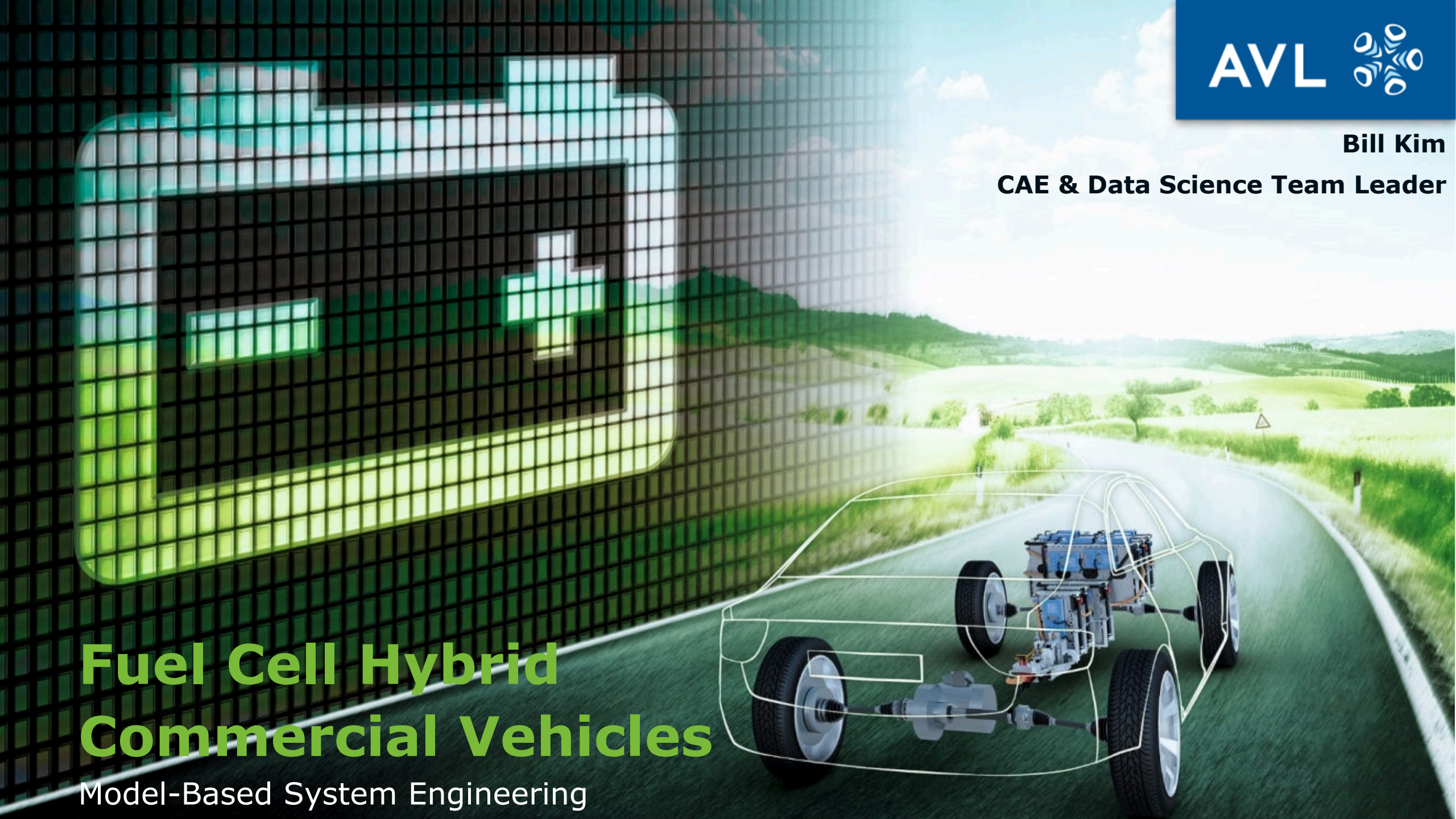


Fuel Cell Hybrid Commercial Vehicles

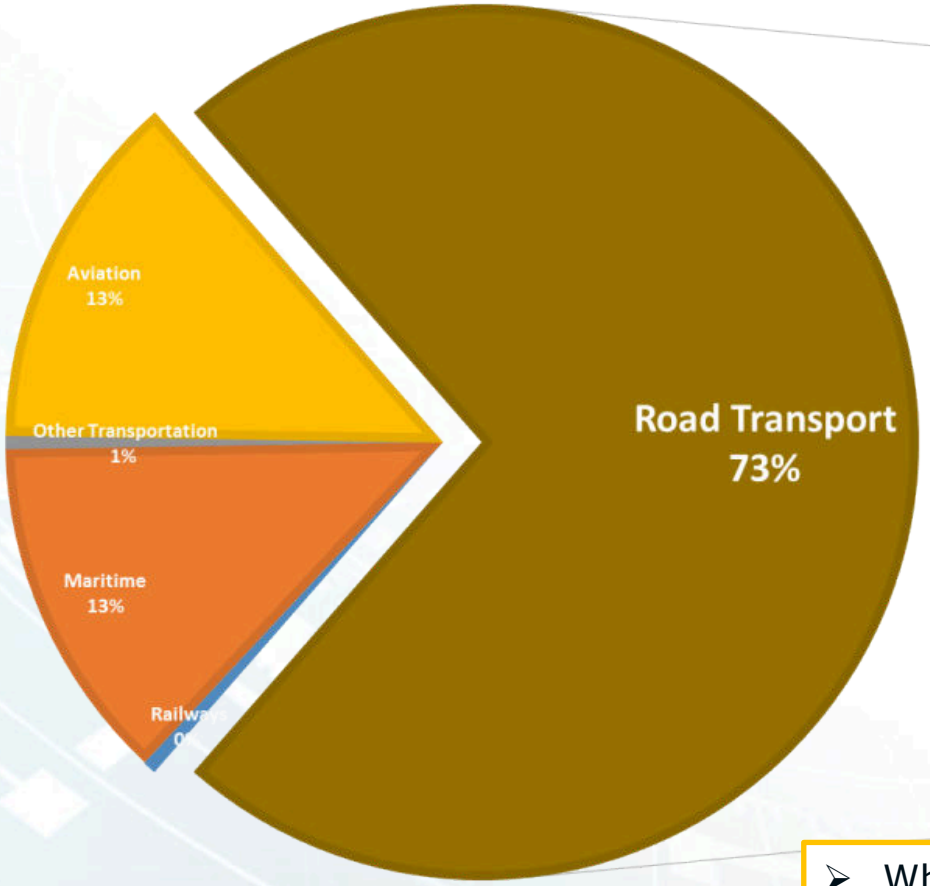
Model-Based System Engineering

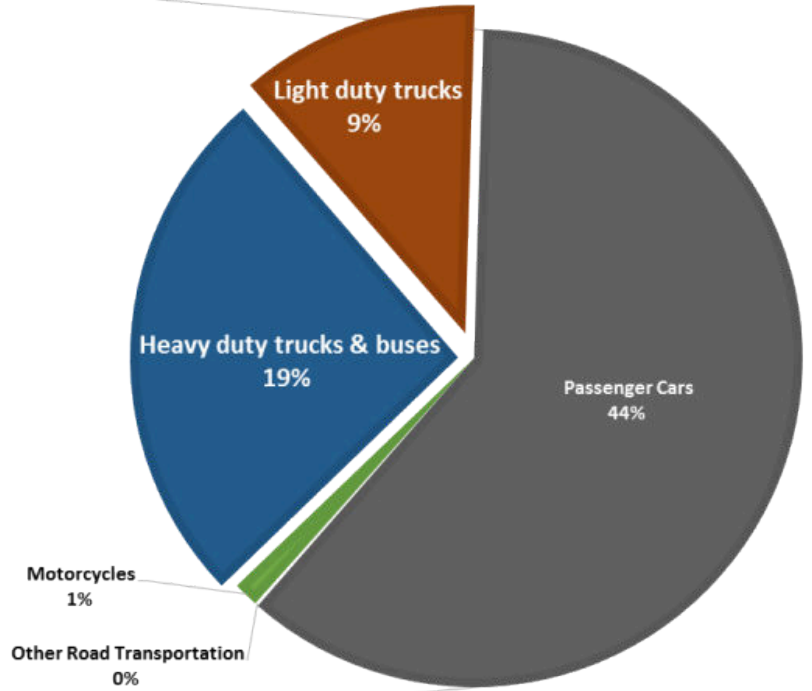
Bill Kim

CAE & Data Science Team Leader

Fuel Cell Vehicle Opportunity - Commercial Vehicle (1)

< Share of Transport GHG emissions (2015) – EU [1)]>





Trucks and buses produced 27% of transport GHG emission in 2015, which will increase to ~40% by 2030 [2)]

- While passenger cars use battery technology to reduce GHG, commercial cars would need another electrification strategy

1) European Environment Agency (EEA)
2) Too big to ignore – truck CO2 emissions in 2030, Transport & Environment, September 2015

Fuel Cell Vehicle Opportunity - Commercial Vehicle (2)

Tesla – Truck BEV

Cummins – Truck BEV

Daimler – Truck BEV

- Electrified Truck has been developing by Tesla, Daimler and Cummins
  → As lorry truck needs to cover long distance (>1,000 km), range extender device is necessary to resolve low energy density issue of pure battery electric truck

