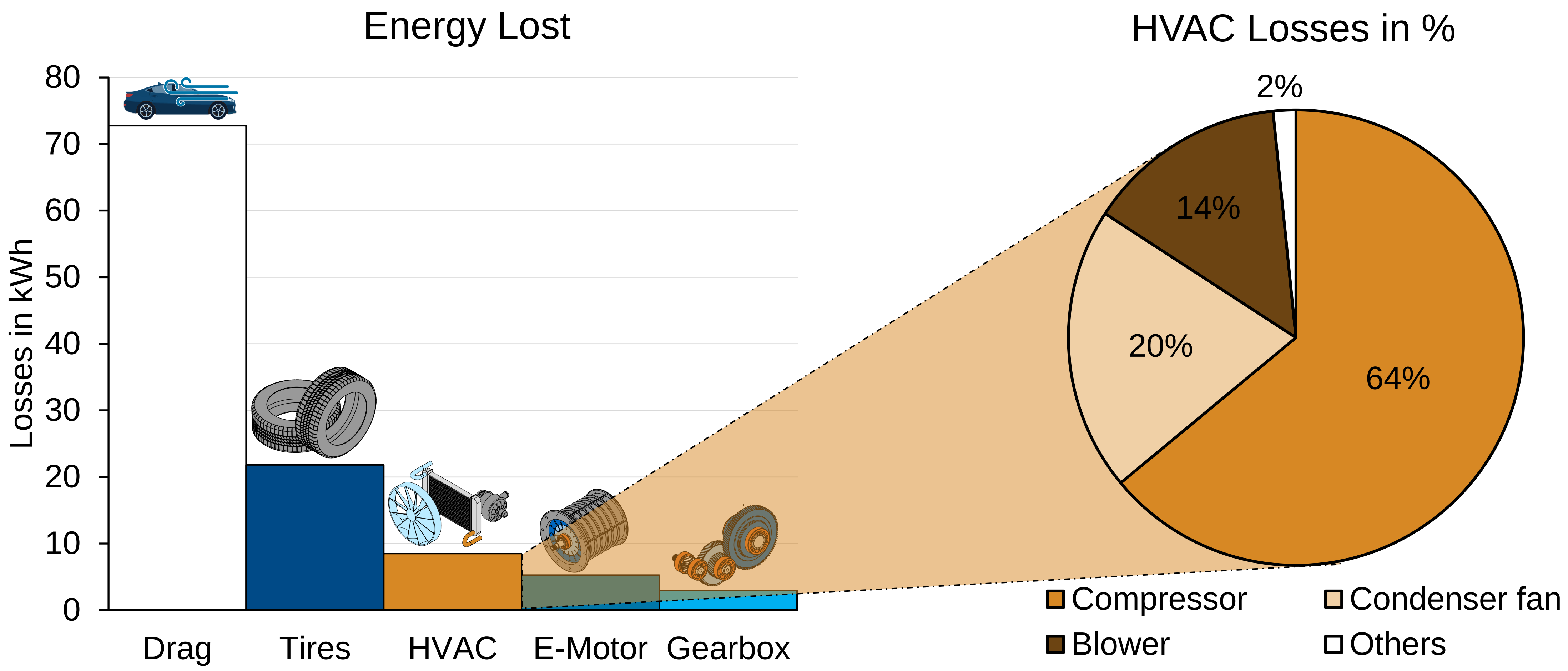
Considering Powertrain, Driveline, and Thermal Management Losses





