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Holistic Energy Analysis of Various Drivetrain Topologies Close to Reality

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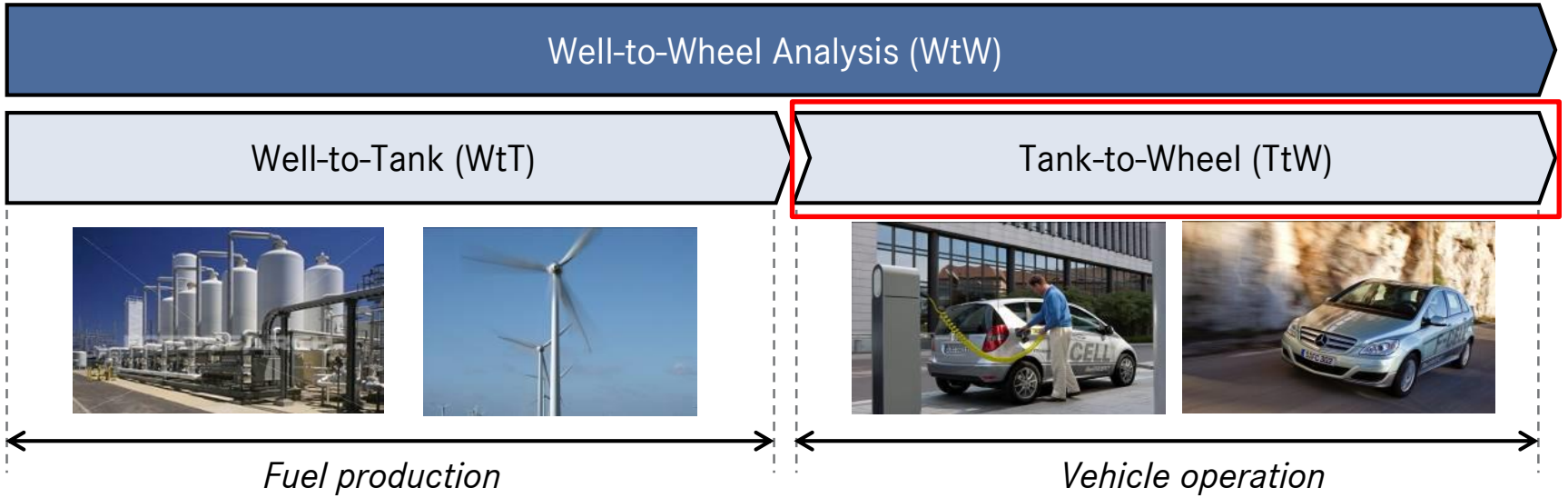
Agenda

1. What is a well-to-wheel analysis and why do we need realistic boundary conditions and user behaviour?
2. Methodology for the approach to represent realistic boundary conditions and user behaviour for a well-to-wheel analysis
3. Drivetrains modelled with GT-SUITE
   - Plug-In Hybrid Electric Vehicle (ICE-PHEV)
   - Range Extender Electric Vehicle (ICE-REEV)
4. Validation/Results of a previous FCEV simulation model
5. Analysis of power losses due to tire rolling resistance
6. Summary

Well-to-Wheel Analysis

A well-to-wheel analysis is the rating of energy consumption and greenhouse gas emissions arising on the path from the energy source to the wheel.