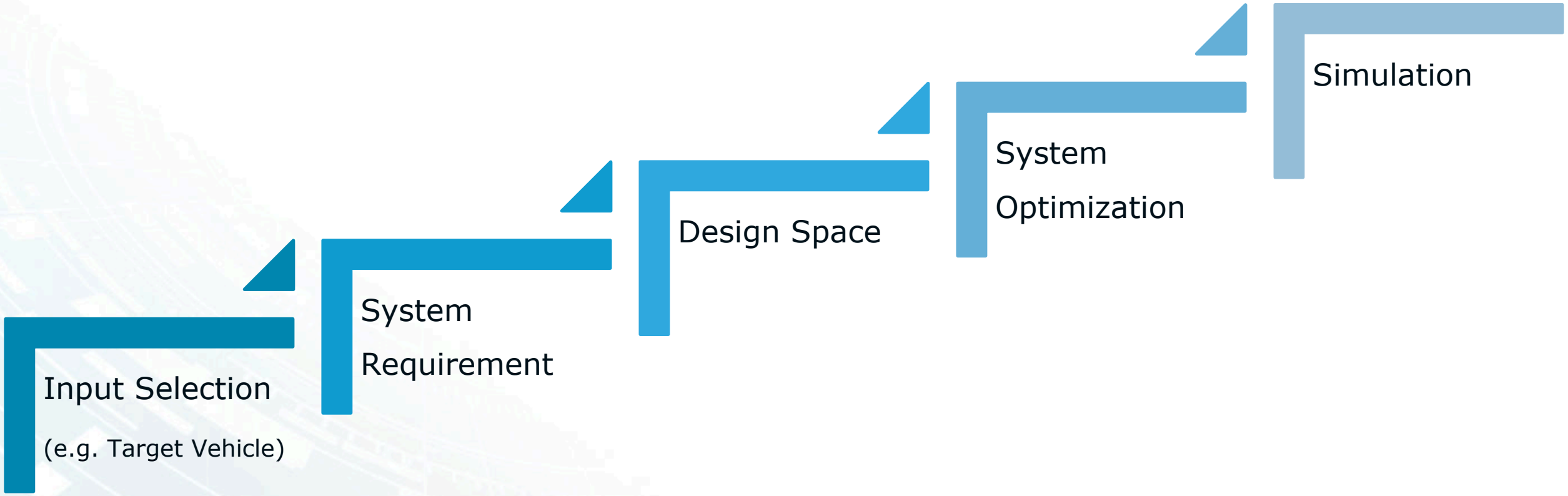
Fuel Cell Vehicle Opportunity - Commercial Vehicle (3)

Hyundai – Fuel Cell Electric Truck

Nikola – Fuel Cell Electric Truck

- Fuel Cell has advantage over battery in terms of energy density and charging time, which is critical for commercial vehicle.

System Optimization Process



Input Selection
- Target Vehicle Selection

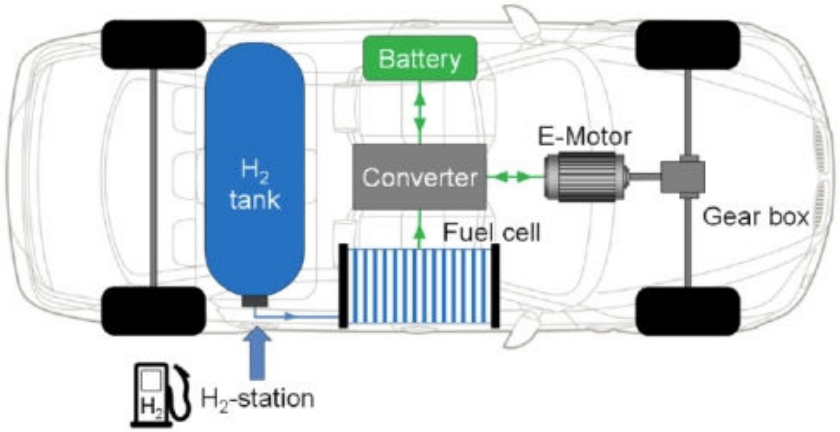
Delivery Van
(2.5 – 3.5t)

