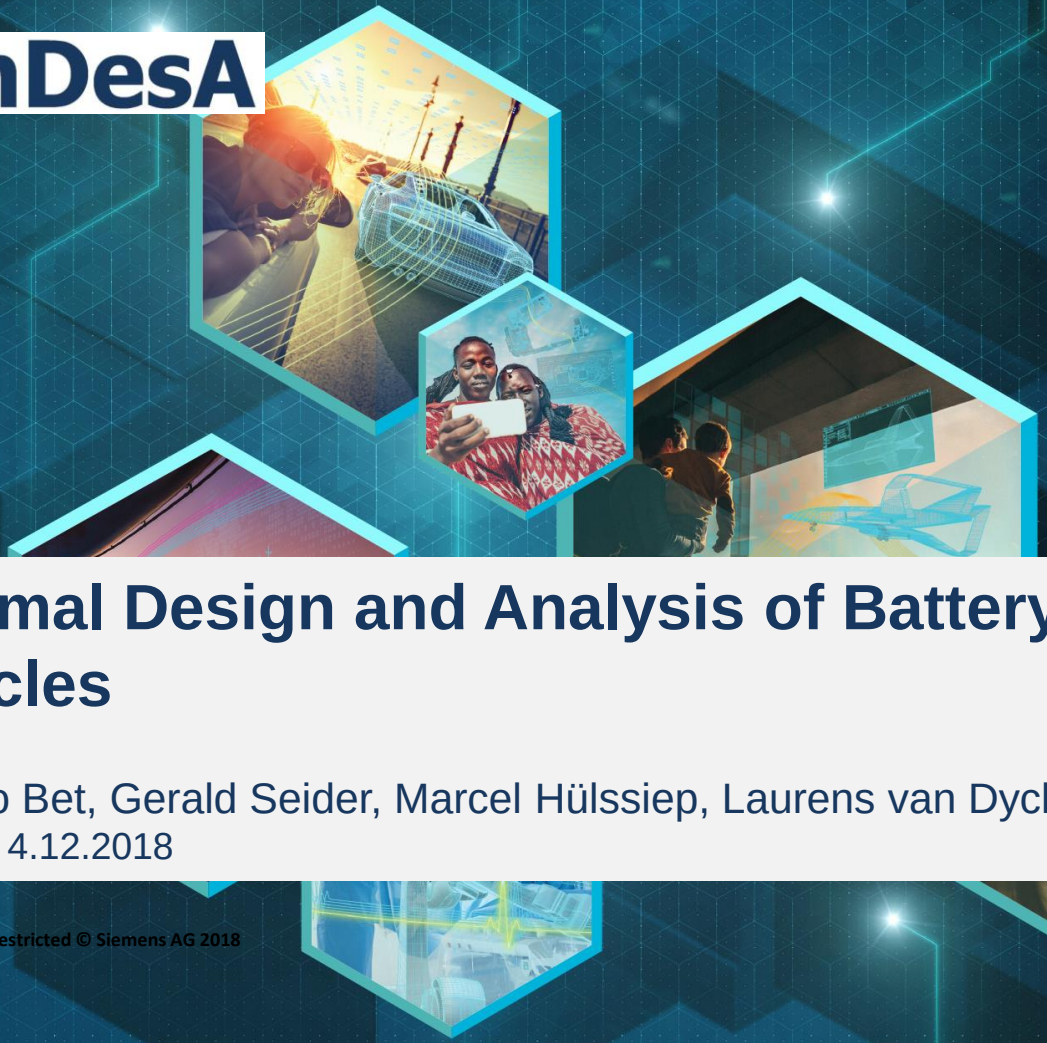
INTEGRATED DESIGN ANALYSIS GmbH InDesA

SIEMENS
Ingenuity for life



Thermal Design and Analysis of Battery Electric Vehicles

Fabiano Bet, Gerald Seider, Marcel Hülssiep, Laurens van Dyck, Denis Palienko

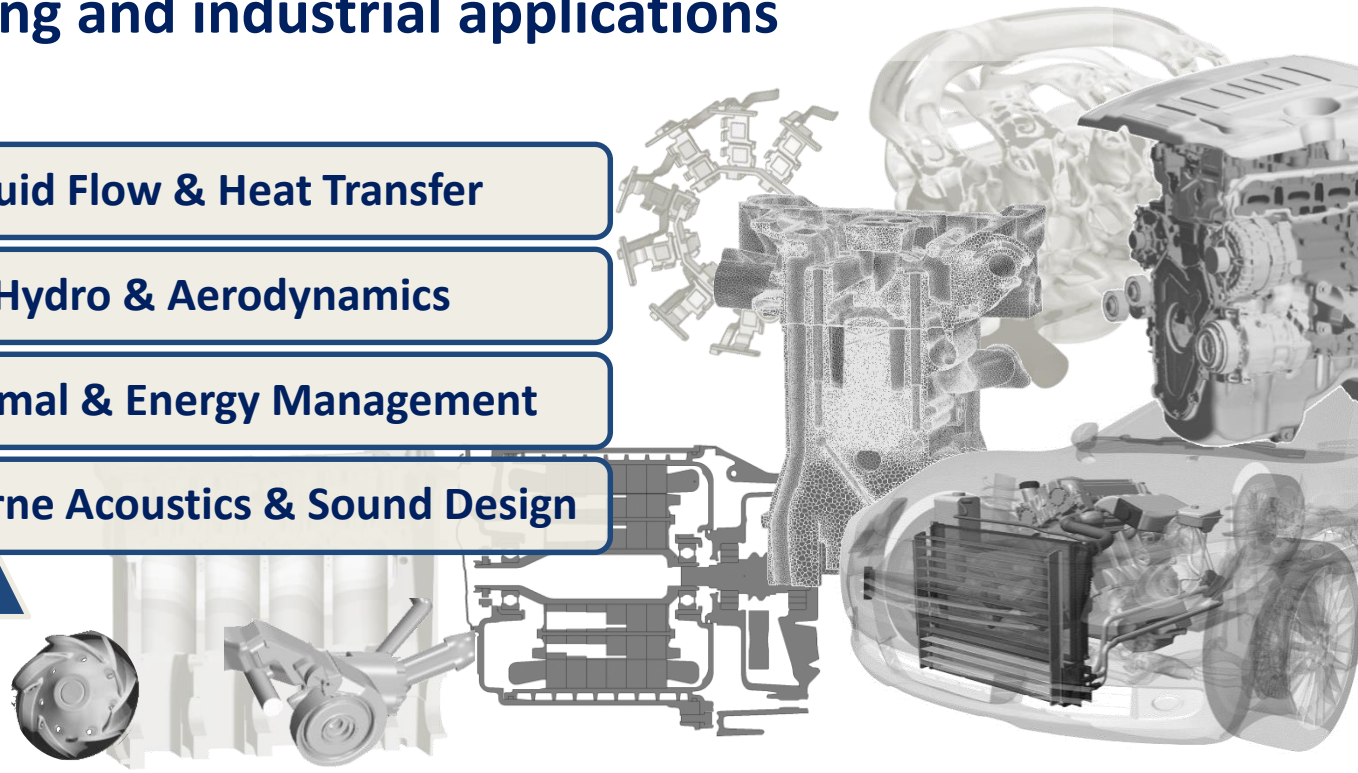
Prague, 4.12.2018

InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
InDesA Competence

Simulation and Design Analysis of complex systems for engineering and industrial applications

- Fluid Flow & Heat Transfer
- Hydro & Aerodynamics
- Thermal & Energy Management
- Air-borne Acoustics & Sound Design



