Powertrain Simulation for Concept Evaluation, Range Estimation, and Calibration

Dr.-Ing. Christian Haupt
Stuttgart, 12 July 2023

AGENDA

ROAD LOGISTICS TRENDS

MAN'S POWERTRAIN SIMULATION ENVIRONMENT

- Basic functionalities
- Modular approach
- Application examples

DEEP DIVE INTO FUEL CELL SYSTEM DESIGN FOR TRUCKS

SUMMARY

ROAD LOGISTICS TRENDS

Reduce CO_2 emissions
→ Straight path to zero emission vehicles: BEV / Fuel Cell EV

Minimize **total cost of ownership**,
Increase **energy efficiency** and vehicle availability

Automated / autonomous commercial vehicles

Digitalization to simplify transport business

OUR GOAL: 50% BEV TRUCKS IN EU 2030

Series production ⟷ Development

2018	2019	2020	2024	2027
eTGM	eTGE 1.0	Lion‘s City E	eTruck	eTruck
# 60 (08/22)	# ~2050 (08/22)	# >1000 (08/22)		

Battery capacity	185 kWh	35,8 kWh	up to 640 kWh	up to 480 kWh	up to 700 kWh
Daily range	~300 km	~110-115 km	~315 km	~600-800 km	~1000 km

AGENDA

ROAD LOGISTICS TRENDS

MAN POWERTRAIN SIMULATION ENVIRONMENT

- Basic functionalities
- Modular approach
- Application examples

DEEP DIVE INTO FUEL CELL SYSTEM DESIGN FOR TRUCKS

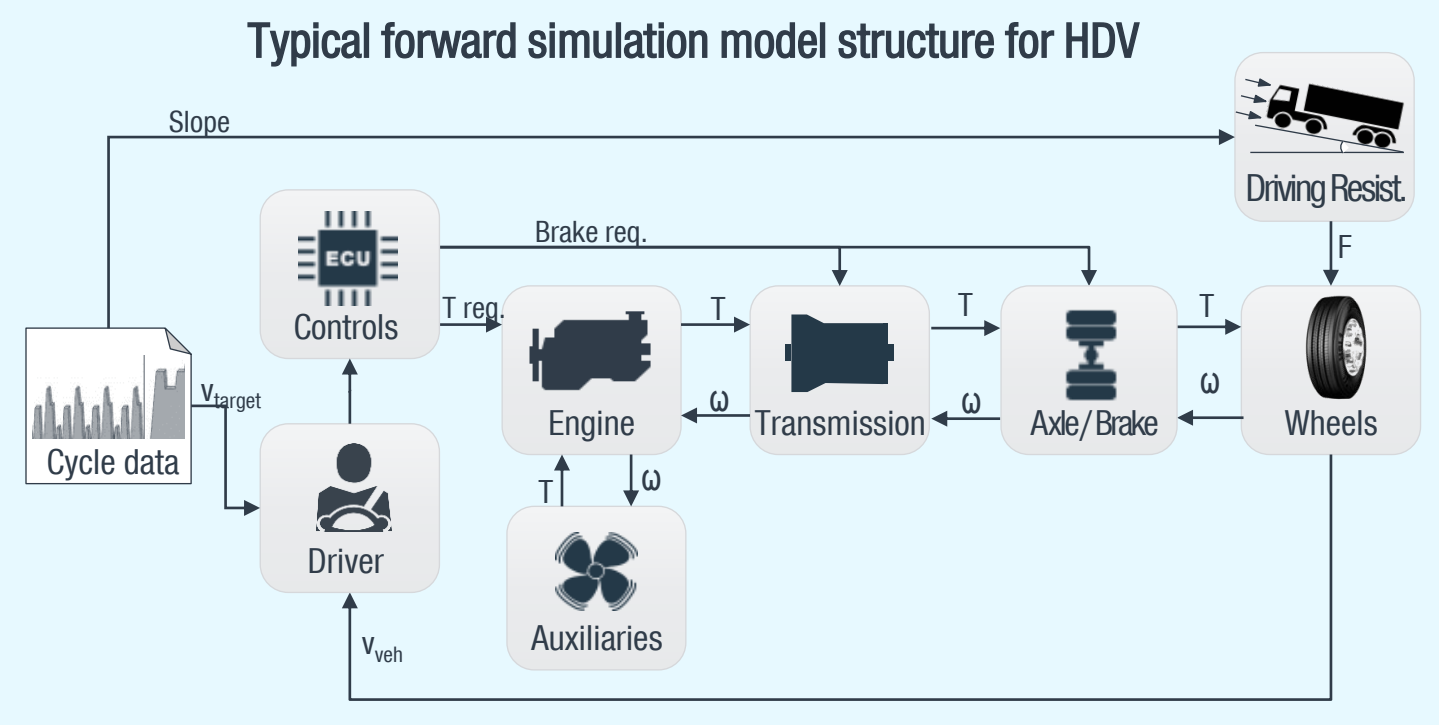
SUMMARY

POWERTRAIN SIMULATION @ MAN

- In house vehicle model **FASIMAN*** in MATLAB / Simulink started in early 2000

Main goals
- Energy efficiency / range
- Performance
- Energy management

Basic modeling principles
- Forward simulation
- Fixed step solver
- Physical component models
- Scripted and scalable process