Coach Bus
- Class M3

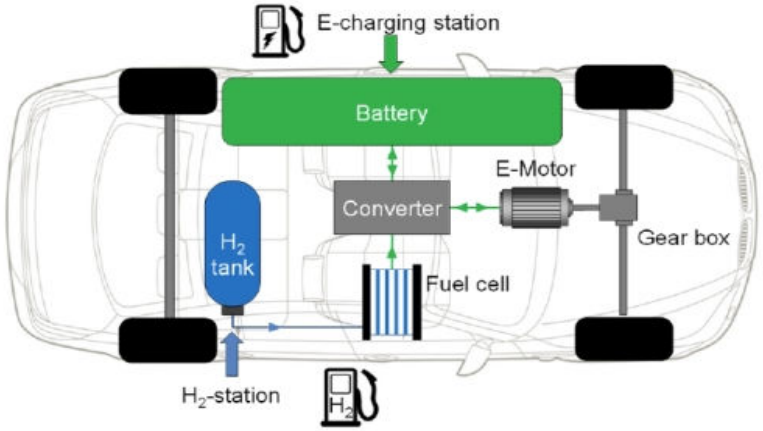
Truck
(Class N3)

Fuel Cell Vehicle System

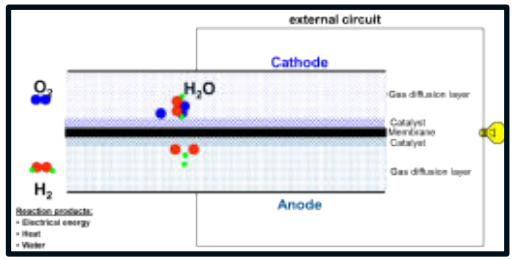
Fuel Cell Hybrid Vehicle



Fuel Cell Range-Extender Vehicle



Input Selection
- Fuel Cell Technology



PAFC

PEMFC

Proton Exchange Membrane Fuel Cell

AFC

SOFC

Solid Oxide Fuel Cell

MCFC

PAFC: Phosphoric Acid Fuel Cell

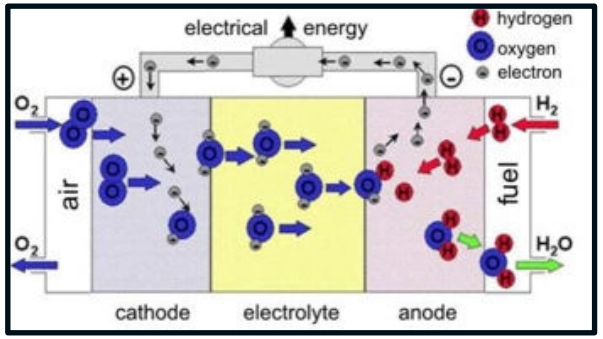
