CAN WE ACHIEVE ULTRA FAST CHARGING AND OPTIMAL PERFORMANCE CONDITIONS USING BETTER THERMAL MANAGEMENT?

Battery Cells & Systems Expo

30th June 2022

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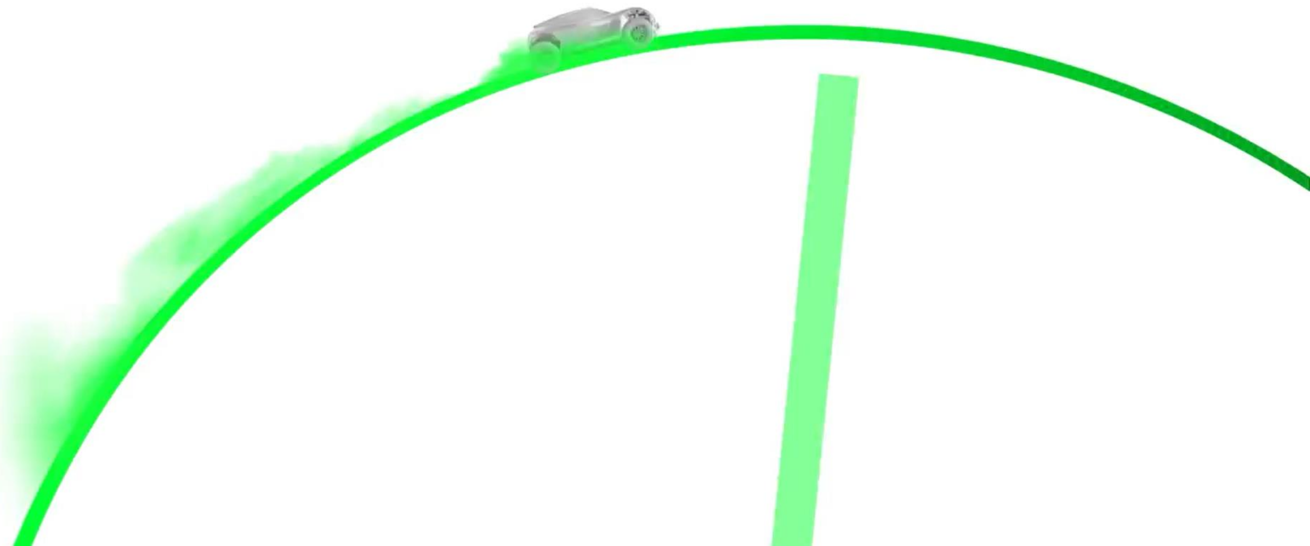
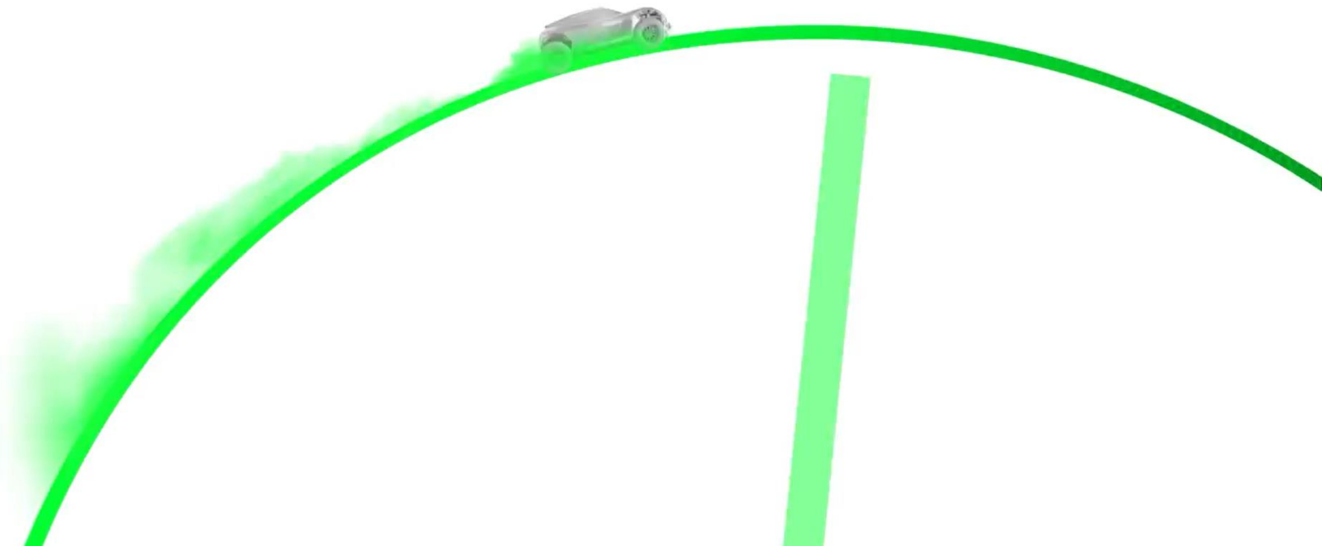
Manager – Battery Performance

