Battery Modelling for FCEV Applications

CAE Modeling and Simulation

Presenter

Nijesh Narayanan

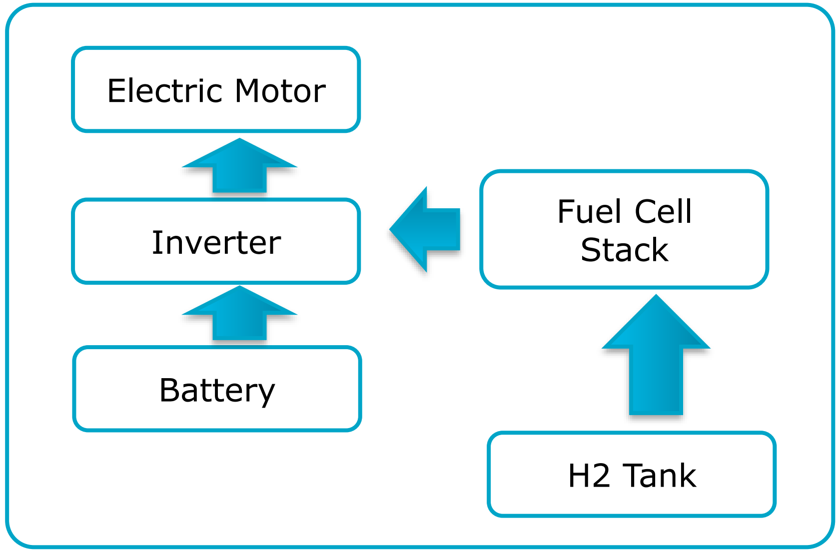
CAE and Data Science Team Leader

Vehicle Applications Department
Engineering Centre Coventry
AVL Powertrain UK Ltd

Battery Modelling for FCEV Applications - Introduction

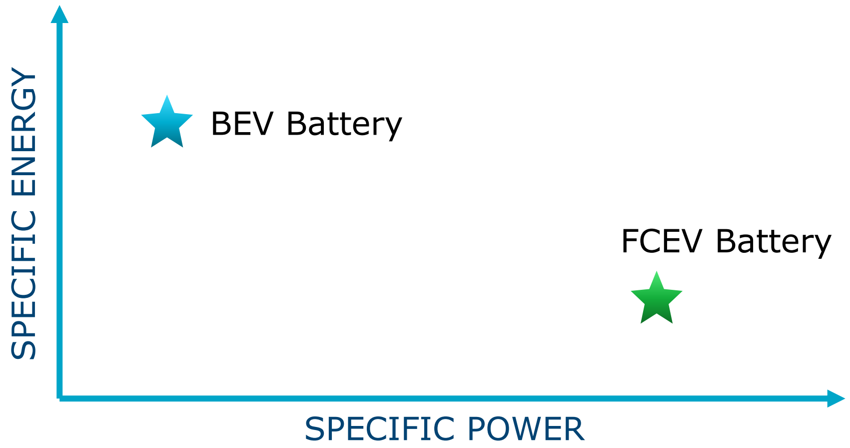
Project Goals

- **Battery Design Optimisation:** Develop lithium-ion batteries with enhanced specific power tailored to the unique needs of FCEVs
- **FCEV Efficiency Improvement**: Aim to reduce hydrogen fuel consumption and improve overall system efficiency by optimising battery design



How would this improve the FCEV system?

- Limiting the load dynamics of FC to increase its reliability
- Lesser overall weight contributing to increased range capability
- With improved power split topologies, downsizing of FC can be considered



Work Packages and Methodology

Literature survey:

1. Current FCEVs and the batteries used
2. Battery parameters and limits

Modelling and Simulation: Sensitivity of Battery electrochemical parameters

Develop Design of Experiment (DoE) & Optimisation of Battery Cell Design

Temperature effect analysis

Vehicle Modelling and Simulation:

Integrating battery model in the vehicle model

Evaluate the performance of the FCEV with optimised Battery design

Literature Review – Electrochemical Parameters

Thickness

POWER ← **Decrease Cathode Thickness** — ENERGY

POWER ← **Decrease Anode Thickness** — ENERGY

Decreasing the electrode thickness will result in the following :

