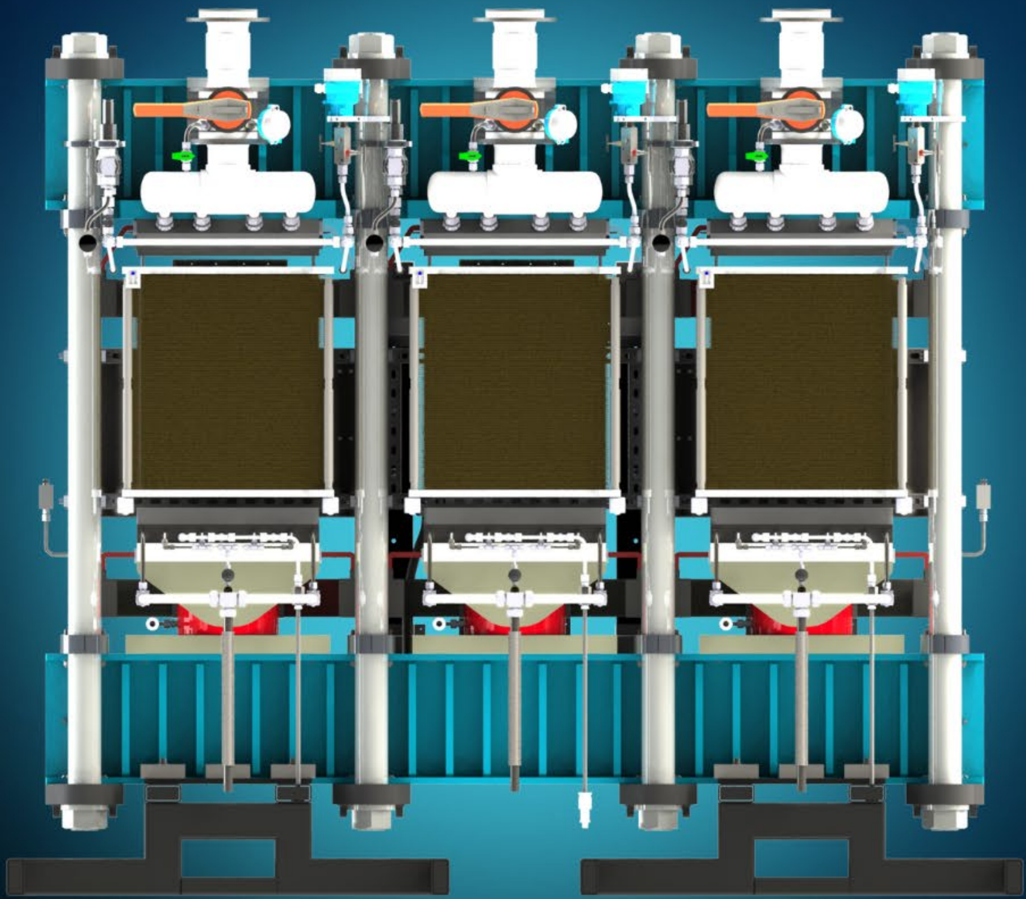

GIGATEST

DESNZ HYS2217 Competition

Final Report

July 2025

TRIDENT

LEADING PEM ELECTROLYSER STACK TECHNOLOGY

Executive summary

Gigatest was a 3 year, £9.7m project, which was rescoped to £7.7m. It started in January 2022 and ended in February 2025. The goal was to meet customer requirements for large 10MW+ projects by piloting a 5MW stack platform with improved specifications and reduced cost (compared with ITM Power's state-of-the-art stack platform). ITM Power (ITM) is a global leader in electrolyser manufacturing. It has grown from a research and development (R&D) company to owning one of the world's largest electrolyser manufacturing facilities selling to key clients such as Linde, Shell, RWE and Yara. The project aims were to:

- Achieve TRL7 - pre-commercial demonstration by the end of the project and MRL6 - capability to produce a prototype system in a production-relevant environment by the end of the project
- Increase stack pressure to 30 bar(g)
- Commission the first 5MW stack, using new design elements and manufacturing techniques.
- Develop, commission and validate semi-automated manufacturing, assembly and inspection systems at ITM's Gigafactory, and hence:
    - Reduce the amount of catalyst used per stack to reduce cost
    - Reduce of the number of parts in the stack to reduce complexity
    - Reduce the manufacturing process time per component
    - Reduce the scrap rate
- Deliver a functional state of the art test bay and quality control processes to support large scale electrolyser manufacturing and fully test and validate stacks under real-world conditions. Stacks should meet ITM's internal key performance indicators (KPIs):
    - Efficiency <53kWh/kg at 3.3A/cm2
    - Ambitious cost targets at various product levels[1]
    - Degradation of <1% per 1,000 hours
    - Hot idle and cold start ramp times of 2s and 10s
- Gain market acceptance of the stack

There was a significant rescope a third of the way through the project to better align the work with customer requirements. Changes in the objectives were to:

- Achieve *TRL8 - First-of-a-kind commercial* rather than TRL7
- Demonstrate the new designs and manufacturing techniques on the existing MEP stack architecture rather than a new GEP stack architecture.
- Addition of a new validation deliverable which included failure modes and effects analysis (FMEA) and specialist testing to demonstrate robustness after being subject to vibrations and assess performance at extreme operating temperatures
- Include field tests (which allowed the project to reach TRL8) to improve customer acceptance.

[1] This is highly dependent on scope of project and complexity of local civil works

Improved stack specifications included a 50% increase in pressure, the introduction of an advanced membrane and an improved electrode structure and required a comprehensive stack redesign due to the effect on overall component loads, assembly tolerances and system dynamics.

The increased stack pressure led to redesign of the cell-plate tooling to tighten tolerances, leading to improved electrode fit and sealing uniformity. A new skid design was also required; ITM used a different material to reduce potential release of membrane-damaging cations into the process water, which also reduced cost and weight.

Other developments include a new volume manufacturing method and quality control (QC) for the catalyst coated membranes (CCMs) at the heart of the stack which include an ink-mixing system, driers, and ultrasonic washing; an electrode specification (plus QC) for operation at high current densities; methods of joining and coating the electrodes (plus QC); a production vision system to reduce stack assembly errors and tolerance stack up; and stack movement aids to streamline loading / unloading operations, improve safety and reduce stack damage. ITM used short stack tests to reduce the time and cost of optimising parameters and validating developments then built and installed a new test skid to assess performance at increased pressures and current densities. The industrialisation of the stack platform was validated using FMEA. ITM worked with its supply chain to improve the quality of goods received, updating their contracting arrangements and implementing a new precedent framework agreement.

Project results include cycle time reductions of 75% (ink-mixing), 75% (part washing) and 40% (electrode assembly). Catalyst loss was also reduced by 75% and the manufacturing equipment led to improved part traceability and cleanliness and tightened tolerances. Staff reported that stack build was significantly improved. First time pass rates for stacks undergoing FAT were ~50% at the project start. This increased to >98% as a direct result of the NZIP funding.

Validation work included static and dynamic testing, vibration, thermal and blast tests. These showed that the stack can produce hydrogen with an output pressure of 30bar(g) and with efficiencies of <52.9kWh/kg at 100% load. No degradation was observed over the duration of the tests. Stacks were able to withstand vibration profiles in excess of those produced by road transport or shipping, could operate between minus 20˚C and 40˚C and remained intact under blast tests. Tests in the field assessed the learning curve for plant operators and led to updated stack installation guidelines and maintenance procedures. The stacks now have >50,000 cumulative operating hours in the field with an availability of >98%. The output was a fully validated stack which is at the heart of ITM's product offerings. These include:

- 2MW Trident stack-skid containing 3 stacks reduced capital costs and improved efficiencies
- 20MW POSEIDON process module which enables further scale-up with an optimised footprint
- 2MW NEPTUNE II, a plug and play system including power conversion and water purification
- 5MW NEPTUNE V, which has the same capacity as the originally proposed GEP stack architecture.

ITM carried out over 150 dissemination activities, engaging with potential customers and allowing them to assess Trident capabilities. Activities included site visits, technical demonstrations, technical audits and sharing of initial test results. It worked with nearly 50 suppliers, developing existing relationships and announcing new collaborations.

As of May 2025, ITM has announced:

- 100MW Trident sales
- 40MW Neptune V sales
- 60MW FEED studies for Neptune V
- 20MW basic design engineering package for POSEIDON, a typical first step for FID
- 500+MW capacity reservations across the different product offerings
- 420+MW where it is selected supplier (which are subject to final investment decisions)

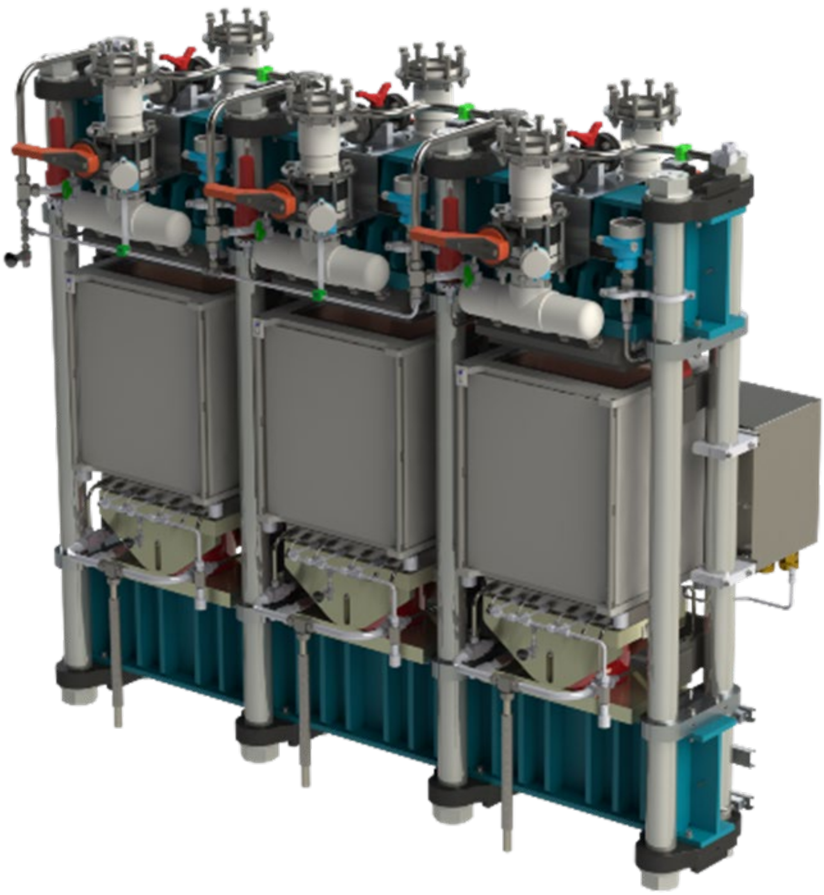

Figure 1: The Trident stack-skid system

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Glossary/Abbreviations/Acronyms