FORTESCUE FUTURE INDUSTRIES x WILLIAMS ADVANCED ENGINEERING



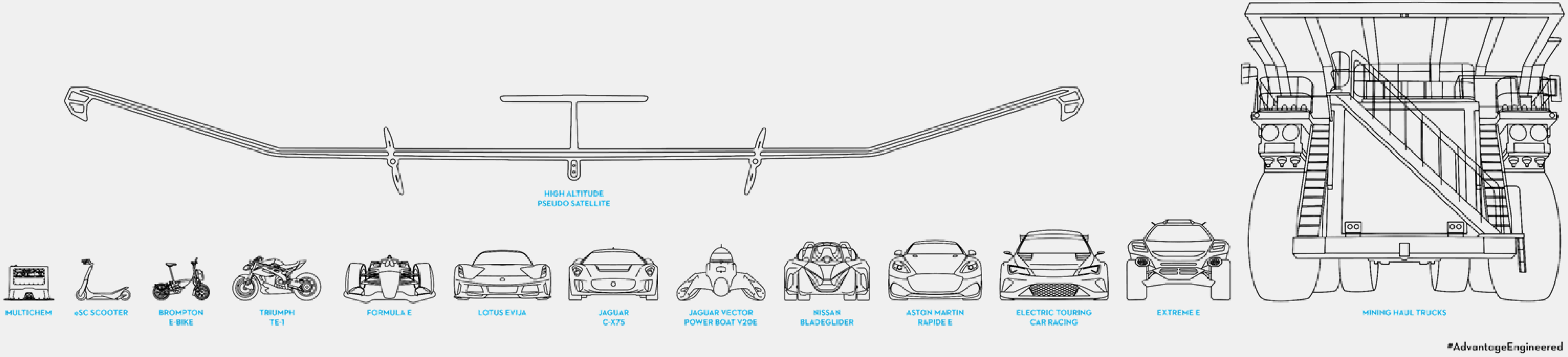
FMG ACQUIRES WILLIAMS ADVANCED ENGINEERING

+ Acquired by Fortescue Metals Group on the 1st of March 2022
+ Fortescue Future Industries (FFI) and Williams Advanced Engineering (WAE) are setting the pace for ground-breaking innovation in the green energy space to drive progress to combat climate change
+ WAE will bring its race bred battery technology to FFI, which will in turn enable Fortescue, one of the largest iron ore producers in the world and a heavy carbon emitter, to realise its industry leading 2030 net-zero target
+ FFI will utilise this expertise and technology to demonstrate to the world that the decarbonisation of heavy industry is possible and then deliver that technology to the significant global market



WILLIAMS ADVANCED ENGINEERING

WE ARE ELECTRIFICATION



CURRENT STATE OF FAST CHARGE

ULTRA FAST CHARGE USING BETTER THERMAL MANAGEMENT

Peak Charge Rate

~4x faster than the fastest charging car on sale in Europe

~2.3% SoC/min

Mercedes EQC

~4.8% SoC/min

Porsche Taycan

>20% SoC/min

WILLIAMS ADVANCED ENGINEERING

Motorsport Battery

Williams Advanced Engineering

WILLIAMS ADVANCED ENGINEERING

CURRENT STATE OF FAST CHARGE

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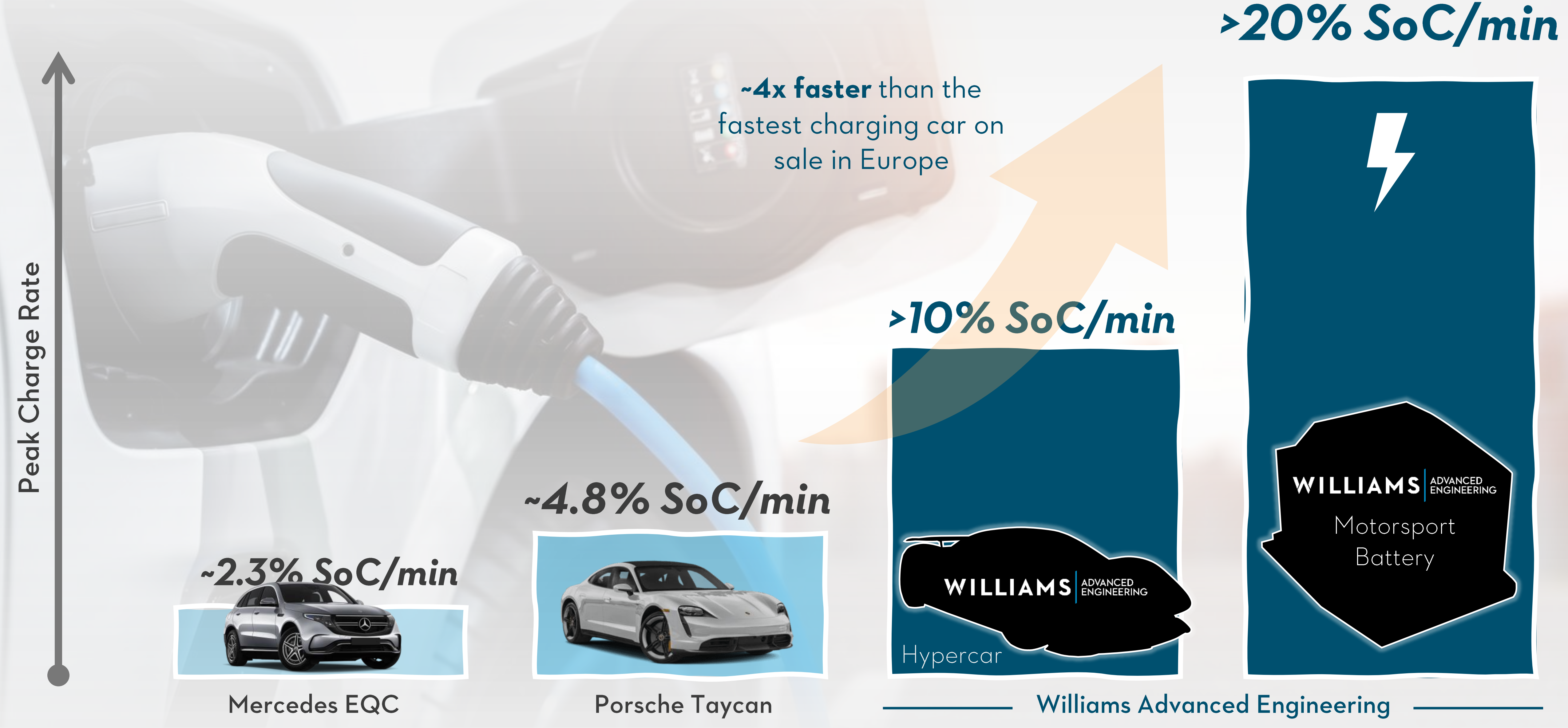


