Design and Analysis of a Regio-Shuttle RS1 Diesel Railcar Converted to Fuel Cell Hybrid Propulsion

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DLR

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1. DLR Overview
2. Next Generation Train (NGT)
3. Motivation
4. Approach
5. Boundary Conditions
6. Simulation
7. Design FC-EMU
8. Operation & H_2 Infrastructure
9. Conclusion & outlook

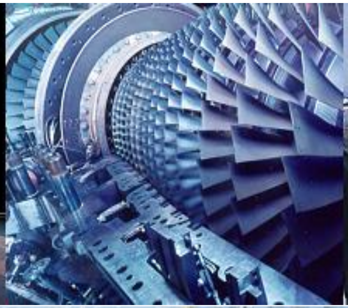
DLR Overview

- Exploration of the Earth and the solar system
- Research aimed at protecting the environment
- Development of environmentally-friendly technologies to promote mobility, communication and security

- Approx. 8,000 employees
- 33 research institutes and facilities
- 20 locations
- Branch offices in Brussels, Paris, Tokyo and Washington

AERONAUTICS	SPACE	ENERGY	Transport	SECURITY





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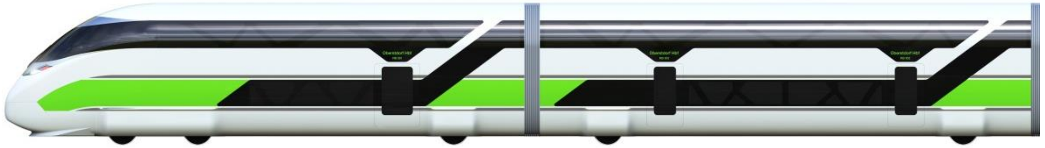
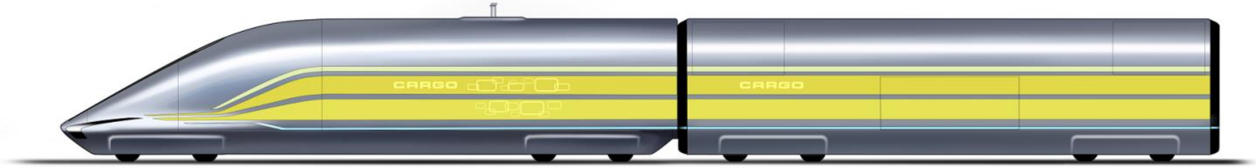
Next Generation Train (NGT)
Project overview

- Ultra-high – speed railcar passenger train (400 km/h)
  - NGT HST

- High – speed railcar passenger train (230 km/h)
  - NGT LINK



- Autonomous railcar freight train (400 km/h)
  - NGT CARGO



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Motivation
EU28: Line electrification and CO_2-emissions from railways

- 46% of railway lines were non electrified in 2012 [1]
- Service on these lines typically provided by diesel traction with significant CO_2-, NO_x and PM emissions
- Example SBB in 2017 [2] [3]:
  - Line electrification > 95%
  - Diesel energy consumption < 5%
  - **But** 35% of total CO_2-emissions
- Internal CO_2 - reduction target of UIC (baseline 1990) [4]:
  - by 2030: -50%
  - by 2050: -75%

- Alternative propulsion systems with zero emissions at point-of-use → Fuel Cell Hybrid propulsion system
  - Presented only as new built concepts (Alstom iLINT, Siemens Mireo announced for 2020)
  - Option → conversion design of existing railway vehicles

[1] International Union of Railways - UIC, “Rail Transport and Environment, Facts & Figures”, 2015
[2] http://www.sbb.ch/sbb-konzern/ueber-die-sbb/zahlen-und-fakten/umwelt/energieverbrauch.html
[3] http://www.sbb.ch/sbb-konzern/ueber-die-sbb/zahlen-und-fakten/umwelt/co2-emissionen.html
[4] International Union of Railways - UIC, “Railway Handbook 2015”, 2015

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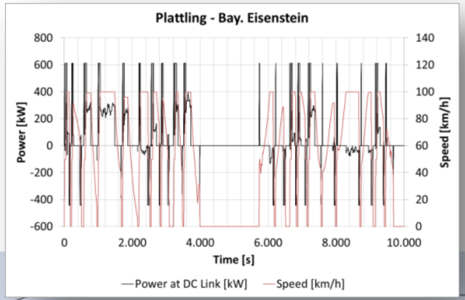
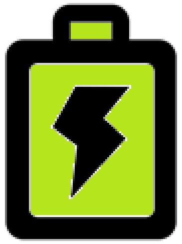
Approach

Way of proceeding





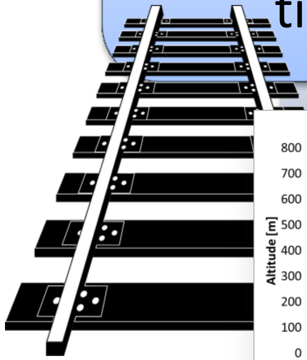
Boundary conditions

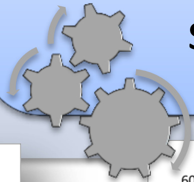
(vehicle, line, gradients, speed, timetable)

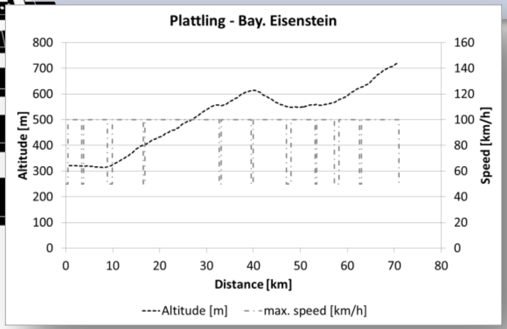
Simulation (longitudinal dynamic simulation, FC-Hybrid system)

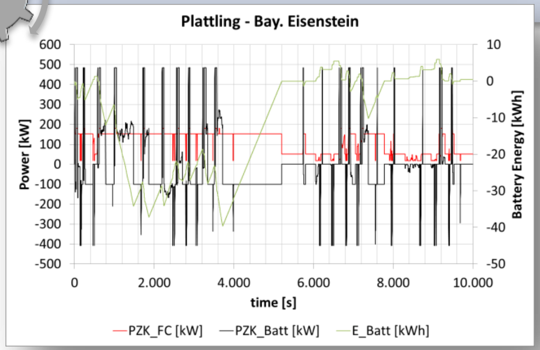
Design FC-EMU (components, packaging)