Analyze Losses of Individual Subsystems

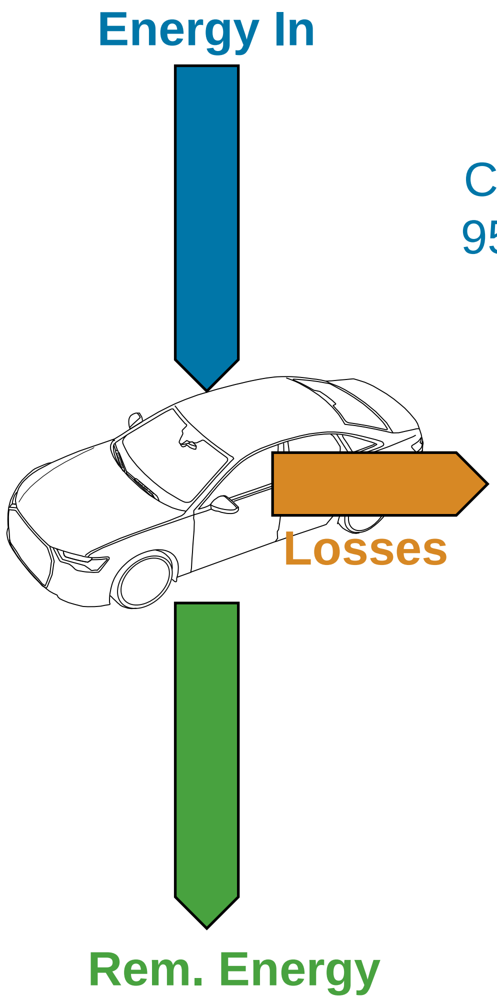
Represent results with bar and pie charts