WHAT ARE THE KEY CHALLENGES

ULTRA FAST CHARGE USING BETTER THERMAL MANAGEMENT

Peak Charge Rate

~2.3% SoC/min

Mercedes EQC

~4.8% SoC/min

Porsche Taycan

>10% SoC/min

WILLIAMS ADVANCED ENGINEERING

Hypercar

>20% SoC/min

WILLIAMS ADVANCED ENGINEERING

Motorsport Battery

Williams Advanced Engineering

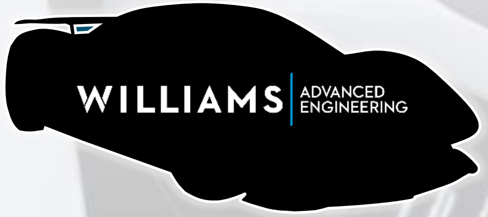
Key Challenges

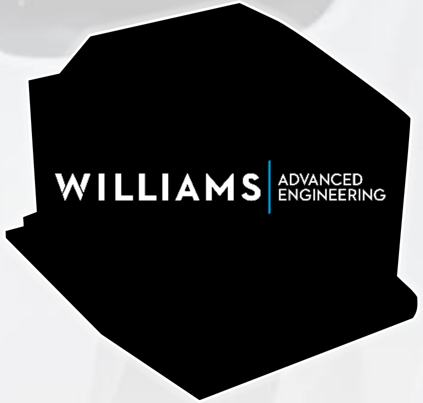
Li Plating & Dendrite Growth

Thermals / Over-heating

ENABLING ULTRA FAST CHARGE

ULTRA FAST CHARGE USING BETTER THERMAL MANAGEMENT





1 **Cell Selection**

High efficiency cells with low heat generation & low overpotentials

2 **Adaptive Electrode-Level Constraints**

Tracking and limiting anode potential. Adapting to SoH.

3 **Thermal Gradient & Hot Spot Estimation**

Feed back into the electrode-level state estimation for safety and accuracy.

4 **Thermal Forecasting**

Optimise charge strategy for future over-heating.

5 **Thermal Management System**

Application specific heating and cooling design to meet power targets.

WAE SOFTWARE APPROACH TO FAST CHARGE

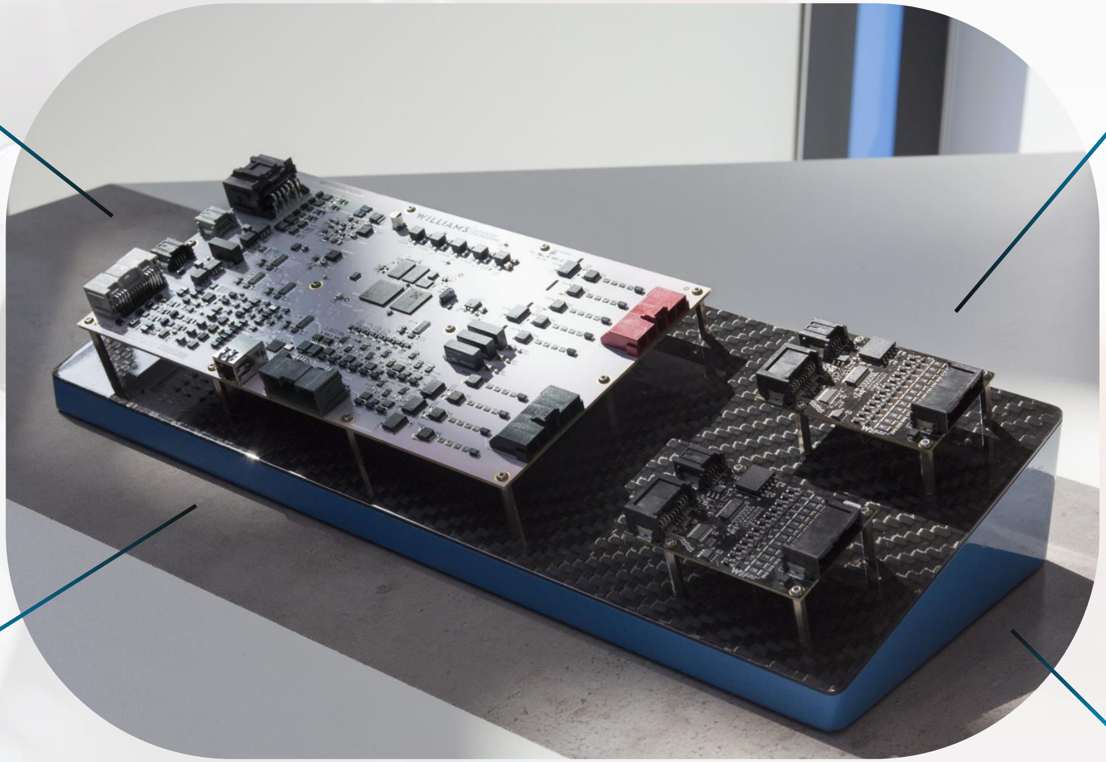
ULTRA FAST CHARGE USING BETTER THERMAL MANAGEMENT

Lithium Plating Observer

Track and constrain anode potential.