ATEX - Atmosphères Explosibles
BOM – Bill of materials
BoP – Balance of plant
BS – British Standard
CAD – Computer aided design
CAPEX – Capital cost
CCM – Catalyst costed membrane
CRL – Customer readiness level
DESNZ – Department of Energy Security and Net Zero
DFMEA – Design failure mode and effect analysis
DNO – Distribution network operator
DSEAR – Dangerous Substances and Explosive Atmospheres Regulations
DVPSOR – Design Verification Plan and Sign-Off Report
EPC – Engineering, procurement and construction
Exec – ITM's executive team
FAT – Factory acceptance test
FCH JU – Fuel Cell and Hydrogen Joint Undertaking
FEED – Front-end engineering design
FID – Final investment decision
FMEA – Failure mode and effect analysis
FP7 – Seventh Framework Programme of the European Commission
GEP – GW electrolyser platform
GHG – Greenhouse gas
GW – Gigawatt
HAZOP – Hazard and operability study
HSE – Health, safety and environment
ISO – International Organization for Standardization
ITM – ITM Power (Trading) Ltd
KPI – Key performance indicator
LCHS – Low Carbon Hydrogen Standard
LCOH – Levelised cost of hydrogen
LOPA – Layers of protection analysis
LVV - Laboratory for Verification and Validation at the University of Sheffield
MEP – Megawatt electrolyser platform
MEP20 – Megawatt electrolyser platform, 20bar(g)
Mk – Mark, version
MRL – Manufacturing readiness level
MSA – Measurement system analysis
MW – Megawatt
NPL – National Physical Laboratory
OPEX – Operating cost
PDS – Product design specification
PEM – Proton exchange membrane
PFMEA – Production failure mode and effect analysis
PPAP – Production part approval process
PPM – Parts per million
PSU – Power supply unit
PTL – Porous transport layer
QC – Quality control
R&D – Research and development
RD&D – Research, development and demonstration
SAT – Site acceptance test
SMA – Stack movement aid
SOP – Standard Operating Procedures
Trident –Stack platform developed within Gigatest
TRL – Technology readiness level

1. Background

1.1. Company Information

ITM, a global leader in electrolyser technology, was the sole contractor for the Gigatest project. ITM has grown from a research, development and demonstration (RD&D) company to owning one of the world's largest electrolyser manufacturing facilities, employing over 300 people and selling to key clients such as Linde, Shell, RWE and Yara. ITM's main factory is at Bessemer Park in Sheffield, and it operates from a further two Sheffield-based research and development (R&D) sites with an after-sales support office in Germany.

ITM has experience in leading and collaborating in various Innovate UK (formerly Technology Strategy Board), Department for Energy Security and Net Zero (DESNZ) (formerly BEIS) and European Union funded research development and demonstration programs including the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) under the Horizon 2020 framework and the previous seventh Framework Programme (FP7).

In 2021, ITM moved into their Bessemer Park facility and began to scale-up the manually intensive manufacture of their existing MEP20 stack. When the project started, ITM had several product offerings, including the MEP20 stack, the cube (a plug and play containerised system comprising four MEP20 stacks and core balance of plant) and various legacy systems. ITM was developing a new stack architecture (GEP) with increased cell active area, current density, and number of cells per stack, targeting 10+MW projects.

1.2. Project Background

The Gigatest project is part of the Department for Energy Security and Net Zero's £1 billion Net Zero Innovation Portfolio (NZIP) which provides funding for low-carbon technologies and systems and aims to decrease the costs of decarbonisation helping enable the UK to end its contribution to climate change.

The original Gigatest project was designed to meet customer requirements for large 10MW+ projects by piloting the 5MW Gigastack platform (GEP) and, through testing, demonstrate that system performance was as expected. The project would also show that the manufacturing plant could be scaled up to achieve volume production of electrolyser stacks.

However, an execution model based on the GEP architecture carried significant technical and schedule risk for customers because it was in development and customers did not want to install first-of-a-kind equipment in large-scale projects. In addition, ITM would require a new manufacturing facility for the GEP, introducing additional risk associated with construction and ramp-up of new factory. In the first months of the project, ITM received strong market feedback that customer financial commitments to large-scale projects requires evidence of an existing product and related manufacturing lines together with a substantiated route to scale-up of production and test. Without this evidence for GEP, final investment decisions (FIDs) on large projects would be delayed.

ITM felt that the best way to deliver 10MW+ systems in a commercial setting was to do so using the existing MEP stack architecture but with increased pressure, current density and efficiency, and reduced cost (as compared with its state-of-the-art MEP20). The component and manufacturing improvements, manufacturing quality control and stack tests all remained in scope and the new stacks could be integrated into larger, 5MW or 10MW modules. Field tests were also added to the project scope. The rescope did not materially affect project outcomes or the business case but did reduce overall project risk and therefore increased customer acceptance. ITM submitted a change of scope request which was subsequently accepted, moving the project from the GEP to the MEP architecture.

The key performance indicators (KPIs) for the stack platform were chosen to align with business and customer requirements.

The key differences between the state-of-the-art stack prior to Gigatest and Gigatest stack when used in a 10MW system include:

- A higher current density to increase hydrogen output
- Increased hydrogen pressure
- Improved membrane to increase efficiency
- Improved mechanical interface to accommodate the increased pressure
- Improved manufacturing methods

2. Project Overview

2.1. Aims and objectives

To achieve its objectives of delivering a fully tested electrolyser offering with increased pressure, current density and efficiency, and reduced cost whilst increasing production capacity for this offering at Bessemer Park, the project was split into different workstreams. These included research into improved stack components (CCMs and electrodes), supply chain development, manufacturing automation development and stack tests both in the field to validate performance under real-world conditions, and at the factory, where longevity testing could be undertaken. This will ensure that the technology is ready for large scale commercialisation.

Gigatest's aims were to:

- Achieve *TRL7 - pre-commercial demonstration: solution working in expected conditions* by the end of the project. This was updated to *TRL8 - First-of-a-kind commercial: commercial demonstration, full-scale deployment in final form* when the project was rescoped.
- Achieve *MRL6 - capability to produce a prototype system or subsystem in a production relevant environment* by the end of the project
- Increase stack pressure to 30 bar(g)
- Manufacture and commission the first 5MW Gigastack stack, including new design elements and manufacturing techniques. During the rescope, this was amended to demonstration of the new designs and manufacturing techniques on the MEP stack architecture.

- Develop, commission and validate semi-automated manufacturing, assembly and inspection systems at ITM Power's Gigafactory, and hence:
  - Reduce the amount of catalyst used per stack to reduce cost
  - Reduce of the number of parts in the stack to reduce complexity
  - Reduce the manufacturing process time per component
  - Reduce the scrap rate
  - Expand ITMs manufacturing capability
- Deliver a functional state of the art test bay and develop quality control processes to support large scale electrolyser manufacturing
- Establish a validation process for the new stack including failure modes and effects analysis (FMEA) and specialist off-site testing to ensure performance at extreme temperatures, and demonstrate robustness when subjected to vibration (new objective added at rescope)
- Fully test and validate stacks under real-world conditions (field tests added during rescope) which meets ITM's internal key performance indicators (KPIs):
  - Efficiency <53kWh/kg at 3.3A/cm^2
  - Ambitious cost targets at various product levels[2]
  - Degradation of <1% per 1,000 hours
  - Hot idle and cold start ramp times of 2s and 10s
- Market acceptance of the stack

2.2. Schedule

Gigatest was originally a 3 year, £9.7m project (there was a proportionate reduction in project value to £7.7m during the rescope). It started in January 2022 and ended in February 2025.

The full committed spend was invoiced. It comprised 7 workstreams:

- Stack technology development
- Catalyst coated membrane (CCM) development
- Electrode development
- Test module development
- Manufacturing at scale
- Electrolyser build and validation
- Project management

The top-level project schedule can be seen in Figure 2 below. The major project deliverables included:

- Short stack test report
- Development of supply chain for new stack components
- Stack bill of materials (BoM)
- Final design review and sign-off
- Report on CCM developments

[2] This is highly dependent on scope of project and complexity of local civil works

- Report on electrode developments
- Component design reports
- Detailed design of new test area
- Test bay set up and compliance sign-off
- Manufacturing validation reports
- Component design reports
- Manufacturing scale-up report
- Report on logistics development
- Stack and skid standard operating procedures
- FAT documentation
- Field test report
- In-house test report
- Final design review and sign-off
- Declaration of conformity
- Management and dissemination reports

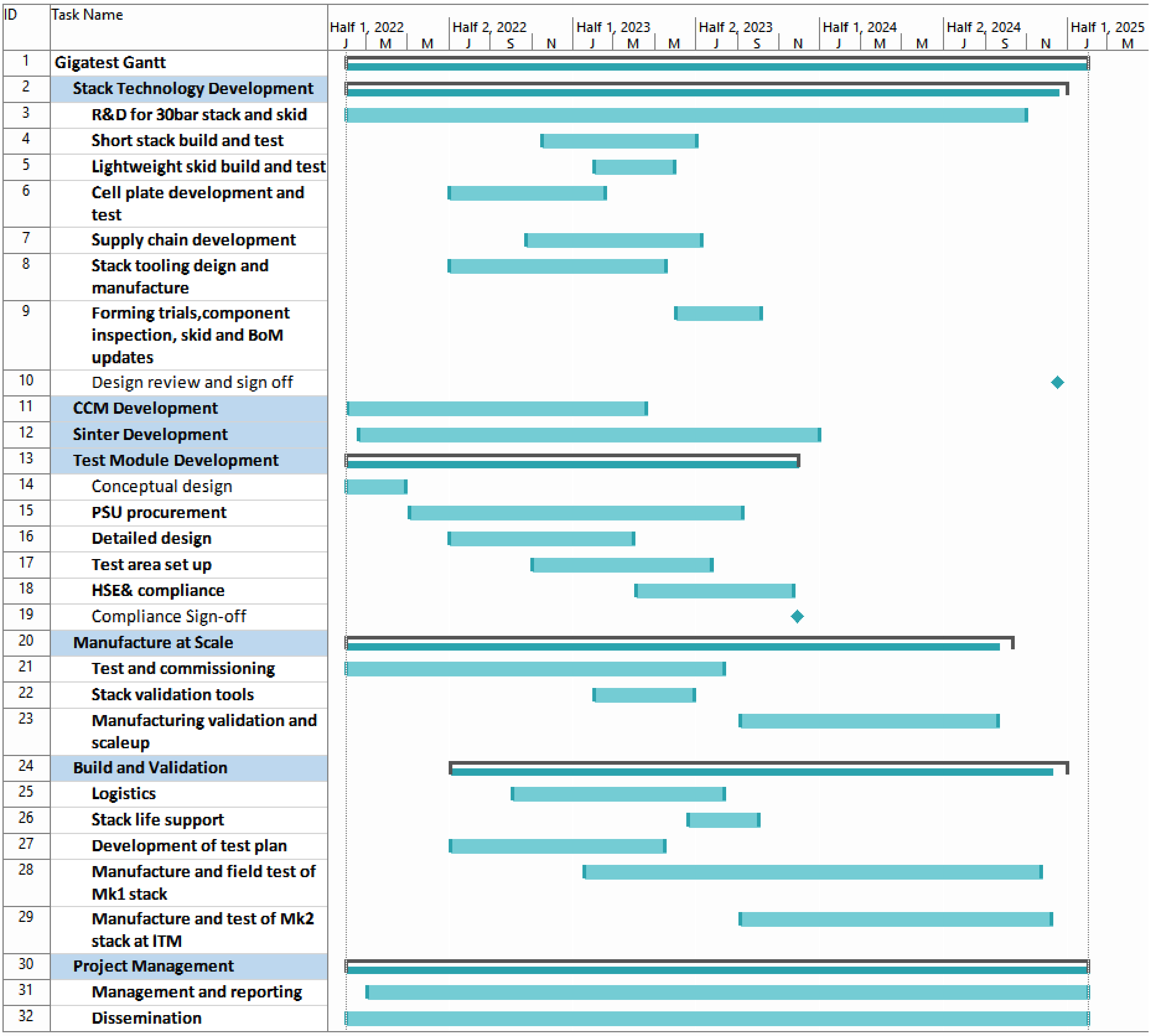

Figure 2: Gigatest Project Schedule

3. Design Considerations and Challenges

3.1. Stack Technology Development

3.1.1. 30bar(g) stack and skid design

Stack and skid design covered two main areas, original research and development (R&D) work for the new 30 bar(g) system at the project start, followed by analysis of any stacks which failed onsite or during validation trials.