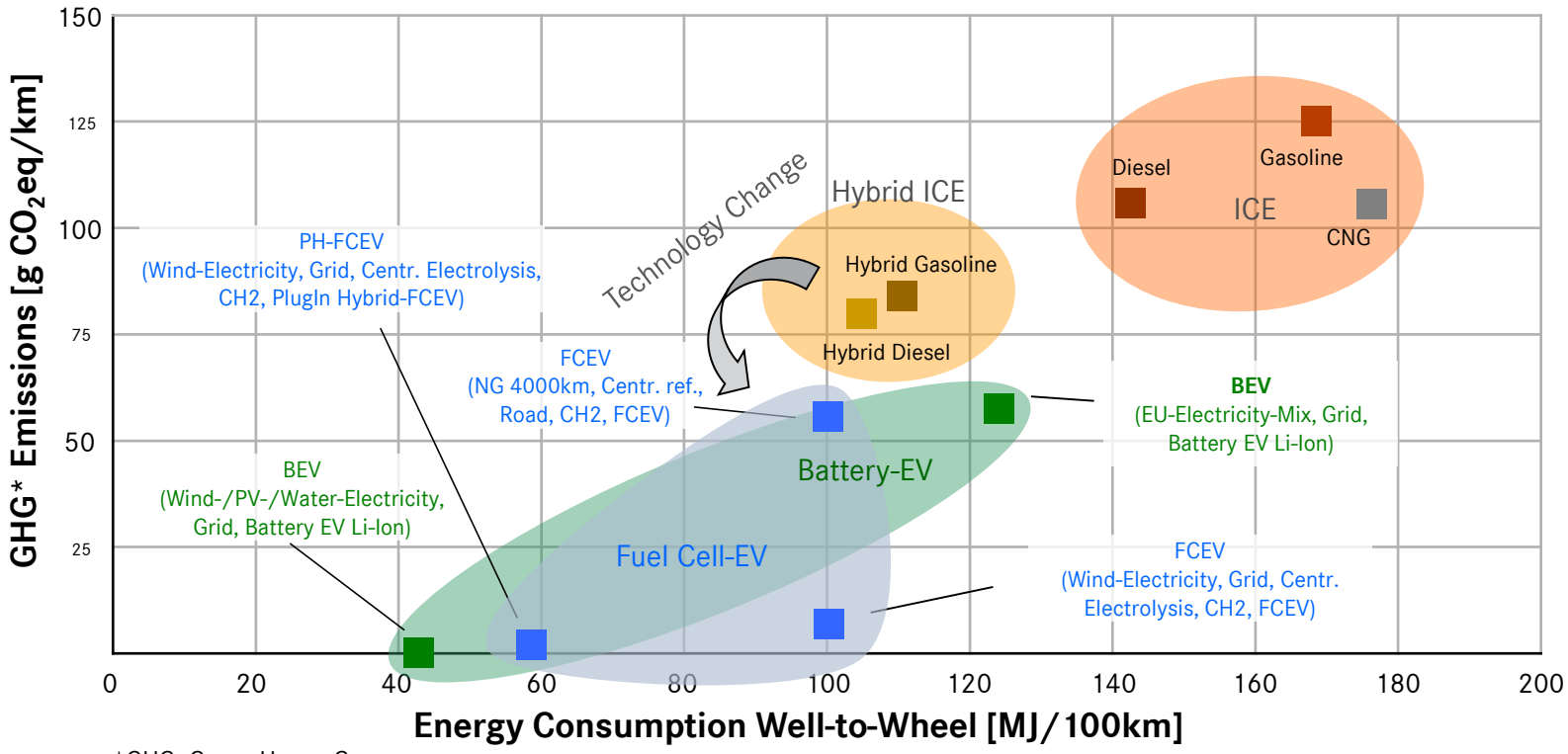
Evaluation criteria:

Energy consumption	Greenhouse gas emissions

WtW-Analysis: CO_2- and Energy comparison of EUCAR reference vehicles 2020+

Fuel Cell: High range (> 500 km), short refueling time (3 min), applicable for different vehicle concepts

Battery: Optimal operation in compact cars for the city traffic (200 - 250 km), recharging over night