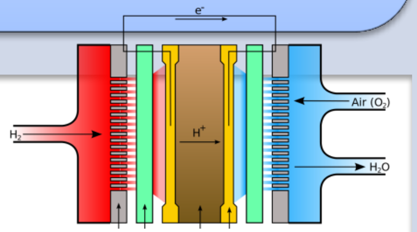
Infrastructure & Operation











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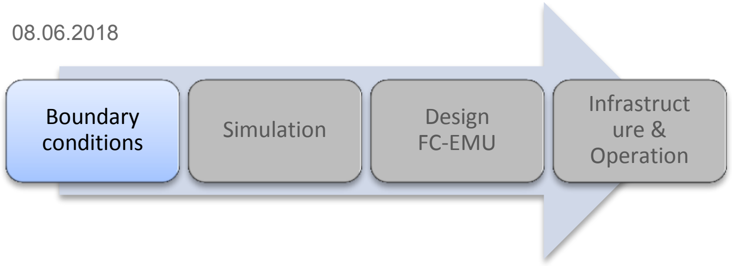

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6. Simulation
7. Design FC-EMU
8. Operation & H_2 Infrastructure
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Boundary conditions → Simulation → Design FC-EMU → Infrastructure & Operation

Boundary Conditions
Reference vehicle 1/2

Source: www.flickr.com

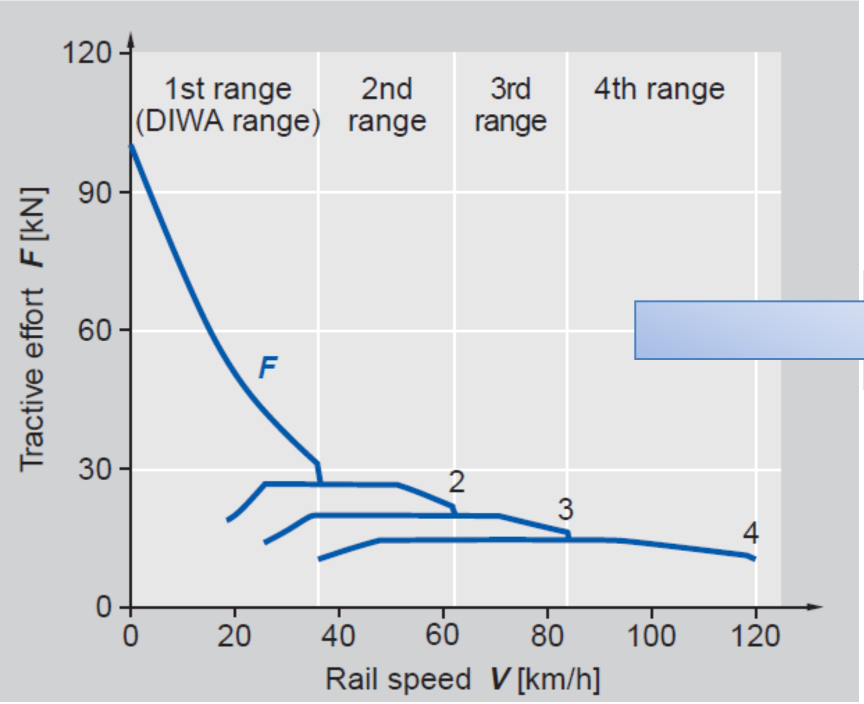
- Regional single-car DMU 650 ("Regio-Shuttle") with a fuel cell hybrid propulsion system as a case for simulation
- Following parameter set was used for the system design:

Parameter	Value
Mass (empty)	42 t
Mass (fully loaded)	56 t
Maximum passenger number	155
Nominal power	2 x 228 kW
Maximum speed	120 km/h
Starting acceleration	1,20 m/s²
Average acceleration up to 50 km/h	0,98 m/s²
Driving range	approx. 1.200 km

Boundary conditions | Simulation | Design FC-EMU | Infrastructure & Operation

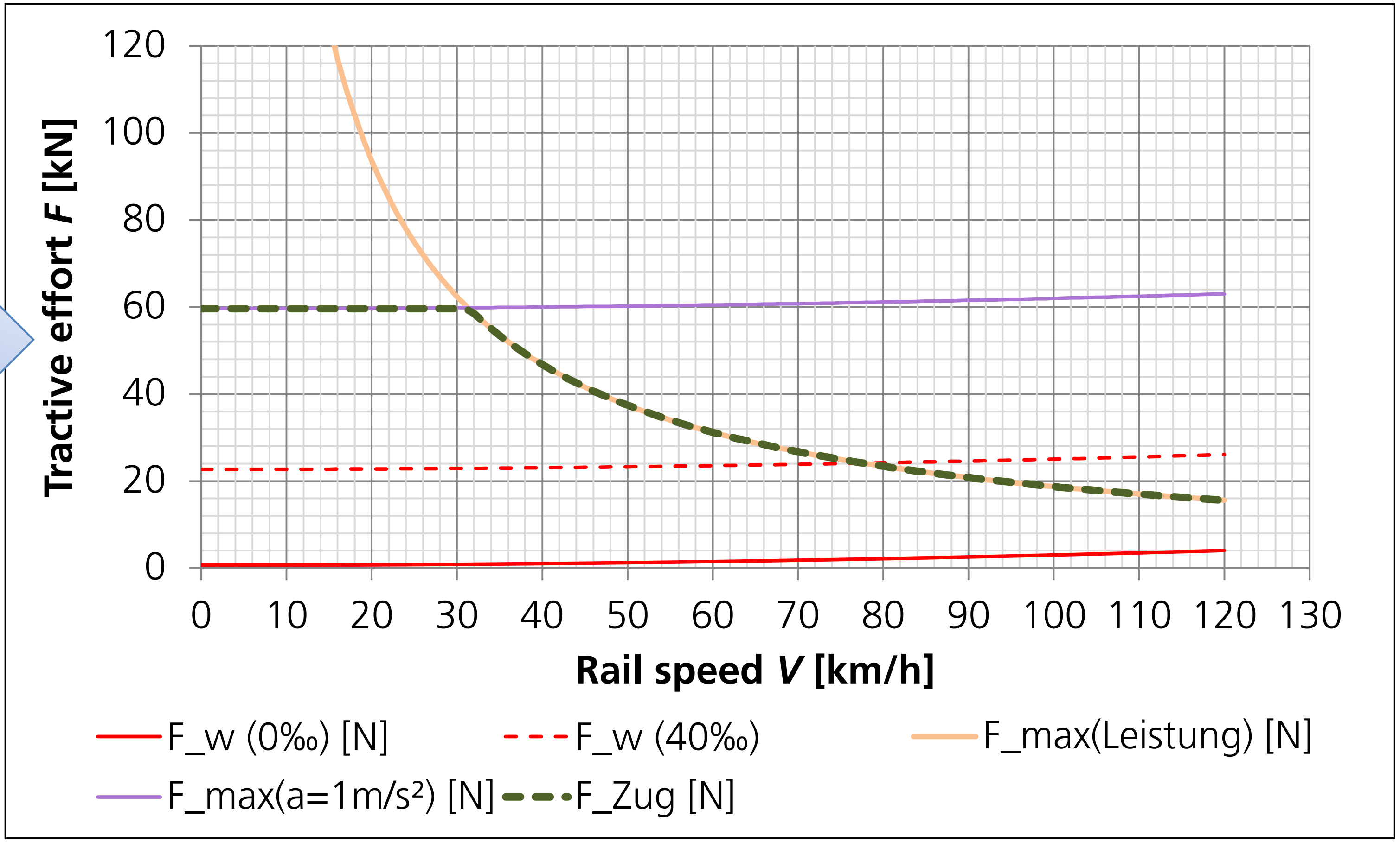
Boundary Conditions
Reference vehicle 2/2

