Fuel Cell Busses:

Toolchain for operation strategy optimization

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HyTechonomy is a COMET Project within the COMET – Competence Centers for Excellent Technologies Programme and funded by BMK, BMDW and the Provinces of Styria and Upper Austria. The COMET Programme is managed by FFG.

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Bundesministerium Digitalisierung und Wirtschaftsstandort

Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie

FFG Promoting Innovation.

Das Land Steiermark

ober österreich

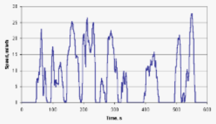
Method Powertrain Development

System Requirements

Customer Requirements

- Power
- Speed
- Efficiency
- Legal conditions

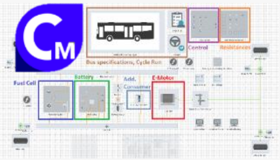
Drive Cycle



- Intercity / urban
- Altitude
- Speed
- Vehicle specs

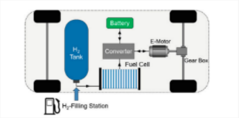
Concept definition

Simulation



- Analyse vehicle performance
- Efficiency, power, lifetime, costs

Powertrain concept



- Fuel Cell
- Battery
- Electric Motor
- Operation Strategy

Development and Validation

Design and Development

- Design criteria
- Modular design

Testing and Validation

- Roller dynamometer tests
- Real Life Operation

Optimisation Loops

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Method Powertrain Development

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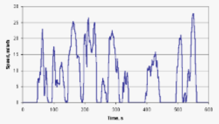

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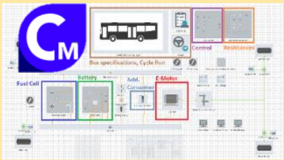

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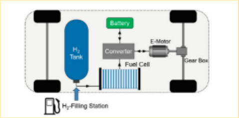

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Optimisation Loops

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Tools for Optimisation

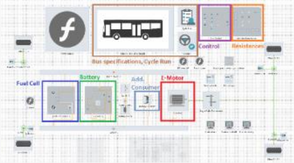
HyCentA

Experiments | **Virtual Tools**

Roller dynamometer Tests

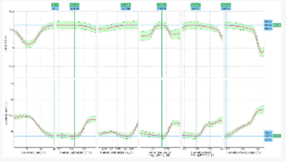
- Testing under **pre-defined** and **reproducible** boundary conditions
- Evaluation of performance **(SoA)**
- **Validation data**
- Real-Life **experience**

Longitudinal Simulation



- In direction of motion
- Variation of **driving conditions** (acceleration, breaking, inclination)
- Variation of **topology** and **design** parameter

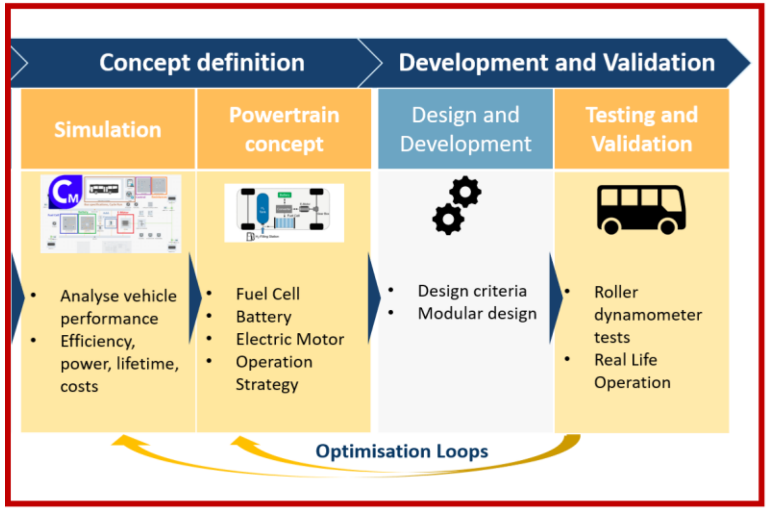
Design of Experiment



- **Systematically varying** input variables
- **Minimizing number of simulation runs**
- **Identify** main influence factors, **quantify** their effects and **interactions**
- Identify **optimum**