InDesA
INTEGRATED DESIGN ANALYSIS

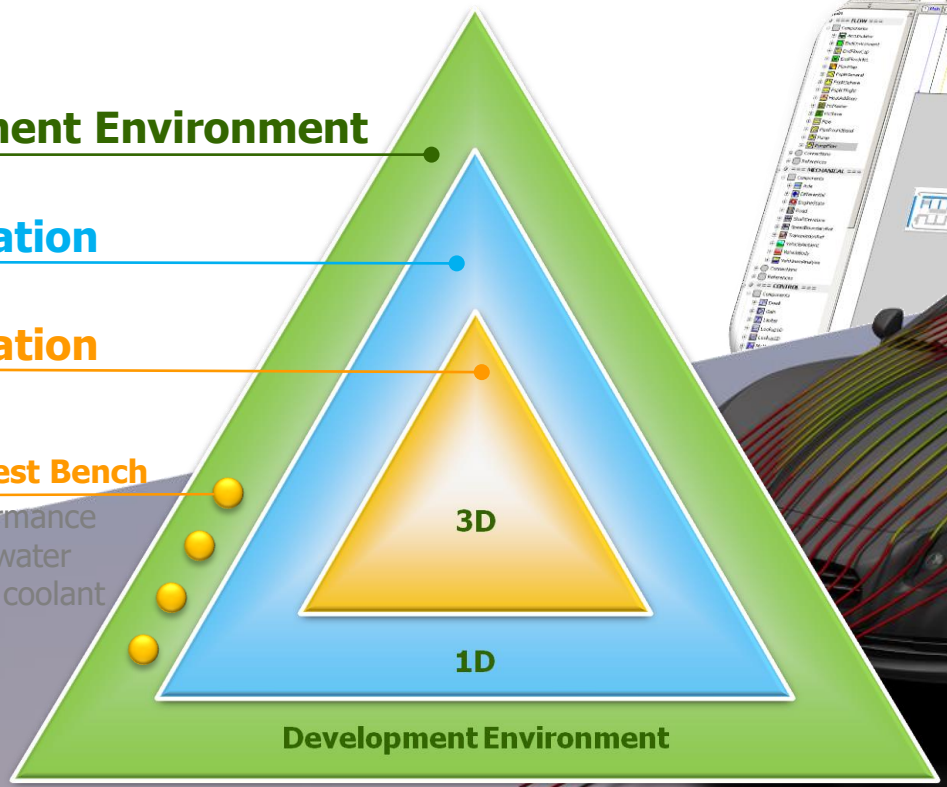
Thermal Design and Analysis of Electric Vehicles
Integrated Design Analysis

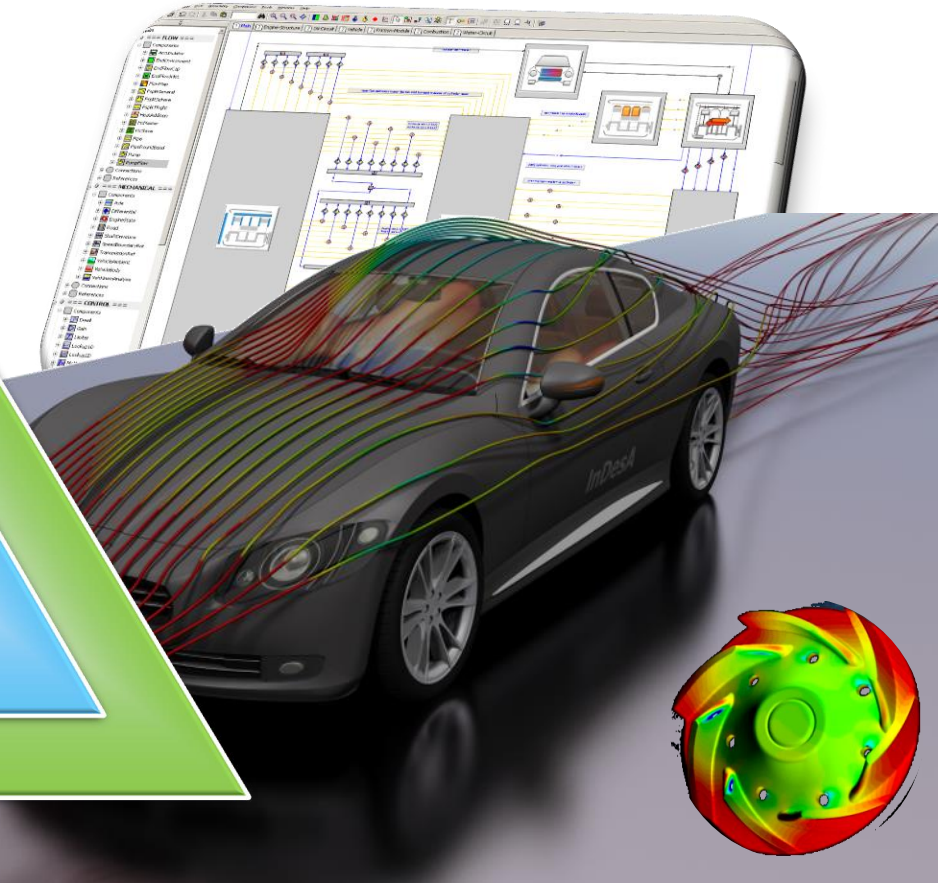
Development Environment
of customer

1D Simulation

3D Simulation

3D Virtual Test Bench
e.g. for performance prediction of water pump for low coolant temperatures





InDesA
INTEGRATED DESIGN ANALYSIS

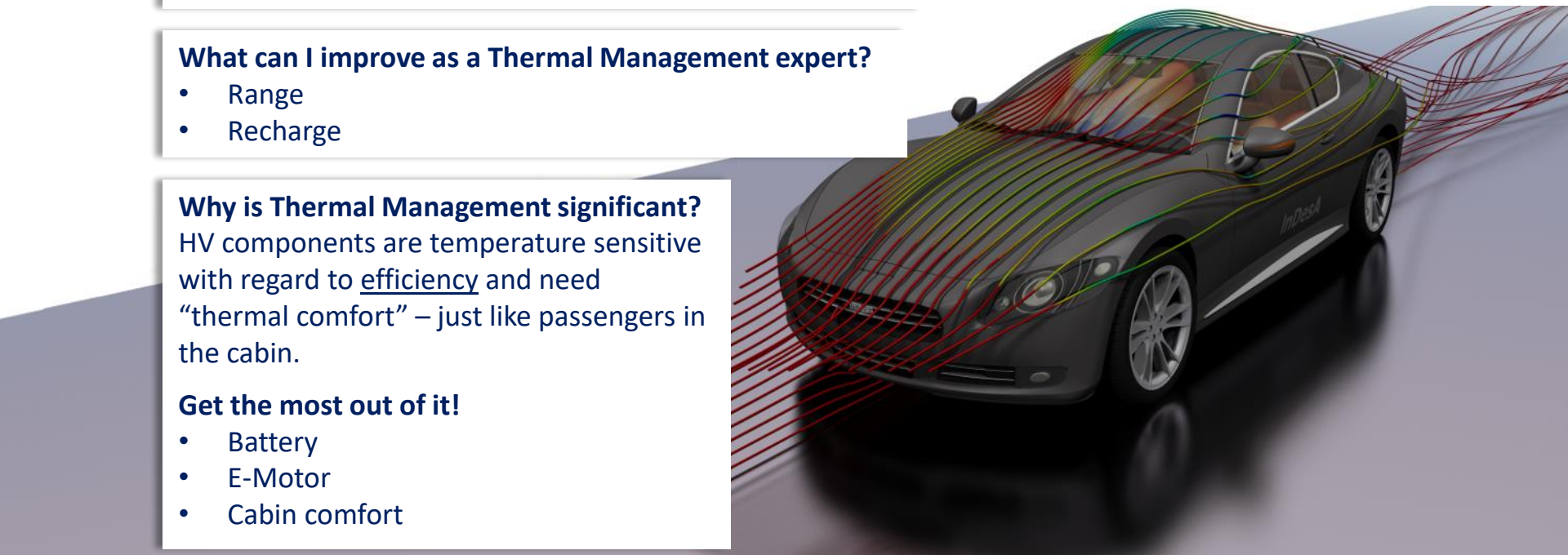
Thermal Design and Analysis of Electric Vehicles
My Personal BEV Challenge

Why did I hesitate to order a Battery Electric Vehicle?
- High price
- Low range
- Long recharge time

What can I improve as a Thermal Management expert?
- Range
- Recharge

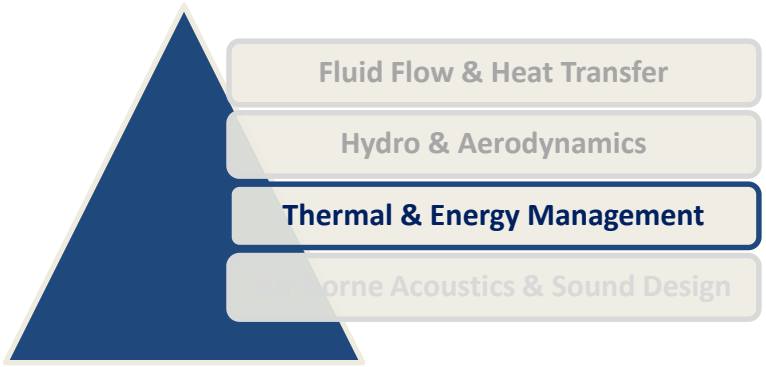
Why is Thermal Management significant?
HV components are temperature sensitive with regard to efficiency and need "thermal comfort" – just like passengers in the cabin.