Diesel traction



Source: Voith – Triebwagen Regio Shuttle RS1 mit DIWA-Getriebe D864, Umkehrgetriebe V863, G 1471 d 8/2004 1000 MSW/WF

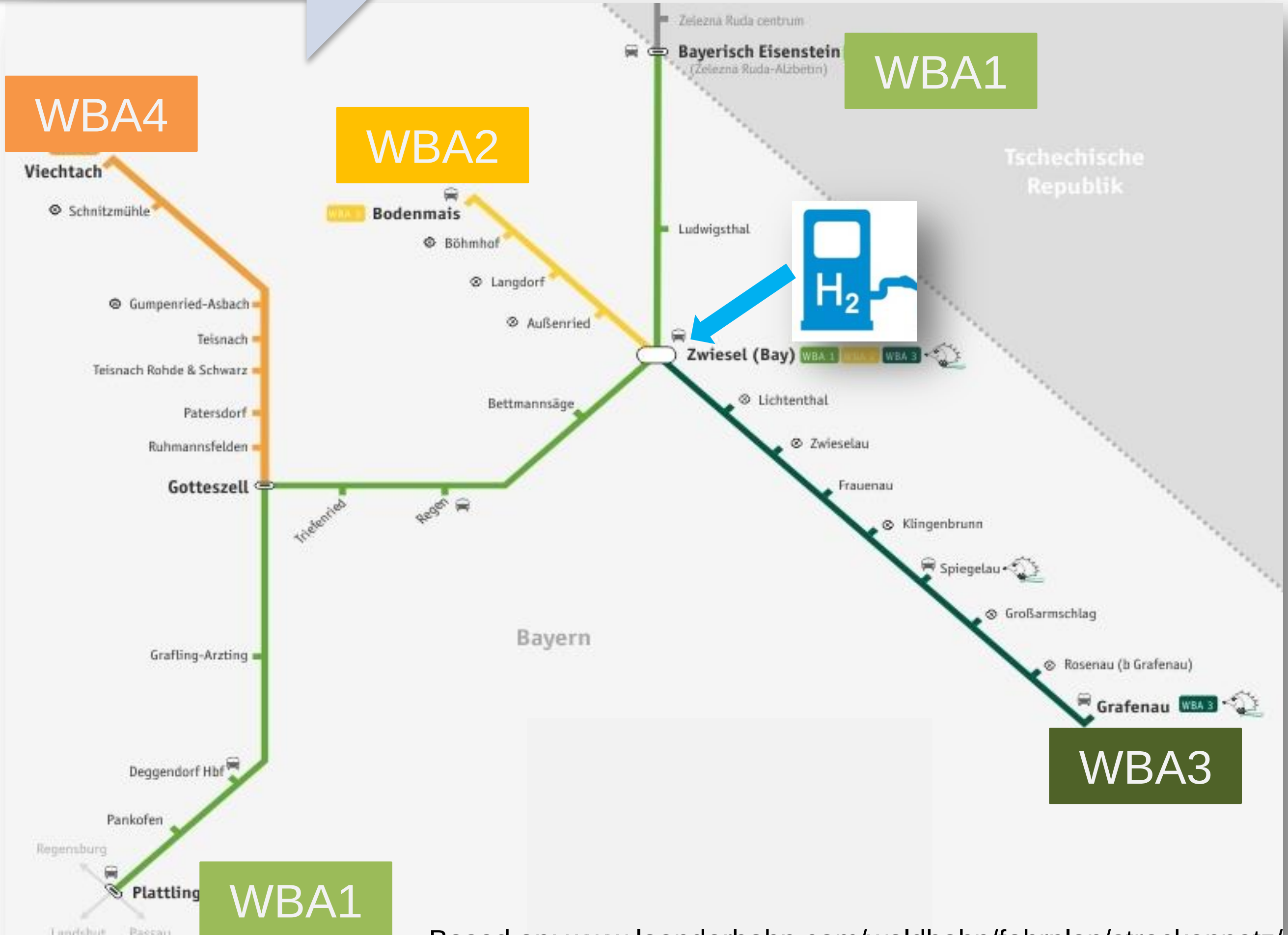
Electric traction



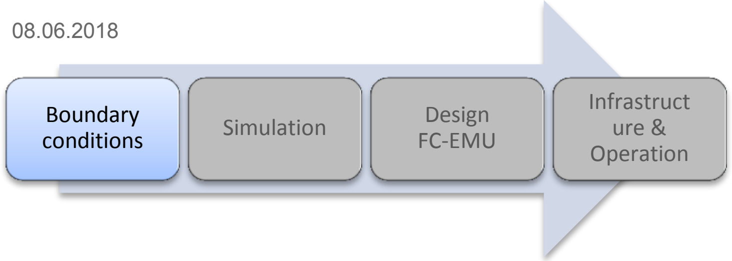
Boundary conditions → Simulation → Design FC-EMU → Infrastructure & Operation