Optimisation Loops

Tools



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Source: HyCentA, ITnA

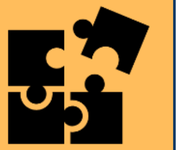
Simulation Target

Goal

- Identify optimal **vehicle topology** (FC, battery and motor size)
- Identify optimal **control strategy**

Sensitivity Analysis

- Identify **main influence parameter** on vehicle performance
- Identify technical **limitations**



Under variation of **boundary conditions, control strategy and topology**

Optimisation

- **Minimize fuel consumption**
- **Maximizing Power**
- Maximize Lifetime
- Minimize costs

Example & Boundary Conditions

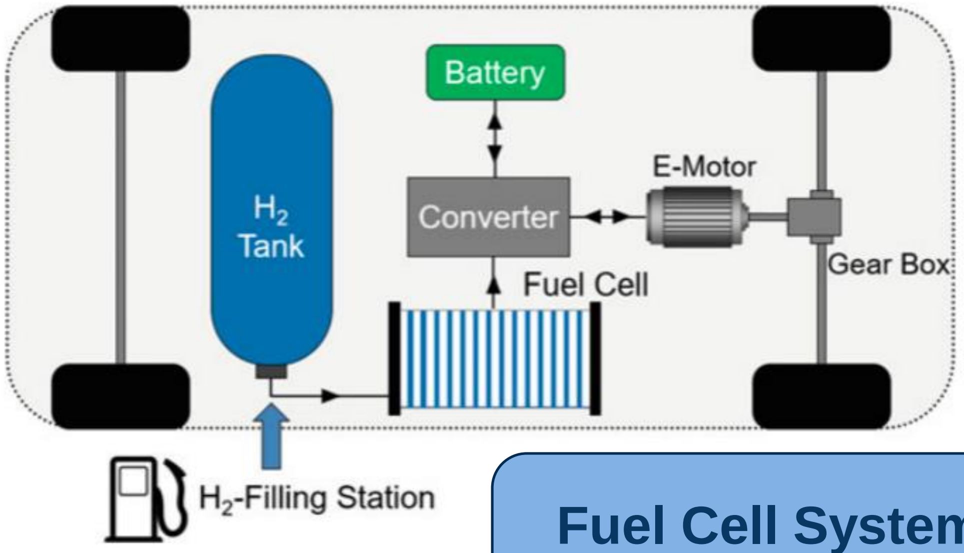
Vehicle: H_2 Bus 12 m

Battery System

30 kWh

Electric Motor

2 x 125 kW

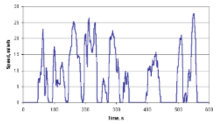


Fuel Cell System

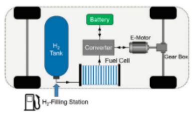
70 kW

Parameter Variations:

- Drive Cycle



- HVAC Power
- Inclination profile
- Powertrain design



- Control Strategy

Source: Klell et. al: Wasserstoff in der Fahrzeugtechnik; 4. Auflage; 2018

Results

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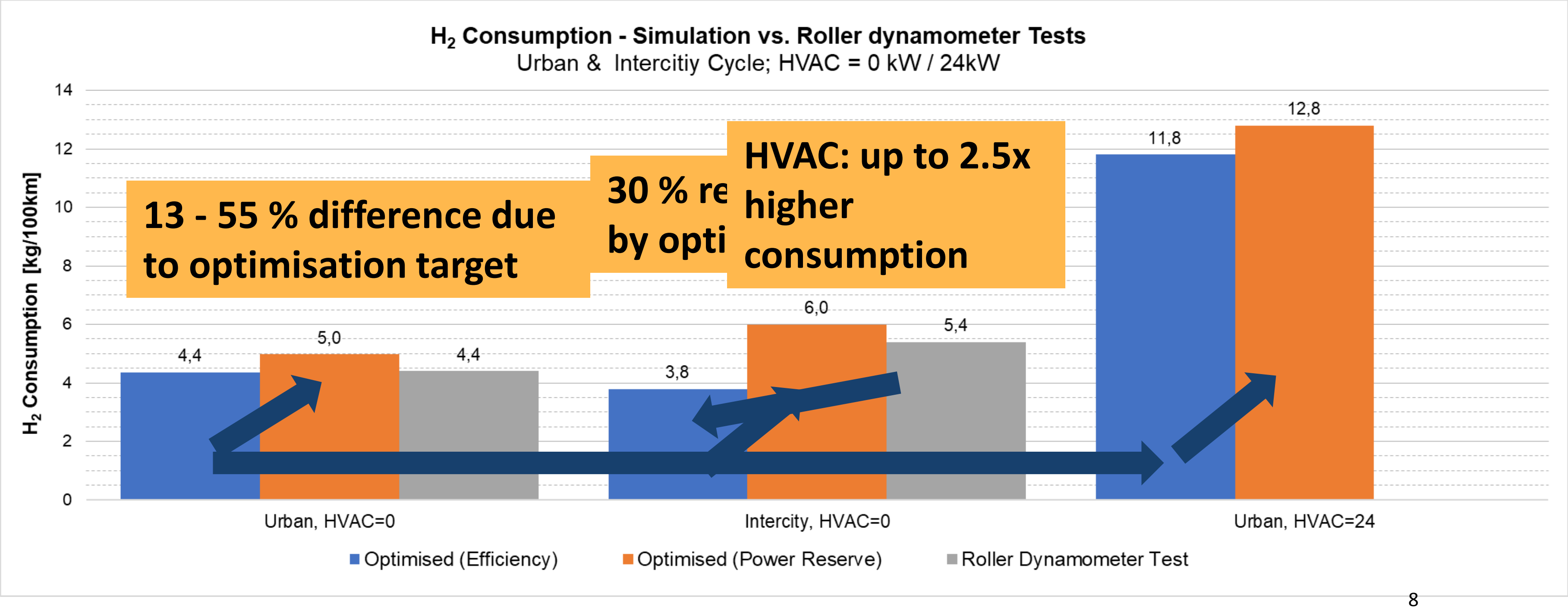
Optimisation

- Design of Experiment Study used to optimize consumption
- Variation of **Drive Cycle & HVAC** → Urban (25.9 km) vs. Intercity (43.9 km)
  - No inclination
  - Passenger Load: curb weight, Battery SoC at start/end: 75 %
  - Consumption includes charging of battery for SoC neutrality

Importance of H_2-consumption **optimization** increase at harsher driving requirements

Significant **increase** in **H_2-consumption** when charging time is **limited & HVAC**



