ASSESSING THE COMMERCIAL VIABILITY OF A UK BATTERY ASSEMBLY FACILITY FOR NICHE VOLUME VEHICLE MANUFACTURERS

Deploying industrialisation strategy to help the UK achieve net zero

CONTENTS

INTRODUCTION

The UK automotive industry has a diverse mix of sector-leading manufacturers that produce vehicles in 'niche volumes' for a range of diverse, specialist market sectors. The volume requirements and flexible product specifications of niche volume manufacturers are not aligned with the high-volume outputs expected from the emerging 'giga-factories' and facilities aimed at mass-market volume production.

Ricardo has been applying its expertise in niche volume manufacturing, battery R&D, second life and recycling, complex supply chain management and strategic consultancy to assess the commercial viability of a facility to assemble battery packs for UK manufacturers which produce fewer than 10,000 electrified vehicles per year. Funded by the Advanced Propulsion Centre's Automotive Transformation Fund supported by the UK Government's Department for Business, Energy and Industrial Strategy, our economic study considers how to meet the battery hardware needs of these diverse manufacturers across a wide range of business sectors, by securing a UK supply chain in critical electric vehicle battery components.

These UK electrified vehicle manufacturers include some of the world's best-known prestige, high performance and specialist brands which create their luxury cars, special vehicles, or off-highway machines for a customer base in the low thousands. This compares with the hundreds of thousands or millions of vehicles produced for the mass market.

A niche volume battery manufacturing facility will help to establish a robust supply chain for these critical electrification components. In doing so, it will deliver national competitive advantage for the UK, and support the mass adoption of electrification by making it more affordable, helping to contribute to the green bounce-back through sustainable practices.

Ricardo's future manufacturing strategy is very much aligned to this emerging need for electrified vehicle components. Leveraging its proven track record in industrialising innovative technology which has been developed over the past decade through completion of multiple powertrain and driveline production programmes, Ricardo identified three clear objectives as part of the project:

- **Strategy:** a strategic market study to confirm demand and guide the development of customer requirements
- **Design:** how to deliver a clean sheet design for a new niche volume assembly facility
- **Deployment:** Deploying the New Product Introduction (NPI) industrialisation experts to develop the solution

The approach, process and outcome, will enable Ricardo to pursue its future manufacturing strategy, and help the UK reach its ambitious targets to achieve its net zero goals.

RICARDO BATTERY ASSEMBLY

MARKET DEMAND

Confirming the market demand is one of the first steps of any product development project. A thorough study was undertaken to review the anticipated target market sectors and build an understanding of the market drivers - legislative, end client requirements, economical, technological, and more - for adoption of electrified technology, including a review of published technology roadmaps. The investment required for a battery assembly facility was already understood to be significant, so it was essential to validate the long-term requirement to support the business case and investment decisions.

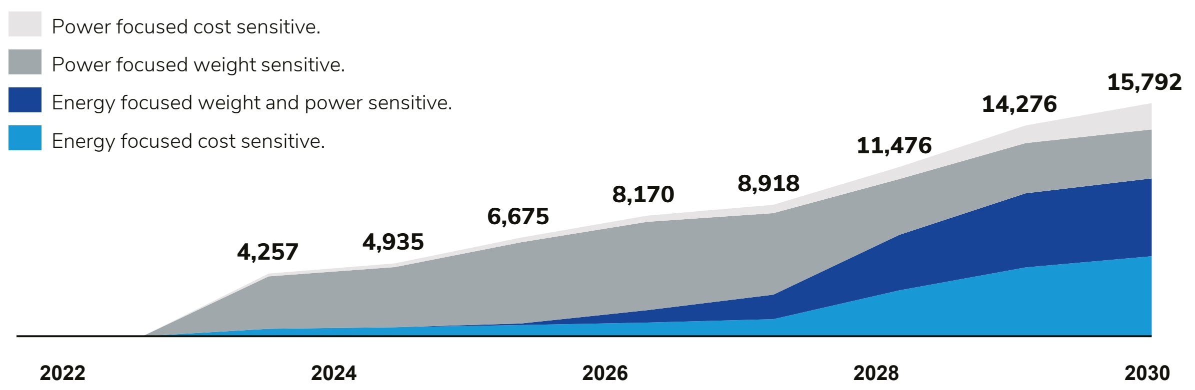
Generating a market forecast for the identified sectors, and assessing to understand the obtainable share, then provided both a volume and value estimation: a fundamental input to any business case.