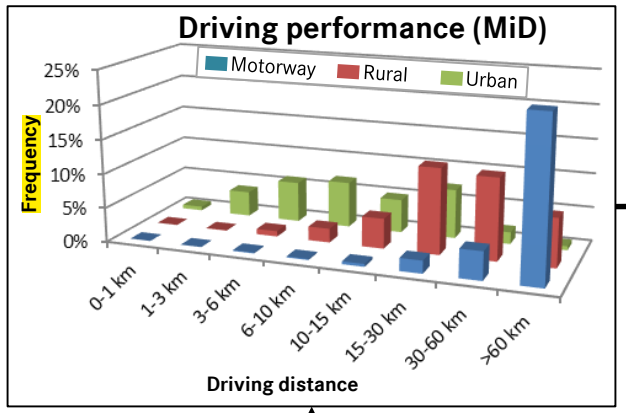
*GHG: Green House Gas

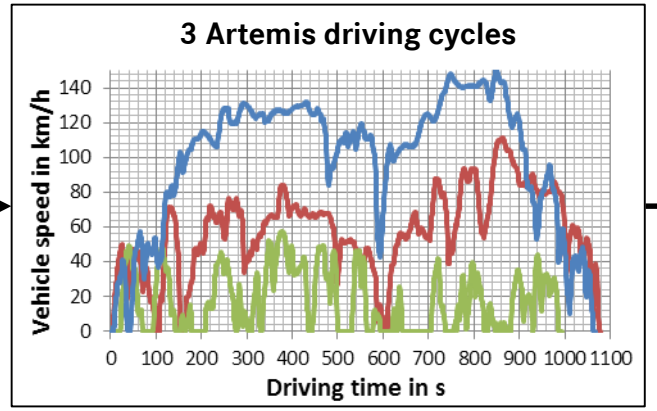
ICE = Internal combustion engine
BEV = Battery electric vehicle
FCV = Fuel cell vehicle
PHFCV = Plug-In hybrid fuel cell vehicle

Source:
JEC, Well-to-Wheel report (version 4), 2014

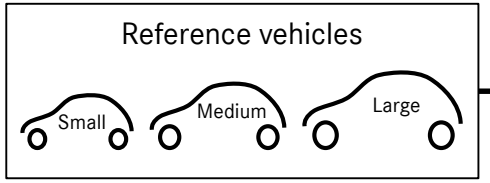
Electric drivetrains are a real step to reduce energy consumption and GHG-emissions. Using EVs means a significant step forward.

Methodology for the approach to represent realistic boundary conditions and user behaviour for a WtW-analysis

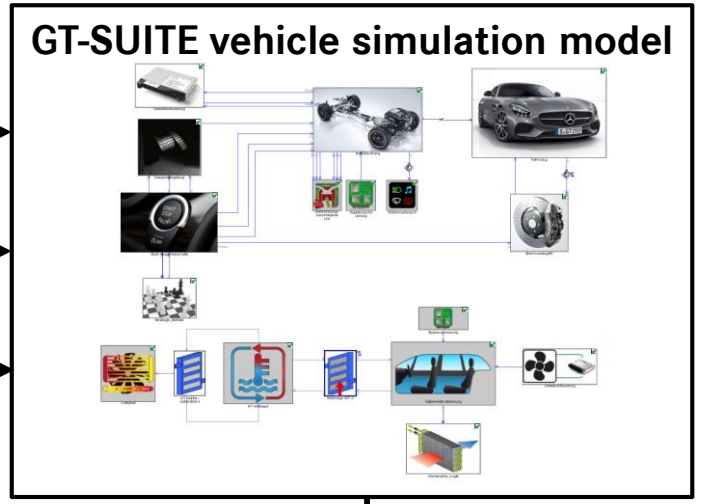




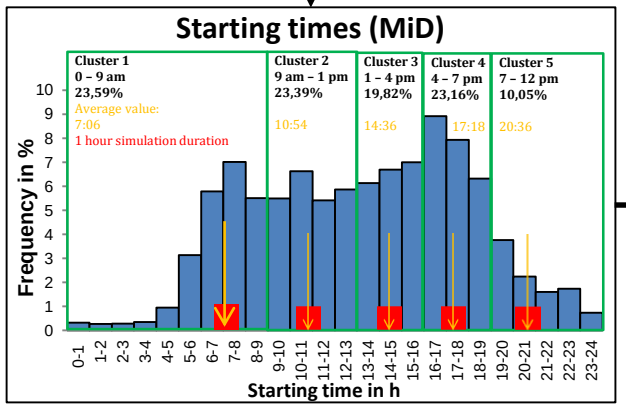
User behaviour
(Track-type, traffic flow, typical driver)

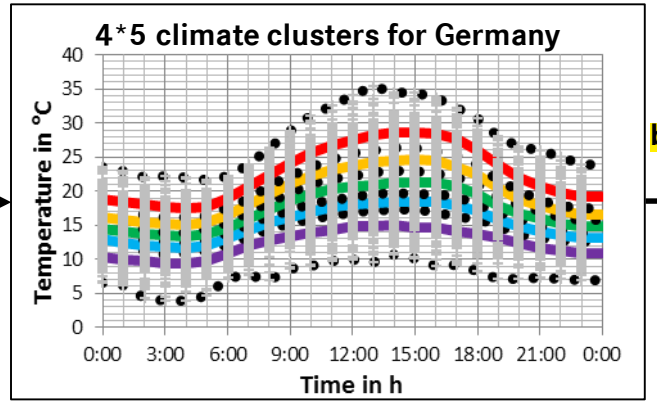


Reference vehicles
(small, medium, large)



Data of the study:
„Mobilität in Deutschland“ (MiD 2008)