* FASIMAN (abbr. Fahrsimulation mit modularen Antriebsstrang und Nebenaggregaten)

WIDE VEHICLE PORTFOLIO – VARIOUS DRIVETRAINS & USE CASES

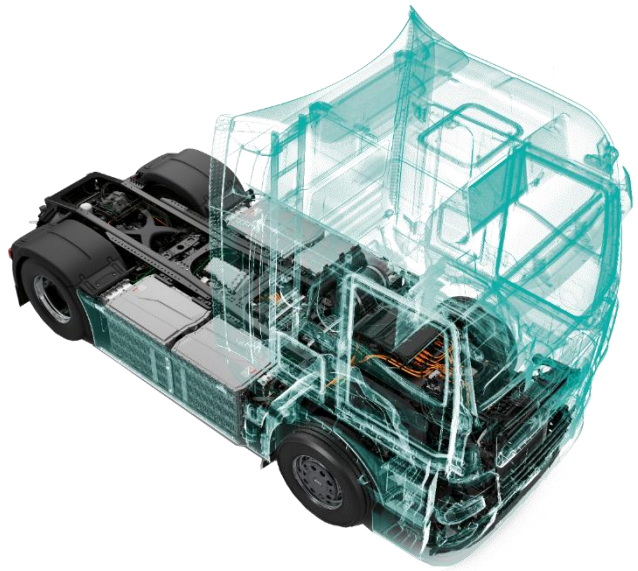
CENTRAL INFLUENCING FACTORS ON POWERTRAIN SIMULATION

Vehicle configuration / properties

Exterior / Aerodynamics	Chassis configuration	Propulsion system	Energy Storage	Transmission	Driven Axle	Auxiliaries	Control strategy / ECUs
• Truck / Bus • Body • Trailer • Cd x A • Curb weight	• No. of axles • No. of driven axles • Tires (size / rolling resist.)	• ICE • BEV • Fuel Cell	• Tank • Battery	• AT / AMT / MT • Transfer case • Power take off • Endurance brake	• Gear type • Axle ratio	• Air system • Steering • HVAC • Elec. system • Cooling system	• Energy management • Thermal management • Predictive functions

Vehicle usage / strategy

Mission / Environment	Driver
• Road profile • Speed profile • Payload • Amb. temp. • Wind flow	• Speed tolerances • Agressivity • Prediction