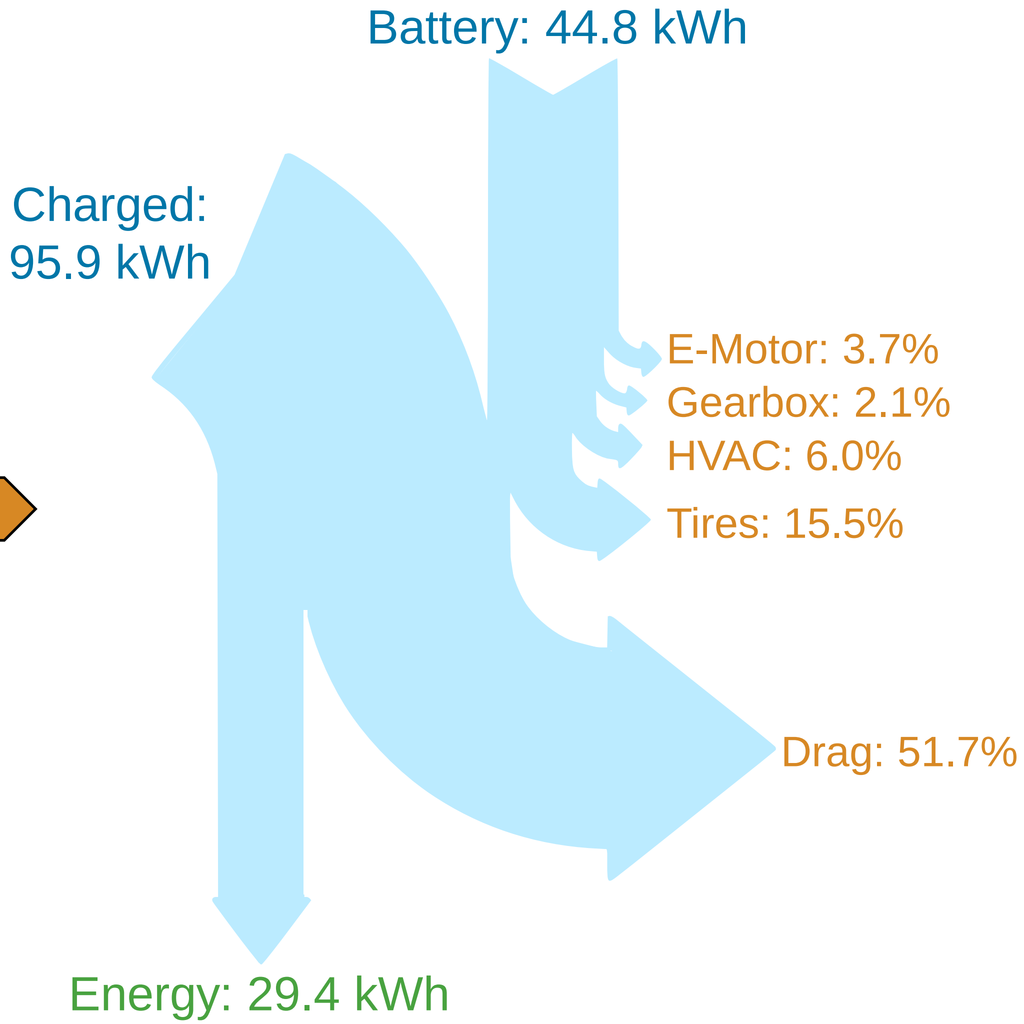


Source: S. Miller and L. Nicoletti, “A Holistic Approach for Designing a Battery Electric Vehicle Thermal Management System”, ELIV, Bonn, 2023

Analyze Losses of Individual Subsystems

Represent results with Sankey charts

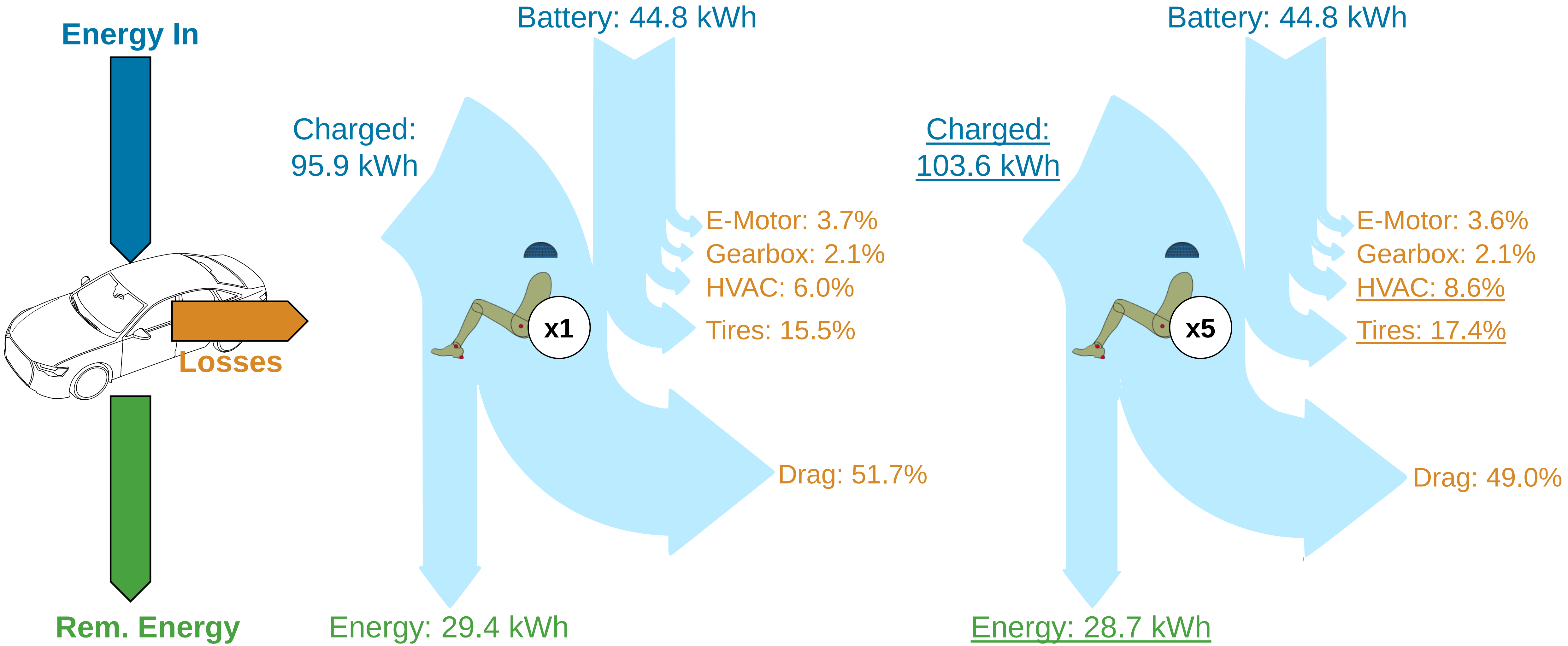




Source: S. Miller and L. Nicoletti, "A Holistic Approach for Designing a Battery Electric Vehicle Thermal Management System", ELIV, Bonn, 2023