Charge Time Estimation

Simulate full charge on a DT to estimate time and thermals



Thermal Forecasting

Optimise charge speed now to avoid overheating later.

Health Adaptive

Combine degradation mode tracking to consider stoichiometric shift.

WILLIAMS ADVANCED ENGINEERING

WAE SOFTWARE APPROACH TO FAST CHARGE

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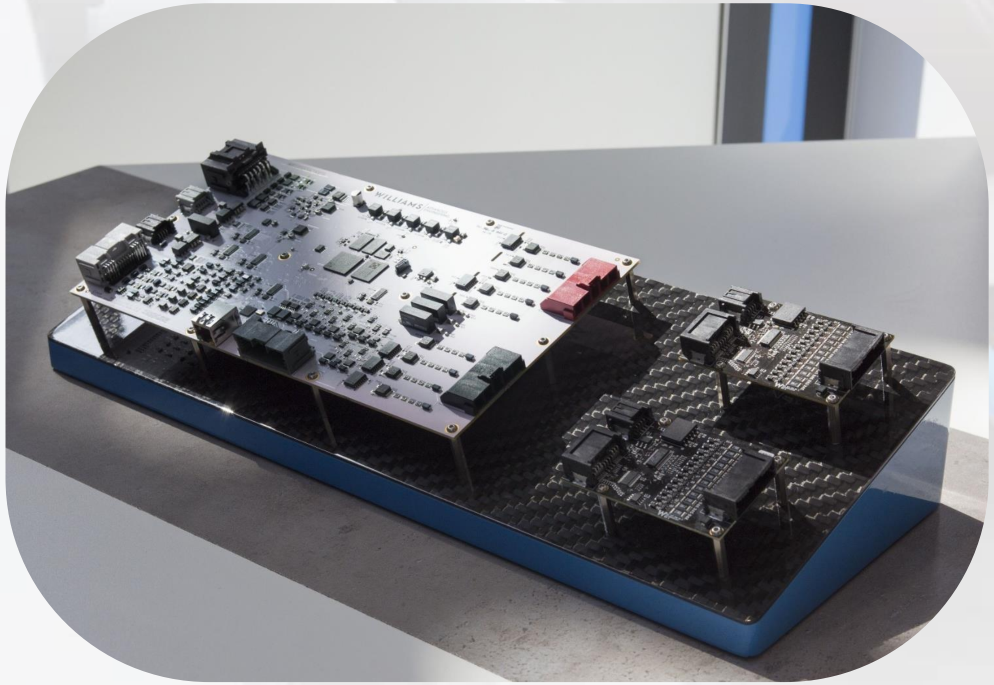