MCFC: Molten Carbonate Fuel Cell

AFC: Alkaline Fuel Cell

DMFC: Direct Methanol Fuel Cell

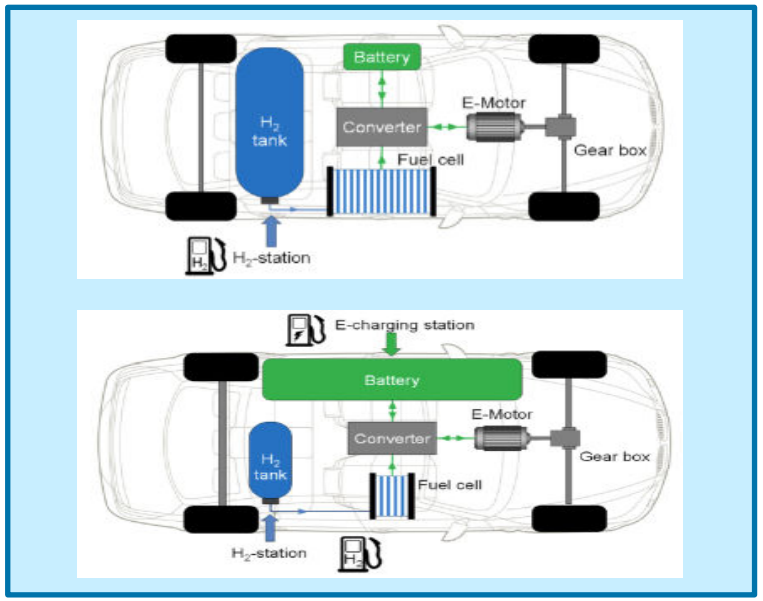
PEMFC: Polymer Electrolyte Fuel Cell

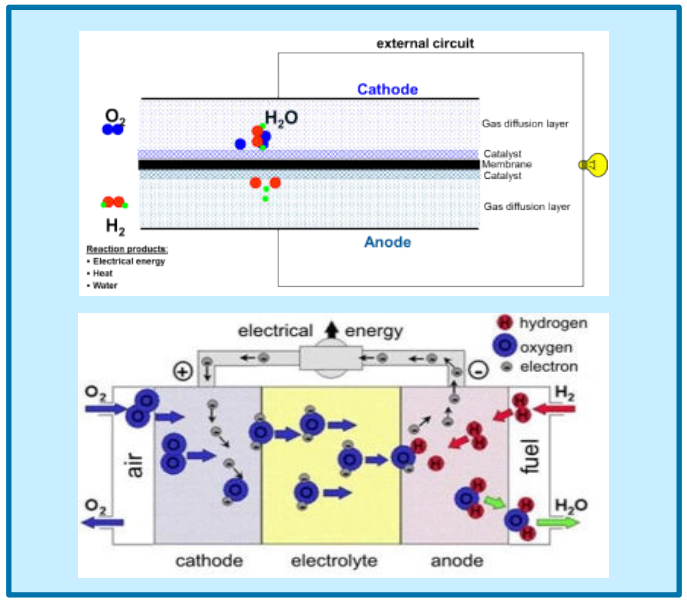
SOFC: Solid Oxide Fuel Cell



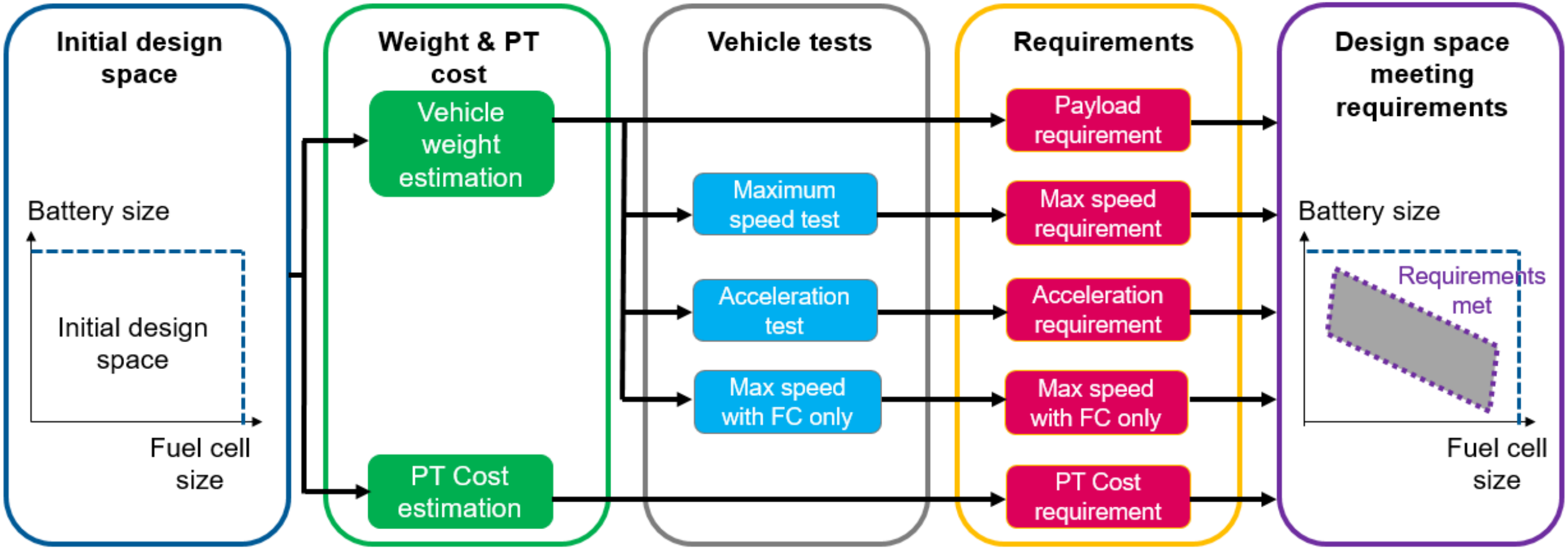
System Optimization

What is the best combination of system (e.g. fuel cell type, system architecture, and sizing) for each commercial vehicle applications ?