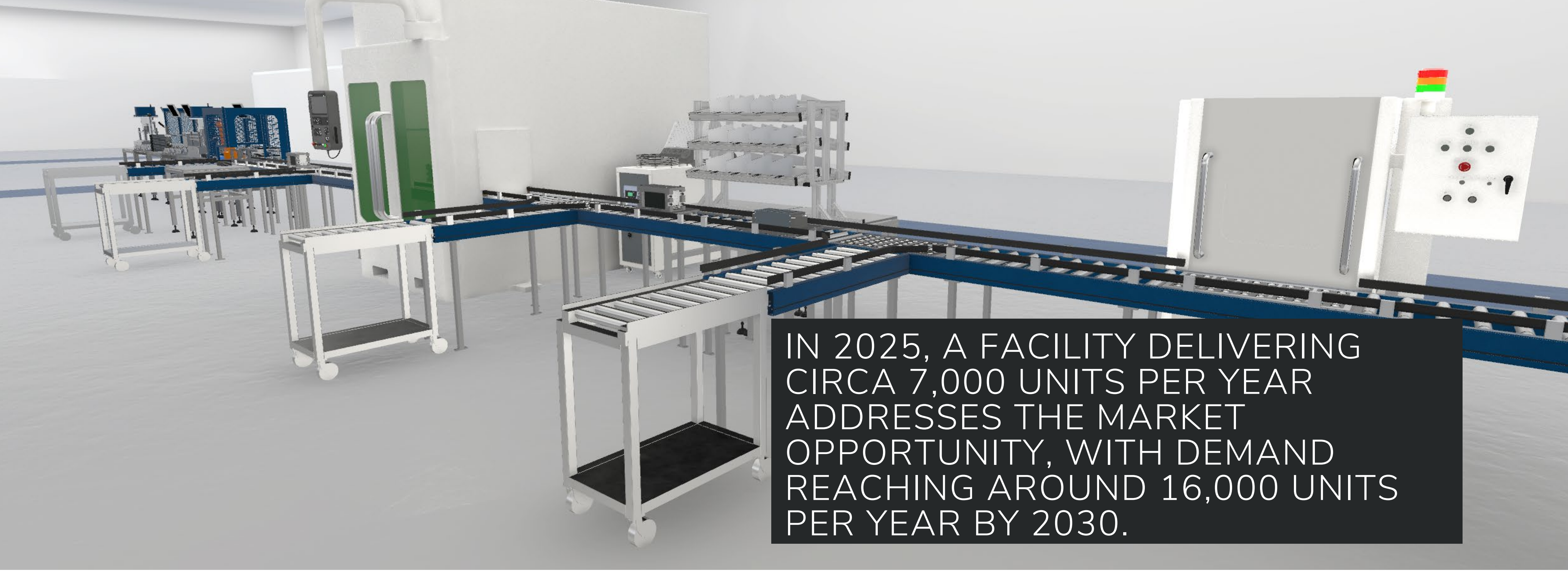
Engaging with customers in parallel enabled a clear understanding of both their commercial and technical requirements and desires. This activity, combined with a technical study of the target applications, provided the input for a design study to develop a range of battery pack specifications that would meet the varying needs of our customers while also suiting the requirements of a niche volume assembly facility.

The market forecast concluded with the expectation that high-performance automotive – an area of high activity for the UK - will represent the lion's share of the addressable demand and should therefore be the key target for a battery assembly facility. In addition, the commercial vehicle and off highway sectors also present an opportunity, sharing similar volume requirements.

In 2025, a facility delivering circa 7,000 units per year addresses the market opportunity; although plug-in hybrid electric vehicle (PHEV) packs would be manufactured in higher quantities, battery electric vehicle (BEV) packs will create higher revenues. Later in the decade a significant shift in market share from PHEV battery packs to BEV battery packs is expected, with demand reaching around 16,000 units per year by 2030.

CELL FORMAT





IN 2025, A FACILITY DELIVERING CIRCA 7,000 UNITS PER YEAR ADDRESSES THE MARKET OPPORTUNITY, WITH DEMAND REACHING AROUND 16,000 UNITS PER YEAR BY 2030.

the market value will not increase in proportion with the overall capacity demand since PHEV battery cells are more valuable, owing to more expensive chemistries for higher C-rates (C-rate is a measure of the charge or discharge rate of a battery - a battery would fully discharge in 1 hour at a '1C' discharge rate, or in 6 minutes at 10C).

Focusing on the high-performance sector opportunity, using input from customers, cell suppliers and the Ricardo battery engineering teams, some potential specifications were drafted for module designs that would meet the requirements and provide an indication of the capability required from a new facility.