Many different powertrain topologies to be considered

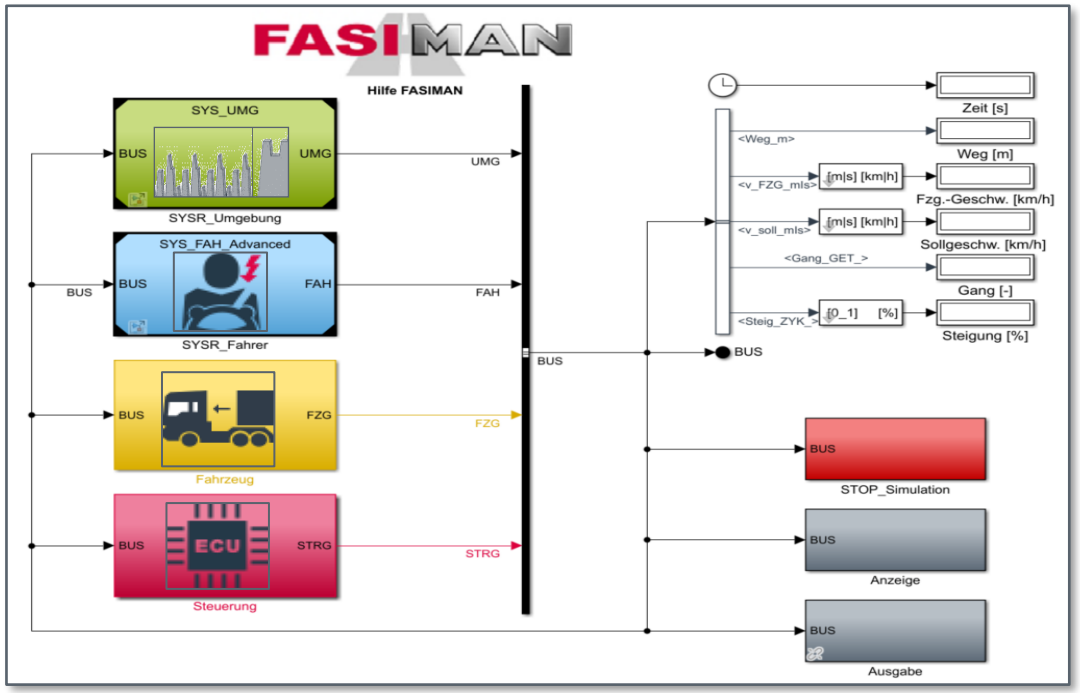
BASIC FEATURES OF FASIMAN

Flexible model structure

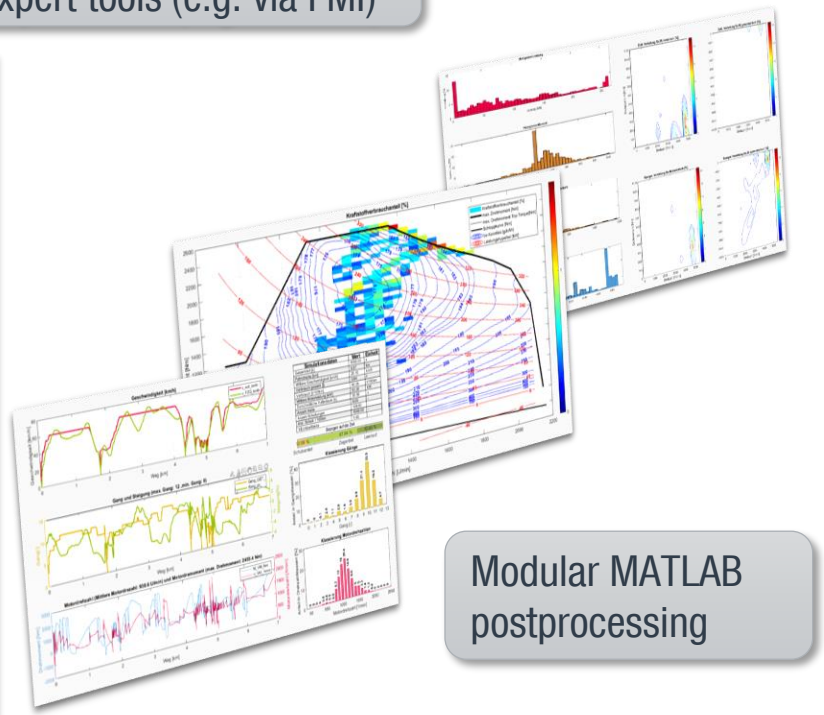
Interchangeable component models with different detail levels

Compatibility with other expert tools (e.g. via FMI)