The stack BoM was generated following a process of design and review work. Some components were redesigned to increase efficiency and robustness or reduce costs. Implementation of design for manufacturing led to changes in other components to enable semi-automated manufacture. ITM sought new suppliers in some cases either to gain supply chain robustness or to obtain higher quality components with reduced variability. During this work, ITM strengthened its procurement procedures (see Section 3.4) and worked with suppliers to ensure that they could meet ITM's quality and volume requirements. For example, delivering the increase in stack pressure was more challenging than anticipated. The effects of increasing system pressure by 50% while simultaneously introducing advanced membranes (to increase stack efficiency) and new electrode manufacturing methods (to reduce stack costs) were not independent because they affected the overall component loads, assembly tolerances and system dynamics. Their introduction required a comprehensive stack redesign to meet ITM's stringent quality targets.

A product design specification (PDS) was then generated and used to develop a computer aided design (CAD) model for technical review. Manufacturing drawings were prepared for all components. The drawings included critical dimensions, material selection and manufacturing instructions where required. A design verification plan and sign off report (DVPSOR) was prepared for both components and the whole system (stack) and included acceptance criteria for suppliers to ensure compliance with both internal and external codes and standards.

The design went through iterative tuning loops until all functional and non-functional requirements were met. Once it was validated, the CAD BOM and drawings were generated, reviewed and approved, and the stack assembly model, together with the individual component manufacturing drawings and the complete BOM were released for final sign-off and product launch as the Trident stack. The final design can be seen in Figure 3, where three Trident stacks are assembled into a skid. The BOM, supplier details and quantities are omitted for this report for reasons of commercial confidentiality.

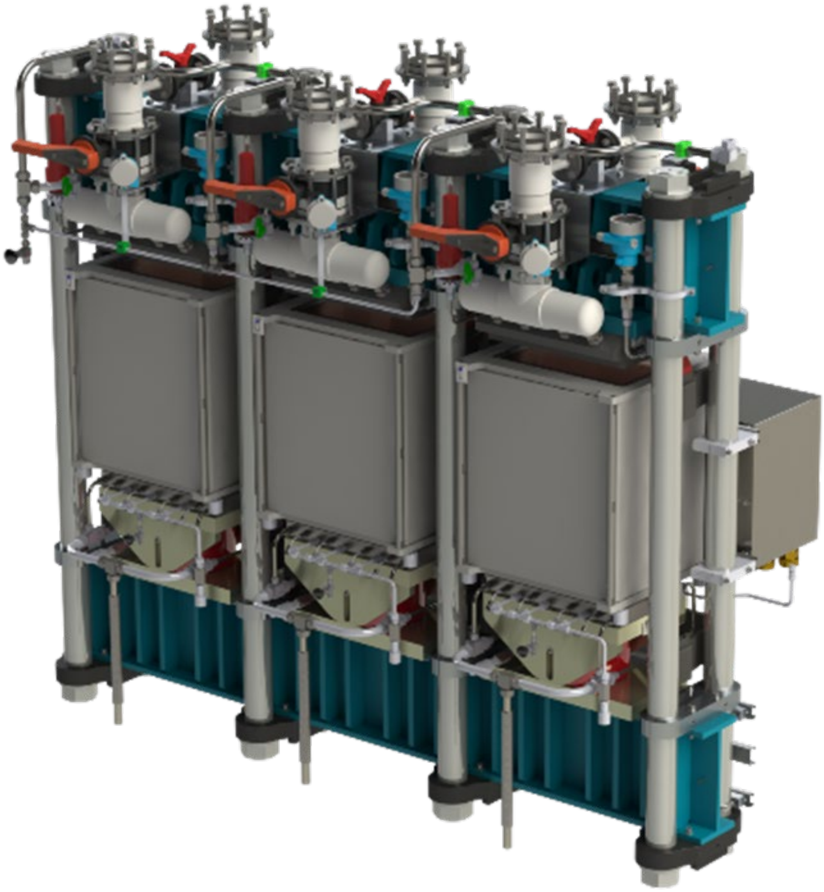

Figure 3: The Trident stack-skid system

3.1.2. Cell Plate Development and Test

With each stack housing >100 cells, to meet the 30 bar(g) pressure requirement, it is important that cell plates are produced with tight tolerances. Design and development work was undertaken so that they could be reproduced at volume. Because the plates are injection moulded, we needed to modify the tooling. The first iteration produced plates which required ~10 hours in house post-production fine-tuning to deliver sufficient cell plates for a stack. While this is acceptable for low output volumes, to achieve volume manufacture, post-production machining steps had to be removed.

Additional modifications were trialled on soft tooling which is cheaper and easier to modify than hard tooling but not as long-lasting. Tests on the resultant cell plates included dimensional measurements and accelerated pressure cycling to assess fatigue characteristics. Once satisfactory pass rates were achieved, the hard cavity and core moulds were made and introduced to production. All items in the BoM were updated, along with drawings, supplier details, supplier requirement documents and procurement details.

The cell plates now offer improved electrode fit and sealing uniformity. This work produced cells with improved efficiencies; a significant step towards meeting Gigatest targets.

3.1.3. Catalyst Coated Membrane (CCM) Development

The CCM is at the heart of ITM's stack technology. Different catalysts are applied to each side of the membrane to facilitate the electrolysis processes. Water flows to the anode side of the CCM and the catalyst uses electrical energy to break the water down into oxygen, protons, and electrons. The electrons are driven through the external circuit and the protons cross the membrane and combine with the electrons on the cathode to form hydrogen molecules.

A method of volume manufacture for CCMs was developed and standard operating procedures (SOPs) prepared. For each process, a control plan was developed which describes the necessary quality control (QC) inspections for each component and for the final CCM before it can be released to production. It ensures the correct steps are followed and provides reaction plans in case of any deviation from specification. Where appropriate control charts are used for statistical process control to monitor performance, detect changes and apply corrections.

As CCMs were manufactured, a Pareto analysis was used to identify the dominant failure mechanisms at each stage of production. On detection of a failure mechanism, a root cause investigation was carried out and problems addressed. This ongoing analysis helped us to focus our efforts on continuous process improvement and to keep failure rates to acceptable levels.

3.1.4. Electrode Development

At the project start, the industry didn't have a detailed specification for PEM electrolyser porous transport layers (PTLs) because the impact of non-optimised PTLs at lower current densities is minimal. Because ITM's electrolysers have world-beating current densities, it was necessary to develop specifications for its PTLs along with QC methods to ensure high quality parts are available for commercial roll out. In-depth knowledge of PTLs and the impact small changes in parameters can make is key to optimisation.

Using supplier data, literature on PTLs and internal knowledge, ITM produced a list of initial parameters which impact performance (regardless of geometry) for optimisation, including thickness, porosity, particle size and pore size. Work was carried out to determine the optimal value to ensure high quality PTLs and the specification was then finalised. Work was carried out to optimise joining and coating of the new PTLs (section 3.2.6). A batch of 450 PTLs was manufactured using incumbent methods and these were tested in short stacks (section 3.1.5). The findings fed into a PTL component specification for suppliers and an appropriate quality control procedure. Standard QC is now reduced to two tests at eight points on two PTLs from each batch and a material composition test on one part. Previously every PTL in a batch underwent multiple tests.

A production part approval process (PPAP) was introduced which introduces a list of requirements for our suppliers.

3.1.5. Short Stack Build and Test

Short stacks containing five cells were built and tested under a variety of conditions. This is an efficient way to test prototypes as it reduces raw material and the electricity testing costs and allows unpromising solutions to be discarded at an early stage. Short stacks deliver results under ideal conditions and allow different technologies and cell architectures to be compared. This forms part of ITM's extensive validation process. Having been developed over many years and multiple stack generations, it is a robust and effective method to screen different materials and features rapidly. ITM benefits significantly from its extensive test facilities, allowing it to test different materials, components and processes thoroughly and rapidly. To carry out short-stack tests on the Trident components, it was necessary to build and install a new short stack test skid (Figure 4) to accommodate the change in pressure and the new stack design. It required significant modifications which included changes to all the pipework to and from the stack and the O_2 tower; the connection of a heat rejection system to an already installed cooling system; and replacement of the power supply unit (PSU) to allow for tests at higher current densities (>3Acm^{-2}).

Figure 4: Short stack test bay for 30 bar(g) Trident cells

Upon completion of the test rig build, checks were undertaken including torque/tightness measurements on all load bearing fixings and hydrostatic pressure tests on all pressure-bearing components to ensure there were no external leaks from the stack, skid or rig equipment prior to electrolysis.

Performance data was gathered during the initial hours of electrolysis within the allowed cell voltage range. Polarisation curves, used to characterise stack performance at specific temperatures by plotting current against voltage, were taken after 24 hours of operation and repeated following a shut down and restart at 26 hours. The Gigatest technology achieved lower voltages for a given current density compared with the MEP20 stack, the state of the art at the start of the project. Therefore, it produced more hydrogen for the same power input. Cell voltage can be used as a proxy for cell efficiency, with more efficient stacks producing more hydrogen at a given power input, an important metric for customers.

Short stack tests continued for 500+ hours and polarisation curves were repeated at various intervals to determine stack efficiency monitor for early degradation. The results indicated that no degradation had occurred during the period of the test. Cell performance showed that less than 53kWh of electricity was needed to produce one kilogram of hydrogen (<53kWh/kg) at 100% load, meeting Gigatest efficiency targets. Other tests carried out on the short stack, including fluoride release, the amount of hydrogen in the oxygen outlet, and water transport rates, all showed improvements when compared to the state of the art prior to Gigatest.

3.1.6. Lightweight Skid Build and Test

The main function of the skid, which houses the stack assembly, is to supply services to the stacks including electrical current and water, and to remove wastewater and oxygen.

It was necessary to make several design changes to the skid to accommodate the higher operating pressure of the Trident stack. This provided an opportunity to reduce skid weight and cost by using plastic rather than stainless steel components, simultaneously reducing the potential release of membrane-damaging cations into the process water. The redesigned stack / skid assembly was tested to confirm that the skid could uniformly apply the necessary load to a stack (Figure 5); there must be an efficient and reliable seal between stacks and skid.

The experience gained assembling the stacks and skids for test allowed the production team to begin developing build procedures, assembly methods, and checks for the stack-skid system, as described in Section 3.2.

Figure 5: Skid pressure test

3.2. Manufacturing at Scale

Volume manufacture requires a move from mostly manual electrolyser production to semi-automated or automated manufacture. Work in the project focussed on commissioning and testing hardware to achieve this, followed by failure modes and effect analysis (FMEA), manufacturing validation and scaleup.

ITM undertook a review of the existing production process and mapped the bottlenecks to be unlocked as part of the Gigatest project. Sub-projects were created by ITM's manufacturing improvements team, with support from stack design, production, the health, safety and environment (HSE), quality, procurement, and facilities staff. Where subcontractors were used to build equipment, the work was managed by ITM to ensure efficient delivery. Factory FATs were undertaken where appropriate, with further commissioning and testing at ITM facilities before sign-off.