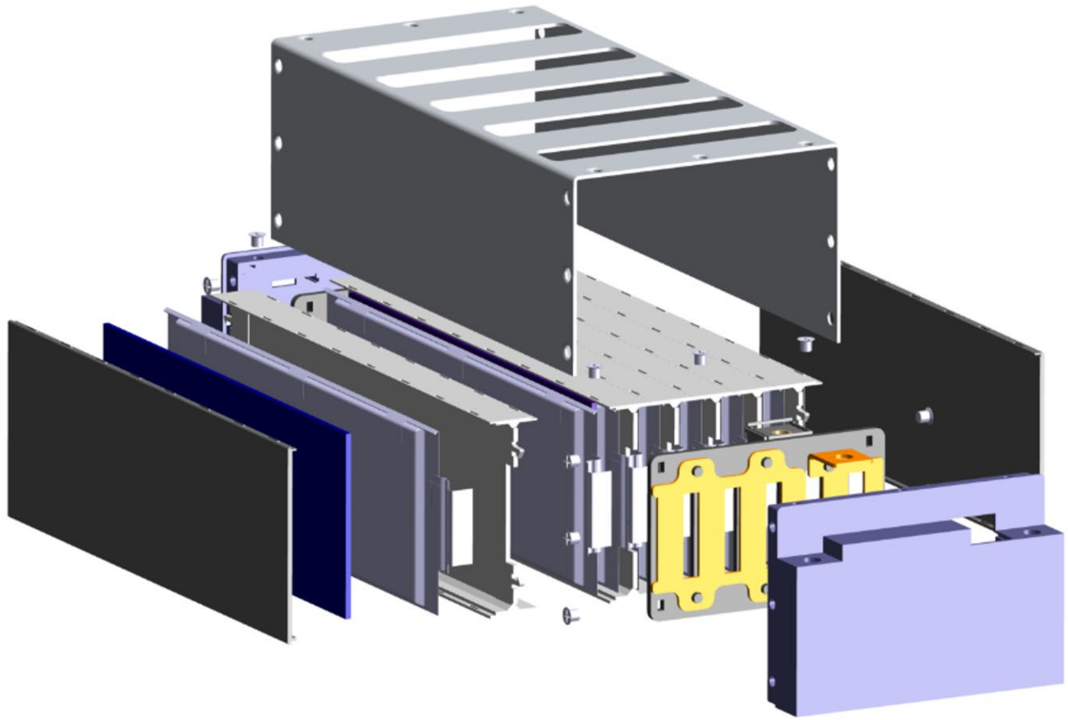
Considering a 'Super PHEV' module, a solution of 12 pouch cells in a module, capable of 20C discharge and energy capacity of >1 kilowatt-hour (kWh) should be achieved. Similarly, for a 'Super BEV' 12 pouch cell module, 4.5C should be achieved while providing capacity of 3.3kWh. Both conductive aluminium cooling plate and immersion cooling were appropriate thermal solutions for these applications, however an ultra-low volume 'Hypercar' PHEV requirement was likely to demand immersion cooling in order to deliver a >40C discharge rate.

The key conclusion from this phase is that considerable thought should be applied to the facility scalability and the decisions regarding investment in manufacturing assets, as increases in demand due to upcoming limitations on internal combustion engine vehicles, combined with the changing focus from PHEV to BEV, will lead to a change in customers' requirements in the relatively near future.

PRODUCT DESIGN

Whether the product design already exists from the customer or a third party, or the design is provided by a turn-key Ricardo project, it must be thoroughly understood to be industrialised. Within the project the Ricardo New Product Introduction (NPI) industrialisation engineers worked closely with the battery design team: an iterative process of Design for Assembly (DFA) and virtual build, in parallel with the assembly process development.

Previous battery projects had shown a wide range of assembly and manufacturing methods used, each with their own advantages and disadvantages. Two key targets of the DFA were to create a process aligned with niche volume assembly, as opposed to a higher volume, more automated approach, and an ambition for a more sustainable design that could support a potential future second-life application. Additionally, a more general requirement was to consider potential future design variants and therefore achieve a modular or scalable design architecture, despite the pressures of vehicle packaging limitations.



A review of the end-of-life and second-life options showed that although this area is still immature and will continue to develop over the next decade, the ability to disassemble battery packs and modules would clearly be a benefit.

The ideal situation would be for cells to be easily replaceable should one fail. Commonly, however, these are permanently joined to their busbars through laser or ultrasonic welding which does not allow easy rework.

Other options to improve the disassembly process include the use of sprung terminals for cylindrical format cells, or mechanical bolted joints on prismatic cells casings.

These solutions would allow the pack to be broken down to a cell level, with modules designed to facilitate the removal and replacement of cells. In reality, many current designs of battery pack include module cases that use welding to join upper and lower parts

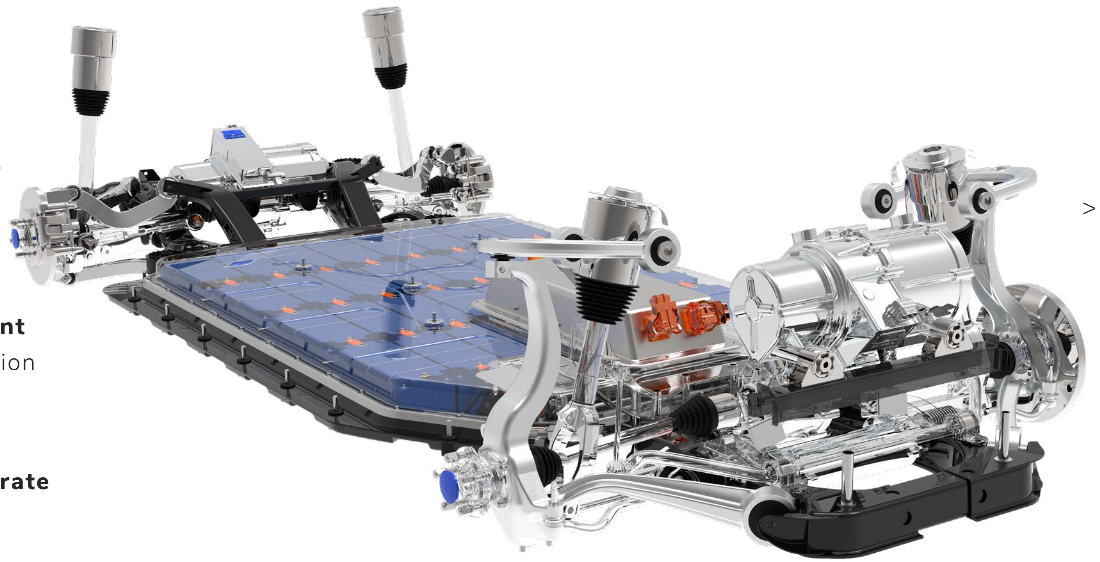
FOR THE HIGH PERFORMANCE VEHICLE SECTOR WE HAVE IDENTIFIED THE FOLLOWING CUSTOMER REQUIREMENTS FOR BATTERY ELECTRIC VEHICLES FROM 2025 ONWARDS