Climate boundary conditions and **start conditions**

Evaluation by track type and track length

Specific daytime, track type and track length

Weighting factors of the study “Mobilität in Deutschland”

Results:
Realistic energy consumption of a **specific user**

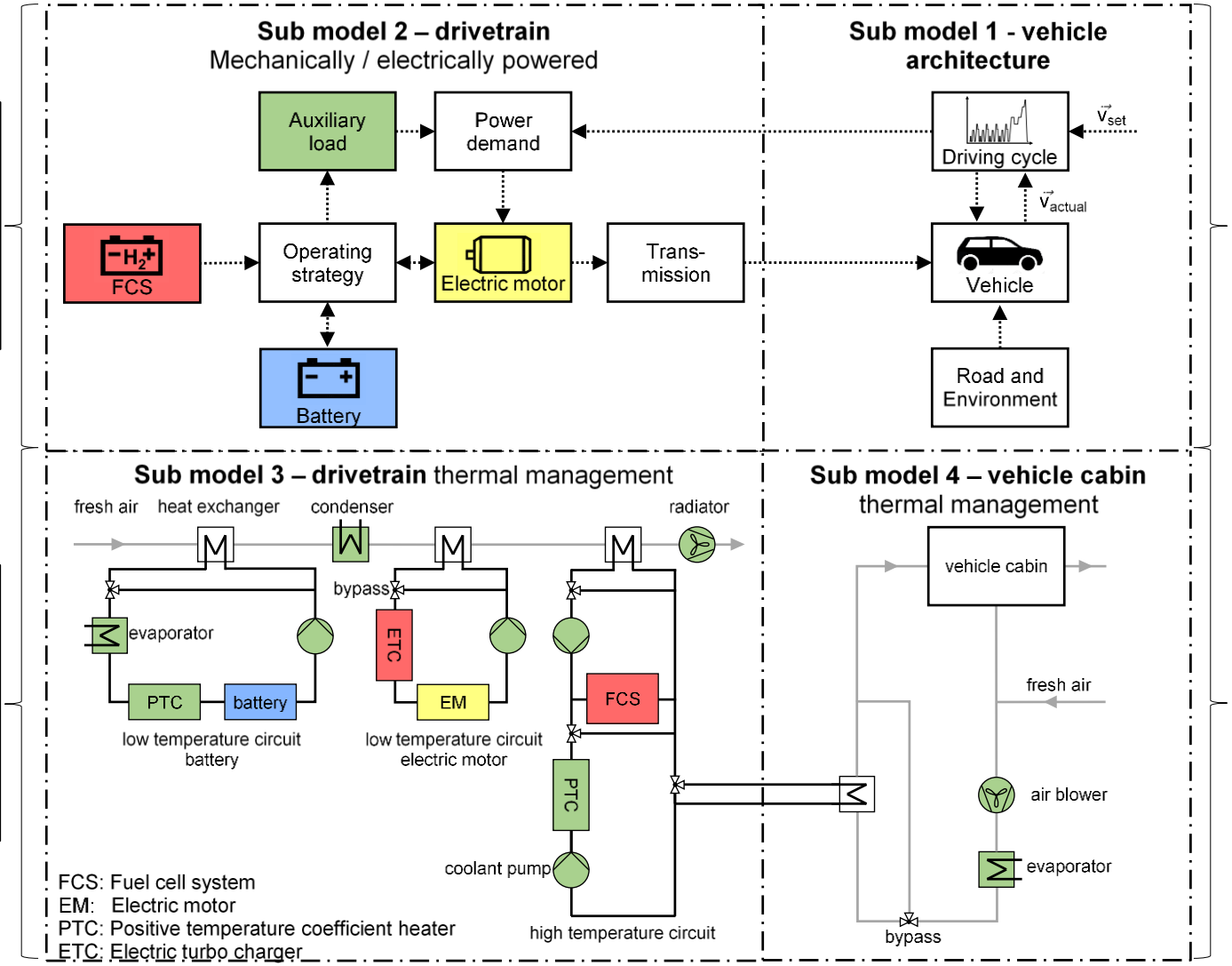
Results:
Realistic energy consumption for a **typical German driver**

Source: B. Hollweck, et. al., Energy analyses of fuel cell electric vehicles (FCEVs) under European weather conditions and various driving behaviours, 6th European PEFC and Electrolyser Forum, Luzern 2017