The following production processes were developed:

- Stack movement aids (SMA) – to enable simple and safe stack movement around the factory, and into and out of test bays, containerised products or skids.
- Vision system – to aid with stack assembly and increase quality. This also enables design for manufacture and ensures that the product design is compatible with future automation.
- Ink-paste mixing – this was automated to reduce waste and produce more consistent and larger batches.
- Screen printing – for anode catalysts onto substrates allowing CCM production scale-up.
- Automated washing sequencer – automated control and handling of all internal stack components.
- Automated electrode welding – fully automatic welding including a vision system and non-contact measurement to meet capacity requirements and ensure critical component quality.
- Precious metal coating line – scale up of a proven prototype line, to bring coating in-house to provide quality and cost improvements and provide control over technical elements of the build.
- Movement robotics – a review of the potential for robotics to carry out stack build.

3.2.1. Stack movement aids

ITM provided a requirements specification and an SMA was designed and built by a subcontractor. The SMA includes sensors for positional accuracy and mechanical operator assistance to reduce the amount of manual handling and associated stack / skid damage.

Initially, a single SMA was ordered for trials within the factory (Figure 6). Validation was achieved through 100 stack builds. During 100 builds, no leaks were found (leaks are an indicator of poor stack assembly or stack damage during insertion into the skid), so a further three units were ordered. As well as lifting and moving stacks, the SMA streamlines and de-risks the operation to load / unload the stack from the skid. They improve factory safety and ensure repeatable build quality. The SMA design is also used during plant operation in the field to allow stacks to be easily removed and replaced during maintenance activities.

Figure 6: Stack movement aid

3.2.2. Vision systems

A stack production vision system was installed and commissioned (Figure 7). It projects instructions onto the stack to guide assembly technicians and ensures that each step is completed correctly through the inclusion of building aids which assess part alignment and straightness.

To validate the system, an external body carried out an industry-standard measurement system analysis (MSA) which proved that the vision system could correctly identify good parts. The system ensures repeatable build-quality and reduces stack build time.

Figure 7: Stack assembly trolley with projector display and camera detection

3.2.3. Ink paste mixing

Precious metal catalysts are an expensive electrolyser component. Analysis of the production process in use prior to Gigatest showed that a significant amount of catalyst adhered to the ink preparation equipment or was applied outside the active area, with a further small percentage scrapped due to operator mixing errors. Manual handling also led to additional defects and waste.

As part of Gigatest, an ink mixing machine was designed, built, installed and commissioned (Figure 8). Validation activities included analysis of the ink, microscopy of the coated parts, electrolysis testing and voltage measurements. These showed that parts made using this ink were at least as good as the incumbent method. The mixer resulted in a 75% reduction in cycle time for ink preparation, as well as reducing material waste / losses and hence decreasing component cost.

Figure 8: Automated ink mixing

3.2.4. Screen printing

ITM investigated the purchase of a screen-printing system, based on machinery used in the circuit-board industry. The aim was to produce a roll of catalyst-coated substrate leading to a significant decrease in printing time. However, implementation of such a system was more challenging than anticipated due to the extremely tight tolerances required by ITM. The supplier encountered technical issues related to the printing speed, non-uniformity of the substrate surface and control of the deposited material which would prevent production of a roll in a single operation. Therefore, ITM split the printing into two phases. Only the first phase (delivery of new dryers) is within the scope of the project and includes items necessary to meet project KPIs.

Robust FAT and SAT were carried out on delivery of the driers (Figure 9). These included tests for temperature and uniformity of drying. Three batches of CCMs on their substrates went through the ovens and the amount of residual solvent was analysed. This validated the driers from a production viewpoint. In addition, the science team carried out cell tests to ensure parts met performance criteria.

One of the challenges with this work related to installation. Because the new dryers were added to the existing screen-printing line, installation had to be done when the line was down, causing commissioning delays. The high cost of ink materials meant that validation took place at a slow place and as part of production.

Figure 9: Phase 1 screen printing driers commissioned in Sheffield

3.2.5. Automated washing and ultra-sonic cleaning

An ultra-sonic washing system with fully automated handling was installed and commissioned (Figure 10). This provides batch traceability and improved operator ergonomics. This system covers all washing and cleaning requirements for production. To validate the machine, ITM used an external body to assess it against the industry standard for part cleanliness. Parts were analysed before and after washing and the cleaned parts were compared to those produced by the machine being replaced. The results were an improvement over the incumbent process and cycle times were reduced by 75%.

Figure 10: Automated washing and ultra-sonic cleaning set up in Sheffield

3.2.6. Electrode welding

A fully automated electrode welding system was developed, building on an existing prototype which had been used to prove out the process. The machine (Figure 11) handles all components, ensures correct placement and inspects part quality. The output is fully inspected, traceable electrodes. Robust FAT and SAT were carried out and a capability study was performed internally on the fixturing. The equipment was run at maximum capacity to ensure performance and it passed all internal production gate reviews. The electrode welder reduces cycle time by 40%.

Figure 11: Electrode welding set up in Sheffield

3.2.7. In-house coating

ITM currently outsources most of its electrode coating but would like to assess the feasibility of bringing it in-house to control output quality and reduce long-term costs. This would also allow ITM to develop bespoke coating parameters for improved electrodes. Prior to Gigatest, laboratory-scale processes were developed and showed improvement when compared with outsourced coated parts.

The internally developed process was scaled up to allow full-sized parts to be coated (Figure 12). Environmental measurement of fumes was undertaken during commissioning to determine whether additional control measures were required (section 3.5). Significant improvements to ITM's extraction system were needed at significant cost (borne by ITM as it was not included in the project), which delayed the commissioning of this piece of equipment. Contingency had been built into the project to cover delayed items and the system was validated in the final month of the project. This meant that the expected efficiency gains from this process were not included in the validated project test results.

Figure 12: R&D plating line set up in Sheffield Factory

A safety consultant was engaged, and a review of extraction requirements undertaken. A wet gas scrubber was ordered and installed (Figure 13) and emission tests were carried out during a run of 20 plates. Results confirmed that the new systems remained within the safe operational limits and met all relevant standards.

Validation of the plating line was done through a design of experiments which was used to determine the optimum process parameters and to prove that the equipment could produce good parts. Production was then ramped up to show repeatability. During this phase, it became evident that condition of supply affects the quality of the coated parts and further experiments were undertaken to determine whether it was possible to mitigate this in-house or whether more stringent quality standards should be imposed on the supplier. Both approaches were taken, with suppliers delivering higher quality parts and ITM putting procedures in place to handle this variation. Sufficient electrode structures were then coated to enable a full stack build. All passed the required performance tests.

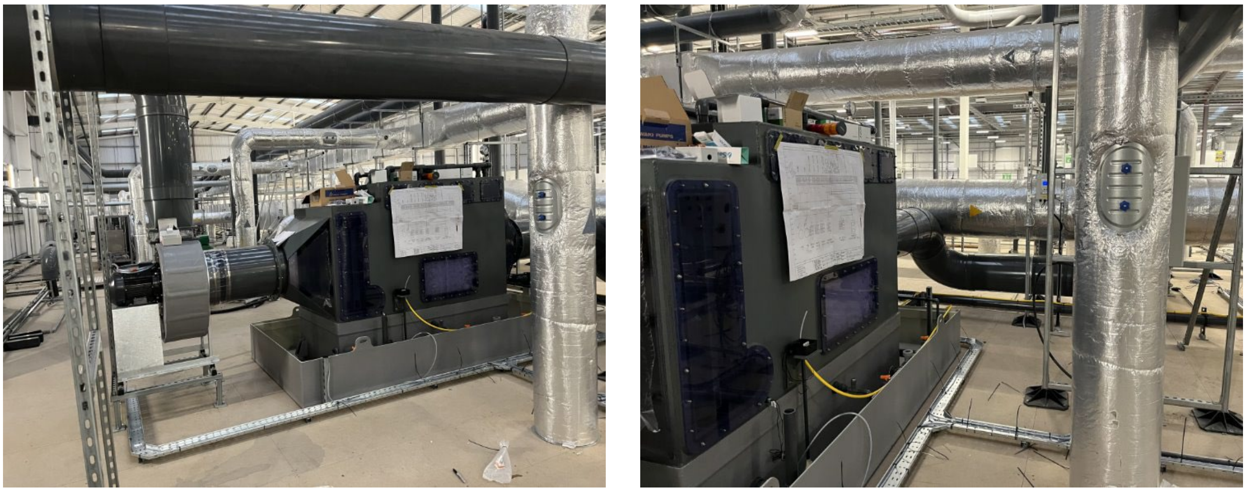

Figure 13: Wet gas scrubber

The stack was electrolysed and polarisation curves used to calculate the efficiency. Internal processes were then tuned which reduced plating production costs. As expected, the optimised coating improved cell efficiencies and, in the final month of the project, allowed ITM to meet its efficiency stretch goal.

3.2.8. Movement Robotics

ITM carried out a feasibility study into automated stack assembly. Benchtop trials led to a test of full-scale assembly (Figure 14) which indicated the necessary process and stack design improvements which would be needed in future products to allow for automated robotic manufacture and assembly.

Figure 14: Robotic trials: robotic arm

The trials demonstrated that robotics would be beneficial to (and feasible for) the stack build process. However, they would require a significant capital investment, and it would take 12 to 18 months to implement a pilot line, both of which were outside the scope of Gigatest, but because of this work, ITM have invested in such a system and will begin commissioning and validation in 2025.

3.2.9. Manufacturing validation and scale-up

ITM undertook a design failure mode and effects analysis (DFMEA) to review the industrialisation of the Gigatest stack platform. Components underwent design improvements to eliminate or reduce failure risks. Improvements for manufacturability were assessed in relation to requirements for the Gigatest stacks and with a view to backwards compatibility with the incumbent MEP20 stacks.

Controlled builds were carried out on Gigatest cells and stacks, providing an early production validation opportunity. A dedicated advanced manufacturing team of experienced engineers and technicians analysed the builds, developed a process FMEA (PFMEA) and built a failure map to guide the design of a bespoke ITM Stack Build Verification System.

To improve part quality, significant work was carried out with the supply chain and more stringent checks were introduced prior to making parts available to downstream processes, including assembly. Previously, misalignment during assembly occurred due to the high number of flexible parts which required precise placement, leading to tolerance stack-up. This was addressed by pre-joining these parts into rigid sub-components, ensuring correct alignment and reducing the number of parts handled during assembly.

Improvements were made to QC methods and small redesigns undertaken to aid manufacturability without impacting stack performance. Forensic investigation of stack and cell failures continued throughout the project, providing information from builds, manufacturing operations and transport. These informed the design review and sign-off in section 4.8.

ITM undertook a review of the manufacturing capacity of the Gigatest hardware. The production team modelled regimes for achieving different annual manufacturing capacities and assessed the steps which would need to be taken to achieve these. Large production runs were undertaken and parts analysed to assess quality at different stages. This informed the frequency of different maintenance operations, allowed realistic down-times to be included in the calculations and informed failure rates. Process bottlenecks to be identified, and mitigation actions sought. For example, cell layout alterations were made to reduce cycle time. This involved repositioning loading and packaging stations to improve operator access and increase process flow. Production cycle times were also measured.

Challenges included complexity of production and the short lead time which meant many tasks had to be completed concurrently, requiring multiple loops and additional resources. Challenges related to simultaneous sequencing were overcome with a phased approach to machine introduction, flexibility in tooling design and managing relationships with key suppliers.