Boundary Conditions
Rail Network

- 4 lines are operated
  - WBA1 – 71,5 km
  - WBA2 – 14,5 km
  - WBA3 – 31,5 km
  - WBA4 – 24,8 km
- At least 8 vehicles (V) are needed
  - 5 V for WBA1 and WBA2
  - 1 V for WBA3
  - 2 V for WBA4
    - Double and triple traction is not considered
    - V names in presentation: A, B, C, D, E, F, G, H
- Hydrogen refueling station in Zwiesel as a hub is recommended



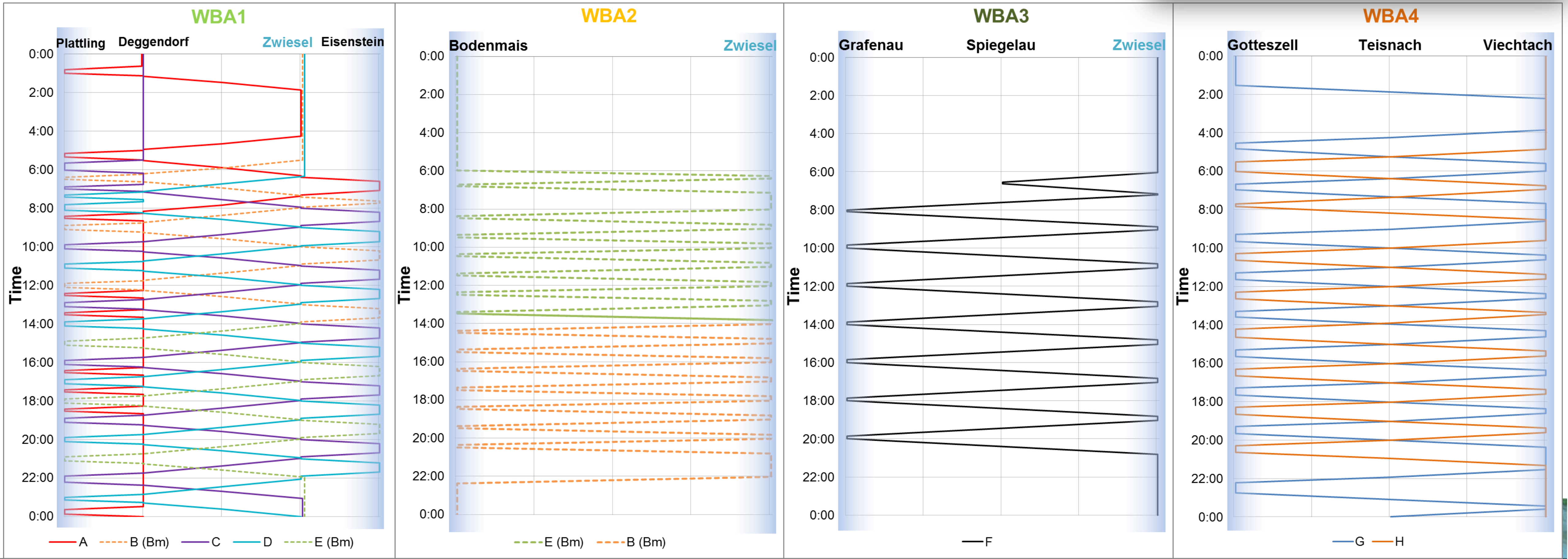
Based on: www.laenderbahn.com/waldbahn/fahrplan/streckennetz/