- Increased cell power
- Lower cell polarisation

Porosity

POWER ← **Increase Anode Porosity** — ENERGY

POWER ← **Increase Cathode Porosity** — ENERGY

Decreasing the electrode porosity will result in the following :

- Increased cell power
- Better pore utilisation
- Enhanced electrolyte impregnation
- Higher active material utilisation
- Lower cell polarisation

Particle Size

POWER ← **Decrease Anode Particle Size** — ENERGY

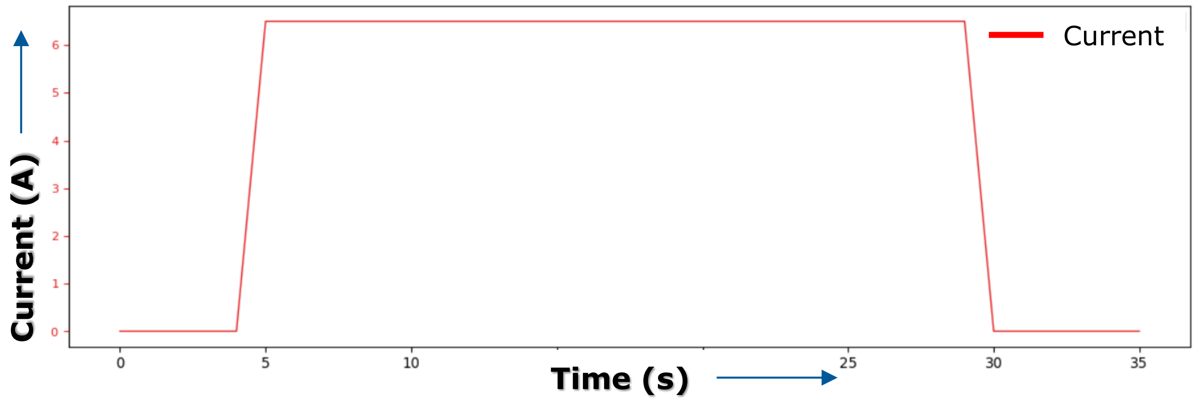
POWER ← **Decrease Anode Particle Size** — ENERGY

Decreasing the electrode particle size will result in the following :

- Increased cell power
- Better pore utilisation
- Lower cell polarisation

Electrochemical Parameters Study - DOE Methodology

- DOE Parameters
  - **Porosity** for Anode and Cathode
  - **Particle Size** for Anode and Cathode
  - **Thickness** of Anode and Cathode
- Pulse discharge test for 30 seconds at 1C (6.5A) Simulated for each case
- The pulse was run at 100% SoC to find the maximum peak power



Used the following equation to find peak power:

$$Peak\ Power = Current * \frac{(V_{ocv_{max}} - V_{ocv_{min}})}{(V|t = 4s - V_{min})}$$

Theoretical OCV (4.2V – 2.78V)