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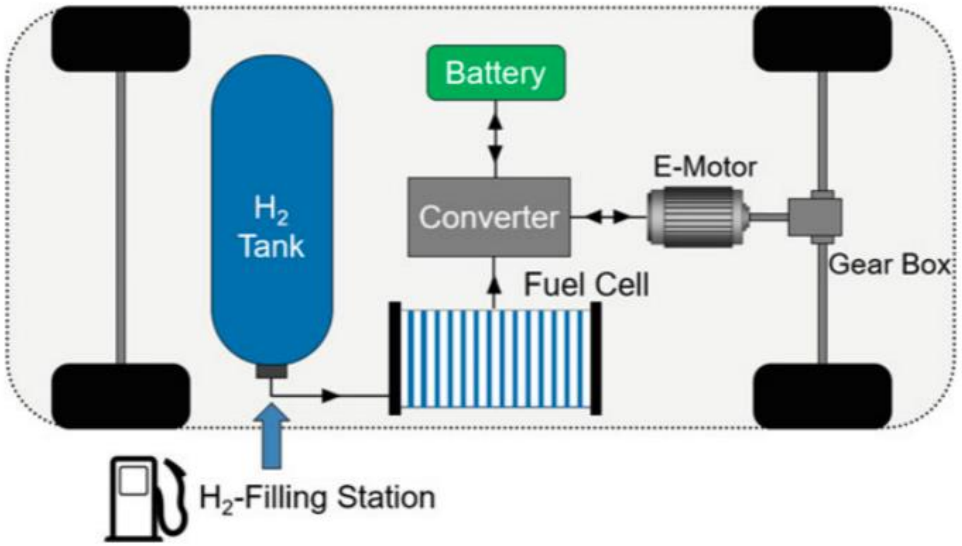
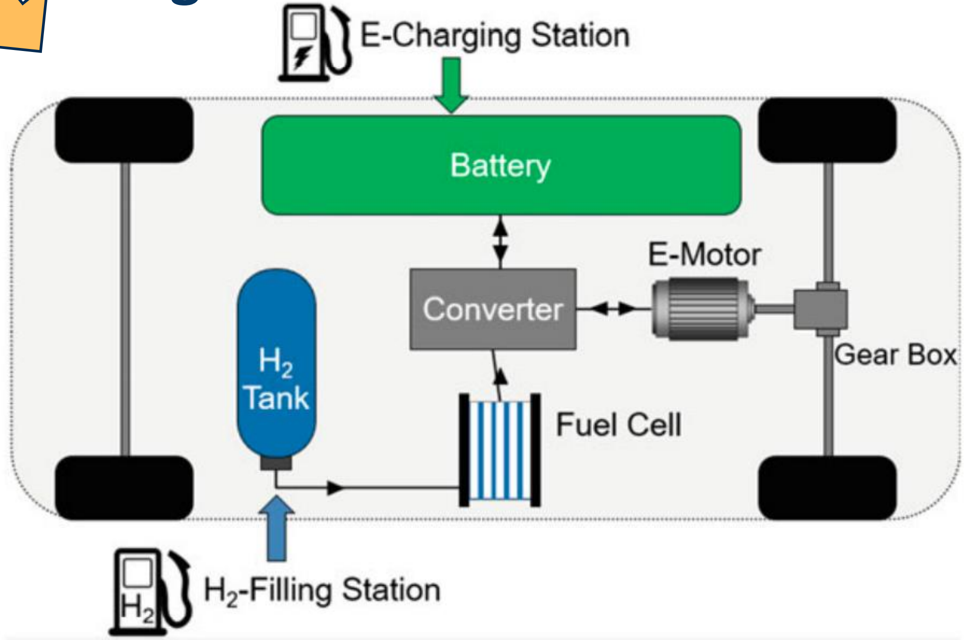
Topology Variation

Base Scenario

Fuel Cell Dominant | **Range Extender**





Source: Klell et. al: Wasserstoff in der Fahrzeugtechnik; 4. Auflage; 2018

	Fuel Cell		Battery Module	
	70kW	105 kW	30 kWh	60 kWh
V1: Actual system	✘		✘	
V2: Battery dominant	✘			✘
V3: Fuel Cell dominant		✘	✘	

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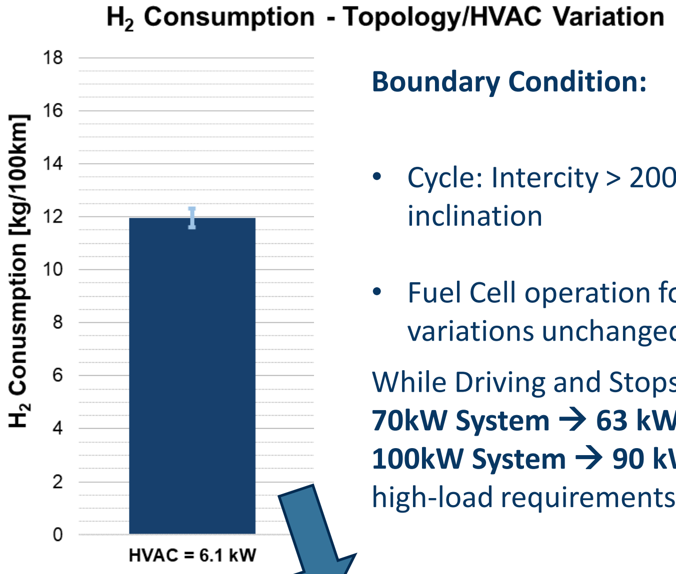
Topology Variation