Sensitivity Analysis: Energy Flow for One and Five Passengers

The percentages refer to the sum of charged and initial battery energy



Source: S. Miller and L. Nicoletti, “A Holistic Approach for Designing a Battery Electric Vehicle Thermal Management System”, ELIV, Bonn, 2023

Sensitivity Analysis: Energy Flow for One and Five Passengers

Main results

- Increasing the passengers from one to five raises consumption by **8.3 kWh**
- On average each additional passenger:
  - Decreases the maximum range by **4 km**
  - Increases required charged energy by **1.9 kWh**

- More sensitivity analyses are documented in:
  - S. Miller and L. Nicoletti, “A Holistic Approach for Designing a Battery Electric Vehicle Thermal Management System”, Electronics In Vehicles (ELIV) Conference, Bonn, 2023

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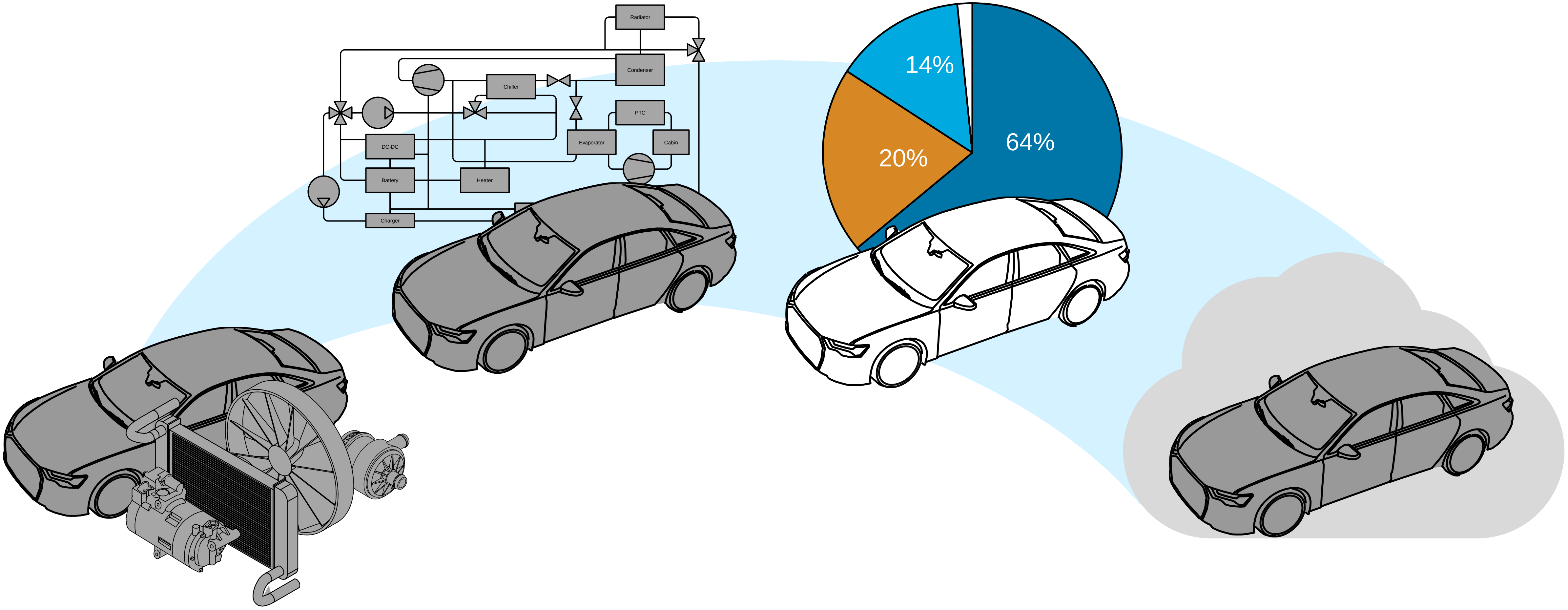