Net voltage before pulse and at minimum

DOE Setup and Optimisation

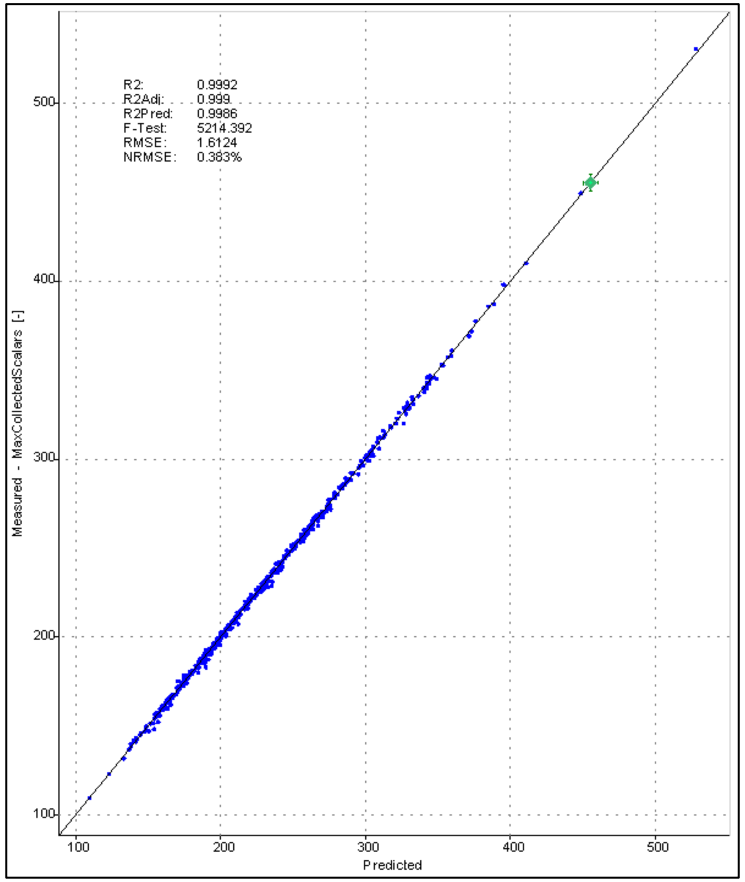
AVL Cameo

AVL Cruise M

DOE Variables			
Parameter Name	**Lower Bound**	**Upper Bound**	**Level**
Anode Thickness	49 micron	85 micron	400
Cathode Thickness	42 micron	74 micron	400
Anode Porosity	0.43 [-]	0.71 [-]	400
Cathode Porosity	0.42 [-]	0.62 [-]	400
Anode Particle Size	5 micron	12 micron	400
Cathode Particle Size	2 micron	6 micron	400

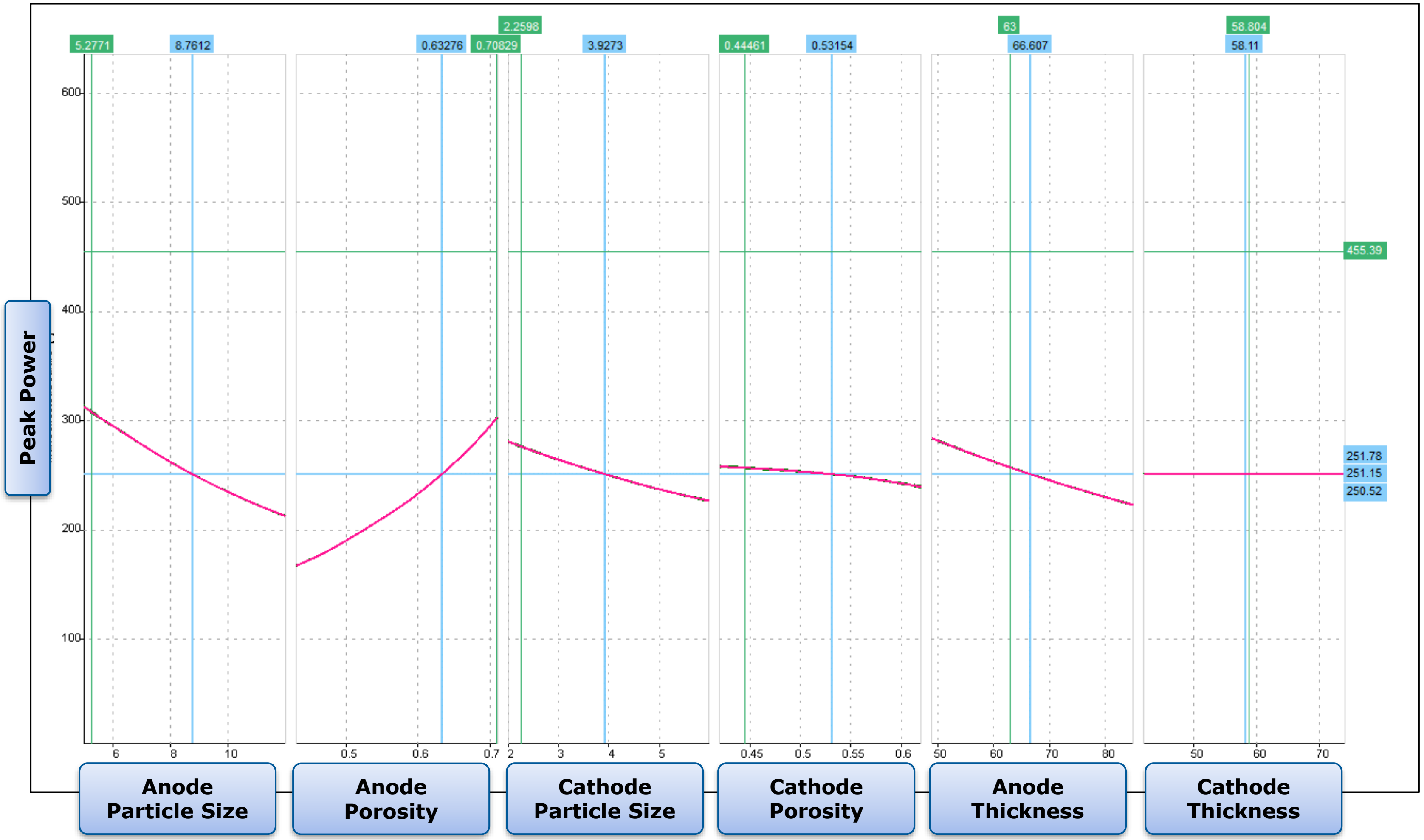
Targets & Constraints			
Parameter Name	**Minimum output**	**Maximum output**	**Type**
Peak Power	- infinity	+ infinity	Maximise