Cells
NMC, Pouch

Peak power density
>1000 W/kg

Thermal management
Dual plate → Immersion

Charge acceptance rate
3C – 5C+



Cost
Niche competitive

Life / Warranty
> 8 years & 160,000km

Pack energy density
> 250 Wh/kg

Voltage
> 900 V

together. The need to maintain a certain level of compression on cells (particularly pouch cells), safety, robustness and the emergence of immersion cooling are key drivers of permanent joining solutions.

The proposed battery design solution in this project explored the option of using mechanical fasteners to secure module parts together. This not only permits future rework, rebuild and reuse but also supports the flexible low volume assembly ethos: it's more straightforward to re-deploy an electric nut-runner than a laser weld station, and requires significantly less investment.

An early decision in the design process was to select the cell format, either pouch, prismatic or cylindrical. In the UK, the availability of cells that would meet the challenging technical requirements of customers was one driver. The responses from UK cell suppliers did not indicate that the industry is converging on a common solution, with all three formats being favoured by different suppliers for different reasons, on top of this each cell format is also available in a variety of sizes. Pouch and prismatic cells appear to fit the market requirements better than cylindrical cells, but cylindrical cells remain a good option for some applications due to the increased standardisation giving more variety of technical options and more flexible battery pack packaging. Pouch cells are a good fit for high-performance applications due to superior power and energy density, but lack of a casing means swell must be controlled in the module design.

Multiple solutions were considered and compared with the requirements, before agreeing that a 300x100mm pouch cell was the best compromise.

Understanding that the pack design must be modular and scalable, which together with the challenging packaging constraints of the high-performance vehicle application, informed the decision to pursue a cell-module-pack structure. The alternative was to investigate a cell-to-pack solution. This emerging approach is beginning to disrupt the battery design status quo and presents advantages in packaging and complexity, but tends to suit a 'skateboard' style battery pack and chassis design. The Porsche Taycan has shown that skateboard style packaging can work: however, other manufacturers may not tolerate raising the cabin and occupants by approximately 150mm with this approach to design.

Another key design decision was the pouch cell tab to busbar joining method. Pouch cells typically use aluminium and copper foil tabs for which the two common joining methods are laser and ultrasonic welding. Ultrasonic welding has three key advantages: significantly lower investment requirements; typically easier process setup; and more tolerant of variation between parts. The reason it wasn't selected, however, was that the extra space it requires to access both sides of the joint – in a pack comprising many modules of opposed tab cells - is significant and impacts the volumetric efficiency beyond what is acceptable.

Laser welding was understood to require more process development to achieve a reliable joint and an automated laser weld station is a significant investment. However, it can achieve short cycle times, good joint characteristics, and be complemented by real time process monitoring equipment.

The resulting BEV pack design comprised 40 modules of 12 pouch cells in a 2P6S arrangement aimed at achieving the target specifications of 130kWh, >500kW in a package weighing circa 600kg.

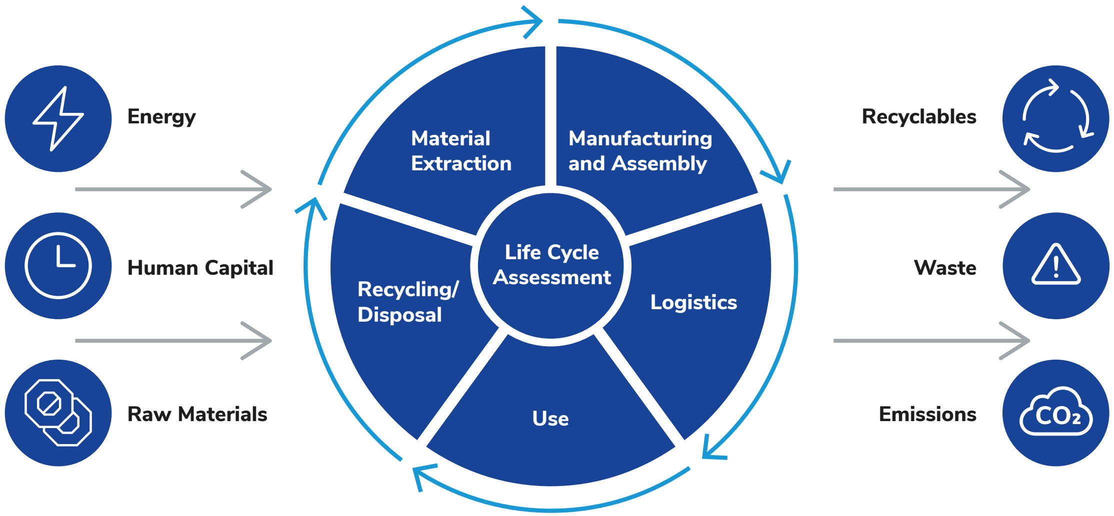
> THE STUDIED BEV PACK DESIGN COMPRISED 40 MODULES OF 12 POUCH CELLS IN A 2P6S ARRANGEMENT AIMED AT ACHIEVING THE TARGET SPECIFICATIONS OF 130KWH, >500KW IN A PACKAGE WEIGHING CIRCA 600KG.