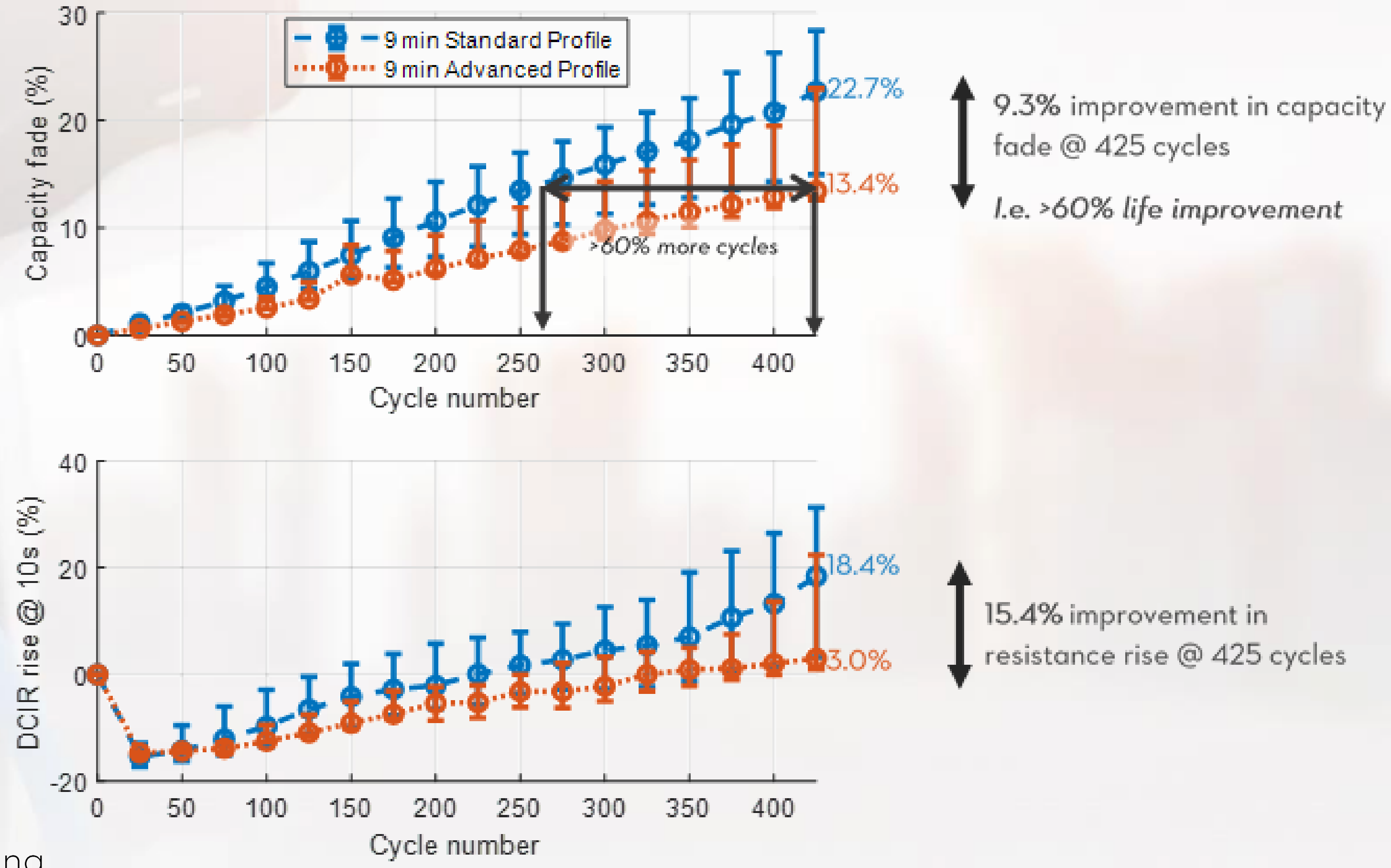
Thermal Forecasting

Optimise charge speed now to avoid overheating later.

Health Adaptive

Combine degradation mode tracking to consider stoichiometric shift.

Figure: WAE Advanced Fast Charge Profile based on minimising lithium plating shows a significant reduction in degradation, for the same charge time



WILLIAMS ADVANCED ENGINEERING

WHY IS THERMAL MANAGEMENT IMPORTANT

ULTRA FAST CHARGE USING BETTER THERMAL MANAGEMENT

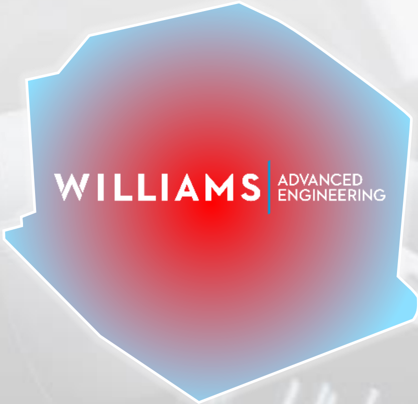
- Increased risk of lithium plating and dendrite growth.
- Higher overpotentials which lead to upper voltage limits at high charge rates.

- Safety risk of battery thermal runaway.
- Rapid degradation (e.g. SEI layer, electrolyte decomposition)

Pre-heating followed by capable and even cooling during charge is required to optimise charge speed, safety and degradation.

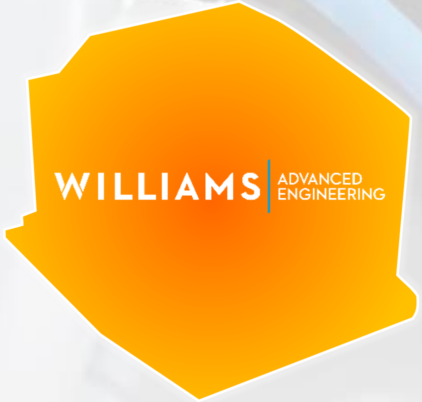
IMPACTS OF THERMAL GRADIENTS

ULTRA FAST CHARGE USING BETTER THERMAL MANAGEMENT



High Thermal Gradients and Hot Spots

VS



Even Temperature Distribution

Lack of visibility increases thermal safety margin needs.

State estimation accuracy compromised.

Unequal degradation.

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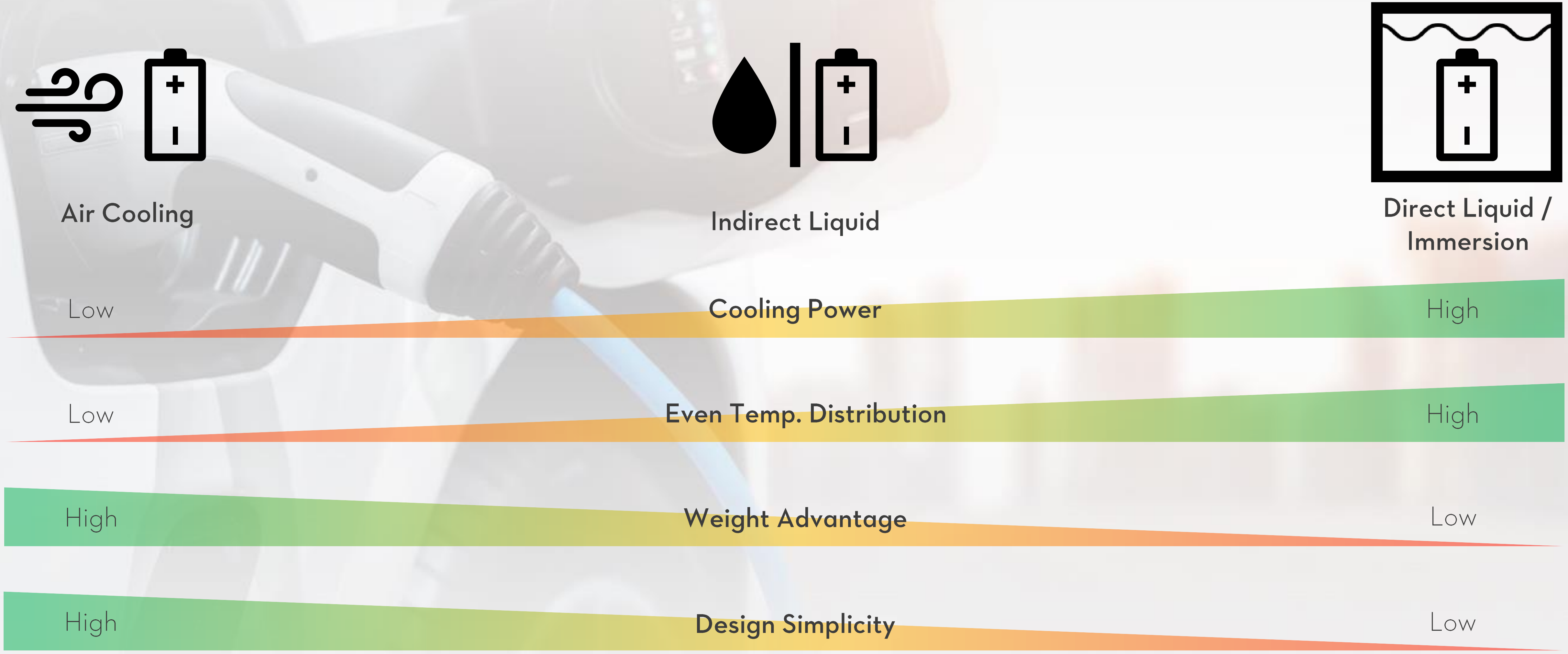
THERMAL MANAGEMENT DESIGNS