The DFMEA study took place over a long duration (~6 months) broken down into weekly sessions. This prolonged exercise made it challenging to ensure continuity of attendance. Design Validation and Process Validation were concurrent due to short project timescales, resulting in component changes occurring mid project. A design error was identified in the first design review which had not been picked up in the initial design. It was only recognised when production staff were included.

To scale up factory capacity, new operators and different shift patterns were considered along with repeat orders of existing equipment and alterations to production layouts, bearing in mind costs and lead-times. ITM found that no new development would be necessary to meet the

Gigatest target output; it could be achieved through additional shifts and repeat orders although this would require significant capital expenditure.

3.2.10. Outcome

The ease of build of the first and second iterations of the Gigatest stack were compared. The first build contained the redesigned components described in section 3.1 whilst the second iteration was manufactured after the processes described in this section (3.2) were being used in production. Staff reported significantly easier stack build and no specific challenges were reported.

At the start of the project, first time pass rate for stacks undergoing FAT was ~50%. As a direct result of Gigatest, this has increased to ~98%, which shows that the measures taken have generated tangible improvements.

3.3. Test Area Development

Once built, stacks undergo static and dynamic tests, including hydrogen generation to show that they operate as expected. ITM needed to set up a new test bay for the Gigatest stacks due to the physical redesign. The increased operating pressures and efficiencies affect connection points, water flow and controls. The new test bay should also be safe, comply with regulations (see section 3.5) and optimially use available space.,

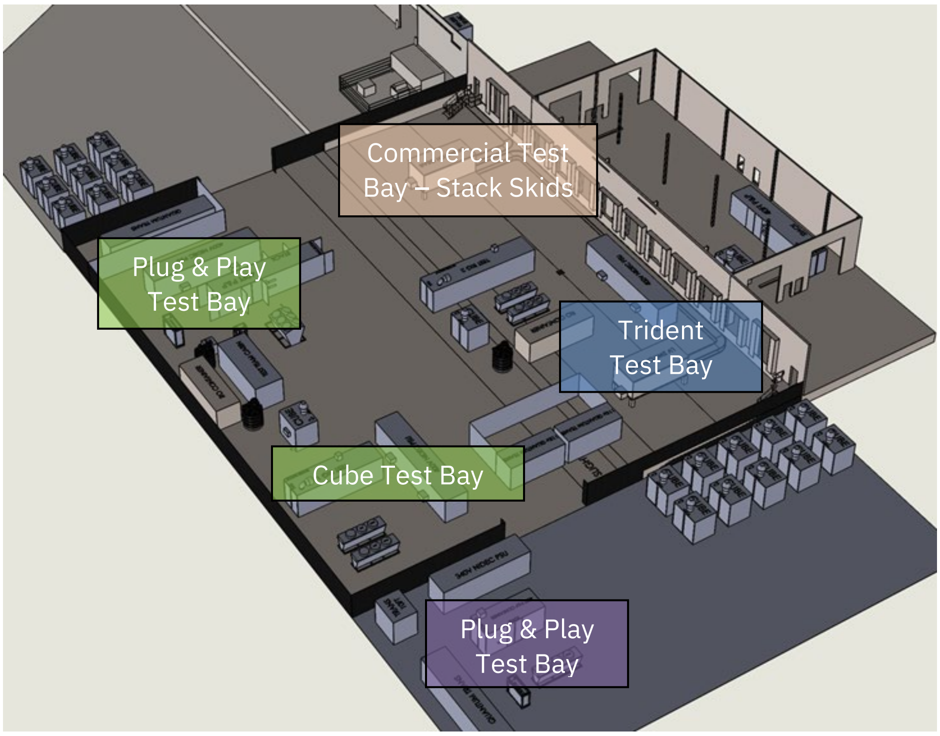

Figure 15: Bessemer Park Test Area Layout Plan

A power upgrade from 5MVa to 7.5MVa was necessary to allow all test bays to function at the same time. This was on the critical path of the project due to both the long lead times and the importance to the testing activities. Similarly, a new water connection was required to meet the maximum anticipated demand at the test site.

A detailed design and parts list was generated for the test rig based on ITM's experience in developing previous rigs, and the site layout was prepared (Figure 15). Detailed design and layout of the test bay which would house the rig was then undertaken. The test bay integrates the following distinct modules:

- Module to hold Trident stacks
- Power Supply Unit (PSU)
- Test rig – Balance of Plant (BoP)
- Air Blast Coolers
- Glycol pumping skid

Additional activities were required for site readiness, including installation of equipment to allow existing coolers to be used, connections to the new test rig, and installation of low-voltage switchgear which would allow the PSU to be used for tests.

After all safety assessments were complete, and control measures put into place, senior production, testing and safety staff carried out a final safety walk around to sign off on the control measures.

Figure 16: Gigatest test-bay

3.4. Supply chain and Logistics

3.4.1. Supply chain

As part of the project, ITM established a group of suppliers who could provide the necessary high-quality stack components at the volumes required. Whilst some components are straightforward and readily available (and therefore require little supply chain development) there are several sensitive components which are either ITM-specific, or which need to be manufactured to very tight tolerances.

External suppliers were selected, and an assessment was made as to whether they could support ITM's requirements. We identified improvements which could be made to our current contracting arrangements, so we developed and rolled out a precedent framework agreement, supported by our standard terms and conditions and a new supplier requirements document. This details the minimum requirements for any suppliers. ITM concluded and signed formal contracts with Mott

Corporation (PTLs) and with Gore (membranes) and began a review of the supply chain for medium-high risk components.

ITM also established a supplier planning assessment document which now forms part of the supplier selection process and implemented a production part approval process. This controls all aspects of part manufacture from material certification to processes used to ensure suppliers only send parts which meets our requirements.

3.4.2. Logistics

It is important that stacks can be moved around the factory and shipped without suffering damage. Initial vibration tests which replicate real-world conditions were conducted by transporting stacks around the factory over uneven ground and then shipping them using the storage prototype and installing them at ITM's German facility. These stacks passed all integrity tests. We then subcontracted an ISO gold-standard vibration test. FAT results pre- and post- test indicated that there was no noticeable effect on the stack. Finally, we installed vibration monitors on stacks being shipped to our German facility to ensure that the ISO test exceeded the vibrations experienced during transit.

Longevity testing has shown that simple shipping/storage is possible for extended periods on all shipping routes for ITM markets. During Gigatest, we developed a skid storage rig capable of compression and water circulation for use at our German facility (Figure 17).

Figure 17: Storage skid prototype

3.5. HSE aspects

3.5.1. Test bay

A safety assessment was initiated to enable a HAZOP, LOPA, DSEAR and ATEX to be undertaken. These are process safety studies that follow a standard methodology to identify the likely outcome of unintended deviations.

- HAZOP identifies, evaluates, and controls hazards and risks in complex processes.
- LOPA is a risk assessment and hazard evaluation tool for assessing high-consequence hazard scenarios.
- DSEAR places duties on employers to eliminate or control risks from explosive atmospheres in the workplace.
- ATEX outlines the minimum safety requirements for workplaces and equipment used in explosive atmospheres.

This information is used to add any necessary safety features to ensure safe plant operation. For example, ITM were able to mitigate risks which had been classed as “intolerable” with the additional protection in the form of a blast withstand barrier that will prevent effects of a failure within the external test bay from breaching the site boundary. The study outcomes were implemented.

The safety studies also included a hazardous areas classification assessment. ITM implemented the assessment’s recommendations, carrying out additional staff training, and revisiting emergency evacuation procedures and signage. A safety walkaround was undertaken, with the Operations Director, HSE representative and a Production and Test representative. The appropriate recommendations were confirmed as complete and the compliance for the test bay was therefore signed off.

One of the challenges in this task related to the power supply unit. The original supplier subcontracted a large part of the scope. ITM followed its standard procedure for critical items, including a kick-off meeting and regular progress calls which indicated that delivery was on track. However, close to the point of delivery, it became apparent that there were delays to some subcomponents. ITM’s head of procurement visited the subcontractor and discovered that the delayed components were not part of their business-as-usual. A PSU was secured from another supplier to mitigate against further delays. This was the unit which was ultimately used in the test-bay. This required additional work from the in-house electrical team and visits from our control logic supplier. The availability of the test-bay was delayed, but valuable learnings were gained.

3.5.2. Manufacturing lines

One stage of the in-house coating process uses acid which requires very careful handling and which produces harmful fumes. A safety consultant was engaged to review safety procedures and extraction requirements. This resulted in the installation of a wet gas scrubber, which took 4 months to design, install and test and was not included within the project scope. The cost of this item was borne by ITM. The mitigation against the delay is covered in section 3.2.7.

Emission tests were carried out over a run of 20 plates with reference to the following standards, covering volumetric flow and potential emissions:

- BS EN ISO 16911-1 EC-SE024a
- BS EN 1911 ETC-SE-05
- US EPA M8 ETC-SE-31
- BS EN 14790 ETC-SE-11

Results confirmed that the new systems remained within the safe operational limits for the acids used and handover of the plant to production was therefore completed.

3.5.3. Factory operation

An environmental assessment was undertaken to fully understand the impact of ITM's activities on neighbouring businesses.

Test area inputs are water and electricity; the outputs are hydrogen, oxygen and wastewater. Hydrogen and oxygen emissions are currently not classed as regulated activities, whilst water emissions need approval via a trade effluent permit. Assessments were undertaken to determine the wastewater composition and identify potential pollutants. Samples were taken from existing test rig systems to provide a baseline.

To monitor noise that could affect the environment, a qualified noise testing engineer was employed to assess whether noise from ITM's operations affects local homes and businesses. Variables which contribute to the noise levels include the weather, the location, the time of day, and type of area (residential, industrial etc). A baseline was taken during a period of non-operation, and a second test performed during operation to assess whether the noise produced falls within permitted limits. If that were the case, walls could be erected to mitigate this. The results indicate that sources other than ITM Power have a greater influence on the acoustic environment. A further test is planned during site operation later in 2025 to provide an additional data point.

4. Demonstration Study

An extensive testing program was undertaken to validate the new stack design and to provide information for customers the expected performance of electrolyser. Tests included:

- Validation tests
- Field tests
- Extended dynamic tests (electrolysis)
- Vibration tests
- Thermal tests
- Blast tests
- Stack pass rates during factory acceptance tests (FAT)

4.1. Validation tests

Design validation tests were performed for the Mk1 and Mk2 stacks. These consist of tests under varying loads on three different stacks to ensure they operate as expected. The stacks are electrolysers in a container system and subjected to mechanical and process conditions which are representative of conditions experienced in the field.

Hydrogen generation took place at 30bar(g) and at ITM standard temperature. Stacks underwent discrete and continuous operation to assess integrity. Pressure ramp tests were undertaken on start-up and pressure decay was measured every four hours. The differential pressure between the stacks was continuously assessed. Stacks were characterised up to 100% load to assess efficiency.

The Mk1 stacks passed these tests and were released for testing in the field (section 4.2). These tests complete the validation of the design of the new stacks.

The Mk2 stacks (Figure 18) were tested at Bessemer Park. They initially underwent pressure and leak tests prior to electrolysis.

Figure 18: Trident Mk2 in test-bay

The Mk2 stacks passed the tests and were released for production, with different stacks undergoing the additional tests described in section 4.3 to 4.6. This set of tests further validated the stack design as well as the manufacturing process improvements made.