SUPPLY CHAIN

One aim of the feasibility study was to understand the UK supply chain for battery components in greater detail. To achieve this, the Ricardo procurement team undertook an investigation into the status of the UK supply chain, focusing on cells and the other major battery components.

Various sources were used to build a database of relevant suppliers with presence in the UK. By conducting interviews with cell suppliers to understand their outlook and product offering relevant to a niche volume battery pack, then profiling suppliers for other key components such as battery management systems, thermal systems, enclosures, and thermal materials and fluids, the team has acquired an in-depth understanding of the current and future cell UK supply options. The assessment also aimed to understand a supplier's technical capability and identify gaps in the UK supply chain relative to off-shore supply chains.

A LIFE CYCLE ASSESSMENT IS THE HOLISTIC TABULATION AND INTERPRETATION OF ENVIRONMENTAL IMPACT RESULTING FROM THE LIFE OF A PRODUCT



The key findings from the supply chain study:

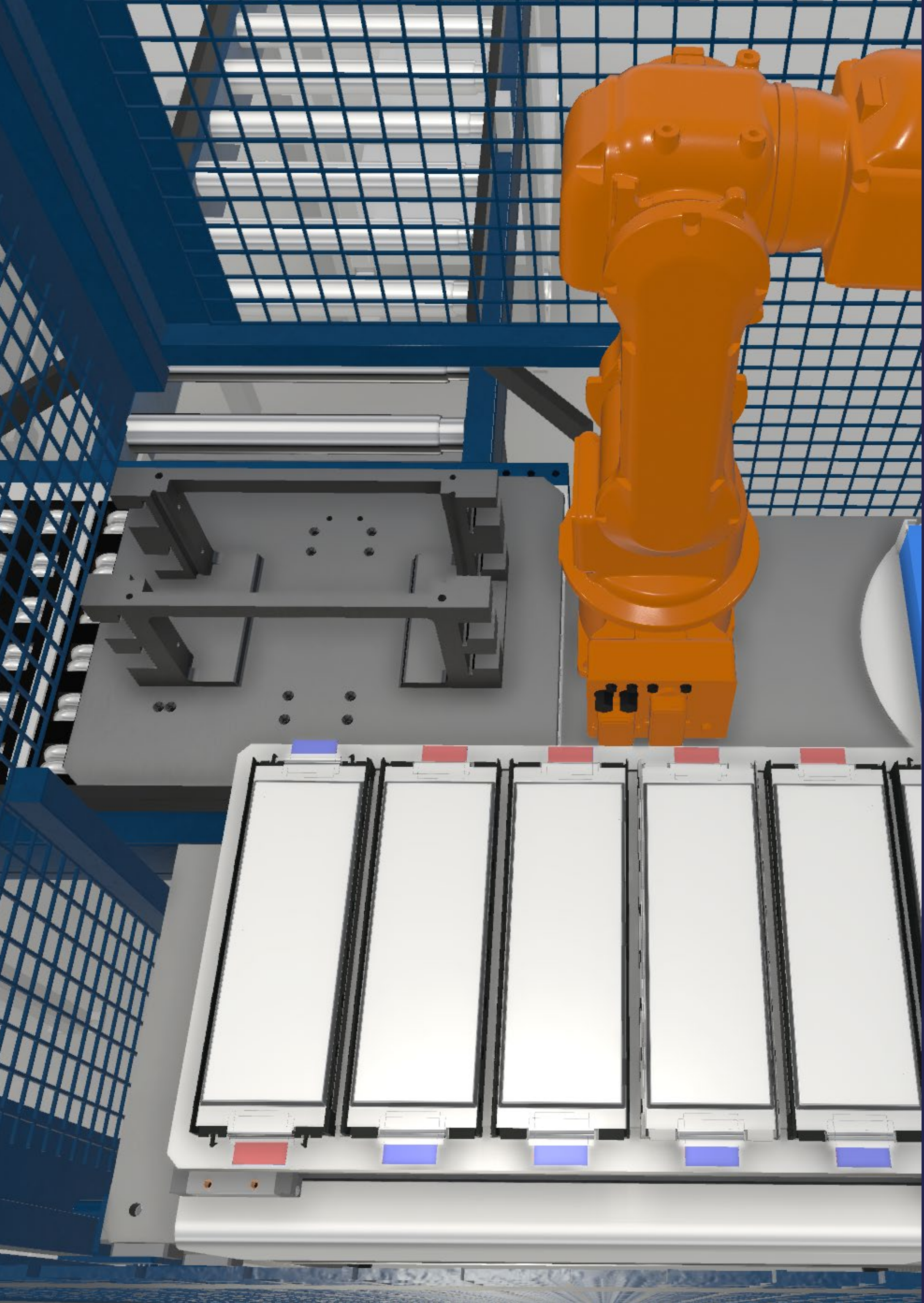
- UK cell suppliers are currently at an earlier stage of technology development compared to counterparts in the EU and rest of the world, but the technology roadmaps from UK suppliers are encouraging and forecast a technical development outlook that will fulfil the future demands of the niche volume sector. In the short-term supply is limited and supply may be needed from Europe or Asia, while the UK supply chain completes the development identified in its roadmap
- For procurement of high value, high complexity components in the near term, the UK market will rely on a diverse mix of global companies with bases or distribution networks in the UK
- Aside from the cells currently, there does not seem to be a significant gap in component availability and quality in the UK, although supply lines are in early-stage development so capacity limitations may be evident in the near term