Active DoE Model Quality



The DoE was run on AVL Cameo which used the electrochemical model built in AVL Cruise M

Sensitivity Analysis



Key takeaways:

- Anode parameters are more sensitive than cathode parameters
- Anode porosity is the most sensitive parameter
- Cathode thickness has an insignificant effect
- Majority of the parameters have a somewhat linear relationship apart from anode porosity

Optimised Battery Cell Design

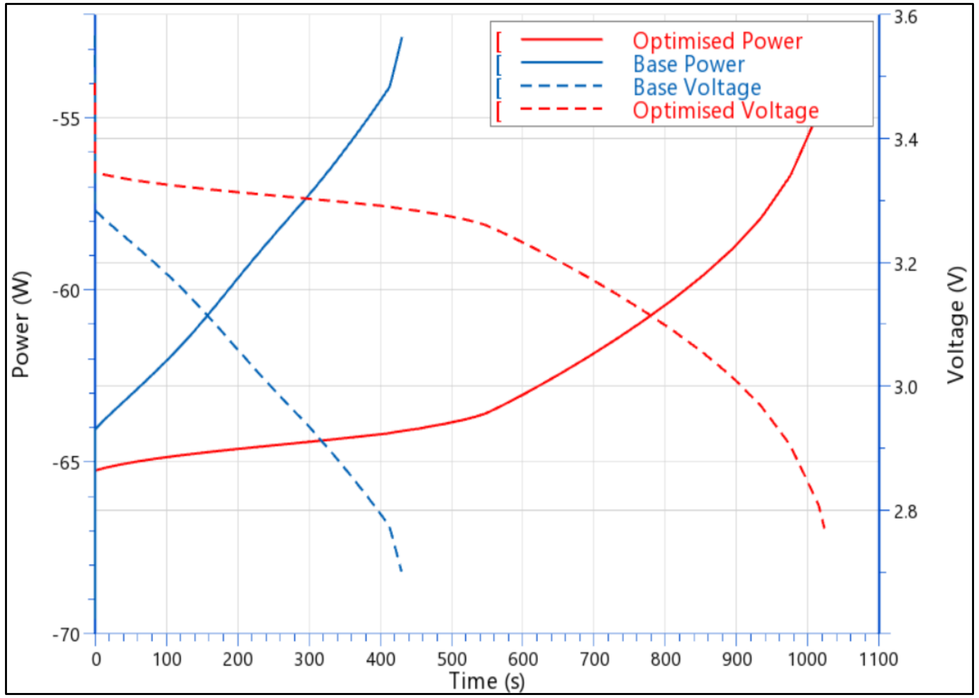
Parameters Baseline Battery

Parameter	Cell
Cathode	NMC622
Anode	Graphite
Anode Thickness (Microns)	85
Cathode Thickness (Microns)	74
Separator Thickness (Microns)	13
Anode Porosity	0.43
Cathode Porosity	0.42
Anode Particle Size (Microns)	12
Cathode Particle Size (Microns)	6