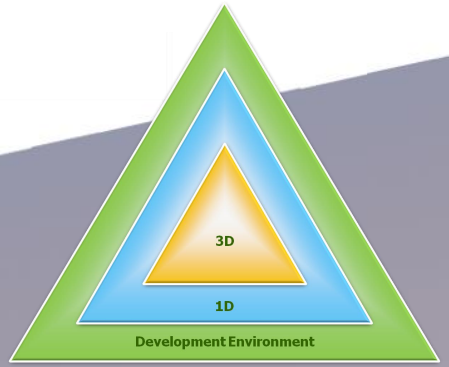
Get the most out of it!
- Battery
- E-Motor
- Cabin comfort



InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
Thermal & Energy Management





Simulation Methodology

1. Build system to predict vehicle energy consumption for arbitrary drive cycles with 1D methodology.
2. Solve Fluid Flow and Heat Transfer problems for vehicle and HV components with 3D CFD/CHT solver STAR-CCM+
3. Feed back results to 1D system model for calibration.
4. Validate filling and degas function for coolant system with 3D CFD solver STAR-CCM+

InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
Pandora VEV (Virtual Electric Vehicle)

Pandora Electric Vehicle

… designed to demonstrate thermal simulation techniques with options for different thermal management technologies.

Specification MY 2019:

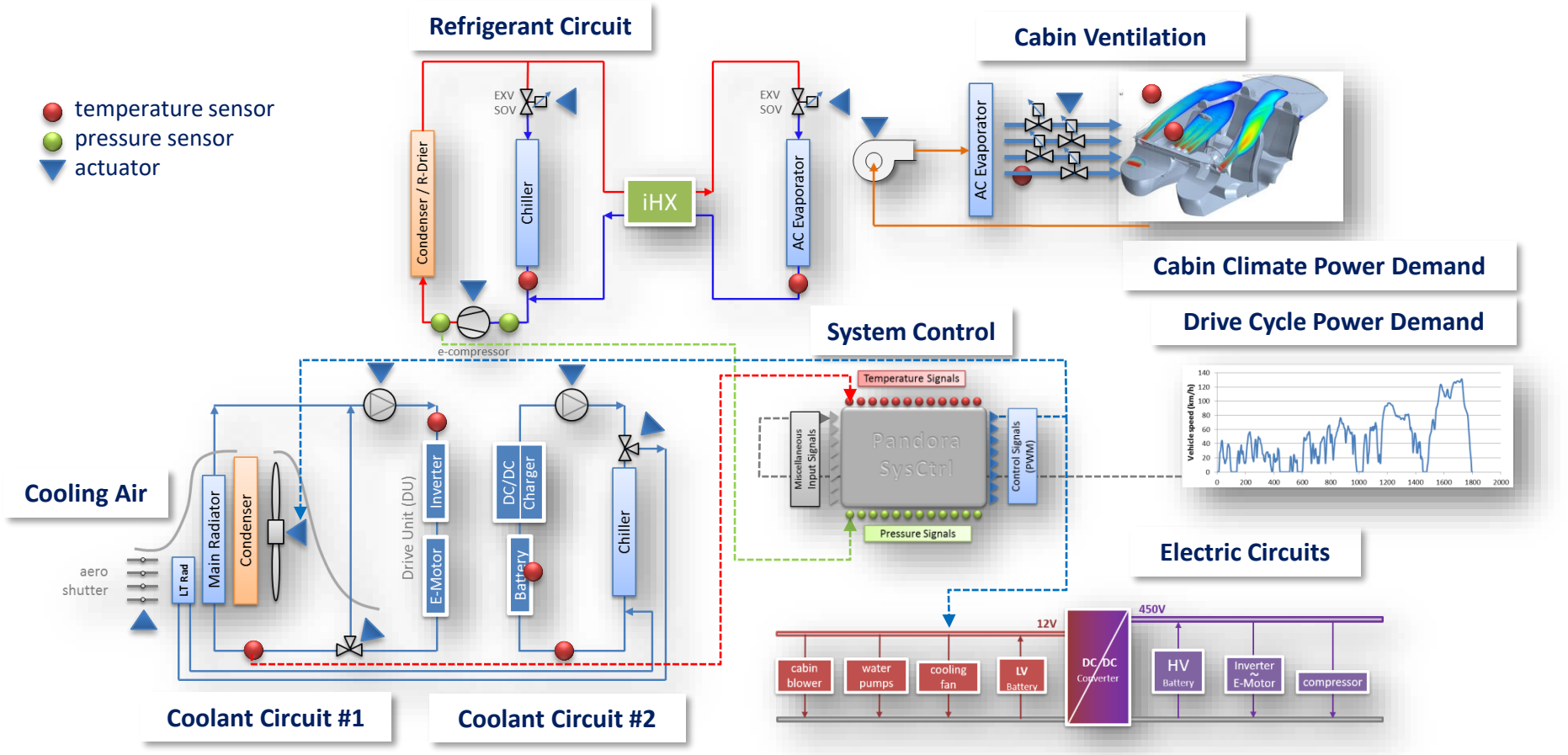
Rear wheel drive with 160 kW/360 Nm E-Motor
Battery 72 kWh, 448 V
Battery Cell: 50 Ah; 3.7 V_{nom}

InDesA Design includes

- Exterior
- Radiator/Condenser and Fan Module
- Cabin and HVAC unit
- Battery and E-Drive Coolant System
- Refrigerant Circuit
- HV components (Battery, Motor, Inverter)

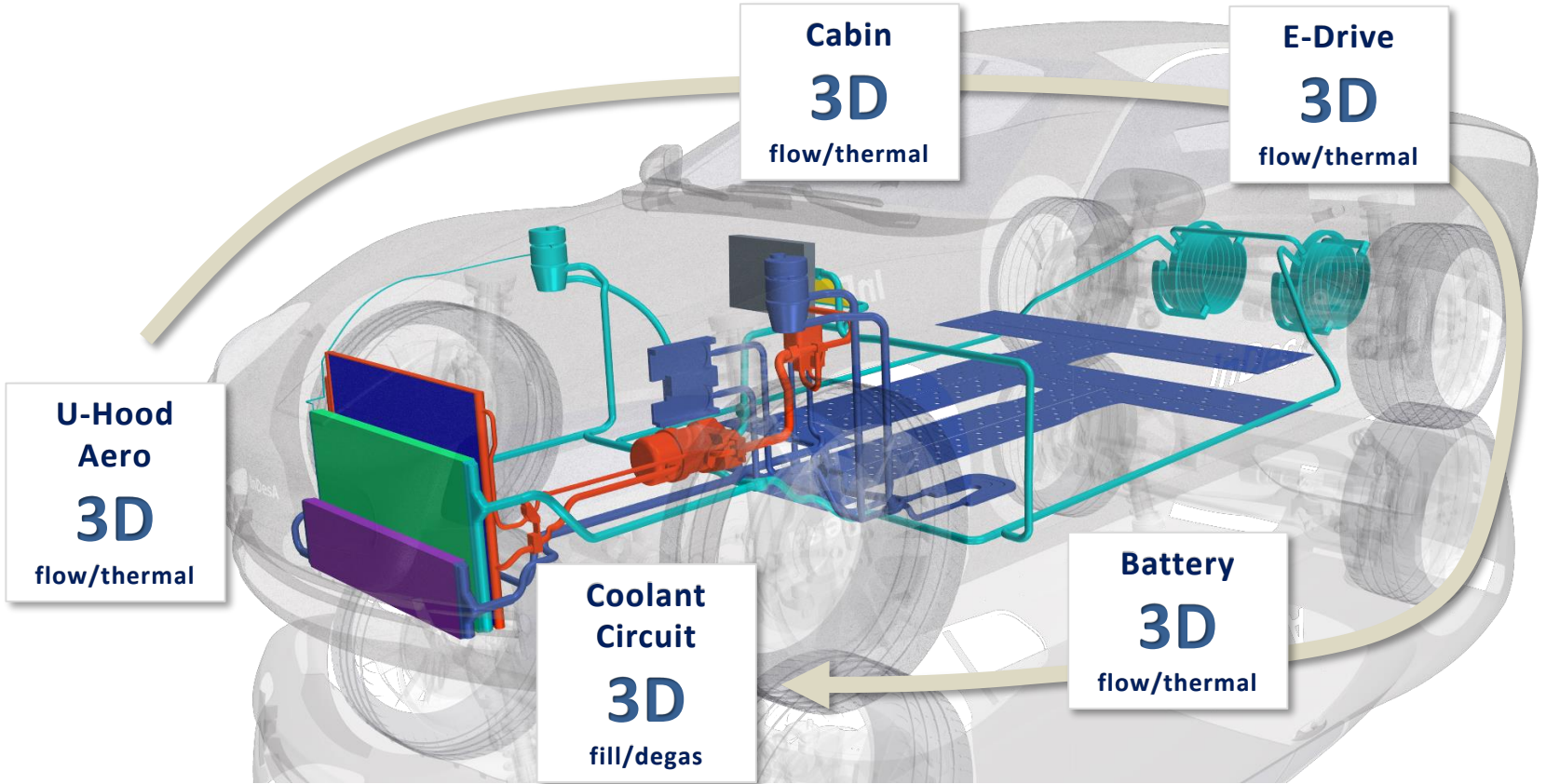
InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
Schematic of Pandora Thermal and Electric System



InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
The Pandora Thermal System



InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
Aerodynamic and Underhood Flow

Exterior and Underhood Flow Simulation

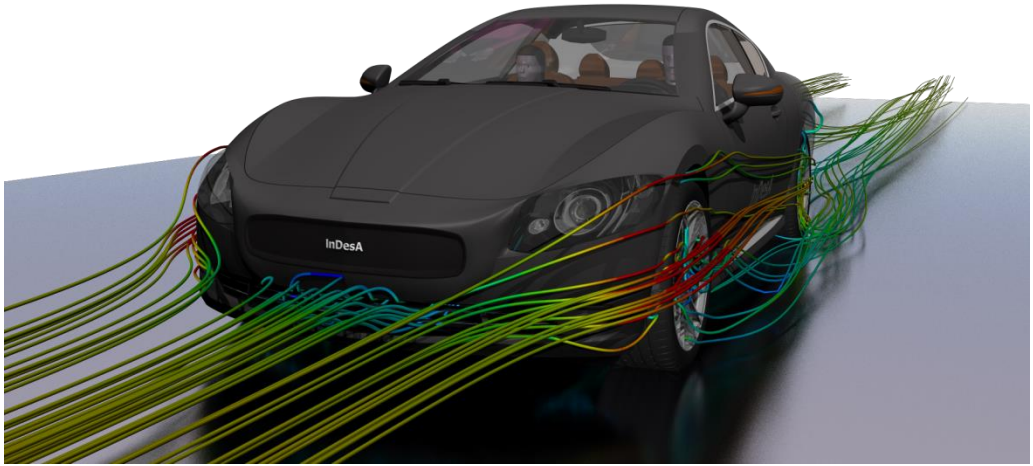
- Vehicle Aerodynamics
- Flow through Condenser/Radiator and Fan Module (CRFM)
- Vehicle underfloor Flow

Prediction of

- Aerodynamic drag
- Mass flow rates and losses through CRFM
- Heat Release from Radiator/Condenser
- Heat Transfer Coefficients (Cabin, E-Motor)

Relevance for 1D System Simulation

- Aerodynamic drag
- Calibration of cooling air flow model (CRFM)
- HTC's for cabin exterior



InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
Cabin Flow and Heat Transfer with Solar Radiation

Cabin Thermal Comfort Simulation

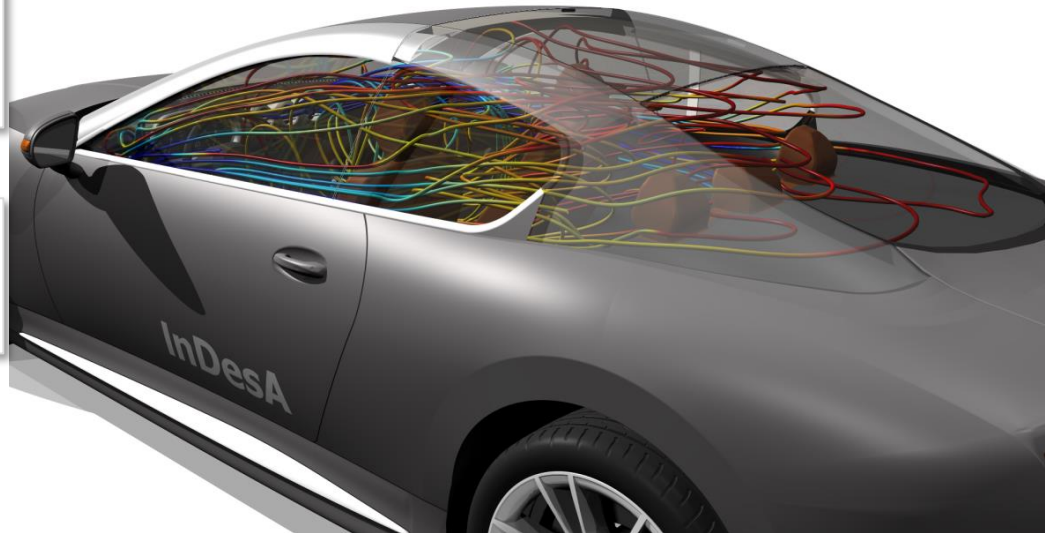
- CFD Cabin flow
- CHT Cabin Structure (body frame, windows, seats, etc.)
- Solar Radiation

Prediction of

- Cabin warm-up / cool-down
- Thermal comfort
- Thermal Balance Analysis

Relevance for 1D System Simulation

- Calibration of multi-zone cabin model
- HTC's at windows, walls and other boundaries



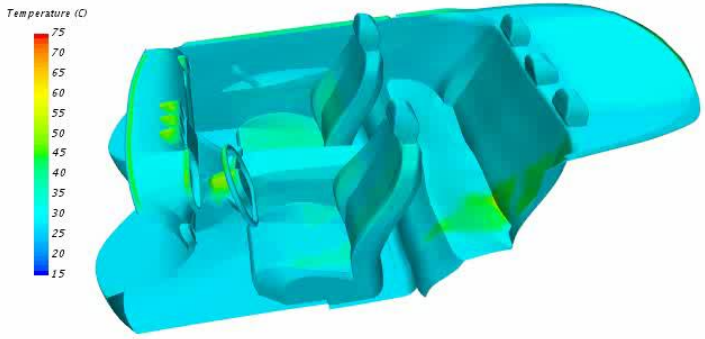
InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
I. Cabin Warm-up through Solar Radiation

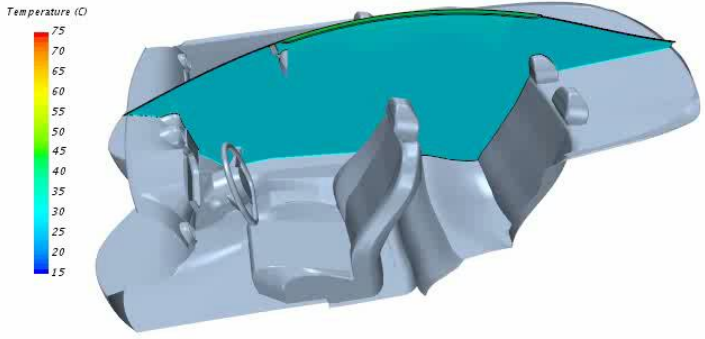
Warm-up Scenario:

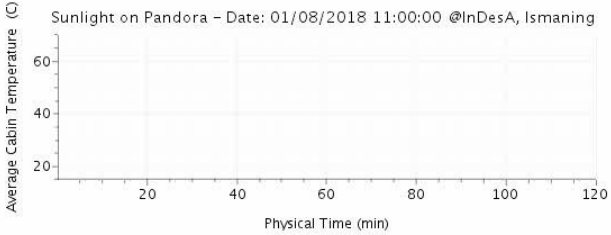
01/08/2018 11:00 CET
Parking lot @ InDesA office
Site elevation 490 m
N 48° 13’ E 011° 40’
sun shine; no clouds

Simulation time 2 hours
Cabin start temp. 28°C



animation not visible in pdf





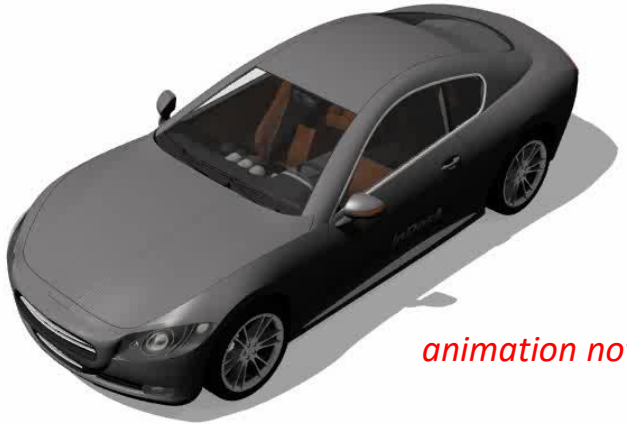
InDesA
INTEGRATED DESIGN ANALYSIS

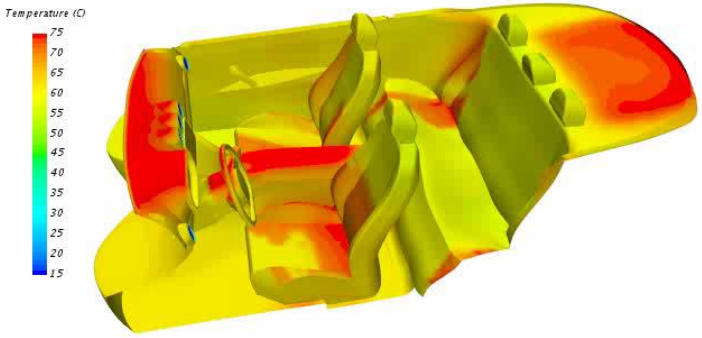
Thermal Design and Analysis of Electric Vehicles
II. Cabin Cool Down through Air Conditioning

Cool-Down Scenario:

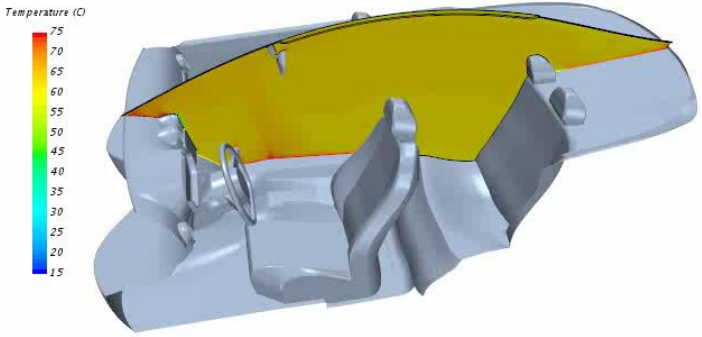
01/08/2018 13:00 CET
Parking lot @ InDesA office
Site elevation 490 m
N 48° 13’ E 11° 40’
sun shine; no clouds

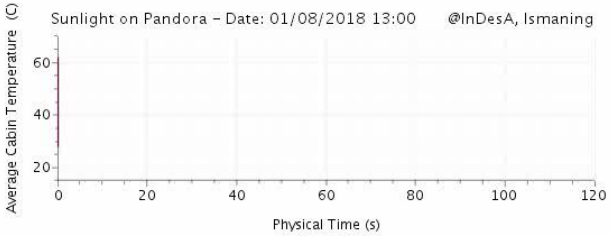
Simulation time 2 minutes
Avg. cabin start temp. 62°C
Vent temp. 10°C
Vehicle speed: 0 kph





animation not visible in pdf





InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
E-Drive Thermal Analysis

E-Drive Thermal Analysis

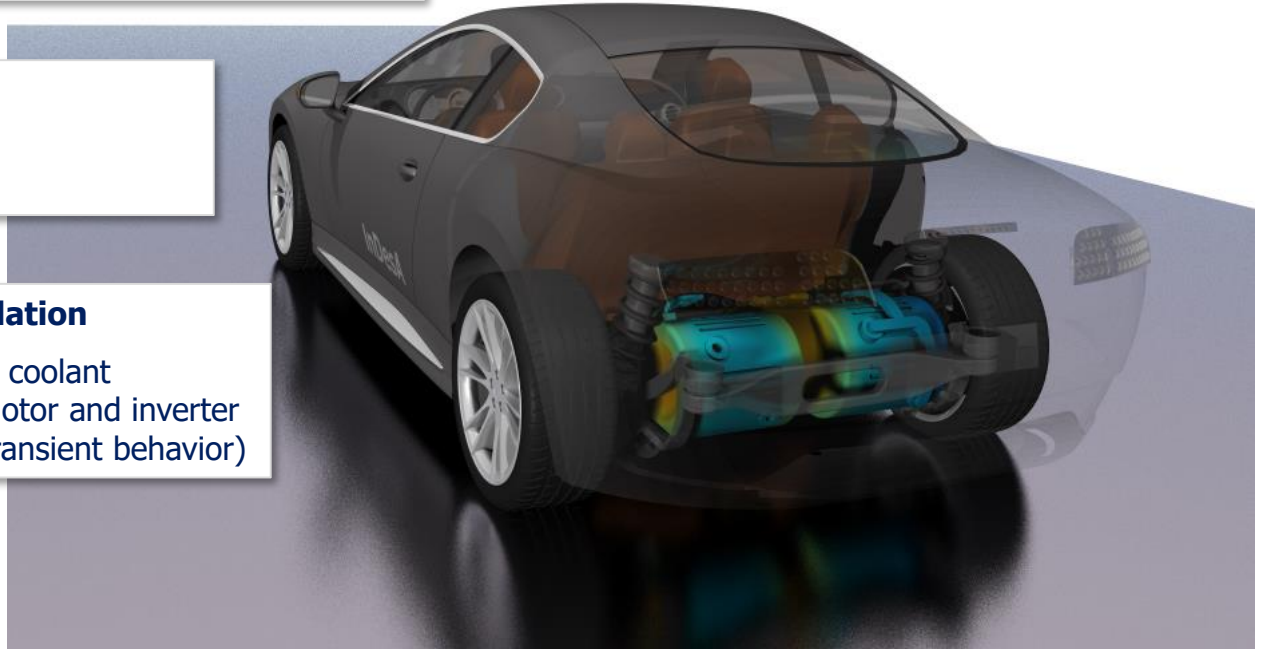
- E-Motor (water cooled)
- Inverter (water cooled)
- Transmission (air cooled)

Prediction of

- Local component temperatures
- Heat transfer analysis

Relevance for 1D System Simulation

- Heat release from component to coolant
- Calibration of 1D models for e-motor and inverter with regard to thermal inertia (transient behavior)



InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
E-Drive Thermal Analysis

E-Drive Thermal Analysis

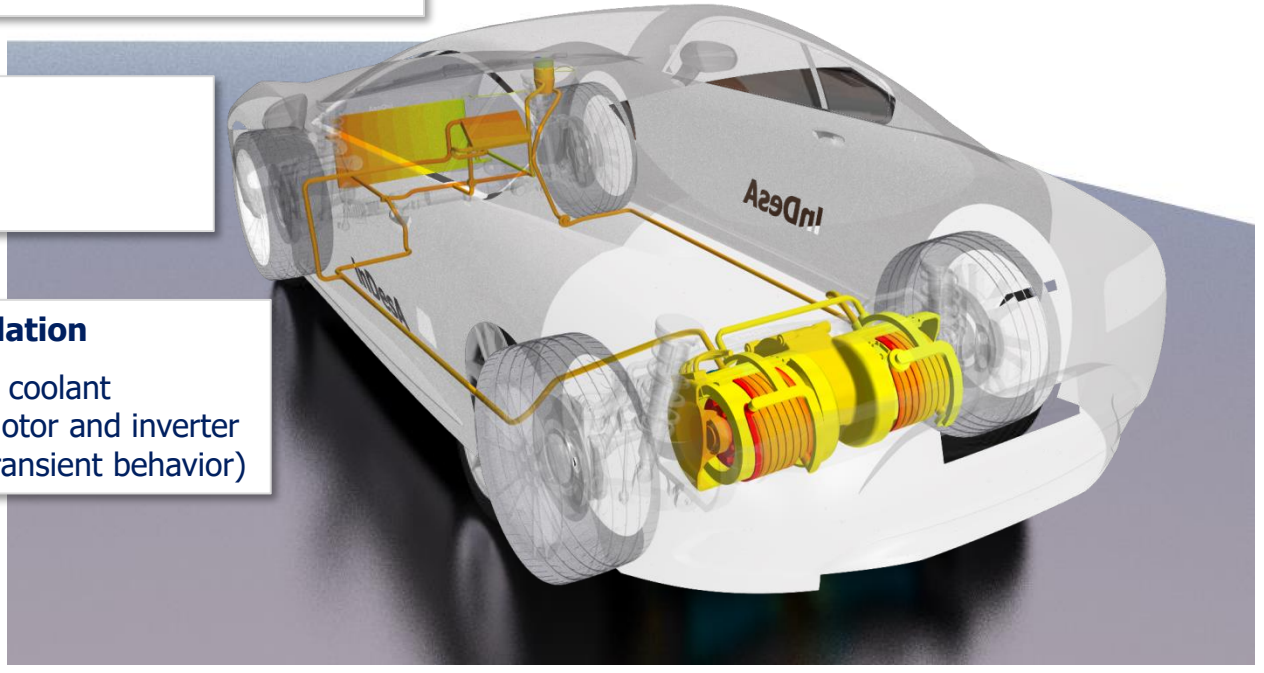
- E-Motor (water cooled)
- Inverter (water cooled)
- Transmission (air cooled)

Prediction of

- Local component temperatures
- Heat transfer analysis

Relevance for 1D System Simulation

- Heat release from component to coolant
- Calibration of 1D models for e-motor and inverter with regard to thermal inertia (transient behavior)



InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
Battery Thermal Analysis

Battery Thermal Analysis

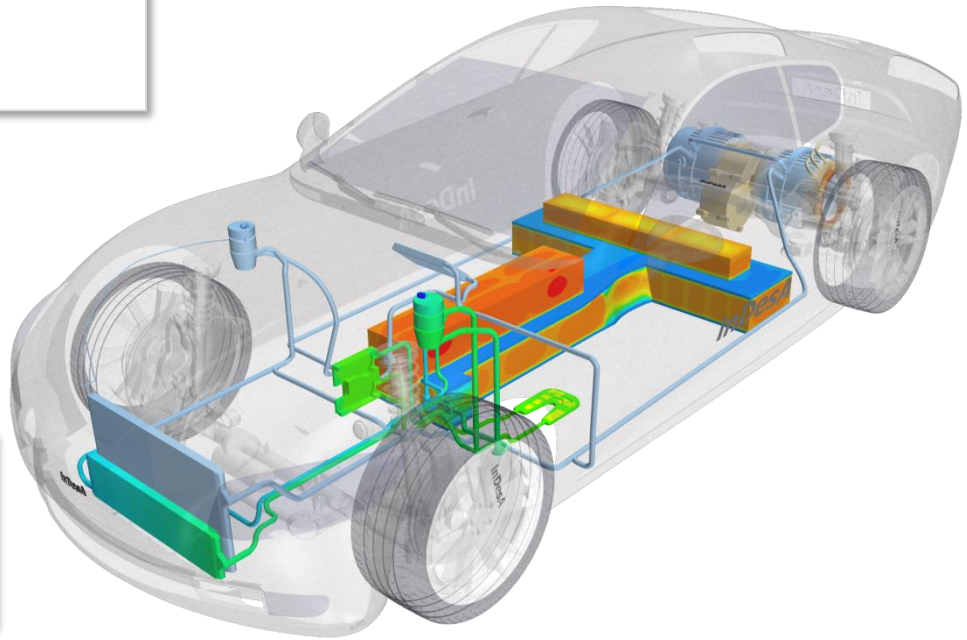
- Battery packs
- Cold Plate (water cooled)

Prediction of

- Local component/cell temperatures
- Heat transfer analysis

Relevance for 1D System Simulation

- Heat release from battery to coolant
- Calibration of 1D models for battery with regard to thermal inertia (transient behavior)



InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
E-Drive Coolant Circuit Fill and Degas Analysis

Fill and Degas Simulation

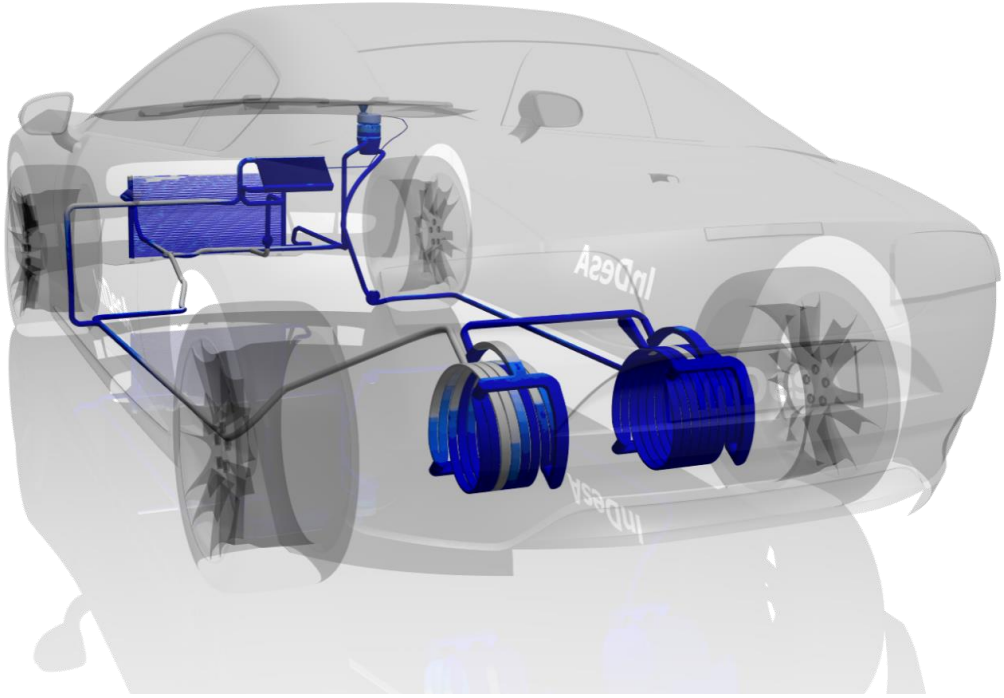
- Battery Coolant Circuit
- E-Drive Coolant Circuit

Simulation of

- Gravity fill
- Vacuum fill (2000/20000 Pa)
- Degas through bleed points
- Degas with active pump and valve control