4.2. Field tests

Field tests were conducted at two customer sites to assess stack performance under real-world conditions and at different extremes of temperature. First hydrogen from the Trident Mk1 was generated in September 2023. As well as determining technical factors, ease of operation for the plant workers was also assessed. By working in close collaboration with ITM staff during setup, commissioning and test, plant operators were able to improve their knowledge of electrolyser operation and ITM gained valuable knowledge around ways in which the look and feel of the electrolyser can be improved for future products.

For example, ITM implemented existing maintenance schedules which are based on small, bespoke plant operation. These are necessarily detailed due to the bespoke, first of a kind nature of the smaller plants and are more onerous if used for larger, 100MW+ installations. Maintenance requirements were reviewed by a team including design managers, process engineers, an electrical, control and instrumentation (EC&I) engineers and field engineers, focussing on the minimum requirements to maintain a safe system. It was found that it was safe to reschedule some monthly actions as annual, and some annual actions as biennial. For example, instrument calibrations moved from annual to biennial based on the known rate of drift for those instruments. Maintenance procedures were also refined. This was possible because ITM has gained experience in stack operation.

Experience on-site highlighted the need to use ultra-pure water for the electrolysers since issues with balance of plant could allow poor quality water to contaminate and damage stacks.

To assess the operation, pre-startup checks were completed, including integrity checks, and measurement of water flow rate to ensure enough for stack cooling. The hydrogen generation pressure and output were also measured. These, together with stack voltage at varying current, were used to calculate efficiency. The stacks passed all tests.

Onsite stack performance showed a close match with the efficiencies shown during factory acceptance tests (within one percentage point). Small differences in efficiency can be observed between factory and site testing when there are variations in process conditions. Stack to stack performance variation reduced as ITM staff gained experience with the new design and improved further when the semi-automated manufacturing equipment was brought online. Variations due to process temperature can now be compensated for mathematically.

A key capability of PEM stacks is their ability to load modulate. Stacks were operated using a highly variable load profile. As the current increases, the measured hydrogen production rate increases. The predicted performance model shows that each stack module should generate hydrogen at a rate of 72kg/h at 100% load, which was confirmed by site measurements. The system was then operated for 4 days with a varying load profile. Rapid load changes increase system stress, but the stacks performed well and without any faults. In these tests, the oxygen content was within specification, demonstrating that good hydrogen quality can be achieved at an industrial scale.

The Yara plant was officially opened in autumn 2024 (Figure 19) and has produced 280t of hydrogen over the first 30,843 hours. The system has the capacity to produce 10 tonnes of H2 per day and 20,500 tonnes of ammonia per year, providing CO2 reduction of 41,000 tonnes per year. This is an important reference plant for ITM. Being able to show plant operating in the field, with a high number of operating hours, supplying large quantities of hydrogen to an industrial process helps build confidence in potential customers.

Figure 19: Yara green hydrogen plant at Porsgrunn, Norway

4.3. Extended dynamic tests (electrolysis)

The purpose of these tests is to assess stack durability under the most aggressive conditions and to evaluate the way in which hydrogen production efficiency changes with time. ITM stacks have a nominal lifetime of 10 years, and it is important for us to assess the way they change with operational duration. This is normally carried out using short-stack tests, but additional information can be obtained by testing full stacks.

Testing in the factory allows ITM to control of all relevant variables. For the extended tests, three Mk2 stacks underwent baseline factory acceptance tests and were then installed in a NEPTUNE 2 unit in the Gigatest test bay. They were electrolysed for over 400 hours, 338 hours of which were at 100% load. Frequent current-voltage readings were plotted (IV curves) and used to assess stack performance and investigate any changes as a function of time. Water samples were taken to assess the rate of fluoride release, which can be used to measure membrane degradation. Issues encountered during testing were recorded and reviewed for lessons learned.

The extended testing enabled ITM to calculate a temperature correction factor at different current using a regression analysis. This can be used to normalise performance to any given temperature and means that the effect of unavoidable temperature variations on stack efficiency can be removed and stack performance at elevated temperatures can be modelled.

Hydrogen generation rates were measured across the full operating range, characterising generation rates at different currents. A range of KPIs were measured against operating time at minimum and maximum loads to calculate changes in performance. There was no statistical correlation between run-time and efficiency, meaning no degradation was observed over the duration of the test.

Further tests included current-voltage (IV) tests with differing ramp up step size and duration, temperature measurement to ensure that the materials meet the design criteria, and dynamic load tests to measure sensor response times.

Water quality measurements were used to assess the release of fluorides during the tests. As expected, the fluoride release rate and conductivity reduced across the test period, but the results are within tolerance for ITM stacks. The stack and sensor response times were assessed by changing the power supplied in large increments. Sensor response time and measurement stabilisation increased with larger demand steps. The response times were used to calibrate system alarms, and all were considered adequate for their function. Stack temperatures were also measured at various points to ensure they met design criteria.

4.4. Vibration tests

A stack and single transportation skid (both developed as part of Gigatest) were subjected to a series of vibration tests based on the BS EN 60068-2-64:2008 standard. The purpose was to assess their response when exposed to road and shipping vibrations and to confirm their robustness.

Internal tests were carried out on stacks at Bessemer Park using a fork-lift truck to replicate conditions seen during manufacture and installation. Additional stack-skid units were sent to ITM Germany and the stacks were tested for integrity on arrival. No negative effects were seen, so ITM subcontracted the Laboratory for Verification and Validation (LVV) at the University of Sheffield to perform the BS standard tests using a multi-axis shake table. Before testing, the stack had passed standard factory acceptance tests, to confirm functionality and measure electrical performance. It was then installed in the skid and the units underwent and passed BS standard tests, although some fasteners became loose on the skid. Improved fasteners were therefore included in the skid design.

The stack underwent factory acceptance tests to ensure it was still functional and to measure any changed in performance. It did not suffer any functional damage or performance degradation from the test program and there was no significant difference between performance before and after the vibration tests.

Finally, a vibration logger was installed in a crate transporting stack-skid units between Germany and the UK to ensure that the tests covered typical conditions experienced during transport. The subcontracted tests were more aggressive than those observed during transportation, adding robustness to the test procedure and providing further confidence in the results.

4.5. Thermal tests

LVV also undertook thermal tests on a stack in one of their large climatic chambers. The environment was varied between -20˚C and 50˚C, covering the range of expected operational temperatures. The results showed that there is only a very small change (<0.5C) in inlet and outlet water temperatures demonstrating that the stack is well insulated. A minimal allowable storage temperature will be added to the storage procedures to avoid any risk of freezing during periods of storage. After the thermal tests, the stacks underwent standard factory acceptance tests. Minimal difference was seen between the pre- and post-test results and these are within normal test variation. No performance degradation was observed.

4.6. Blast tests

ITM believes that it is not possible for detonation / deflagration to occur during normal stack operation as flowing water prevents gas pockets from accumulating and there are no credible sources of ignition.

ITM uses plastic materials in the balance of plant to avoid the risk of water contamination. Because these are not commonly used in pressure applications, they require a high level of qualification. As an example of the extreme tests carried out, ITM subcontracted DNV Spadeadam to perform explosion testing on the end plate and manifold assembly under conditions simulating a failure mode. It was necessary to artificially establish and ignite the environment within the component because this cannot occur during operation.

To pass these tests, no parts can be ejected from the test assembly in any situation and there should be no visible flames. Leakage tests were also conducted to assess system integrity post-explosion.

During the test, no projectiles were produced and there was no visible flame. After the test, the assembly was stripped down and examined. The assembly remained intact and was watertight. It was agreed that the test assembly had passed.

Our EPC partner, Linde, tested the full stack, end plate, manifold, pipework and separating vessel under more aggressive conditions at both extremes of process temperature to assess the way the electrolysers would react under two different exceptional explosion scenarios. The tests were caried out using a replica of the electrolyser module at the field test site. The only modifications were for the inclusion of sensors and flushing connections. Again, no projectiles were produced and there was no visible flame. It was agreed that the system had passed.

4.7. Stack pass rates during factory acceptance tests (FAT)

All the stacks produced at ITM are subjected to standard factory acceptance tests. ITM continues to monitor first-time pass rates at FAT as a key operational metric and part of its continuous improvement activities.

Performance of the Mk1 and Mk2 stacks are comparable, although there is less variation in the Mk2 results because of the tighter tolerances and improved consistency achieved through semi-automation of the manufacturing process.

As a result of the design and manufacturing improvements in Gigatest, at the end of January 2025, the first-time stack pass rate had improved from below 90% pre-Gigatest to >98%.

4.8. Design Review and Sign Off

During Gigatest, ITM developed and validated both component improvements and process improvements prior to fully testing the stack. The first iteration of the stack included CCM and PTL improvements. The second iteration focussed on changes necessary due to the process improvement work.

Quality was monitored during production and any reduction in part quality was investigated and a root cause analysis conducted. The first version of the stacks was field tested at customer sites. The second version underwent stringent in-house tests, and external vibration and blast tests.

Learnings from field and in-house then fed back into the stack design and production processes as part of our continuous improvement work. These included:

- Redesign of some cell plate features to improve tolerances
- Change in the mesh size of the PTL to improve performance
- Change to the spider plate assembly process to reduce complexity
- Purchase of a height-setting jig to reduce variation in CCMs
- New screen-printing procedures to reduce scrap
- New membrane preparation procedures to mitigate variations in supply
- Updated customer site readiness checklists to reduce delays and contamination
- Updated installation documents

On successful completion of all the tests, the stack design was reviewed and signed off, freezing both the design and its manufacturing route.

5. Project Metrics

5.1. Status of Gigatest objectives

Gigatest has achieved its aims and objectives as set out in section 2.1 as shown in Table 1. A fuller description of some achievements can be found in the sections below.

Table 1: Status of Gigatest objectives at the project end.

Gigatest Aim	Status
Increase stack pressure to 30 bar(g)	Achieved. The stack produces hydrogen at 30bar(g) and has passed all pressure and leak tests.
Demonstrate the new designs and manufacturing techniques on the MEP stack architecture	Achieved. The new stack includes all the design and manufacturing techniques developed as part of Gigatest. They have been successfully demonstrated on the 2MW Trident stack-skid.
Reduce the amount of catalyst used per stack to reduce cost	Achieved The amount of catalyst used in production was reduced by 15% - 20% by using improved manufacturing processes and the reducing scrap.

Reduce of the number of parts in the stack to reduce complexity	Achieved. The number of components at the final assembly stage has been reduced by >40% by joining parts.
Reduce the manufacturing process time per component	Achieved. Overall process time reduction is ~37% Major contributors include cycle time reductions in ink mixing (75%), automated washing (75%), and electrode welding (40%).
Reduce the scrap rate	Achieved. Semi-automated manufacture reduced scrap in all processes. Stack first-time pass rates have increased from ~50% pre-project to ~93% with the Mk1 stack and >98% for the Mk2 stack.
Deliver a functional state of the art test bay Develop quality control processes to support large scale electrolyser manufacturing	Achieved. The test bay for Trident stacks is operational at Bessemer Park. Quality control processes have been implemented throughout production
Establish a validation process for the new stack including FMEA and specialist off-site testing	Achieved. FMEA was undertaken and validation tests for all components and for the stack have been designed.
Fully test and validate stacks under real-world conditions (field tests added during rescope) which meets ITM's internal key performance indicators (KPIs)	Achieved. Field tests have taken place at Lingen for RWE and at Herøya Industrial Park for Yara. Extended testing took place at Bessemer Park and additional tests to assess performance under extreme conditions were subcontracted.
Efficiency <53kWh/kg	Achieved. Each iteration of the stack has shown improved efficiencies. Trident reliably achieves production efficiencies of <53kWh/kg.
Degradation of <1% per 1,000 hours	Achieved.