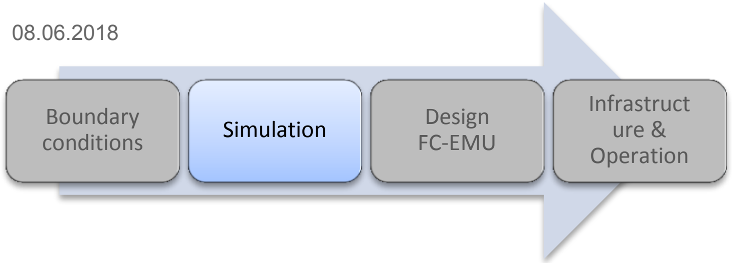


Boundary Conditions
Timetable

- Timetable derived from Waldbahn schedule

Based on: www.laenderbahn.com





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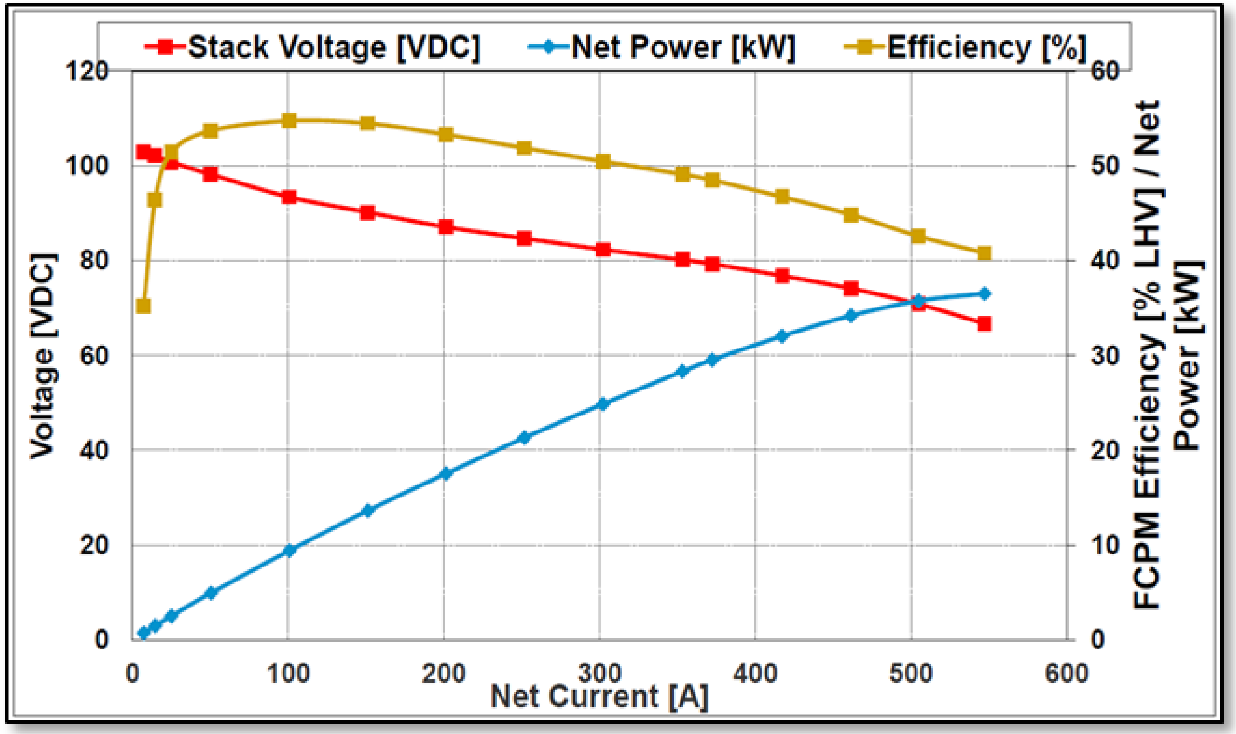
Boundary conditions | Simulation | Design FC-EMU | Infrastructure & Operation

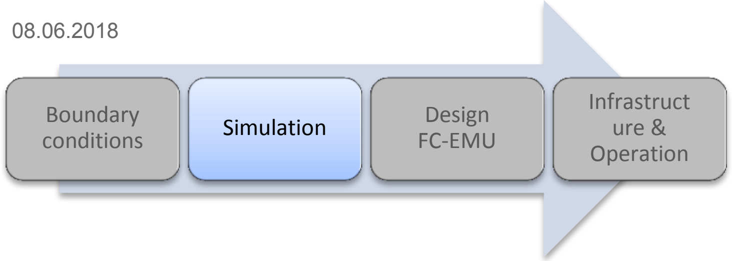
Simulation
Design Constraints

- Balanced battery state of charge at start and end position
- Auxiliary power = 52 kW (constant)
- H_2 consumption
  - based on Hydrogenics HD30 curve
  - Calculated regarding operation with 50% passenger volume
- Efficiency of Battery charge/discharge (incl. DC/DC-converter) = 0,94

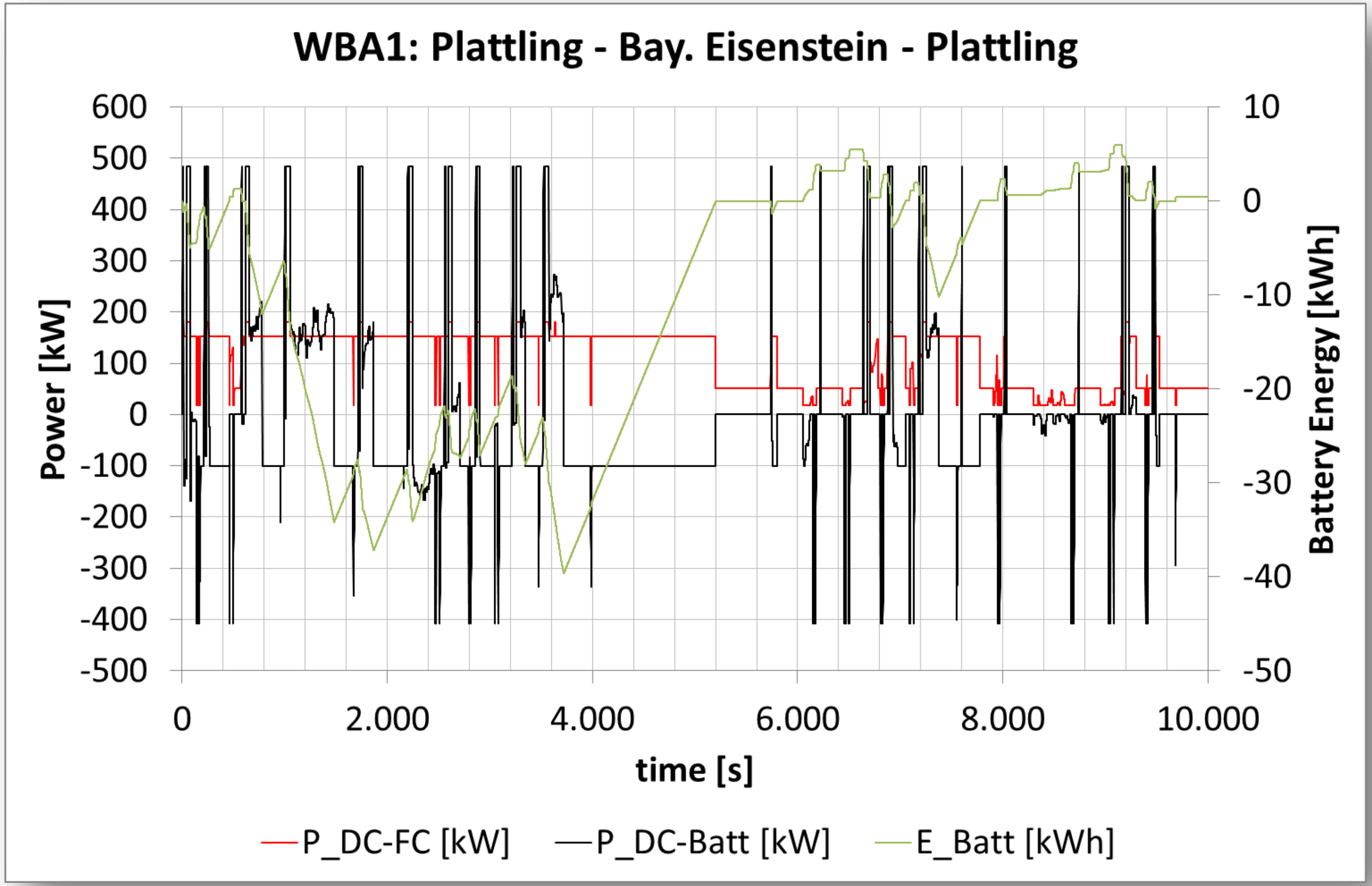
Hydrogenics HD30 Performance



Source: International Hydrail Conference, HyPM™ Fuel Cell Power Modules & Systems, Hydrogenics GmbH, 18.06.2014