ULTRA FAST CHARGE USING BETTER THERMAL MANAGEMENT



THERMAL MANAGEMENT DESIGNS

ULTRA FAST CHARGE USING BETTER THERMAL MANAGEMENT

Air Cooling

Indirect Liquid

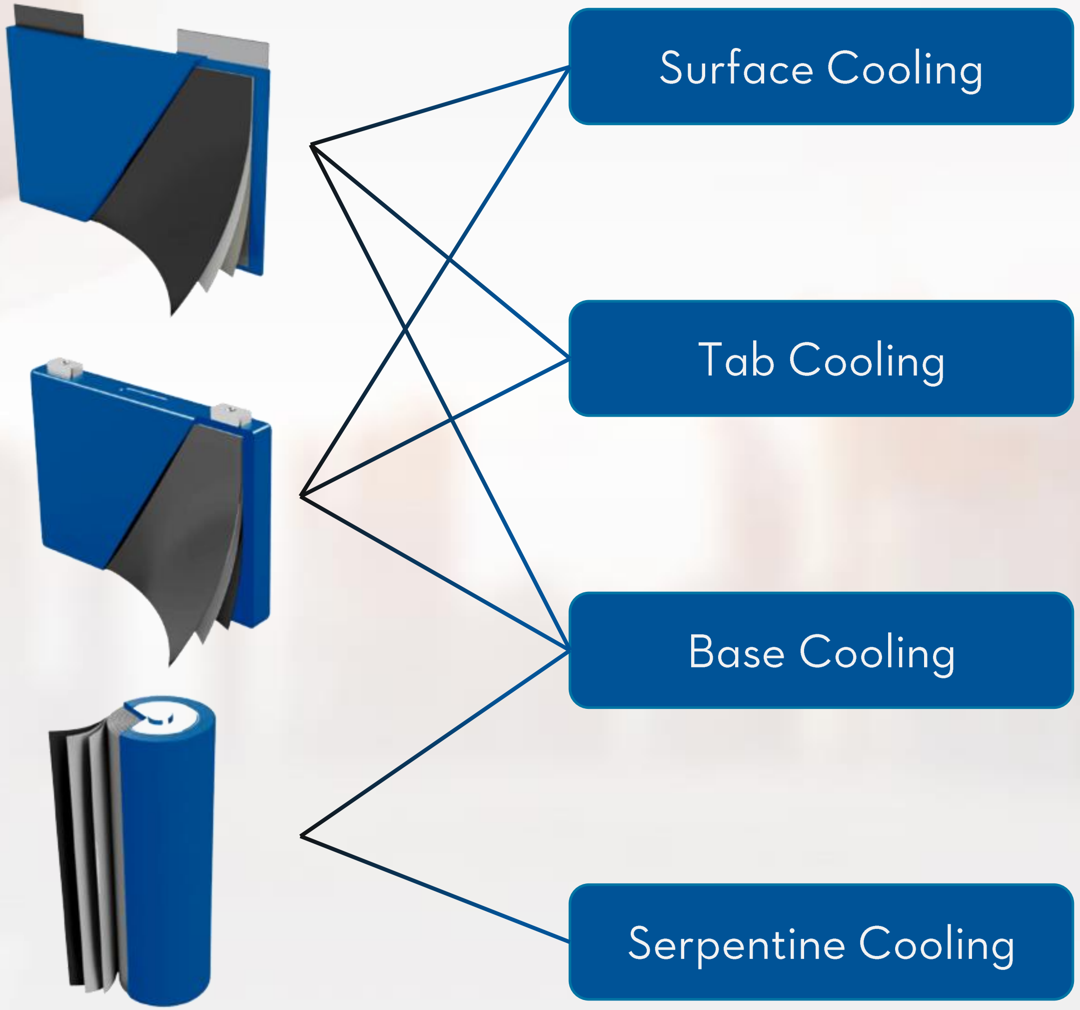
Direct Liquid / Immersion

Low — Cooling Power — High

Low — Even Temp. Distribution — High

High — Weight Advantage — Low

High — Design Simplicity — Low



WILLIAMS ADVANCED ENGINEERING

ULTRA HIGH PERFORMANCE EV

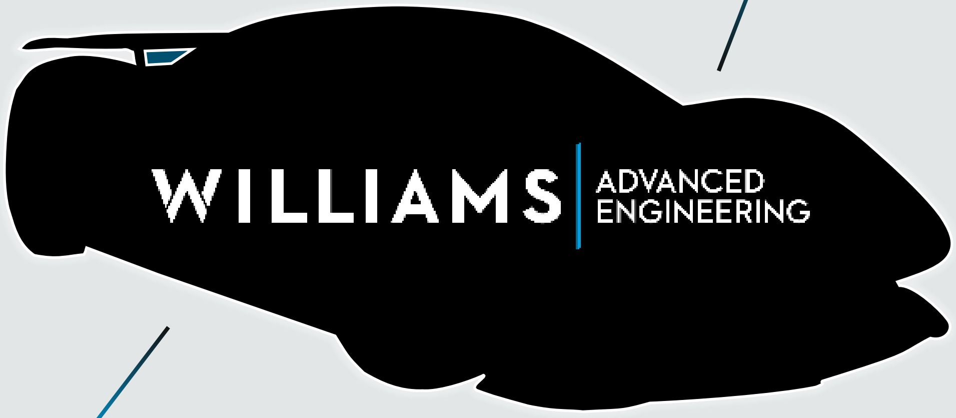
ULTRA FAST CHARGE USING BETTER THERMAL MANAGEMENT

2,000 kW Battery

Ultra high power dense battery.

>350 kW HV Charging

Sub 10 mins ultra fast charge demonstrated at pack level

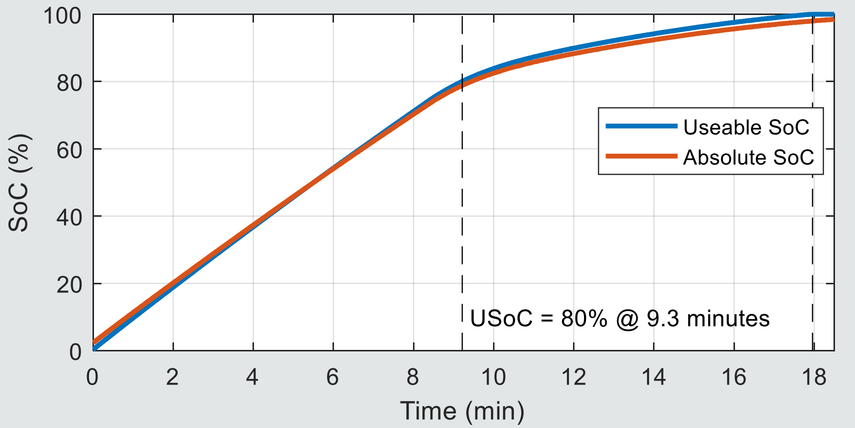