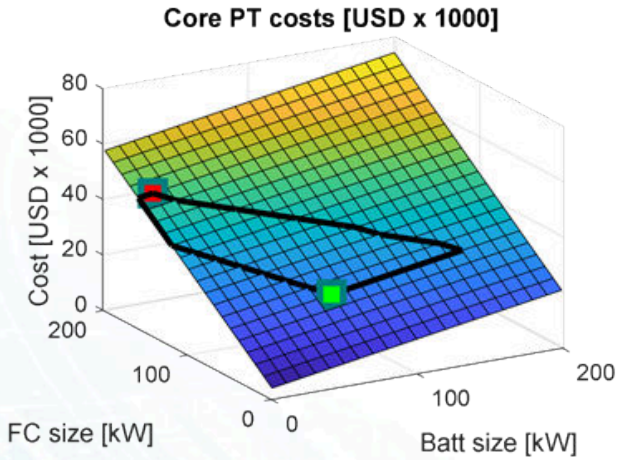


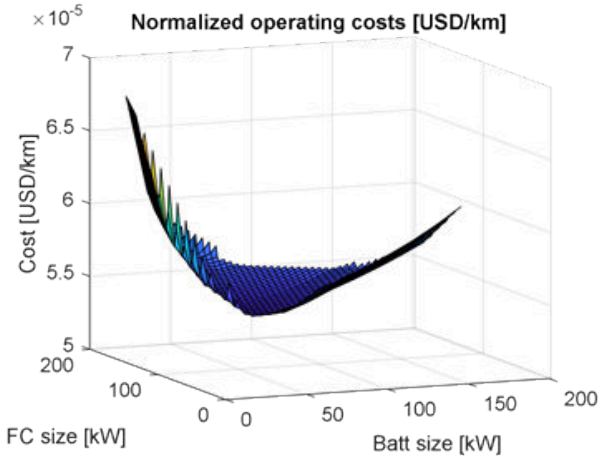


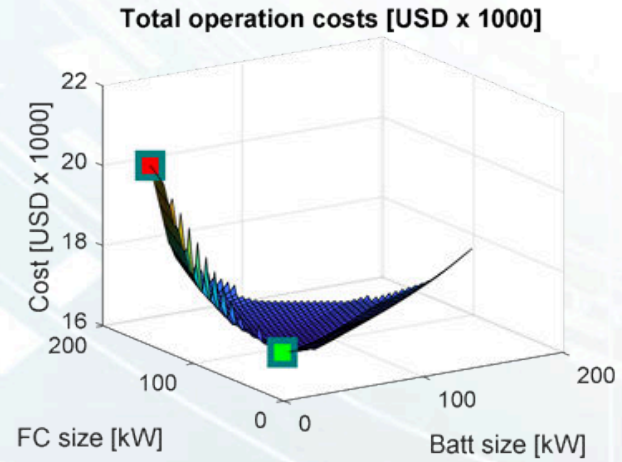
Model-based System Optimization - Design Space Methodology