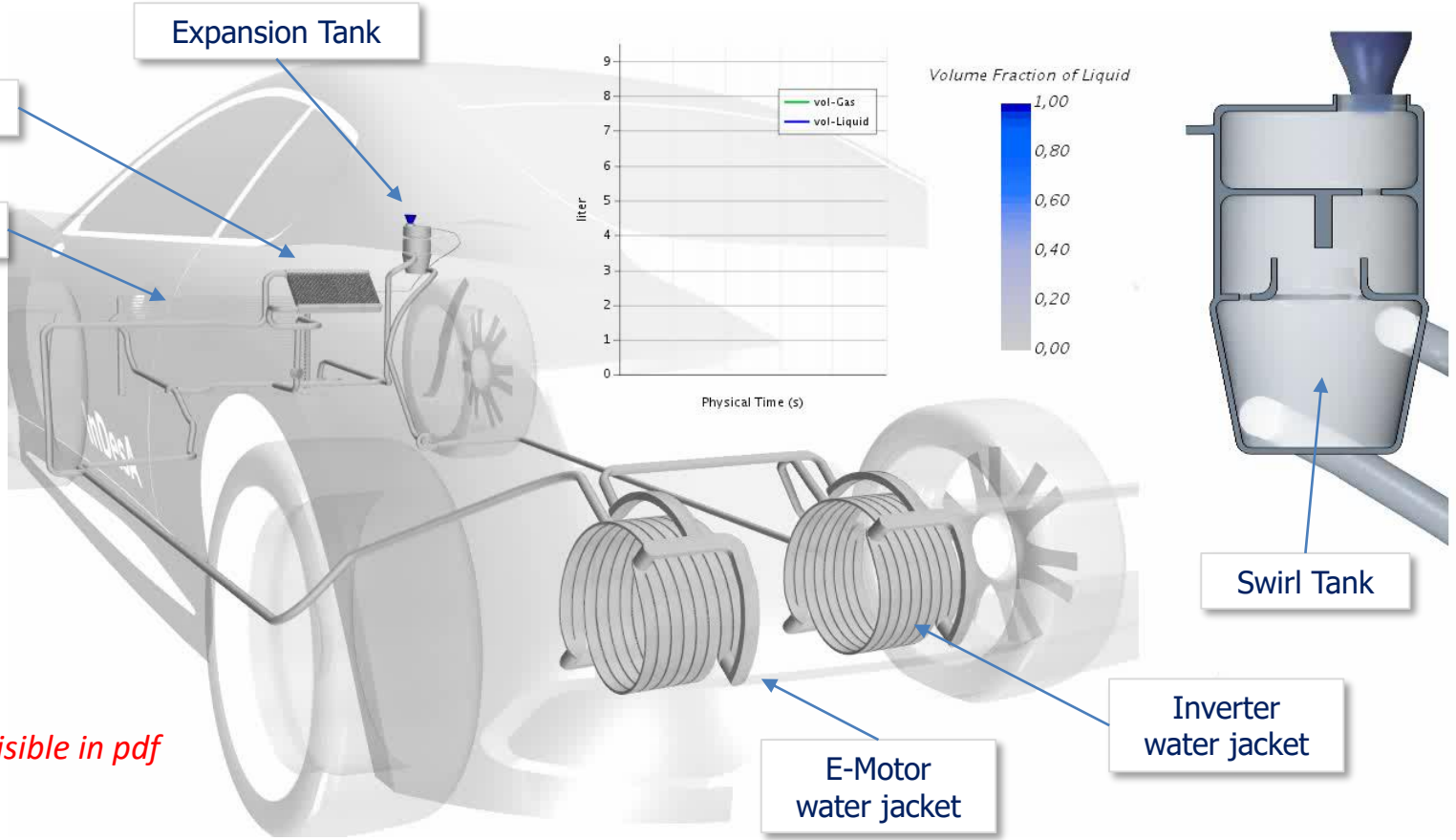
with the following goals:

- Identification of remaining air pockets
- Removal of remaining air in system
- Control strategies
- Identification of degas potential (design optimization)



InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
E-Drive Coolant Circuit Vacuum Fill @ 20000 Pa

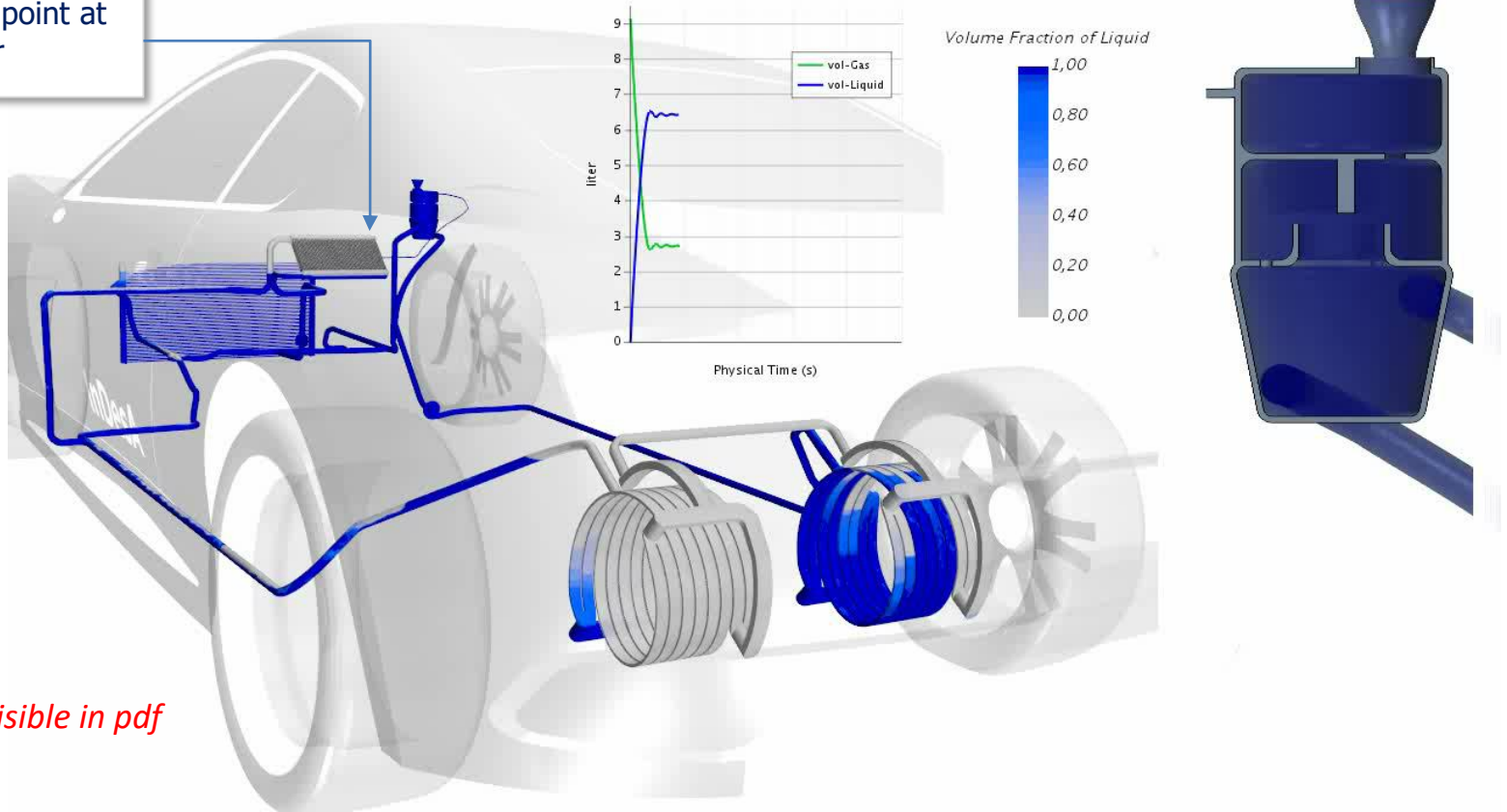


animation not visible in pdf

InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
E-Drive Coolant Circuit Degas of Cabin Heater