Methodology – Modular vehicle simulation with GT-SUITE

Drivetrain:
- **BEV**
- **FC-PHEV / FC-RE**
- **FCEV**
- **PHEV / REEV**
- **ICE gasoline**
- **ICE diesel**
- HEV

Thermal management:
- Drivetrain BEV
- Drivetrain ATS FCPHEV
- Drivetrain ATS FCEV
- Drivetrain ATS PHEV
- Drivetrain ATS HEV
- Drivetrain *ATS ICE gasoline*
- Drivetrain *ATS ICE diesel*



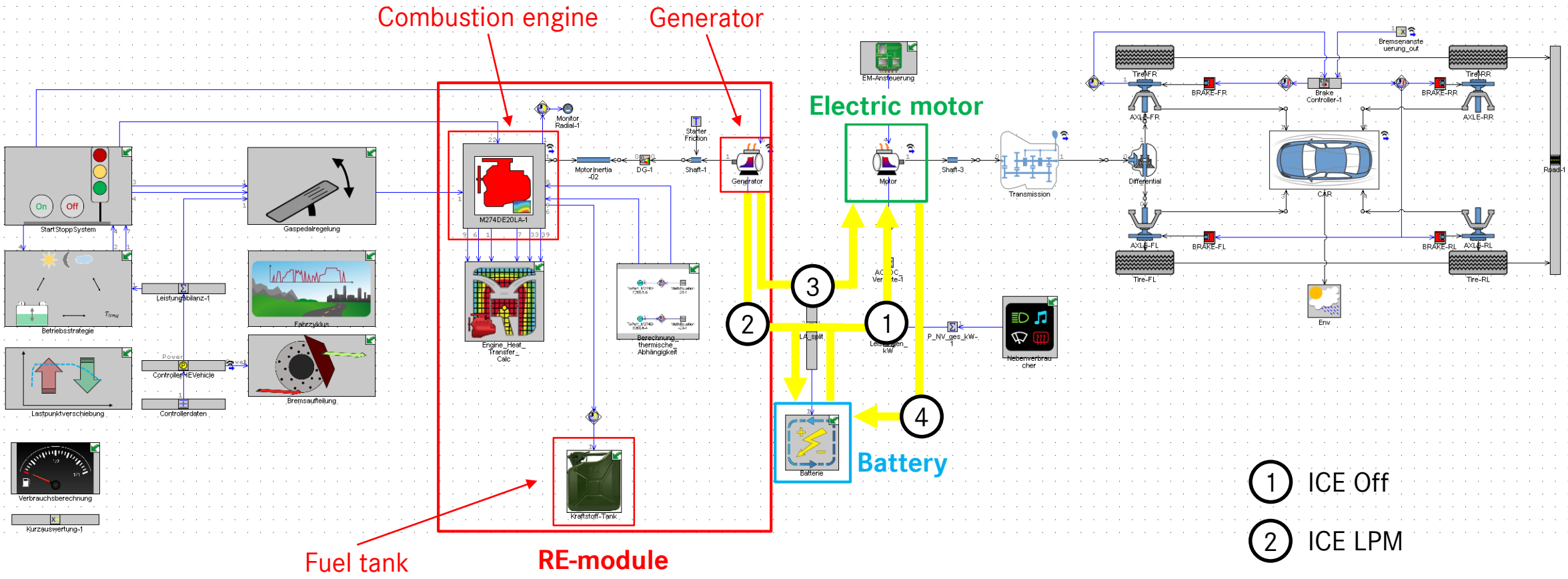
Vehicle architecture :
- Reference vehicle small
- Reference vehicle medium
- Reference vehicle large

- Driving cycle NEDC
- Driving cycle WLTP
- 3 x Driving cycles user behaviour

Vehicle cabin:
- Vehicle cabin small
- Vehicle cabin medium
- Vehicle cabin large

Source: B. Hollweck, et. al., Energy analyses of fuel cell electric vehicles (FCEVs) under European weather conditions and various driving behaviours, 6th European PEFC and Electrolyser Forum, Luzern 2017

Simulation model – ICE Range Extender Electric Vehicle (ICE-REEV)