Optimised Battery Cell Design

Parameter	Cell
Cathode	NMC622
Anode	Graphite
Anode Thickness (Microns)	63
Cathode Thickness (Microns)	59
Separator Thickness (Microns)	13
Anode Porosity	0.71
Cathode Porosity	0.44
Anode Particle Size (Microns)	5
Cathode Particle Size (Microns)	2

Power comparison at 3C from 100% SoC

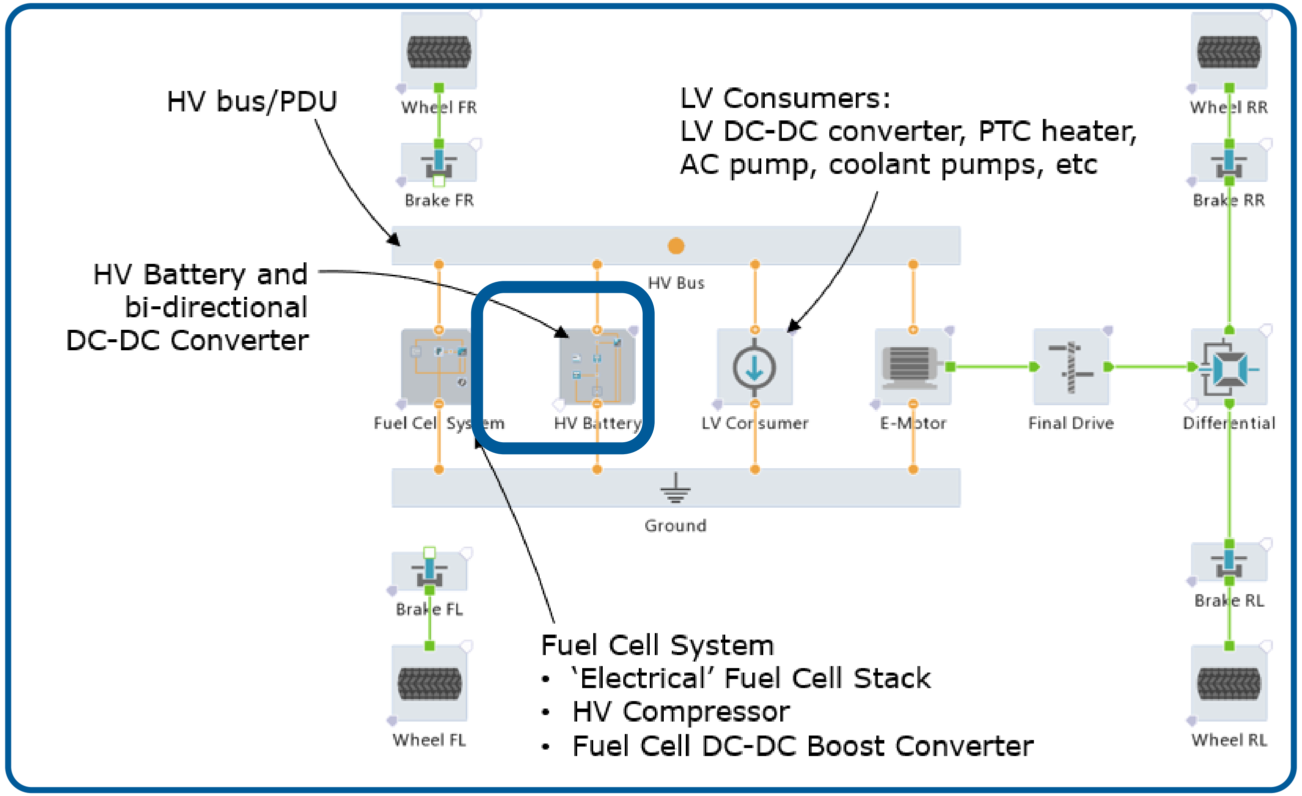


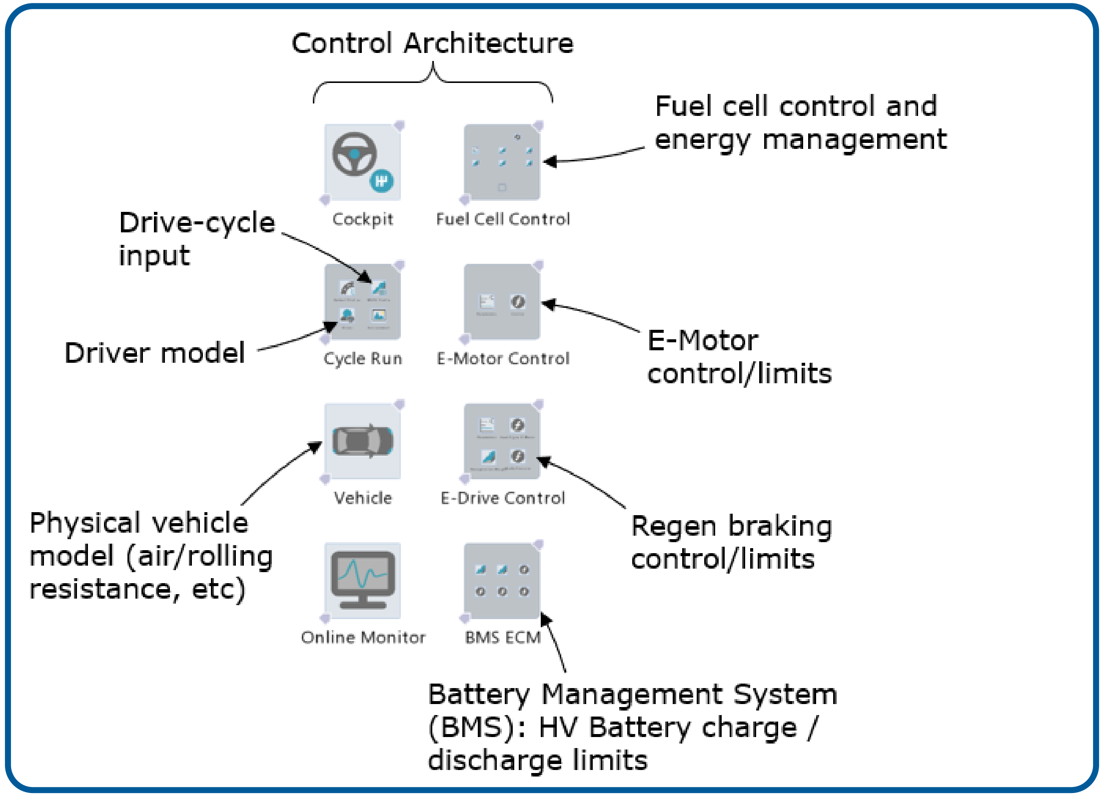
Optimised battery is able to produce more power

Parameters optimised for electrode thickness ratio (anode/cathode) to be greater than 1

FCEV Vehicle Simulation Model (AVL Cruise –M)