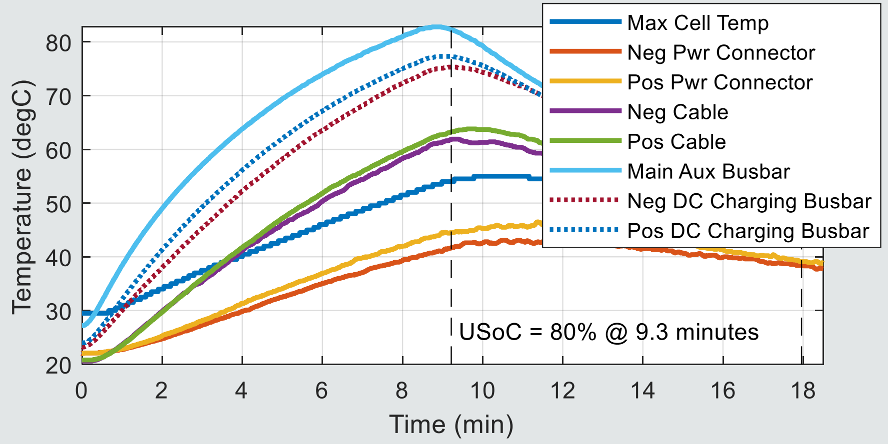
1.4 MW E-drive

Advanced integration for power-dense e-axles.

High Performance BMS

WAE BMS combining high spec HW with intelligent algorithms.





2014 – FORMULA E GEN 1

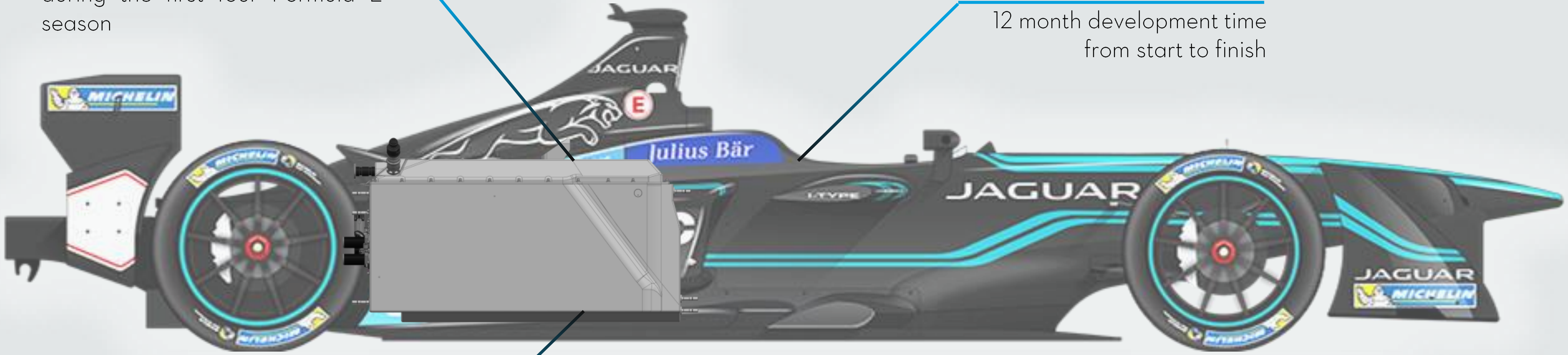
THE STAKES ARE HIGH FOR ELECTRIFICATION IN THE RACE TO NET-ZERO

SIGNATURE RELIABILITY

99.8% reliability out of 440 starts during the first four Formula E season

RAPID END-TO-END DEVELOPMENT

12 month development time from start to finish



PUSHING TECHNOLOGICAL BOUNDARIES

Data-rich motorsport environment encourages a 'fail-fast' development cycle that pushes engineering teams outside their comfort zone.