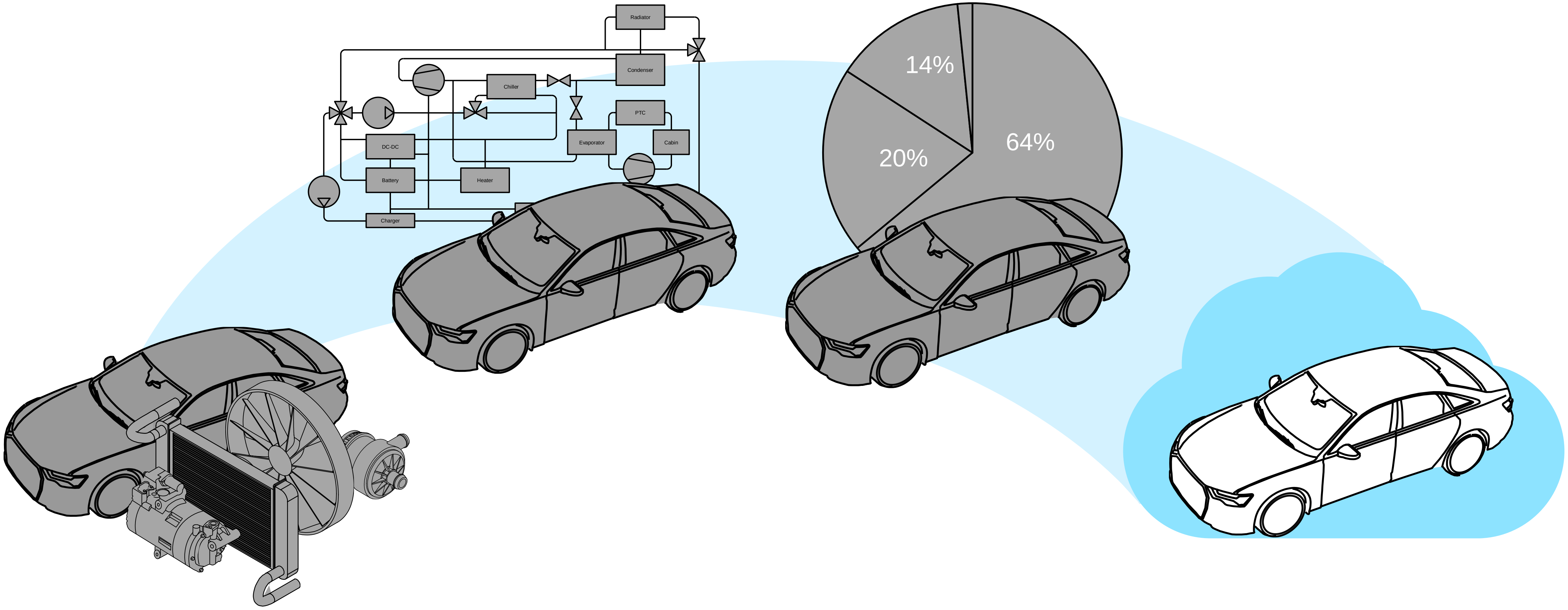
Simulating a Drive Cycle with the Virtual Vehicle Model



Design and Analyze a BEV with Thermal Management

Summary and Outlook



Summary and Outlook

Where to go next?

- Key Takeaway:
  - You can use Simscape to build a virtual vehicle model with thermal management
  - You can use the virtual vehicle to gain insights on range, consumption, and costs
  - You can easily extend and detail the virtual vehicle
- The virtual vehicle is available on GitHub (in 24a and 23b)
- Use Simulink® Design Optimization™ for more complex sensitivity analyses
- Use Optimization Toolbox™ to optimize your design
- Deploy the model in the cloud to accelerate your optimization studies

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Thank you

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