	No performance degradation was observed during the extensive testing.
Hot idle and cold start ramp times of 2s and 10s	Achieved.
Market acceptance of the stack	Achieved. ITM have announced capacity reservations and sales of the stack developed in Gigatest (launched as Trident), the NEPTUNE modules which contain the Trident at their core and the POSEIDON engineering module based around Trident. As of March 2025, these are: • 100MW Trident sales • 40MW Neptune V sales • 60MW FEED studies for Neptune V • 20MW basic design engineering package for POSEIDON, a typical first step for FID • 500+MW capacity reservations • 420+MW where it is selected supplier (which are subject to final investment decisions)

5.2. TRL at start and end of project

The project technology readiness level (TRL) at project start was TRL6 (technology demonstrated in a relevant environment) and finished at TRL8 (system complete and qualified).

At the project start, the design improvements had been demonstrated on single cells separately in the laboratory. They had not yet been combined into a single system or tested at short- and full-stack scales. After the project, all the design improvements had been implemented into the electrolyser stack and fully tested both in-house and in the field. The design had been signed off and the system was qualified and CE-marked.

The manufacturing readiness level (MRL) prior to the project varied for the different manufacturing technologies being implemented. Prior to the project start, some, such as the plating line, were at MRL4 (capable of producing the technology in a laboratory environment), whilst others had been proved in different industries and were at MRL5 (capable of producing the components in a production relevant environment) but needed to be transferred to the field of electrolyser manufacture, which has different requirements and tighter tolerances.

Post-project, the MRL of the technologies implemented was MRL9 (low-rate production demonstrated) with the integration of the semi-automated line in Bessemer Park. The plating line and the screen-printing lines were not fully implemented during the project and are at MRL6 (capable of producing components in a production-relevant environment.

The commercial readiness levels (CRL) pre- and post-project were CRL1, showing a basic understanding of the commercial opportunity for the new stack, and CRL3a, with a route to market and supply chain determined. Select partners have beta-tested the product and price-points has been determined for the different product options.

5.3. Trident stack metrics

The lifetime of the Gigatest stacks under normal operating conditions is expected to be 10 years.

The stacks are specified for operation from -20˚C to 40˚C and from 12.5% to 100% load. The large operating range means that they are particularly suited to use with renewable energy.

The 5MW NEPTUNE V (containing 8 Trident stacks) will produce 90kg of hydrogen per hour at 100% load.

5.3.1. Efficiency

Stack efficiencies which were repeatably below 53kWh/kg were achieved during the different tests, allowing each stack to produce a maximum of 12kg of hydrogen per hour. The Trident electrolyser consists of 3 stacks and so can produce up to 36kg of hydrogen per hour.

The average stack efficiencies showed improvement for Mk2 stacks than for Mk1 stacks at full load, due to improved part consistency and catalyst coatings. Stacks efficiencies just outside the project target were achieved during the extended tests, but these stacks did not contain electrode structures which had been coated in-house. The first full stack containing these plates was tested after the Gigatest project had finished and showed efficiencies which exceeded the Gigatest target.

5.3.2. Levelised cost of hydrogen

The levelized costs of hydrogen (LCOH) was calculated according to DESNZ suggested methodology[3] and the data used is compatible with that required for input into the calculator for the hydrogen allocation rounds[4]. Price data has been taken from the Green Book supplementary guidance[5].

The levelized cost of hydrogen varies depending on the electrolyser load and electricity source. The Gigatest electrolyser is more efficient at lower loads, but the capital cost (CAPEX) will contribute more to the LCOH. At higher loads, the efficiency will be reduced, and the operating cost (electricity price) will dominate. Electrolysers which are directly connected to renewables, or which use curtailed electricity will have the lowest LCOH.

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[3] https://www.gov.uk/government/publications/hydrogen-production-costs-2021
[4] https://www.gov.uk/government/publications/hydrogen-allocation-round-2
[5] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

For a 10MW module, taking the central case for estimated electricity costs over an assumed 20-year plant lifetime, and factoring in maintenance, operational and stack replacement costs, the LCOH varies between £2.50 and £6.50 per kg depending on the use, load and electricity source. Because the cost is driven by electricity price, the efficiency gains from the Gigatest project will lead to a significantly lower LCOH.

Installed cost is highly dependent on the scope of the project, required ground works etc. and is also dependent on inflation. ITM met its cost reduction targets for the installed £/kW of a single stack, reducing this cost significantly from the state of the art at the project start. The reduction in the £/kW module costs were harder to assess as ITM no longer offer the same module as was available at the project start. This was a shipping container which contained 3 stacks and a skid, and was sold with a power supply unit, water cleanup, controls and cabinet, cables and pipework. ITM's 5MW Neptune V has an increased scope to meet market demand for plug and play systems which contain all the necessary balance of plant for operation. The increased scope includes separating vessels, process pumps, hydrogen cleanup, more sensors and instruments, additional containers, increased functionality, a wider operating temperature range and a cooling system. At the end of the project the savings realised on stack materials and manufacture delivered a cost in line with the project target for the equipment used in the original module, once inflation was taken into account. Without that, ITM would have achieved its target if it were still manufacturing the same module. The £/kW for the Neptune V is higher than the project target due to the increased scope, but larger plants will be able to optimise balance of plant and achieve lower costs.

5.3.3. Hydrogen purity

The main pollutant in hydrogen from ITM stacks is oxygen from cross-over. The moisture content is not relevant, as this is dealt with post gas-treatment in any hydrogen system.

The official conformity requirement is detailed in BS EN 17124:2022.

Table 2: Conformity requirements for electrolysers

Impurity	Threshold for BS EN 17124:2022 Requirements	ITM Requirement for "Pass"
	Measured amount fraction µmol/mol	
Nitrogen	300	5
Oxygen	5	5
Water	5	5
Carbon Dioxide	2	2

The hydrogen gas output from the Trident short stack system was sampled at ITM Power internally and analysed by the National Physical Laboratory (NPL) for oxygen contamination at three current densities. This spot sampling represents a snapshot in time of the oxygen level in hydrogen from the 5-cell short stack; the percentage of oxygen will remain the same as the oxygen crossover will scale linearly with the number of cells. The oxygen levels detected by NPL were below the limit of detection (<0.06 μmol/mol) which equates to < part per million (mass) oxygen in all samples measured. This confirms that the hydrogen from Trident stacks meets the required purity standards.

NPL also analysed hydrogen from a Neptune II system containing 3 Trident stacks. The amount of Oxygen present was <1 μmol/mol, considerably below the amount allowed by the ISO standard.

5.3.4. Low Carbon Hydrogen Standard

The Trident stacks produced as a result of this project can be used with renewable energy to create hydrogen. Such a production facility is likely[6] to meet the UK Government's low carbon hydrogen standard[7] (LCHS) since electrolysis is an eligible hydrogen production pathway.

5.3.5. Greenhouse gas mitigation potential

Because the project related to improved stack design and electrolyser manufacturing improvements, there were no direct greenhouse gas (GHG) mitigations.

The 15%-20% catalyst reduction per manufactured stack will reduce the embodied carbon from catalyst mining and transport. Catalysts production varies between 20kg CO_2e and 40kg CO_2e per gram[8], although this is offset if they are used to mitigate emissions elsewhere. ITM meets the Clean Hydrogen Joint Undertaking guidelines for 2030, using <0.25mg/W of critical raw materials, so a 15% reduction in catalyst use for a 2MW Trident stack, assuming emissions of 20kg CO_2e, equates to a reduction of 1.5 tonnes of embodied carbon per stack.

The improved first-time pass rate and increased throughput reduce the amount of energy and raw materials required to manufacture a stack.

GHG mitigation will depend largely on factors such as the end-use of the hydrogen and the embodied carbon in the electricity used to create the hydrogen. The Yara plant which formed one of the field test sites in this report produced 280t of hydrogen during Gigatest which was used to make ammonia, mitigating 560t of CO_2.

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[6] Because the LCHS applies to consignments rather than production facilities (or pathways), according to the Standard, "Until hydrogen production begins, only claims of *likely* Standard Compliance may be made."

[7] https://assets.publishing.service.gov.uk/media/6584407fed3c3400133bfd47/uk-low-carbon-hydrogen-standard-v3-december-2023.pdf

[8] https://summerhavenindex.com/assets/PL_Note-1.pdf

6. Intellectual Property and Patents

During the project, we have generated significant intellectual property of which some is being kept as a trade secret. We have applied for patents. This is relevant not just for internal stack technology improvements but also includes stack manufacturing processes, controls and test methodologies.

7. Secondary Project Benefits

7.1. Dissemination activities undertaken including media coverage

ITM carried out over 150 dissemination activities as part of the project. We engaged with potential customers, allowing them to assess Trident capabilities prior to making an FID. Activities included site visits, technical demonstrations, technical audits and sharing of initial test results. We collated technical and economic KPIs and developed customer specific reports using information from the field trials and in-house testing. One key channel to market is through our engineering, procurement and construction (EPC) partner, Linde, as they integrate our stacks into the wider plant; we regularly discussed progress and challenges with them.

Key achievements include the launch of the stack developed during Gigatest, branded as Trident, and the launch of our 5MW Neptune V containerised product

7.2. New partnerships formed from project (UK and International)

ITM worked with nearly 50 suppliers during Gigatest. We worked with suppliers to improve the quality of purchased parts, and where this was not possible, we switched to companies which could offer higher quality parts. We developed our relationships with existing suppliers and announced strategic collaborations with Friem (power supply units), Gore (membranes) and Mott (PTLs). We worked with new suppliers of manufacturing and assembly equipment as part of our drive to automate stack production and improved our contractual arrangements with existing suppliers to improve parts quality and avoid negative impacts from supply chain disruption.

7.3. Supply chain development

The stack contains several sensitive components which are either specific to ITM or require very tight tolerances to meet our specifications. We assessed the capability of our supply chain and identified suppliers able to meet our standards. We developed and rolled out a new precedent framework agreement and supplier requirements document which details our minimum requirements. We also provided supplemental training for the procurement team. More detail is provided in section 3.4.1.

8. Project Management

The project was carried out according to ITM's Business Management System (BMS), which is compliant with ISO 9001:2008. This provides a framework for ensuring the highest standard of project management and guarantees a high level of quality. The project was originally managed by one of ITM's project management team who oversaw all the technical and financial aspects and completed the reporting. Workpackage (WP) and task leaders reported to the project manager. However, there was some conflict between commercial and non-commercial projects, because the latter were not considered in strategic company plans. The project manager was not involved in strategic company discussions.

During the project, ITM undertook a major restructure. The Executive Team ensured that the resource required to deliver Gigatest remained in place, but changes were made to the management structure to balance ITM's commercial and research needs. The Executive Team created a "special projects" function, which improved Exec-level visibility of high-profile, company-critical projects and separated this from the daily demands of commercial project delivery. An executive-level project director now managed the project and each work package (WP) was assigned to the relevant head of department to increase oversight and governance. The WP leaders managed task leaders and ensured tasks remained on-track. An Administrative Project Manager tracked costs and financial risks and compiled the claims and quarterly reports. The Project Director collated deliverables and escalated any risks or delays to ITM's executive committee. This was a strategically significant project for ITM Power and was supported at the highest levels within the organisation. The project is regularly reviewed by C-level directors ensuring that any potential strategic or commercial risks were known and mitigated in a timely manner.