Referenced models and subsystems



Model topology defined by vehicle type



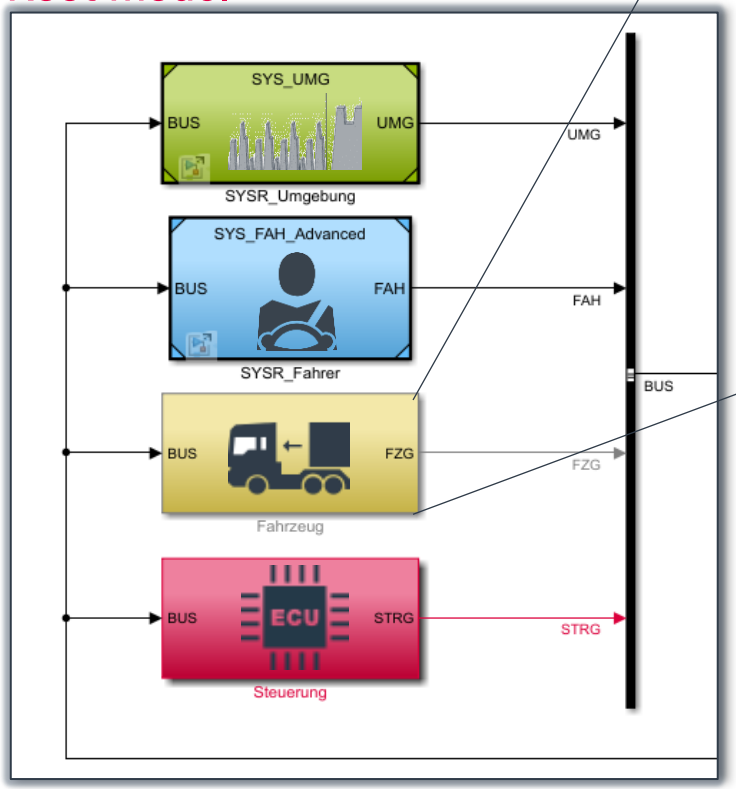
Modular MATLAB postprocessing

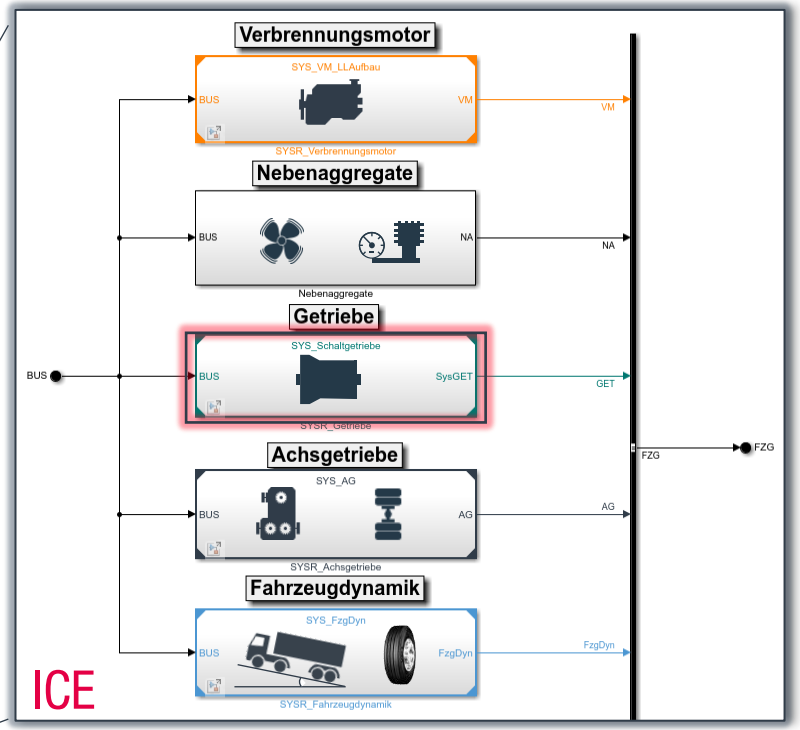
ECU integration

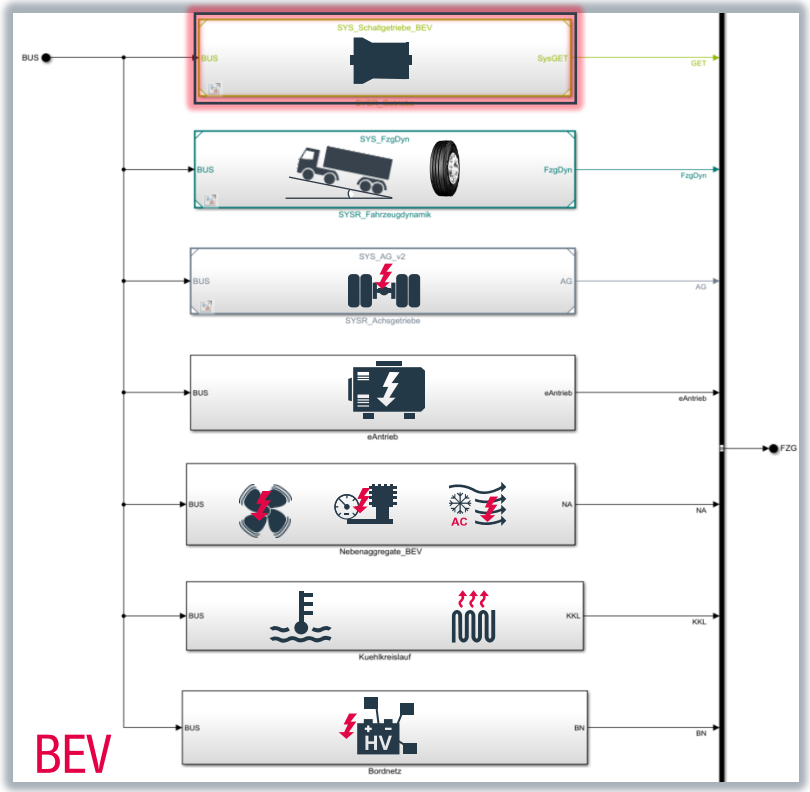
Central signal bus with bus elements

MODEL STRUCTURE

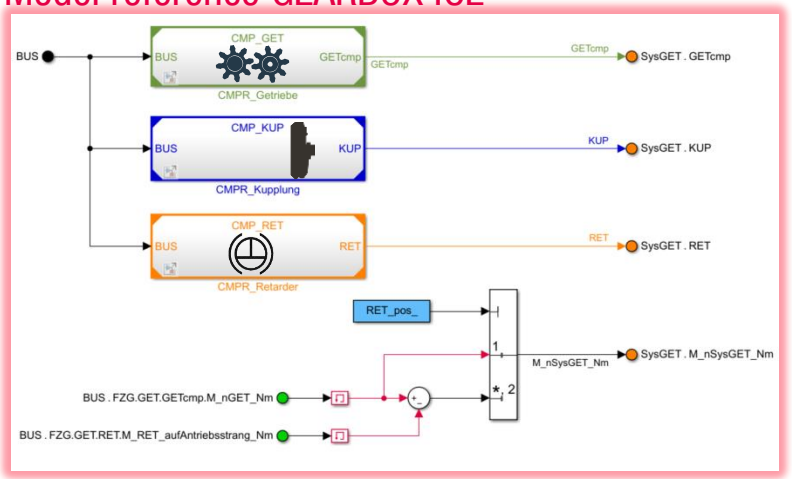
Root model



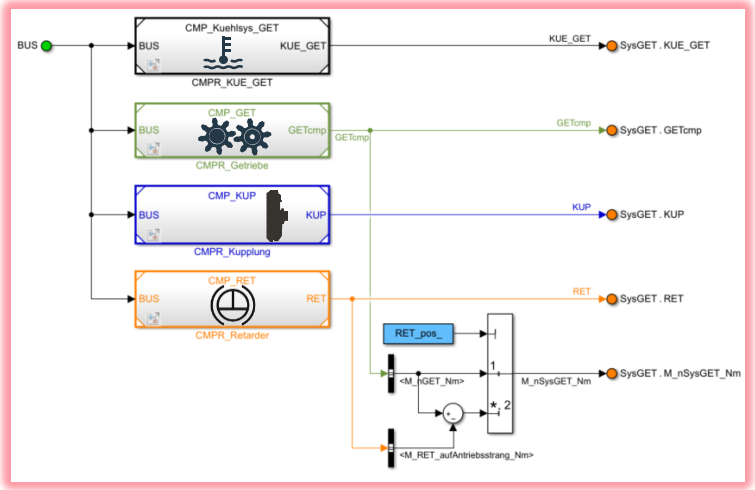




Model reference GEARBOX ICE



Model reference GEARBOX BEV



MAN POWERTRAIN SIMULATION ENVIRONMENT

Model Quality

SVN Revision management

Continuous Integration Server Jenkins

ECU model / function integration

eese

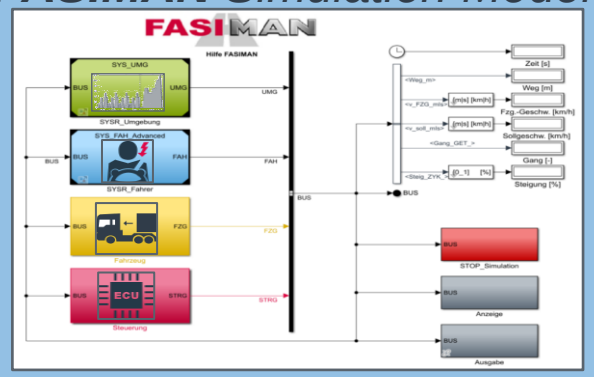
Drive Cycle Generation

here, VMC, Fraunhofer ITWM

Central Parameter Database

MAN Panda

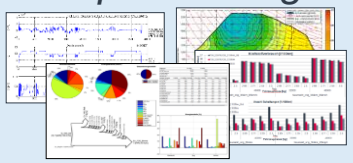
***FASIMAN** Simulation Model*



Model Interfaces

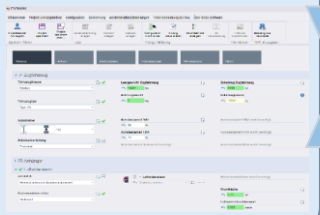
fmi Functional Mock-up Interface, S-Fcn