HVAC = 6.1 kW

- **Base System** — 70 kW / 30,4 kWh
- **Bigger Battery System** — 70 kW / <u>60,8 kWh</u>
- **Bigger Fuel Cell System** — <u>100 kW</u> / 30,4 kWh

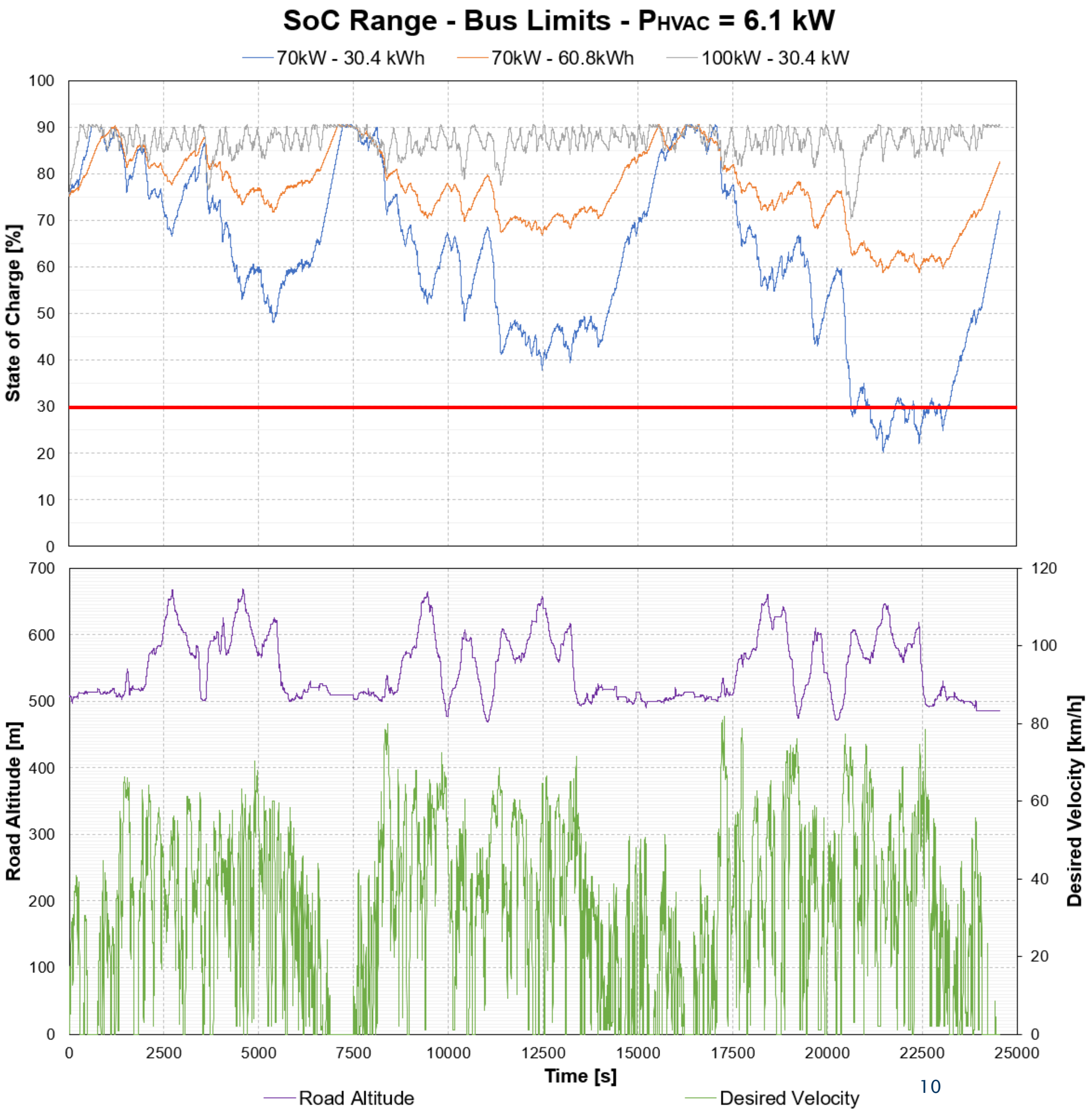


Boundary Condition:

- Cycle: Intercity > 200 km, including inclination
- Fuel Cell operation for all variations unchanged:

While Driving and Stops: **90% Full Load**
70kW System → 63 kW;
100kW System → 90 kW
high-load requirements: **95% Full Load**

Enormous **optimisation potential** for powertrain with bigger fuel cell or battery



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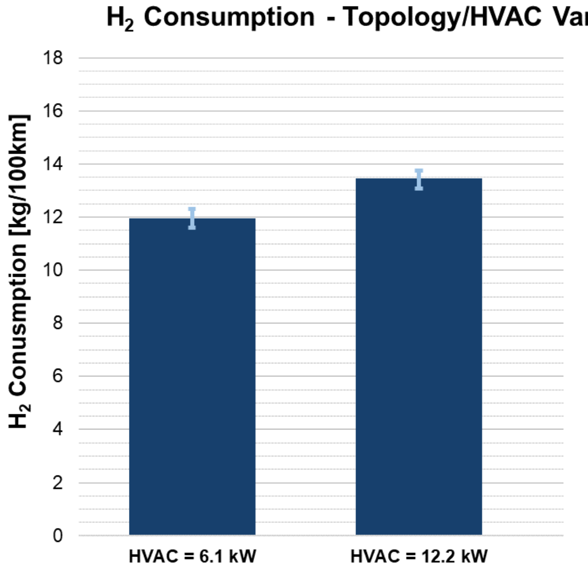
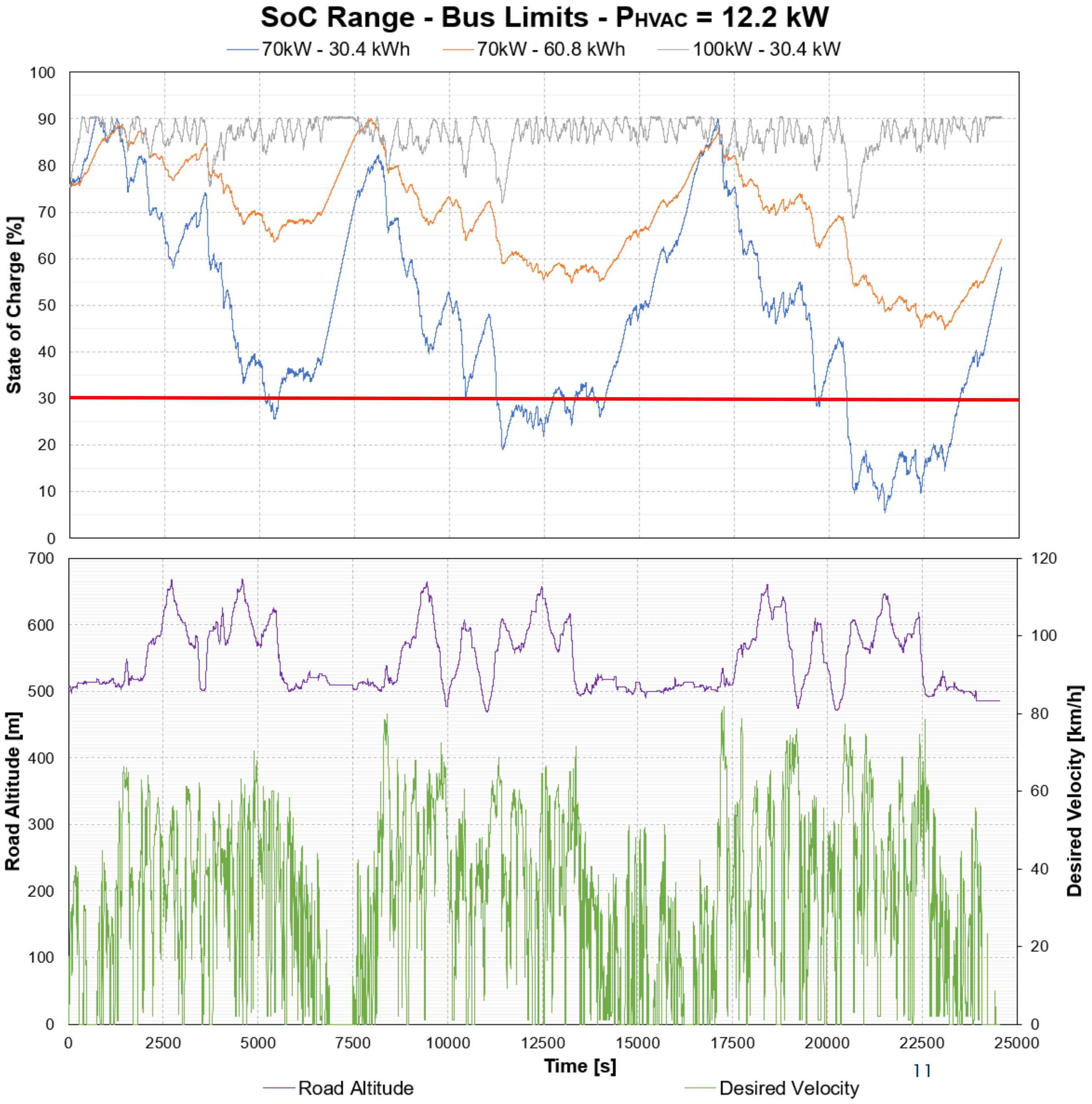
Topology Variation