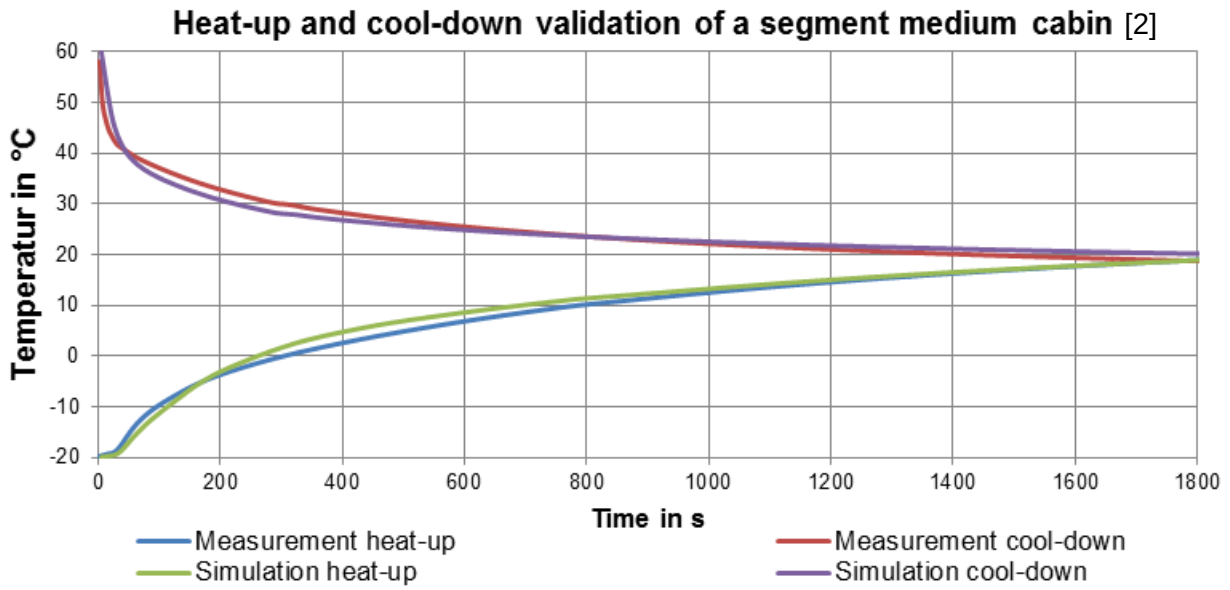


Validation/Results of a previous FCEV simulation model

NEDC Energy consumption:

Characteristic	**Original** NEDC energy consumption JEC FCEV 2010 [1]	**Simulated** NEDC energy consumption JEC FCEV 2010	**Original** NEDC energy consumption JEC FCEV 2020 [1]	**Simulated** NEDC energy consumption JEC FCEV 2020
H_2 consumption [$kgH_2/100km$]	0,624	0,634	0,448	0,434

Cabin heat-up and cool-down:



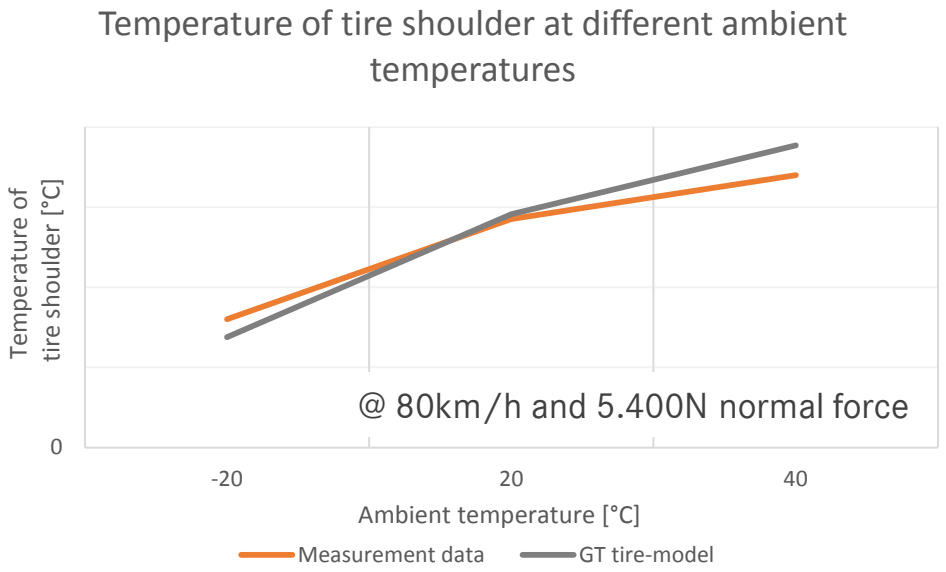
[1] HUSS, A., HASS, H., MAAS, H., TANK-TO-WHEELS Report Version 4.0, JRC Technical Reports, European Commission, 2013