Modular Postprocessing



***FASIMAN4Sales** (Energy Consumption Bus - SORT)*

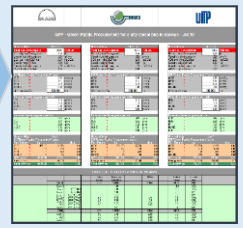
GUI-Configurator



Server Simulation

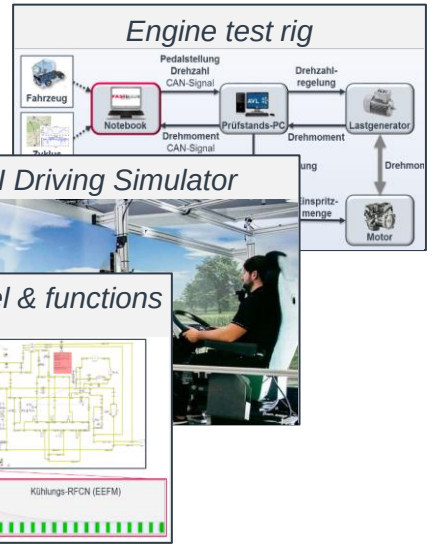
FASIMAN

Report Generator

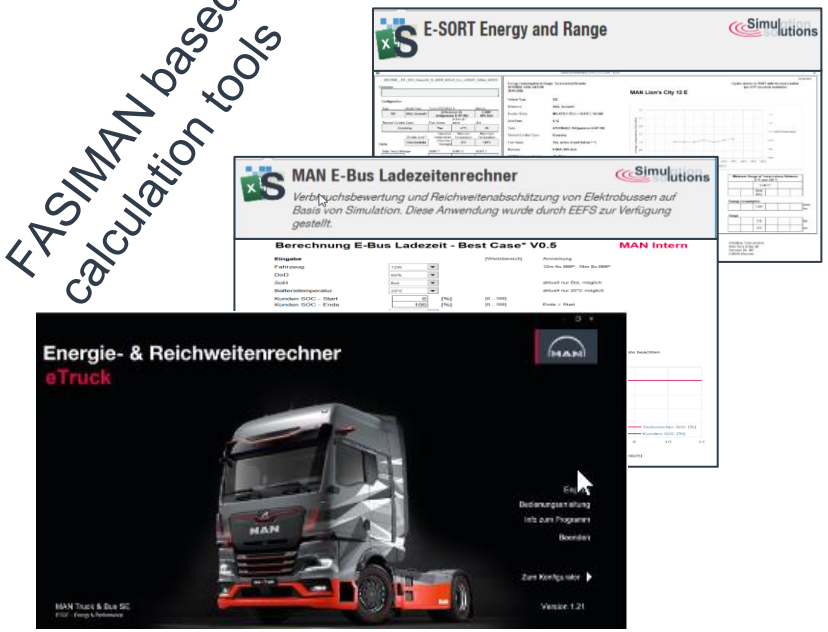


TÜV SÜD

FASIMAN Co-Simulation



FASIMAN based calculation tools



AGENDA

ROAD LOGISTICS TRENDS

MAN'S POWERTRAIN SIMULATION ENVIRONMENT

- Basic functionalities
- Modular approach
- Application examples

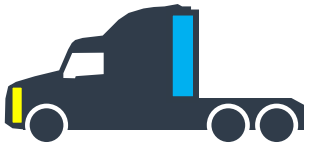
DEEP DIVE INTO FUEL CELL SYSTEM DESIGN FOR TRUCKS

SUMMARY

FUEL CELL LONG HAUL TRUCK - DESIGN SPACE AND USE CASES

Cooling system
Hydrogen tank





Cab concept	Cab over	Cab over	Behind engine
Wheel formula	4x2	6x2	6x4
H_2 tank tower	no	yes	yes
Cool. radiator pos.	front	front & tower	front
Control strategy	To be adapted according vehicle config, components, use case		