WAE was tasked to design and manufacture the Gen 1 Formula E battery for the first four seasons. WAE had just 12 months to complete the project end-to-end and completed four seasons of Formula E with a reliability rating of 99.8% out of 440 starts. WAE has recently committed to designing and manufacturing the Gen 3 Formula E battery starting in 2023 onwards.

2010 2012 **2014 Formula E Gen 1** 2016 2018

2023 - FORMULA E GEN 3

ULTRA FAST CHARGE USING BETTER THERMAL MANAGEMENT

600kW Rapid Charge Ready

600kW charge capability

Ultra High Efficiency

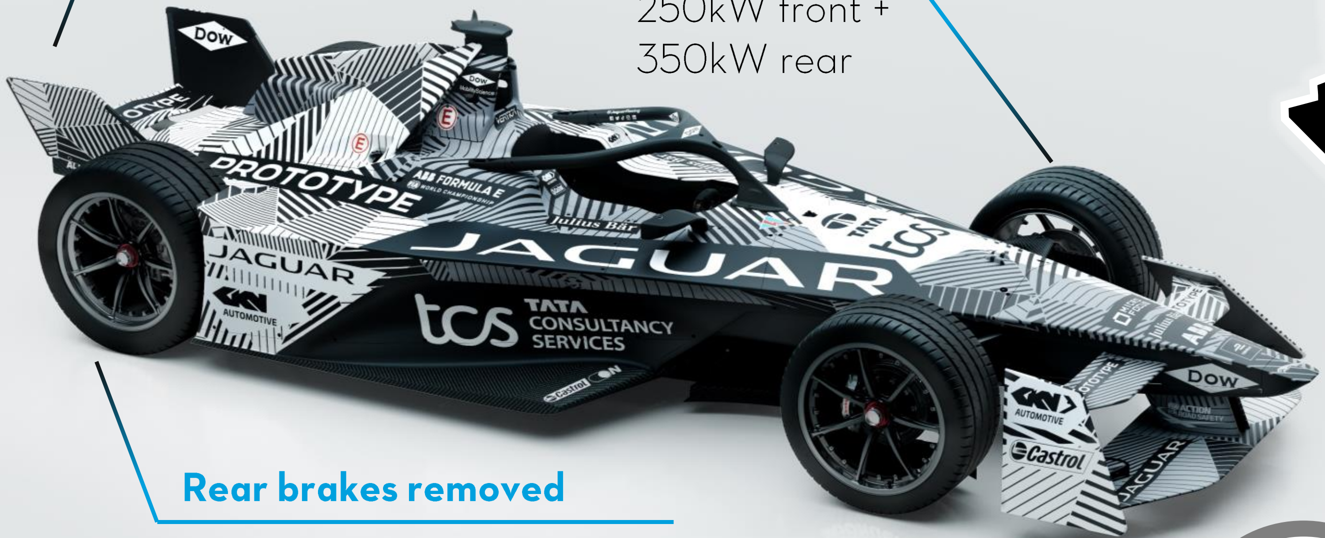
>40% energy deployed from regenerative braking @ 600kW

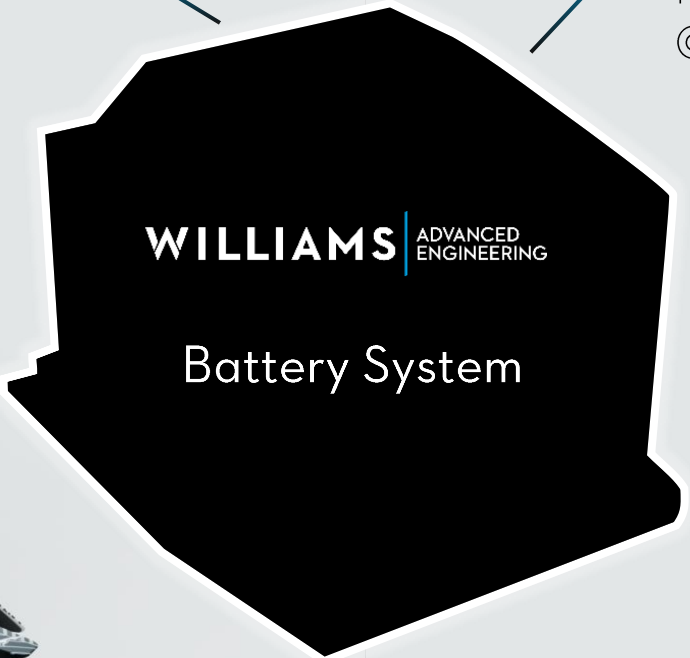
350 kW Rear Electric Motor

Capable of 200mph (320kph) top speed

600kW Regen

250kW front + 350kW rear





Ultra Lightweight

High packing efficiency from tailored cell design

Rear brakes removed

No rear hydraulic brakes

2018 | 2020 | 2022 | **2023 Formula E Gen 3** | 2024 | 2026 | 2028

WILLIAMS ADVANCED ENGINEERING

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