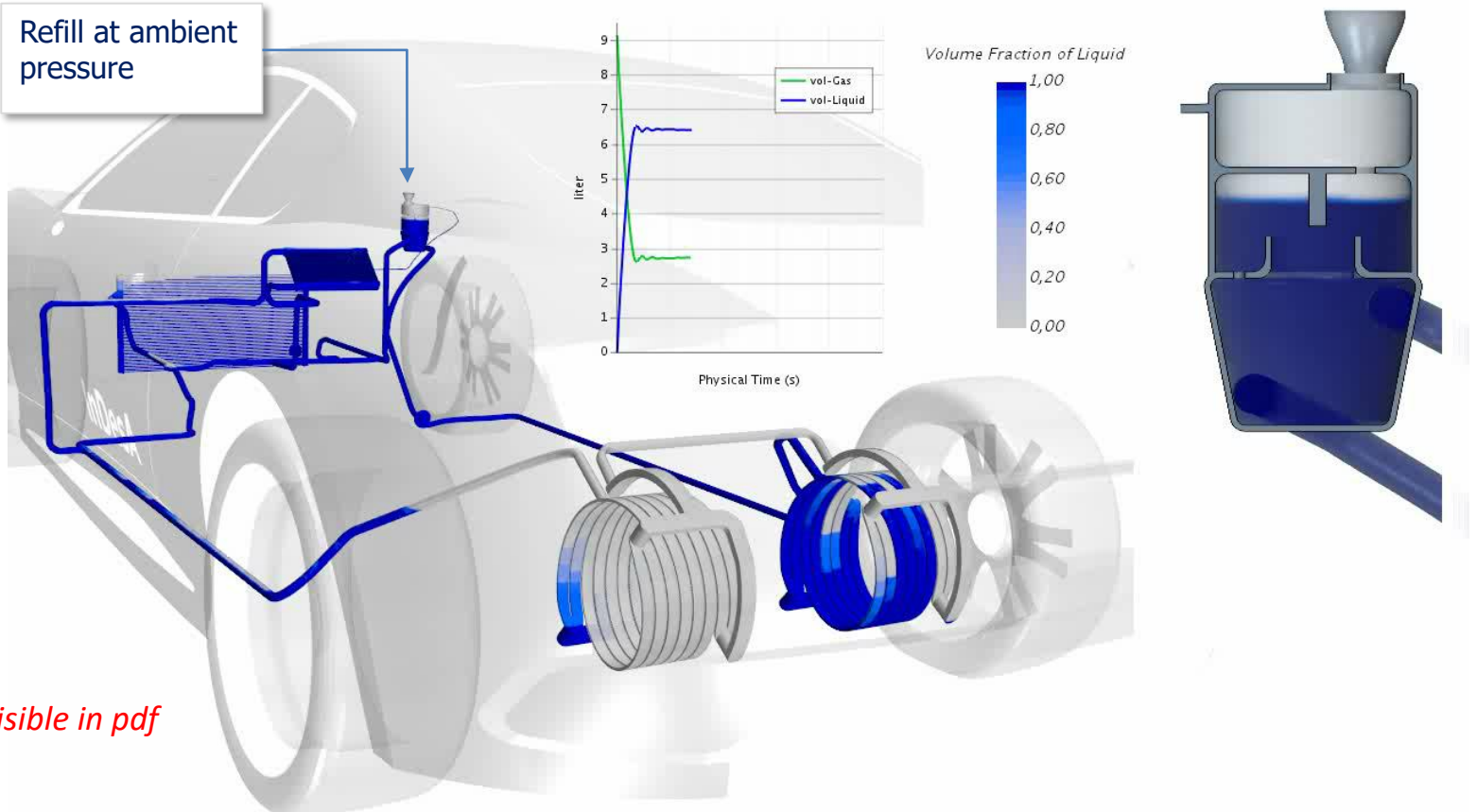
Open bleed point at cabin heater



animation not visible in pdf

InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
E-Drive Coolant Circuit - Gravity ReFill



animation not visible in pdf

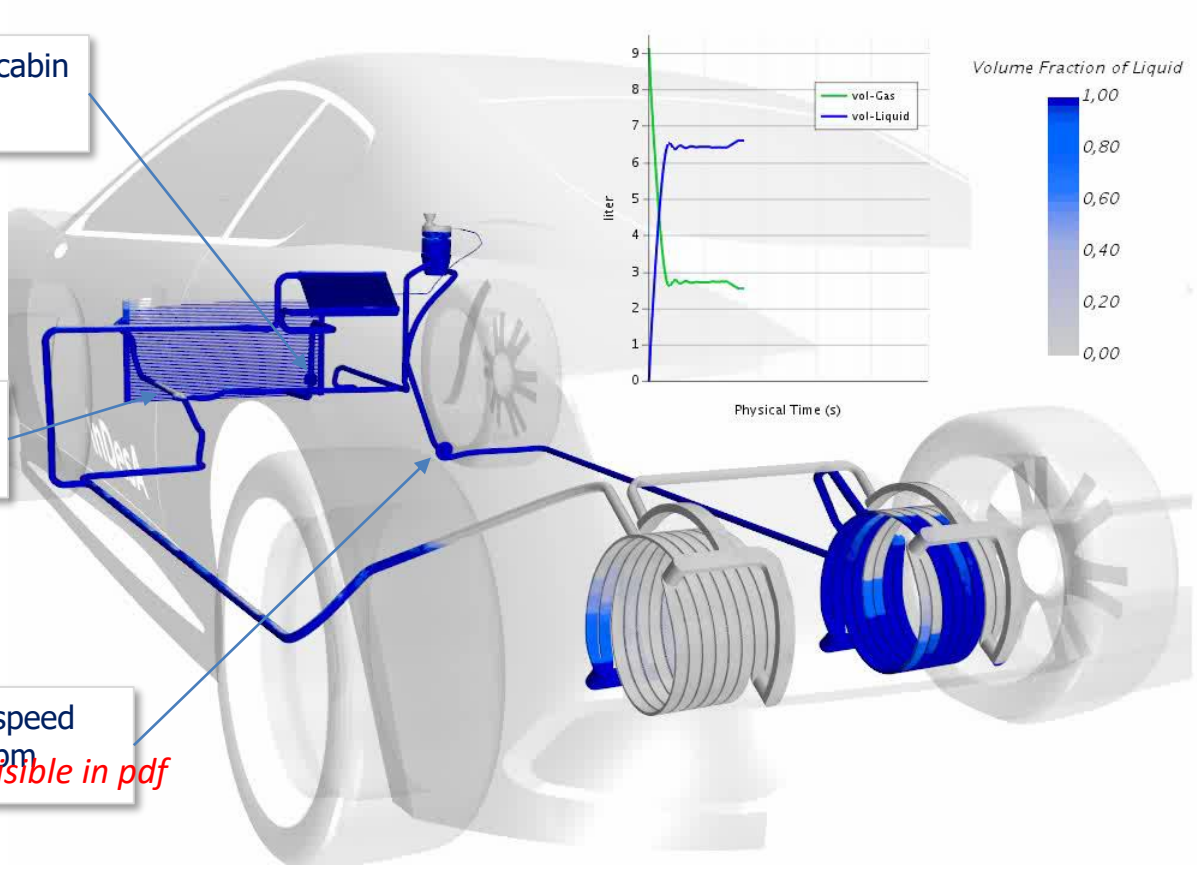
InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
E-Drive Coolant Circuit – Degas with Pumping

valve closed at cabin heater return

valve closed to radiator

pump speed 2500 rpm



degas through swirl tank below expansion tank

animation not visible in pdf

InDesA
INTEGRATED DESIGN ANALYSIS

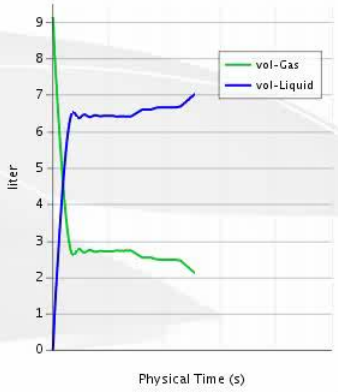
Thermal Design and Analysis of Electric Vehicles
E-Drive Coolant Circuit – Degas with Pump OFF

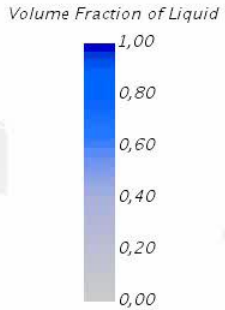
valve closed at cabin heater return

valve closed to radiator

pump speed 2500 rpm

animation not visible in pdf





degas through swirl tank below expansion tank

InDesA
INTEGRATED DESIGN ANALYSIS

Thermal Design and Analysis of Electric Vehicles
Summary and Conclusion

Simulation Methodology presented for
Thermal Design and Analysis of Battery Electric Vehicles

Demonstrator Vehicle Pandora VEV presented
to demonstrate simulation techniques
with refrigerant and coolant circuits as well as HV components.

STAR-CCM+ 3D CFD/CHT simulation application shown
for vehicle and various HV components to

- prove concepts and functions
- derive, optimize, and calibrate 1D objects for thermal system simulation

STAR-CCM+ 3D CFD Fill and Degas simulation presented
to validate functioning of coolant system.