Simulation
Example



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Boundary conditions → Simulation → Design FC-EMU → Infrastructure & Operation

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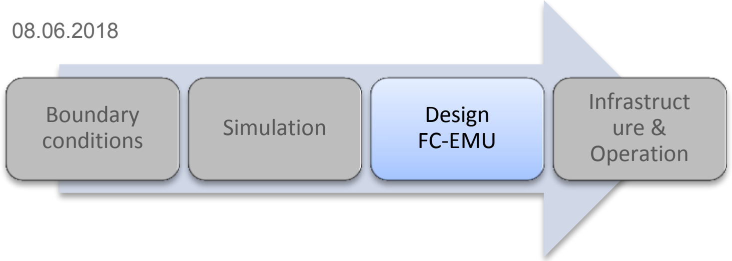


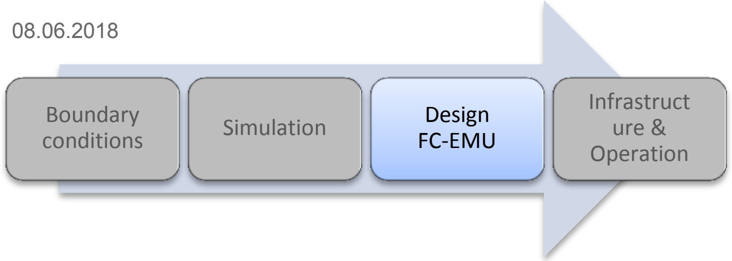
Design FC-EMU
Fuel Cell system

Fuel Cell

Statistics Fuel Cell	Vehicle							
	A	B	C	D	E	F	G	H
$P_{requiered}$ [kW]	178	**180**	179	179	179	102	98	98
H_2-consumption 50% load [kg/km]	**0,16**	0,15	0,15	0,14	0,15	**0,16**	0,15	0,15
H_2-consumption 100% load [kg/km]	0,17	0,16	0,16	0,15	0,16	0,17	0,17	0,17

Source: www.hydrogenics.com

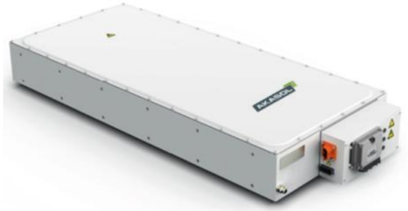
➔ P_{FC} (7 x HD30) = 210 kW



Design FC-EMU
Battery system

Battery

Statistics Battery	Vehicle							
	A	B	C	D	E	F	G	H
$P_{chg,max}{}^1$ [kW]	**627**	**627**	**627**	**627**	**627**	**627**	**627**	**627**
$P_{dchg,max}{}^1$ [kW]	607	**664**	612	594	598	597	599	599
$P_{RMS}{}^1$ [kW]	199	**201**	197	197	197	161	147	147
$E_{Batt,use}{}^2$ [kWh]	**46**	**46**	**46**	**46**	**46**	30	12	12
$E_{Batt,throughput,day}{}^2$ [kWh]	755	1.310	1.626	**1.686**	1.246	937	812	650

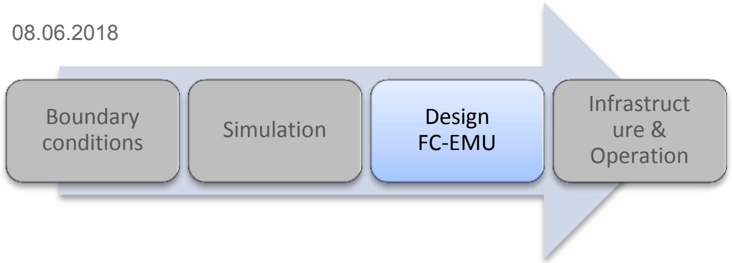


Source: www.Akasol.com

➔ 4 x Akasol AKM 18M NANO (12s1p)

U = 583 – 907 V
E = 4 x 36,8 kWh = 147,2 kWh
P_{chg}(10s) = 4 x 184 kW = 736 kW
P_{dchg}(10s) = 4 x 487 = 1.948 kW
P_{RMS} = 4 x 92 kW = 368 kW

[1] 100% payload
[2] 50% payload



Design FC-EMU
Packaging concept

- As many H_2 tanks on available roof area as possible
- H_2 capacity @ 95% extraction rate = 157 kg
- Worst case demand at 100% load = 128 kg

→Sufficient energy on board for daily operation

→Approx. 1,100 kg heavier than DMU

→ Battery (Akasol 18M Nano)