Fuel Cell*

component design space & dimensioning

e-axle**

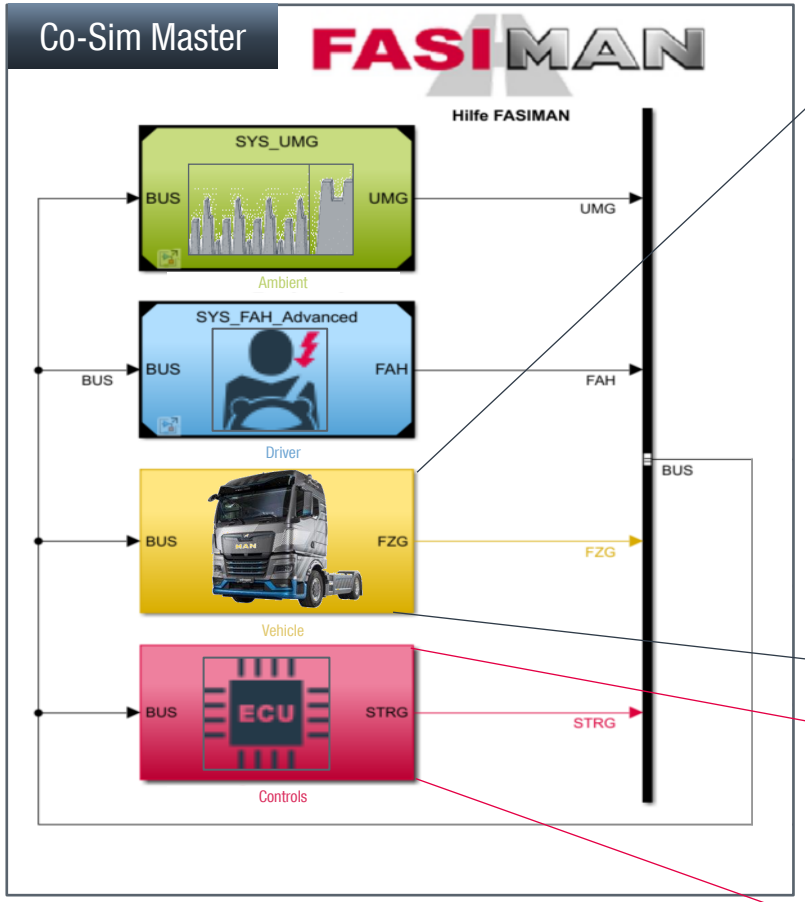

Brake resistor

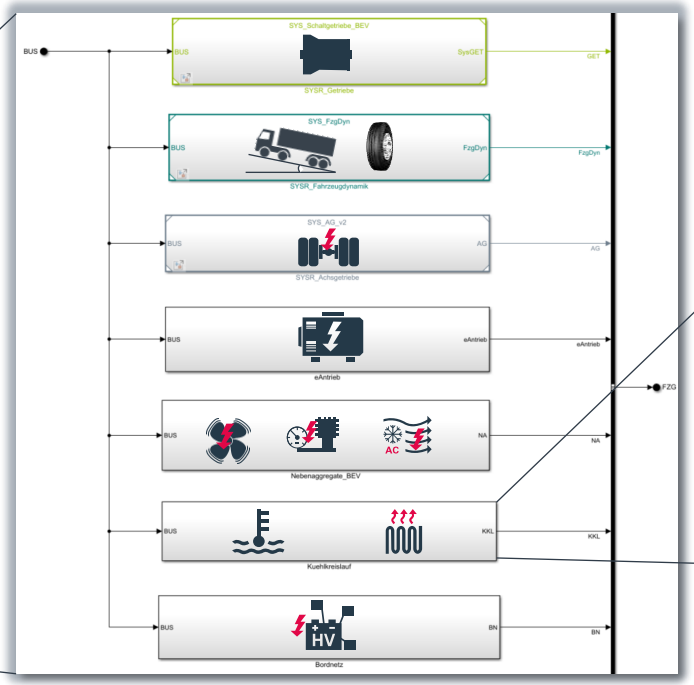

Boundary conditions

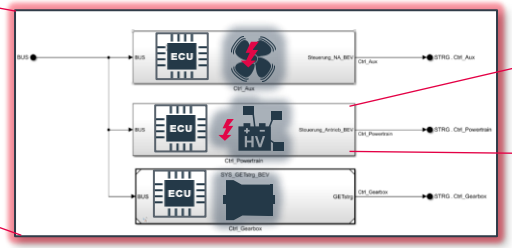
- Load profile: efficiency / performance evaluation
- Ambient temperature / pressure
- State of health fuel cell: begin / end of life