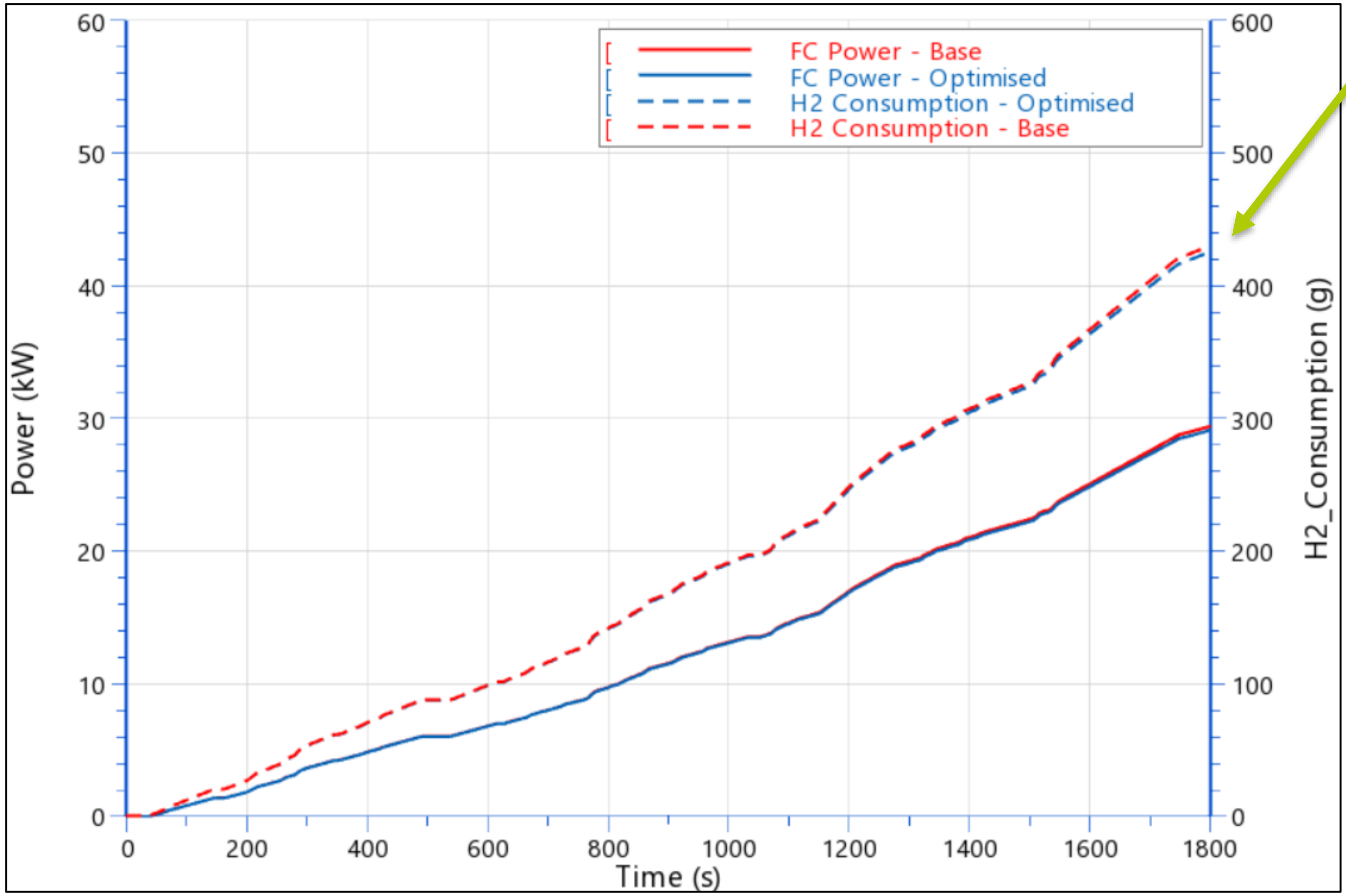
- Below is an overview of the Ford FCVGen1.0 vehicle model in CRUISE M, with the major components annotated.
- Within the highlighted HV Battery module, the circuit equivalent battery model was replaced with an electrochemical battery model developed in this project.





Base Model vs Optimised Model – WLTC

Fuel Cell Load and H2 Consumption Comparison



- Optimised Vehicle uses 1.02% less FC load
- Optimised vehicle uses 1.06% less Hydrogen

- The below table shows the potential reduction in cell capacity to complete the WLTC cycle.
- Therefore, the optimised battery could be 63% smaller in terms of capacity
- The optimised model can also withstand significantly higher c-rates.

	Base	Optimised
Capacity	11Ah	4Ah
Max C-Rate	23.92 1/h	59.68 1/h

Thank you

AVL

www.avl.com