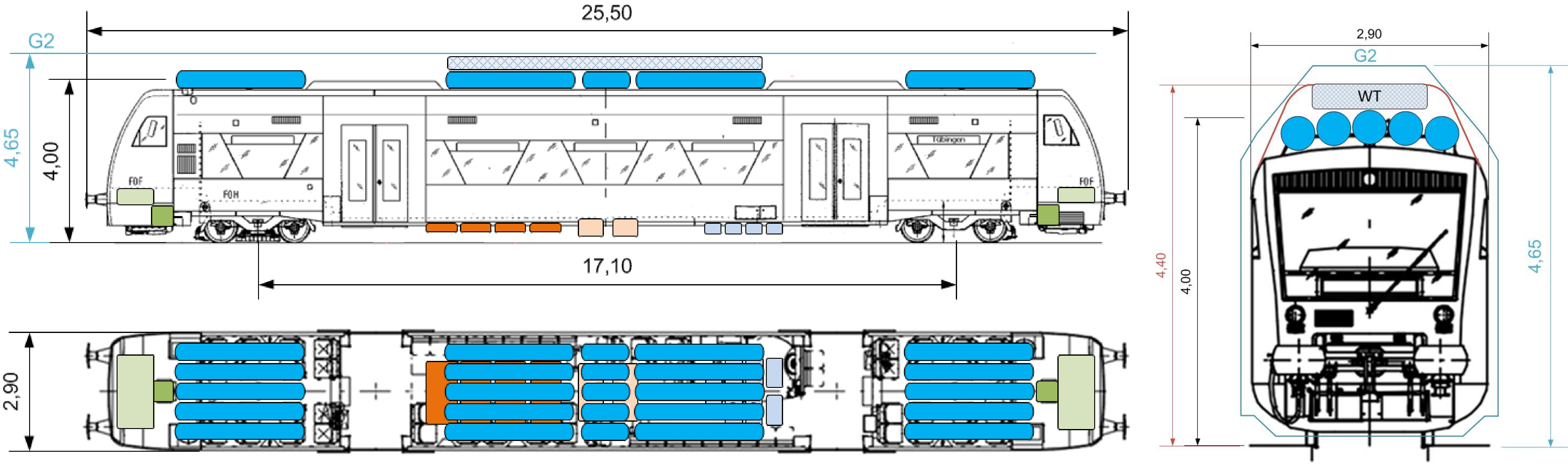
→ BTMS

→ Fuel Cell (Hydrogenics HD30)

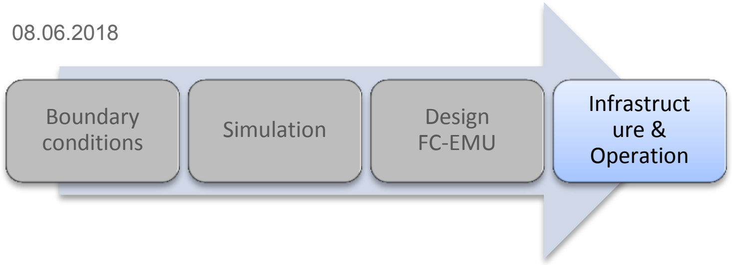
→ Hydrogen tanks (Luxfer)

→ Propulsion converter (Primove 140-2)

→ Traction motor



Based on www.bahnseite.de/rs102.htm



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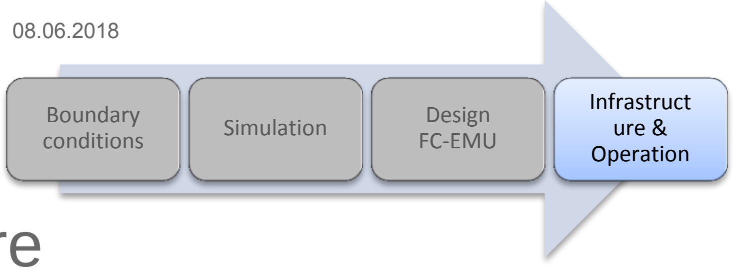
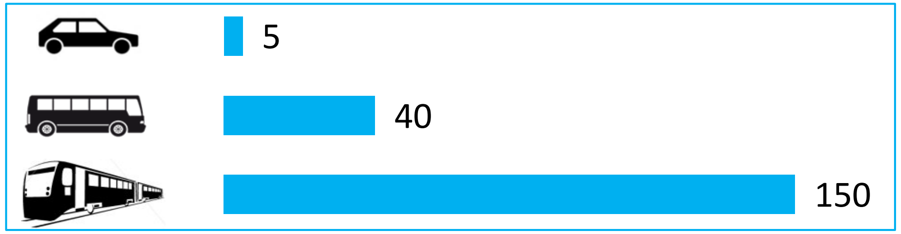


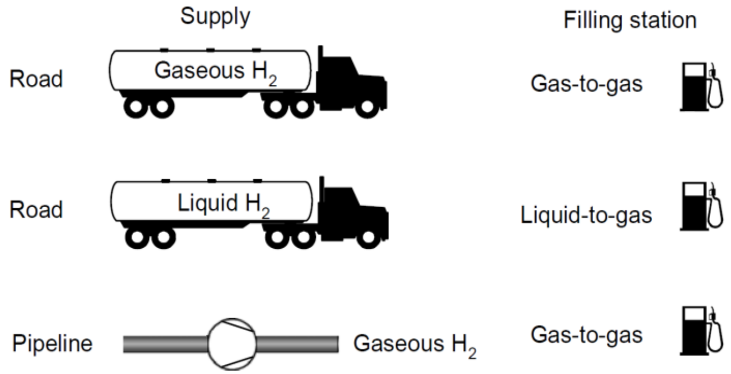
Operation & H_2 Infrastructure
Hydrogen refueling infrastructure

- Full fill of one train max. 150 kg, a 8-train fleet would consume ~1,000 kg hydrogen per day (capacity of existing HRS for cars/buses: 4-40 kg per refueling)