* https://www.bosch-presse.de/pressportal/de/en/fuel-cell-power-module-227991.htm
** https://www.zf.com/products/de/cv/products_75784.html

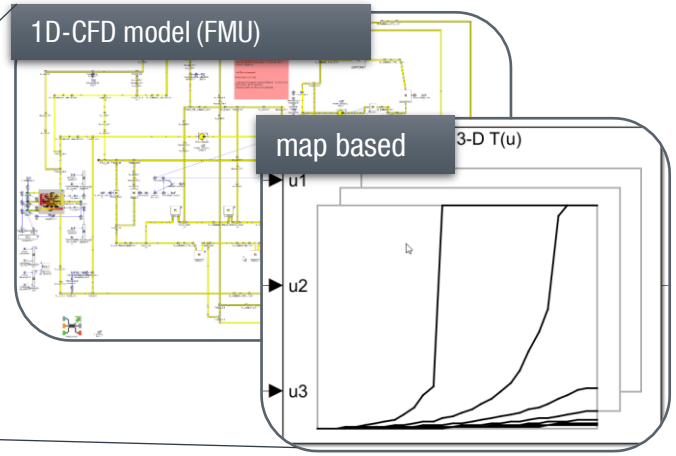
MODEL WITH FUEL CELL SPECIFIC KEY SUBSYSTEMS



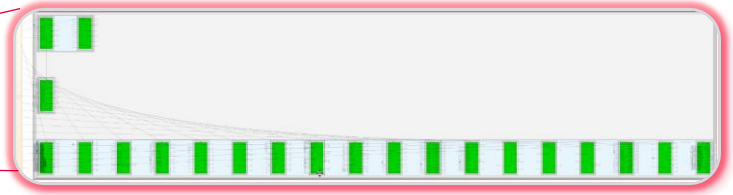




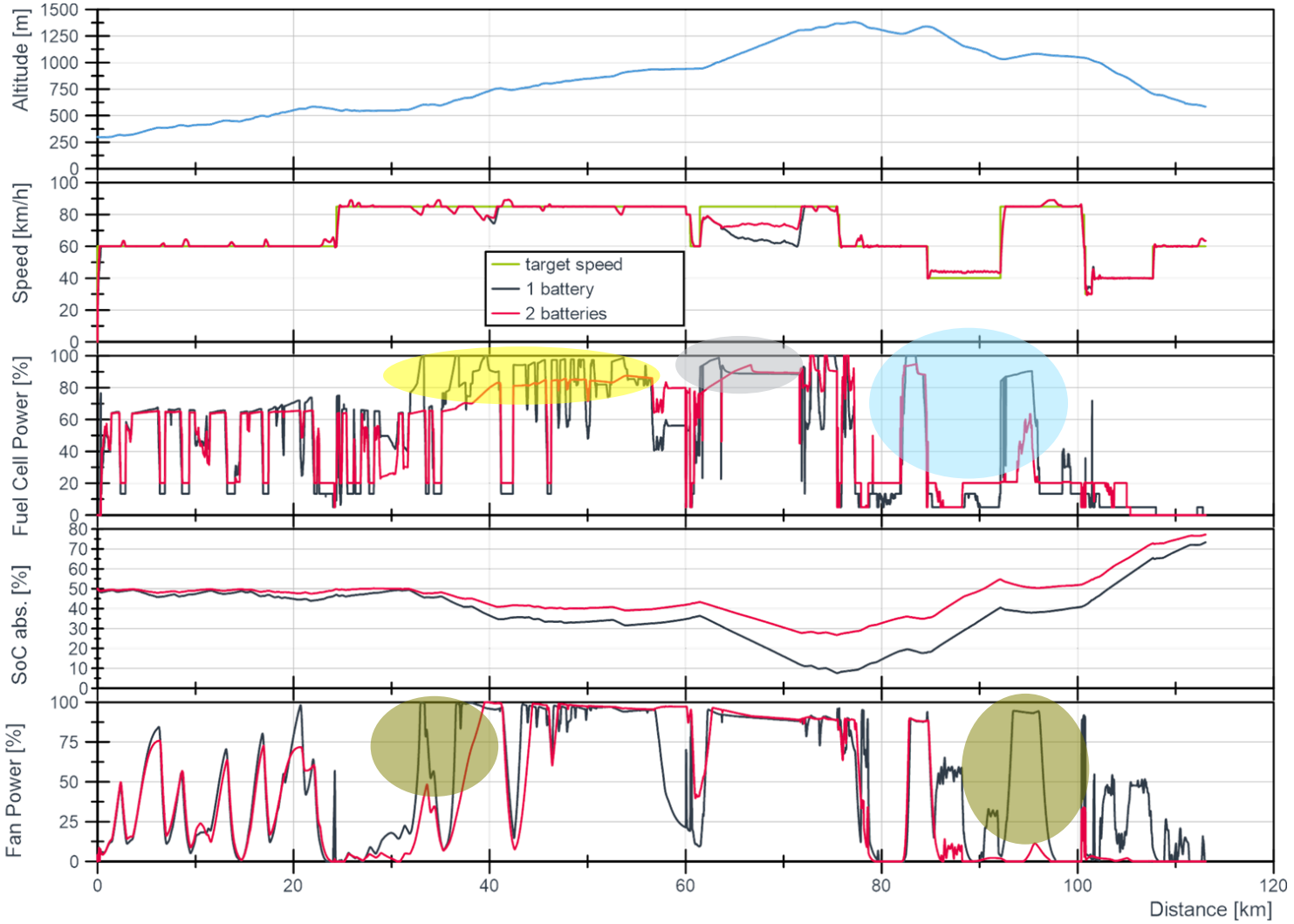
Different levels of detail
e.g. cooling system