THE TECHNOLOGY ROADMAPS FROM UK SUPPLIERS ARE ENCOURAGING AND FORECAST A TECHNICAL DEVELOPMENT OUTLOOK THAT WILL FULFIL THE FUTURE DEMANDS OF THE NICHE VOLUME SECTOR.

The supply chain assessment also reviewed the logistics and transport requirements for electric vehicle batteries and their major components. Battery logistics and the requirements for safe packaging and transportation are well defined, with the major logistics service providers offering or developing dedicated battery services to support the rapid growth in this market. The costs and safety requirements of moving batteries mean that there is significant advantage in locating cell manufacture, module/pack assembly and the original equipment manufacturer within close proximity of one another.

The impacts of UK trade agreements on electric vehicle battery and component logistics were also factored into the project. The EU-UK Trade and Cooperation Agreement and the six-year phase in period to a permanent state from 2027 allows for a progressive move towards a greater percentage of local (UK/EU) Bill of Material (BoM) content, while driving local investment in local electric supply chains.

Increasingly, the market has a rising focus on sustainability, with significant effort being directed towards the development of industry standards and internal processes that enable all members of the customer base and supply chain to follow a similar path to becoming net zero operations. Existing and future Ricardo manufacturing projects are focusing on future improvement, with life cycle assessment and revised supplier nomination processes being put in place.



PROCESS DESIGN

The assembly process starts early in the design phase, in parallel with the Design For Assembly activity. 3D design data is used to plan an assembly sequence and conduct 'virtual builds': identifying any assembly issues such as tooling access, inadequate glidepaths, and quality concerns.

The tabulated assembly process flow can be populated with estimated step times using experience and estimator tools, and complemented by practical trials, if needed. Using the volume demand, the takt time is calculated for each assembly operation, after making allowances for inefficiencies (scrap, rework etc.) the target cycle time is derived. Reviewing the assembly steps against the target cycle time allows assembly station quantity and content to be developed. It is important to also consider any quality check steps and the stage in the assembly process at which they are completed, to maintain a no faults forwards philosophy. This working practice and the process steps form the basis of the process FMEA that is further developed through the pre-production phases.

As the number of assembly stations are understood, the assembly team requirements can be planned - a key business case input. As well as main-line assembly operators, this planning must also include team members to support supervision, sub-assemblies, and any end of line quality checks or tests.

EQUIPMENT AND FACILITY

The facility was developed from initial layout sketches through 2D into 3D CAD and a full digital twin was created using virtual reality software. The virtual environment was created to enable the ergonomics and equipment layout to be trialled digitally before any physical work could take place.

To deliver the battery pack products identified, an iterative design process was used to define a facility with:

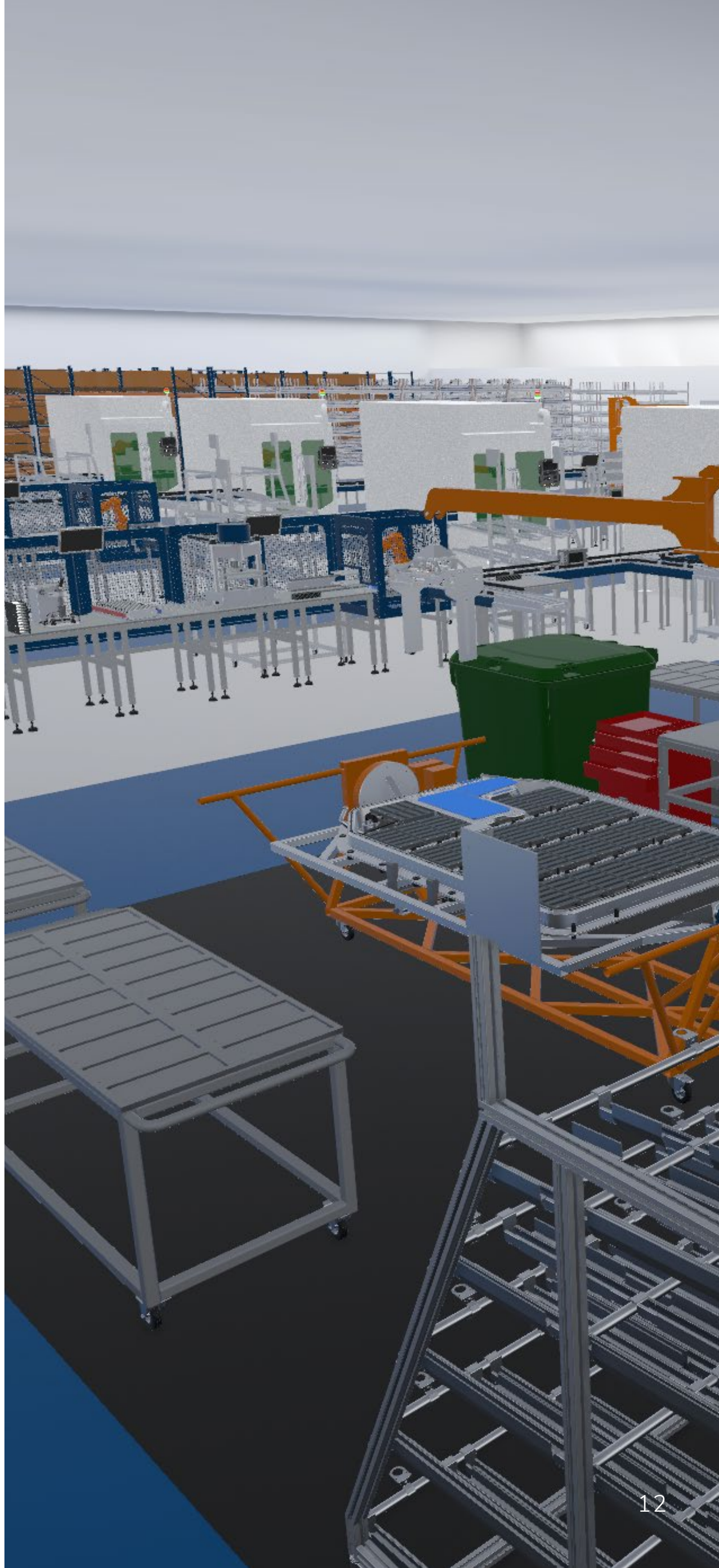
- Four module assembly and test lines
- Five pack assembly stations
- Pack end of line test
- Prototype and ultra-low volume module assembly area
- All additional functions needed to support the manufacturing operation

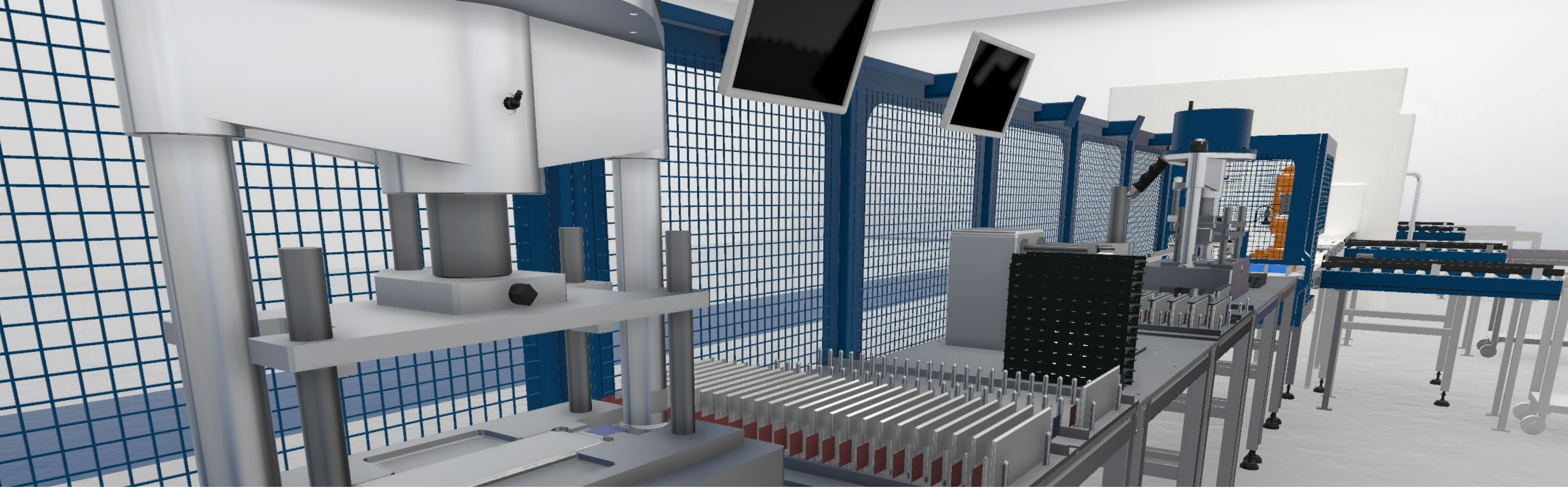
The proposed solution is a 5,000m² facility capable of producing up to 10,000 battery packs per year for multiple customers and able to accommodate a range of variants.