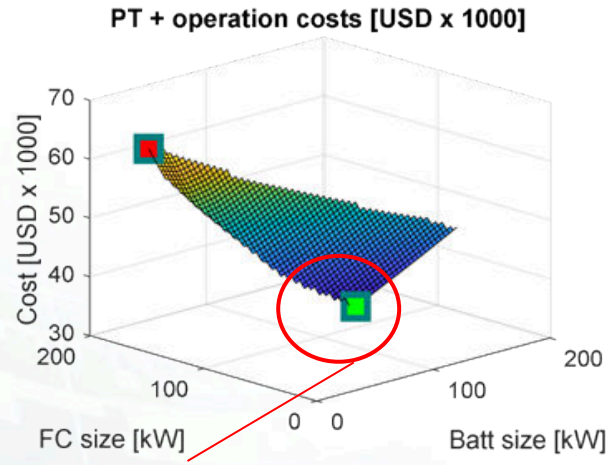


Model-based System Optimization - Dynamic Programming







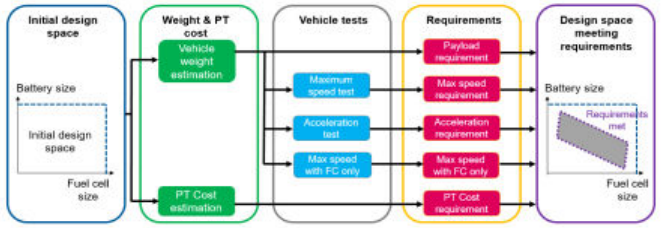


Lowest total costs

< System Optimization Results - Van FCHCV PEMFC >

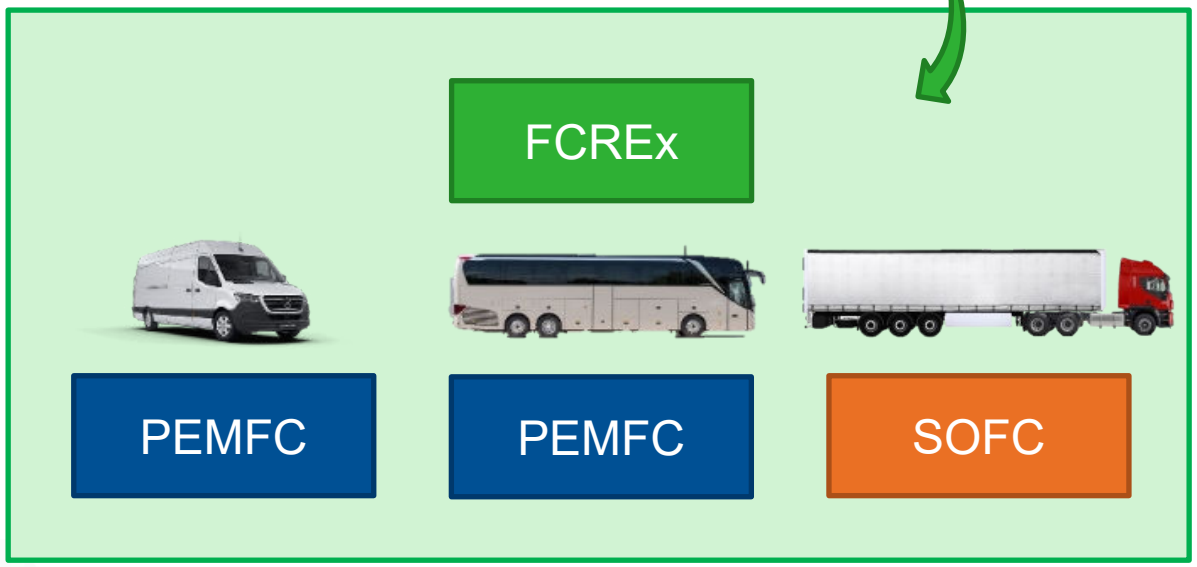
Item	Value	Comments
Operating Cost	20k – 24k USD	Assumption : 30,000 km/year, 10 year operation
Powertrain Cost	24k – 47k USD	Based on component costs defined for 2020
Total Cost	39k – 60k USD	Operating cost + Powertrain cost

Model-based System Optimization - System Selection



min{ H_2 } with DP

selection criteria



Simulation

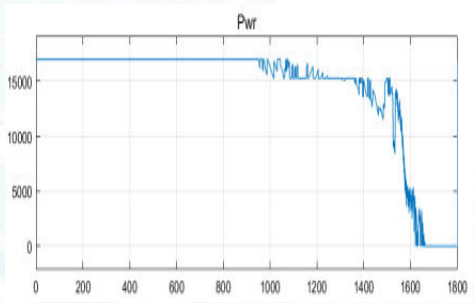
< Conventional Vehicle >

< Fuel Cell Vehicle >

Plant - Baseline	Control
Engine	Engine Control
Gear box / Final drive	Gearbox Control
Brake / Wheel	Driver
Vehicle	

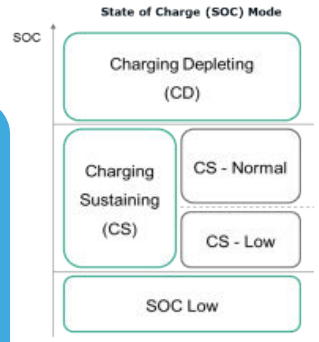
Plant – Fuel Cell	Control
Fuel Cell / Battery	FCHV Control
Motor / Final drive	Fuel Cell Control
Brake / Wheel	Driver
Vehicle	

Simulation – Fuel Cell Vehicle Control



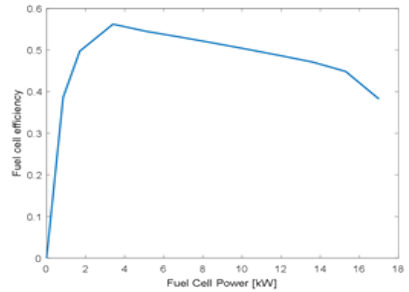
DP Results

SoC Control



Components Analysis

Rule-based Strategy



Simulation – Results (Van)

Item	Baseline	Fuel Cell Hybrid Vehicle
Fuel consumption (WLTC)	**7.32 L/100 km**	**1.74 kg/100km**
Well-to-Wheels [1)]	237.8 CO2e g/km	214.2 CO2e g/km
Fuel Cost [2)]	£3,000 / year	£2,070 /year
Engine / Fuel Cell	2.2L / 114 kW (with Stop/Start)	17 kW Fuel Cell
Battery	N/A	98kW
Transmission	6-speed manual	Single-step Gearbox
Final drive ratio	4.19	8.6
Test weight	2,270kg	2,349 kg