ECU functions
e.g. energy management



SIMULATION RESULTS FC TRUCK – 1 VS. 2 BATTERIES



Performance Scenario

- Bozen – Innsbruck (Brenner)
- m_{veh} = 44 t, EoL, T_{amb} = 35 °C

Findings

- Limited cooling power leads to temperature derating of fuel cells
- 2 battery concept can compensate the limited FC-power to avoid low efficiency points in full load
- 2 battery concept reduces cooling fan-power
- Prediction can be used to increase performance and efficiency

AGENDA

ROAD LOGISTICS TRENDS

MAN'S POWERTRAIN SIMULATION ENVIRONMENT

- Basic functionalities
- Modular approach
- Application examples

DEEP DIVE INTO FUEL CELL SYSTEM DESIGN FOR TRUCKS

SUMMARY

MODELING CHALLENGES

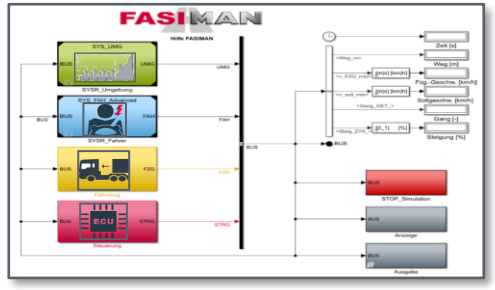
- Reduced performance with model references in Accelerator mode since R2019b compared to 2015b (long time for compilation and updating the referenced models)
  → Replace model references by subsystem references with standardized bus interfaces & bus elements

- Different root models for base vehicle types lead to high effort to maintain the model
  → combine all main topologies into one root model with subsystem references

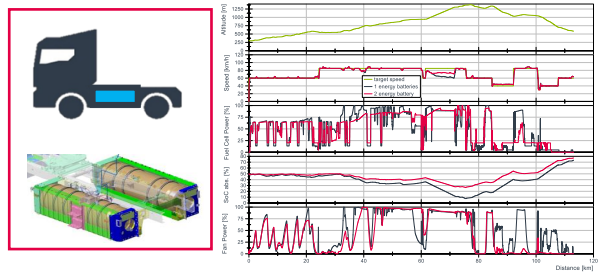
- Accelerator mode with complete Central Vehicle Manager (CVM) S-function is not running
  → Script to adapt the complex CVM data structure is prepared by MathWorks

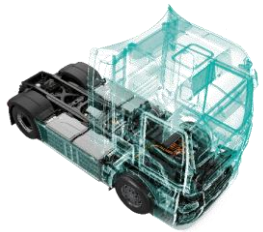
SUMMARY

Simulation plays an essential role to reach the zero emission goals



- FASIMAN offers modular model topology to cover the whole vehicle portfolio and future concepts
- Full vehicle simulation to derive component requirements for various powertrain configurations
- Future focus
  - Optimization of control strategy for complex vehicle layouts
  - Virtual testing and calibration of ECU functions





THANK YOU VERY MUCH FOR YOUR ATTENTION!

Dr.-Ing. Christian Haupt
MAN Truck & Bus