The target was to retain scalability and flexibility within the facility design and to control investment where possible. This required focus on finding the right balance between manual and automated assembly, selecting operator quantities and working patterns to achieve efficiency, while not becoming a high-volume producer with limited scope for future change, and still retaining overall value for money and a high-quality output.

The takt times for module assembly are very short, considering their complexity. For a 40 module BEV pack at a volume of 2,000 packs per year, the takt is approximately two minutes for a single module line working on double shift. Increased shift working and multiple lines were favoured over increased automation to control investment and retain flexibility.

Key areas of focus in this stage were: the laser welding station and its quality monitoring options; and the end of line test equipment for both module and pack assemblies. Enquiries with several suppliers of each piece of equipment yielded valuable feedback that was incorporated back into the design and assembly processes; health and safety planning; and financial investment model.





CONCLUSION

The key strategic, design and deployment findings from the completion of this study can be summarised as follows:

1. The market forecast concluded with the expectation that the UK's high-performance automotive sector will represent a significant and relevant proportion of the addressable demand and should therefore be a key target for a battery assembly facility.
2. In 2025, a facility delivering circa 7,000 units per year addresses the market opportunity; although plug-in hybrid electric vehicle (PHEV) packs would be manufactured in higher quantities, battery electric vehicle (BEV) packs will create higher revenues. Later in the decade a significant shift in market share from PHEV battery packs to BEV battery packs is expected, with demand reaching around 16,000 units per year by 2030.
3. The preferred BEV design studied contained 40 modules of 12 pouch cells in a 2P6S arrangement, aimed at achieving a target specification of 130kWh and >500kW in a package weighing circa 600kg.
4. UK cell suppliers are currently undertaking significant development to ensure their offering is world class and in line with suppliers from the EU and rest of the world, their technology roadmaps are encouraging and look set to fulfil the future demands of the niche volume sectors. In the short-term supply is limited and supply may be needed from Europe or Asia, while the UK supply chain stabilises.
5. For supply of high value, high complexity componentry for battery packs in the near term the UK market will rely on global companies with bases or distribution networks in the UK.

6. With the exception of cell supply, as mentioned, the study shows that there are no other significant gaps in component availability and quality in the UK, although a number of supply lines are in early-stage development so capacity limitations may be evident in the near term.
7. The proposed facility studied is a 5,000m² battery assembly operation, capable of producing up to 10,000 battery packs per year split across multiple customers and variants.
8. The facility must retain scalability and flexibility within the design and limit investment where possible to ensure a competitive product offering. This requires striking the right balance between manual and automated assembly, selecting operator quantities and working patterns to achieve efficiency, and still retaining overall value for money and a high-quality output.

Use of Ricardo's New Product Introduction (NPI) and industrialisation skills provided a fast and efficient route to a complete facility design, as a key output of the feasibility study, achieving high confidence in the solutions specified before any investment is undertaken. The NPI disciplines of leadership, manufacturing, procurement, and quality were deployed in this project, delivering a thorough market study to define clear targets for the proposed facility.

Understanding the business case is essential at this early project stage. The project brief needs fulfilling but the financial business needs must also be met. To fully understand the cost implications of the facility design studied, a production cost model was built based upon the foundations of the commercial and technical requirements, using inputs from the product bill of materials costing and facility equipment tender activities. This, together with the defined product build cost, gave a detailed commercial model allowing analysis of operating profits and margins, net present value, and funding decisions.

This has resulted in strengthening Ricardo's ability to demonstrate capability in the field of module and battery pack assembly. Additionally, it has enhanced how Ricardo is able to respond rapidly to customer enquiries with a baseline facility design, or to provide NPI consultancy and assist with their own manufacturing ambitions.

USING RICARDO'S NPI PROCESS AND INDUSTRIALISATION SKILLS PROVIDED A FAST, EFFICIENT ROUTE TO A COMPLETE FACILITY DESIGN AND CLEAR TARGETS FOR IT, ACHIEVING HIGH CONFIDENCE IN THE SOLUTIONS SPECIFIED BEFORE ANY INVESTMENT IS UNDERTAKEN.

RICARDO: YOUR TRUSTED ADVISOR

Ricardo is a global environmental, engineering, industrialisation and strategic, consultancy. It is also a specialist niche manufacturer of high-performance products. With over 100 years of engineering excellence, we provide exceptional levels of expertise in delivering leading edge and innovative cross sector sustainable products and solutions, helping our global customers increase efficiencies, achieve growth, and create a clear and safer future.

Ricardo's future manufacturing strategy is very much aligned with the rapidly developing need to establish a robust and sustainable supply chain for electrified vehicle components, building upon long experience and deep knowledge of full vehicle systems and powertrain technologies. Ricardo supports clients to establish manufacturing facilities aligned with market demand and technical requirements to deliver efficient and optimised production processes.

Ricardo is supporting the decarbonisation of global transport and energy sectors, providing organisations with policy, strategy and technology innovation consultancy for solutions on land, air and sea. Clients include the world's major transportation original equipment manufacturers, supply chain organisations, energy companies, financial institutions, governments, intergovernmental organisations and non-governmental organisations.

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