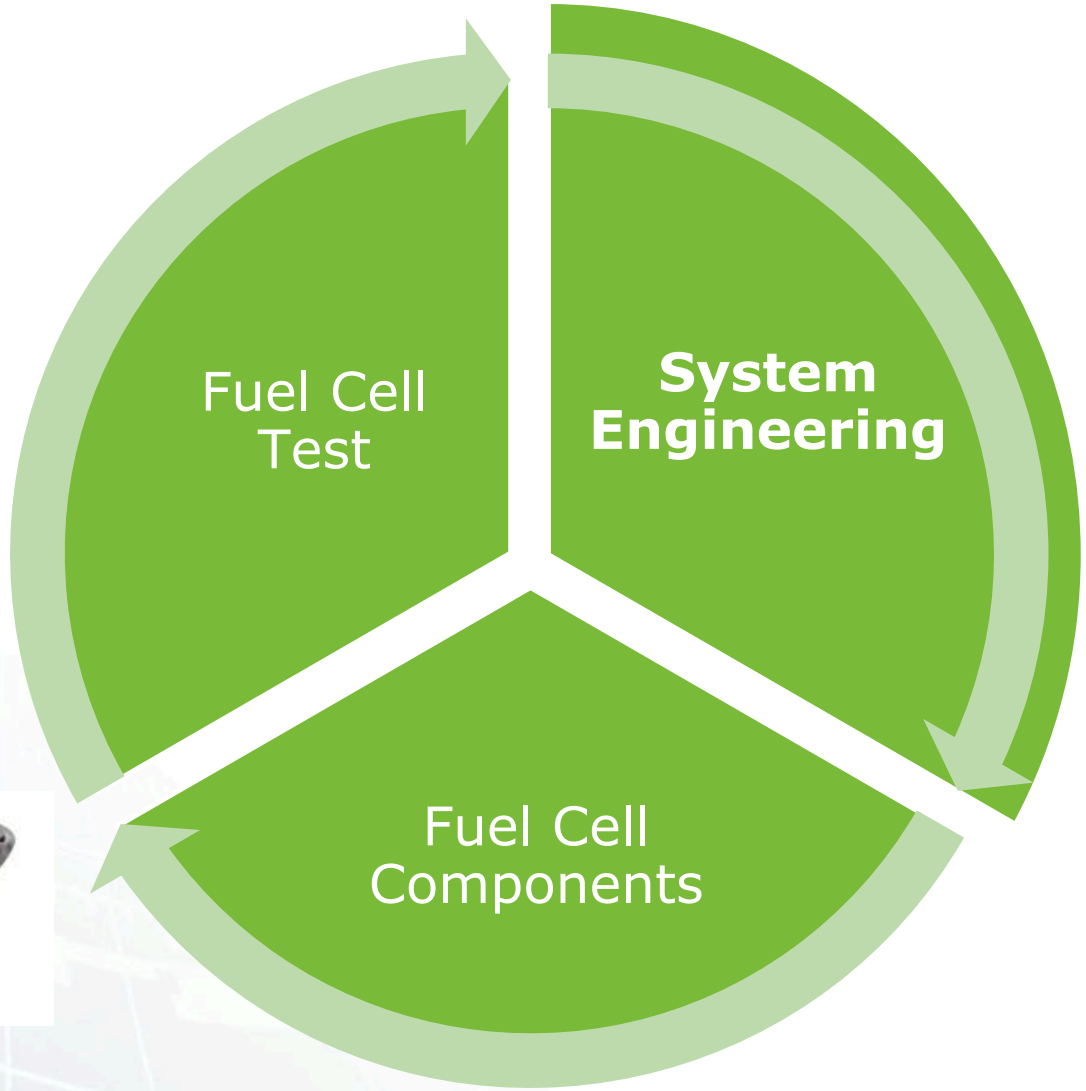
1) Assuming hydrogen production is based on steam methane reforming (SMR) in the UK, Source "UK H_2 Mobility – Phase 1 Results", 2013 and "JEC Well-to-Wheels Analysis", 2014
2) Assuming annual mileage for van is 30,000 km and hydrogen cost 3.69 $/kg projected in 2020

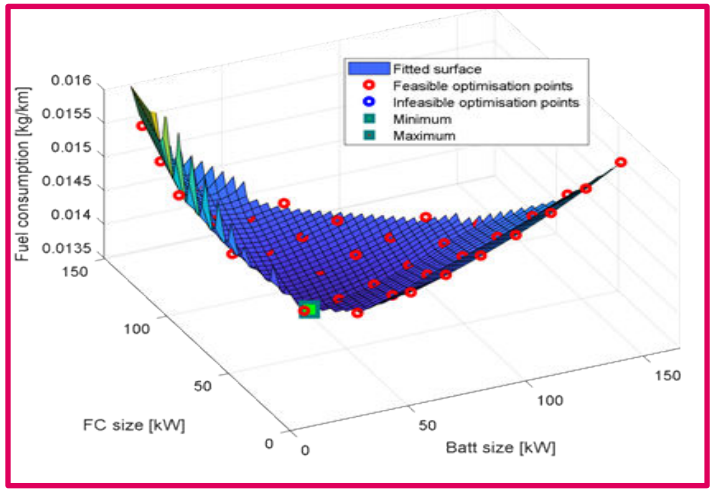
AVL Fuel Cell Business

Measurement & Diagnostic Equipment

Component, Sub-System & System Testbench

System & Sub-System Development





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Bill.Kim@avl.com