HVAC = 12.2kW

- Base System — 70 kW / 30,4 kWh
- Bigger Battery System — 70 kW / <u>60,8 kWh</u>
- Bigger Fuel Cell System — <u>100 kW</u> / 30,4 kWh





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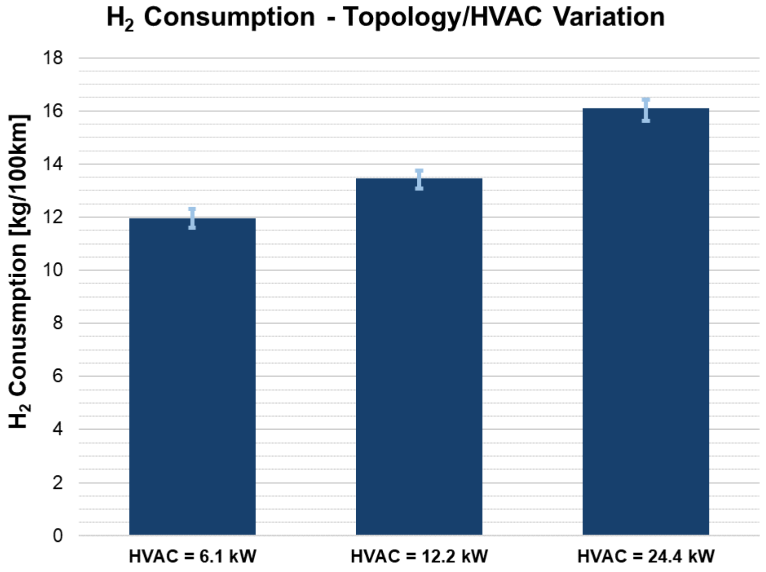
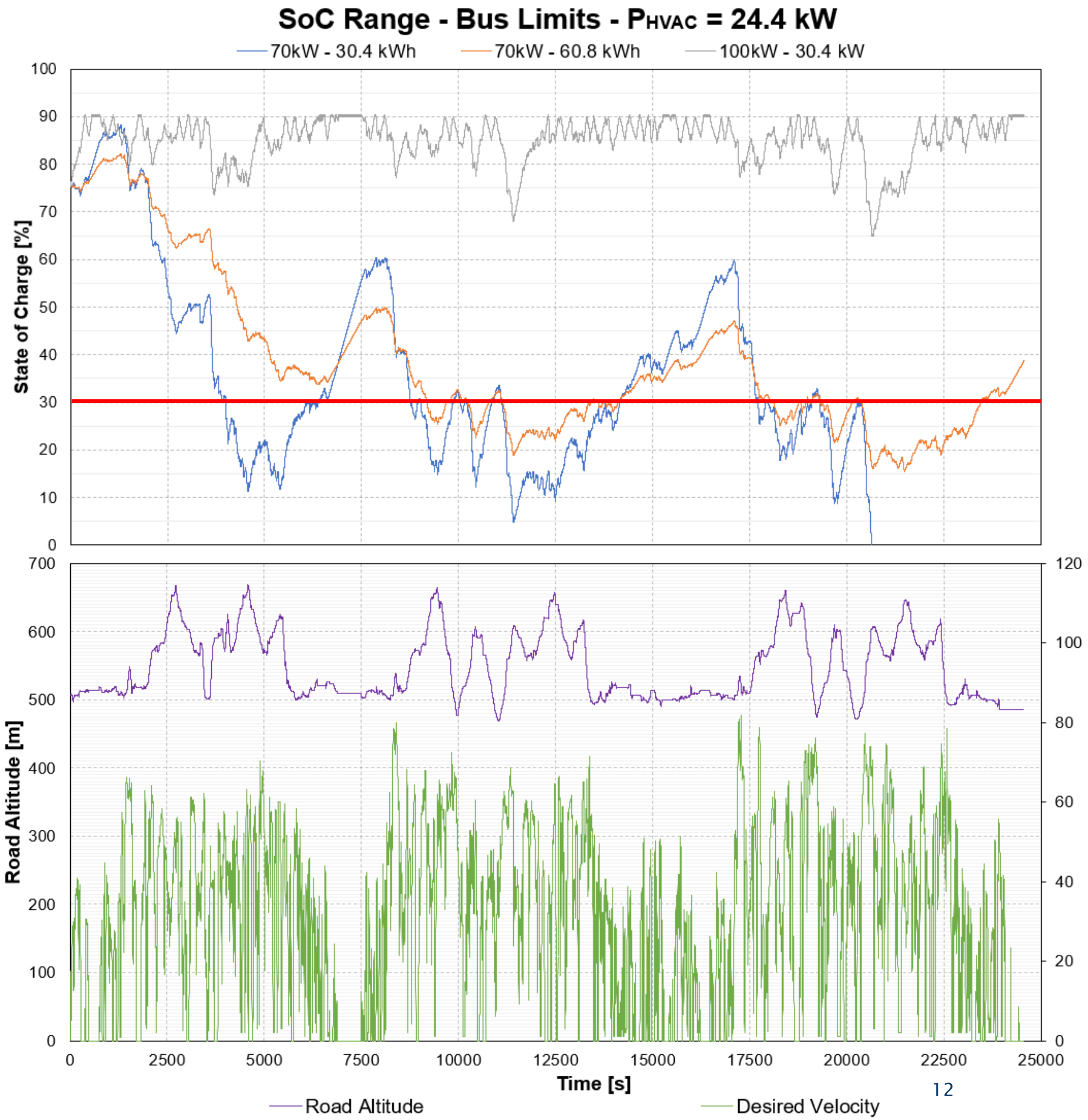
Topology Variation

HVAC = 24.4kW

- **Base System** 70 kW / 30,4 kWh
- **Bigger Battery System** 70 kW / **60,8 kWh**
- **Bigger Fuel Cell System** **100 kW** / 30,4 kWh



Fuel cell dominant system favorable at more challenging conditions



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Conclusion and Outlook

Conclusion Simulation results

- Inclination, HVAC-demand & control strategy have significant influence on **power & H_2 consumption** (up to 60 %)
- **Right sizing** of **battery & FC** depend on requirements of the routs

Potential of Toolchain

- Efficient **optimisation** (Power, H_2 consumption, lifetime)
- Easily **applicable** to other fuel cell vehicle types
- Significant **reduction of simulation** and development **time**

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