Management at such a high level within the company ensured that the assessment of risks was not limited to the technical risks but also included commercial risks such as customer acceptance. It ensured that the project goals remained aligned with strategic company goals and change requests were submitted if the scope no longer met company requirements. This meant that funds and research efforts were focussed on the right place and avoided unnecessary or wasteful spend.

An example of this is the project rescope described in section 1.2. The 5MW modules were originally envisaged as a single stack platform containing numerous scientific and manufacturing advancements. Although the market needs larger electrolyser modules, a new stack platform containing new technical concepts and built on a new manufacturing line in a new factory incorporated a level of risk for first time deployment for large-scale electrolyser plants. The decision was made to rescope Gigatest so that the innovations were demonstrated on the existing stack platform made in the existing factory. Additional deliverables on dissemination and knowledge sharing were added to the project to provide customers with assurance in the performance, reliability and robustness of the Gigatest stack through the provision of real-world data. Dissemination activities include site visits, technical demonstrations and sharing of initial test results. Field tests were also added to the project scope

No recruitment was required to deliver Gigatest, although the project safeguarded jobs at the factory when ITM underwent a restructure. New jobs were created as the new Trident stack and NEPTUNE containerised units moved into beta production as a direct result of Gigatest.

8.1. Risks

Key risks for the project included:

- A commercial risk that end-users would not buy the electrolyser being developed. Although end-users were requesting larger electrolyser platforms when the project was scoped, changing market conditions reduced customer risk-appetite for a first-of-a-kind product produced on new manufacturing lines. The solution was to prove the new stack components and manufacturing processes on the existing stack architecture, providing technical improvements in a well-understood system. Field tests were also added to the project scope, producing hydrogen under real operating conditions and providing robustness and reliability data. ITM engaged with customers (factory and site visits) to provide confidence in the new product.
- A risk that field trials could be delayed due to issues on-site. This was mitigated with additional short-stack tests at Bessemer Park and acquisition of data from more than one installation. This allowed data to be gathered for additional stacks and provided information on repeatability.
- A risk that one or more technical work streams couldn't achieve the Gigatest targets. This was mitigated through extensive short stack testing of the stack components and selection of manufacturing equipment which was proven in other sectors. The risk materialised for the screen printing and the plating lines. The delays with the screen-printing were due to difficulties for the supplier in achieving the required tolerances. To mitigate this, the line was respecified, and equipment installation was split into two phases. The delay in the installation of the plating line was due to emissions exceeding safety limits. This was mitigated by using an external supplier to provide parts whilst additional extraction equipment was installed.
- A risk that there wouldn't be sufficient power for testing. This was mitigated by the move from the GEP to MEP architecture, by prioritising tests and by managing spend. The MEP architecture requires significantly less power to test per product. Cost management enabled us to increase the amount of money available for testing. Tests were carefully planned to maximise the information gained from each. Discussions took place with the distribution network operator (DNO) regarding the power upgrade and progress was monitored on a weekly basis. This risk did not become an issue.
- Loss of key personnel. This was mitigated through having a large technical, engineering and management team to draw on and full support from the Executive team (Exec). Although key staff left during the project, ITM were able to replace these from existing staff and by carefully managing reporting lines and with regular reports to the Exec, negative impacts were avoided.
- Supply chain disruption. This was mitigated by allocating a lead in the purchasing department to develop the supply chain and ensure equipment delivery. The risk did not become an issue.

8.2. Lessons learnt

ITM learnt a number of lessons from Gigatest which they will carry through to new projects.

One key lesson was the importance of communication of project aims and progress with customers. This ensures that the developments will meet their requirements and that the risk to them of using the technology is minimised. During the project, ITM rescoped the project when customer feedback indicated that it would be harder for them to invest in a completely new product manufactured using new processes. The project developments were therefore demonstrated on ITM's existing stack platform made in their existing factory. By focussing on the original project goals rather than specific technologies, ITM was able to deliver the 5MW modules as a containerised solution rather than a completely new stack, reducing barriers to market entry.

Flexibility in project delivery is also important. ITM continuously evaluated project developments to ensure technologies could be delivered within the project timescales and to budget. Where this was not possible, or where gains were not sufficient to justify future spend, these developments were deprioritised. Examples of this include splitting implementation of the screen printers into two phases and moving one of these outside the project scope and the inclusion of additional field tests when operations at one site were delayed.

Clear and honest communication with the project officer and DESNZ was important as it allowed the changing project needs described above to be addressed in a timely manner.

Lessons on activities which could be improved include a reduction in the number of deliverables, especially interim technology reports. These could be time-consuming to produce and, given the monthly meetings with the project officer and the requirement for monthly reports, didn't add significant value to the project.

Another learning was to ensure that the right people are involved in the preparation of deliverables. For example, a design error was identified by production staff which had not been identified at an earlier design stage. Design iterations could have been avoided had the production staff been involved earlier in the process.

9. Conclusions and Next Steps

Gigatest was critical in enabling ITM to develop and integrate improved stack components and to deploy and validate key manufacturing equipment at its Gigafactory at Bessemer Park. The comprehensive testing program allowed us to determine key operational parameters and to offer customers assurance that these could be achieved.

Key scientific achievements include:

- Development of a 30bar(g) stack which included skid redesign for increased pressure
- Improved cell-plate design
- Improved manufacturing methods for CCMs and development of robust quality control procedures
- Qualification of more efficient, composite, reinforced membranes
- Analysis of component stresses and identification of lighter materials for certain components in the skid

- Development, installation and commissioning of:
    - Stack movement aids to reduce manual handing and damage to stacks during loading / unloading operations
    - A vision system and QC processes to improve stack assembly quality and reduce build time
    - An automated ink-mixing system and QC system to supply the screen-printing system
    - Screen-printing techniques for membrane coating
    - Automated component washing
    - An automated electrode welding system with QC to join parts prior to stack assembly
- Understanding of electrochemical and mechanical failure modes and ongoing FMEA
- Development of a new test bay and test rig for the new stacks
- Development of validation tests for the new stacks
- Improvement in ITM CE works and tracking of cell-plate and stack iterations
- Increased understanding of stack storage requirements
- Increased understanding of production ramp-up, including a plan for what to increase and when
- Improved supply chain management to reduce bottlenecks and increased quality

These advances enabled ITM to meet its original project aims to:

- Design and demonstration a fully validated Trident 2MW stack-skid system (3 stacks) which:
    - CE, AS and ASME compliance
    - Output pressure 31bar(g)
    - Produces 36kg of hydrogen per hour
    - Hydrogen output purity - saturated
    - Operational range of 25% - 100% load
    - Ambient temperature range -20˚C to +40˚C
    - Has world-beating stack efficiencies (min to max load) of 45.7 to 52.9 kWh/kg
    - Degradation of <1% per 1,000 hours
    - Modulation range 10% per second ramp up and 50% per second ramp down
- The Trident stack is at the heart of the 5MW NEPTUNE V containerised solution (8 stacks)
    - CE compliance

    - Achieves significant reduction in cost per MW for containerised solutions
    - Operates at 30bar(g)
    - Produces 90kg of hydrogen per hour
    - Hydrogen purity <5ppm H_2O, <5ppm O_2 (EN 17124 & ISO 14687)
    - Operational range of 12.5% - 100% load
    - Ambient temperature range -20˚C to +45˚C
    - Has a system efficiency of 55.9 kWh/kg at beginning of life (including water purification, stack and balance of plant)
    - Degradation of <1% per 1,000 hours
    - Modulation range 10% per second ramp up and 50% per second ramp down
- Design and development of a lightweight skid
- Implementation of semi-automated manufacture at Bessemer Park. This has several advantages:
    - Increase in first-time factory acceptance test pass rates from <50% to >98% because of the manufacturing semi-automation and introduction of the vision system.
    - 15%-20% reduction in the amount of catalyst used per stack due manufacturing improvements
    - Reduction in overall cycle time >37%, which was achieved through cycle time reductions in:
        - 75% in ink manufacturing time due to the ink mixer
        - 75% in component washing times due to the automated washer
        - 40% in electrode joining due to the electrode welder
        - Reduction in assembly complexity
- Rapid introduction of semi-automated manufacture, increasing capacity whilst improving quality.
- Increased manufacturing capability at Bessemer Park and developed a path for further scale-up through equipment replication and shift work as ITM's order book increases.
- Delivery of a fully functioning test-bay for the new systems
- Full testing and validation to determine the stack parameters above, which included:
    - Failure modes and effects analysis
    - 100+ hours of short-stack tests
    - Static tests
    - 400+ hours of extended dynamic tests

- Field tests
- Thermal, vibration and blast tests

ITM's product offering is now centred on the Trident stack developed during the project.

Trident forms the bases of a 2MW electrolyser skid containing three stacks. The Trident stack-skid has multiple competitive advantages, including reduced capital costs and improved efficiencies, which greatly enhance its ability to operate under flexible conditions. This allows it to be coupled to renewable energy and therefore produce green hydrogen at the lowest cost in the market. ITM are confident the Trident stack is globally best in class.

The stack-skid can be scaled to meet customer requirements. The balance of plant services can be optimised for the number of skids, reducing overall cost. This is demonstrated through the development of the 20MW POSEIDON process module which is a modular building block enabling further scale-up with an optimised footprint and suitable for both indoor and outdoor installation. It consists of skid-mounted units which can be fabricated and tested offsite, reducing deployment times and project costs. It incorporates the lessons learnt from commercial projects and from the field tests undertaken during Gigatest.

ITM also offers two, stand-alone containerised solutions which contain all the necessary balance of plant for immediate operation. These are the 2MW NEPTUNE II system and the 5MW NEPTUNE V. The Trident stack is at the heart of these fully autonomous systems, which contain power conversion, water purification, and gas drying units. The NEPTUNE V plug and play unit has the same capacity as the originally proposed GEP stack architecture.

During the project, ITM announced partnerships with key suppliers to help them grow with us and deliver high quality components in sufficient quantities.

As a direct result of Gigatest, ITM have announced capacity reservations and sales of the stack developed in Gigatest (launched as Trident), the NEPTUNE modules which contain the Trident at their core and the POSEIDON engineering module based around Trident (section 7.1)

As of May 2025, these are:

- 100MW Trident sales
- 40MW Neptune V sales
- 60MW FEED studies for Neptune V
- 20MW basic design engineering package for POSEIDON, a typical first step for FID
- 500+MW capacity reservations
- 420+MW where it is selected supplier (which are subject to final investment decisions)

Next steps include the delivery and installation of phase 2 of the screen-printing equipment and integration of the in-house plating line with production. Having undertaken trials, ITM has ordered equipment to automate the stack assembly process. This will be commissioned these later in the year. Together we expect these activities to further reduce costs, improve throughput, and further improve quality. Strong demand for the new Neptune V containerised electrolyser product is requiring additional production and testing capacity to be planned. With current PEM manufacturing capacities and a validated plan for further scale-up, ITM Power's Gigafactory will be crucial in ramping up green hydrogen production in the UK and positioning it as a global export leader of electrolyser technologies.

Gigatest has allowed ITM to begin automating production and to introduce in-line process-monitoring to increase throughput, tighten tolerances and drive quality, leading to a reliable and reproduceable product of the new, core stack. It is now in the process of optimising the facility for increased automation to ramp up production to the nameplate capacity. The resultant layout will be used as a blueprint for ITM's next manufacturing plant.

TRIDENT

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