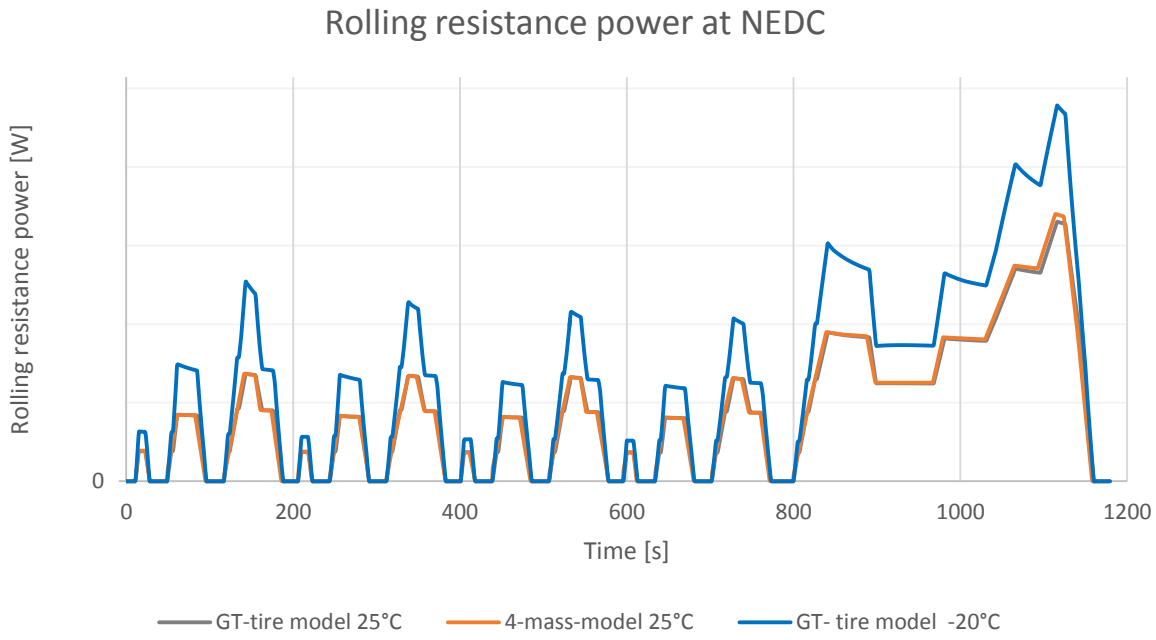
[2] Hollweck, B., Moullion, M., Christ, M., Kolls, G., Wind, J., Energy analyses of fuel cell electric vehicles (FCEVs) under European weather conditions and various driving behaviours, 6th European PEFC and Electrolyser Forum, Luzern 2017

Analysis of power losses due to tire rolling resistance

- Tire rolling resistance depends on the velocity and tire shoulder temperature
- Model was validated on stationary points and verified on a four-mass-model which was validated on stationary and transient measurements
- Model consists of two masses
- Model contains all basic thermal transfers and main geometries
- Model fits our needs best: short calculation time and good accuracy

Analysis of power losses due to tire rolling resistance





→ Difference of Rolling Resistance Factor due to different tire shoulder temperature is <5 % in the range from -20 to 40°C.

	4-mass-model at 25 °C	2-mass-GT-model at 25 °C	2-mass-GT-model at -20 °C
Total Energy for rolling resistance at NEDC	100%	99,9%	148,4%

Source: D. Schuring und S. J.F., „Transient Speed and Temperature Effects on Rolling Loss of Passanger Car Tires," SAE Technical Paper, Detroit, 1989.

Summary

- The approach of a Well-to-Wheel analysis was introduced and the need to compare different drivetrain topologies under realistic boundary conditions and user behaviour was explained.
- A methodology to represent realistic boundary conditions and user behaviour for a Well-to-Wheel Analysis was presented.
- The simulation models of a Plug-In Hybrid Electric Vehicle and a Range Extender Electric Vehicle were shown and explained.
- Validation for energy consumption during NEDC and cabin heat-up for a FC-BEV was shown
- Simulation model for power losses due to tire rolling resistance was explained and results compared

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Thank you for your attention!