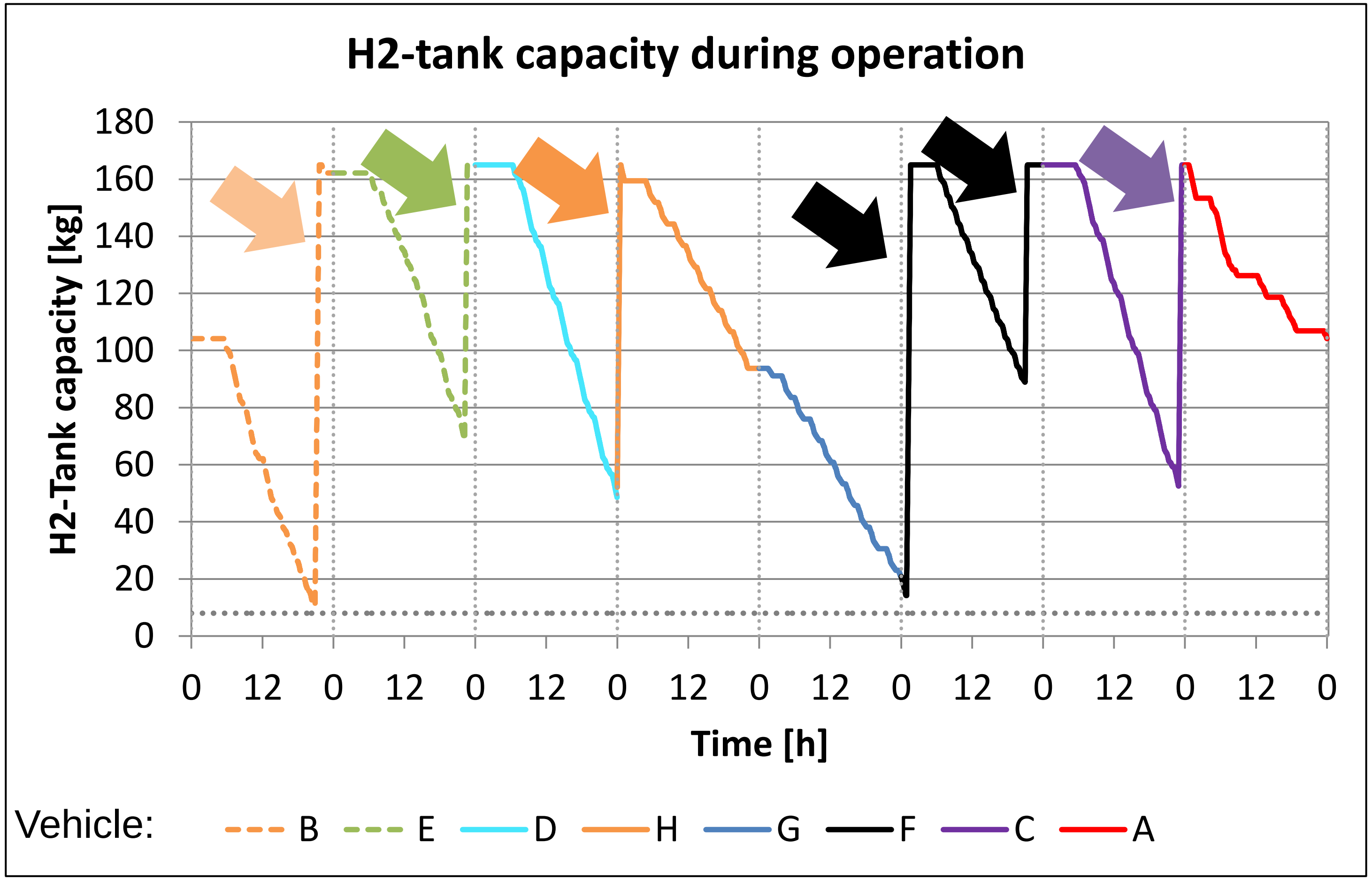
H_2-storage capacity in kg

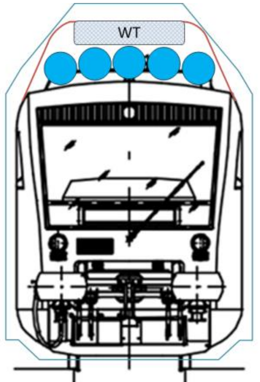
- As a consequence, novel hydrogen refueling concepts for trains are required
- DLR works on identification of suitable refueling concepts and delivery options
  - on-site/off-site delivery
  - LH_2 vs. CGH_2
  - HRS costing
  - Production from renewables
    - Integrated energy
    - Advantage rail car: H_2-demand is plannable (kg, day, location)



Boundary conditions → Simulation → Design FC-EMU → Infrastructure & Operation

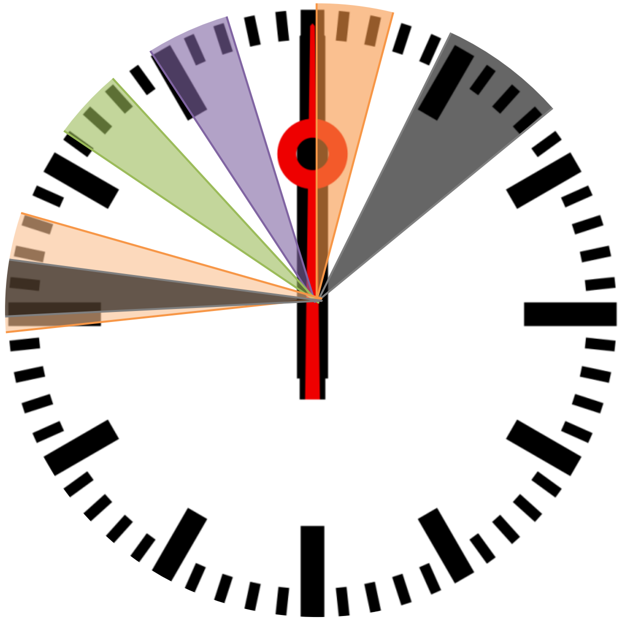
Operation & H_2 Infrastructure
Operation





Based on www.bahnseite.de

Refueling times (during night)



→ Refueling station with two dispenser is required

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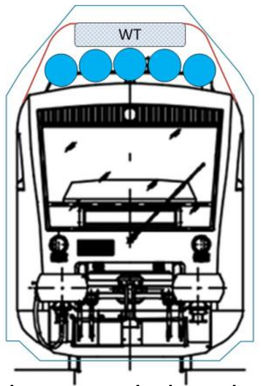

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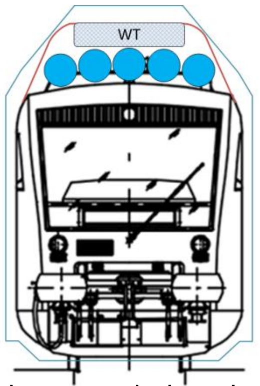

Based on www.bahnseite.de

Conclusion & Outlook

Conclusion

- This study basically proved the feasibility of converting the Regio-Shuttle into a FC-Hybrid railcar in compliance with a given timetable using the Waldbahn rail network as an example
- Due to high space requirements of H_2-tanks, it is essential to consider a network of routes in a differentiated way

Outlook

- Develop fuel cell and battery aging model to make a statement about the lifetime of these components
- Investigate infrastructure and regional conditions regarding H_2 supply/production
- Calculate costs for components, conversion and operation → compare with DMU
- Calculate greenhouse gas emission savings for using FC-EMU instead of DMU on Waldbahn railway network

Thank you for your attendance!

Questions?

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