

Joining engineering

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CATAPULT
High Value Manufacturing



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Joining engineering

The engineering process of integrating materials into complex structures using chemical, electrical, thermal or mechanical methods to reliably combine similar and dissimilar materials to enhance design freedom, enhance performance, improve sustainability and underpin automation, digital assurance and high-integrity advanced manufacturing.

Why: Demand drivers

- Advanced design practices that improve sustainability and circularity
- Through-life assurance that leverages data-driven technologies
- Accessibility to skills – from technicians to engineers
- Process automation to boost productivity and reduce manufacturing costs
- Digitalisation technologies for predicting and optimising manufacturing processes.

What: Priority industry capability needs

- Capabilities for dissimilar materials and recycled materials
- Advanced design practices to support through-life and end-of-life disassembly and recycling
- Advanced automation integrating digital twins, modelling and in-situ monitoring to capture and control joining integrity in real time
- Robust certification, qualification and standardisation processes to support adoption of recycled materials and end-of-life product responsibility
- Standardised high-fidelity design models enabling a whole life cycle engineering ethos – sustainability, repair, maintenance repair and overhaul optimisation, and disassembly.

How: Priority innovation requirements

- Characterisation of joining performance in advanced, recycled and dissimilar materials
- Integrated in-process monitoring and inspection systems for enhanced manufacturing reliability and efficiency
- Integrated cost estimation, sustainability assessments and data governance for environmentally and economically sustainable joining practices
- Developing and validating advanced design and simulation techniques – including digital twins, predictive and life cycle assessment models
- High-fidelity data capture, simulation and AI-assisted validation leveraging large-scale digital twin models for optimisation of joining processes.

Joining engineering is a core pillar of advanced manufacturing, enabling the creation of lighter, cleaner and high-integrity products across critical UK industries. Covering advanced welding, brazing, soldering, adhesive bonding and mechanical fastening, these capabilities support the manufacture of both very large structures and ultra-miniaturised components essential to modern life. As products become more complex and performance requirements intensify, next-generation joining is delivering higher quality, improved sustainability and greater production agility.

Key HVM Catapult capabilities in joining engineering

Adhesive formulation and bonding, CPI (Sedgefield)

Advanced adhesive formulation and bonding expertise, enabling tailored chemistries, scalable processing, rigorous testing and reliable performance for high-value manufacturing and industrial applications worldwide.

Automated and mechanised fusion welding, AMRC (Rotherham) and MTC (Coventry)

Automated and mechanised arc and power beam welding solutions, providing precision control, high productivity, consistent quality and scalable processes for advanced manufacturing and industrial applications.

Brazing and soldering, NCC (Bristol)

Advanced brazing and soldering for composites, delivering robust joining, enhanced thermal performance, precision processing and reliable, scalable solutions for high-performance manufacturing applications.

Hot isostatic bonding and hot plate bonding systems, AMRC (Rotherham)

Delivering precision joining, scalable processing, material integrity and reliable solutions for demanding industries worldwide.

Large and small-scale mechanical fasteners, WMG (Coventry)

Specialist equipment and expertise in precision large and small-scale mechanical fasteners, delivering reliable quality, tailored solutions, rapid turnaround and expert support for industrial, engineering and manufacturing applications worldwide.

Large-scale rotary and inertia friction welding, NMIS (Renfrew)

State-of-the-art capabilities, providing precision-engineered cells, process expertise, rapid deployment and reliable performance for demanding industrial manufacturing environments.

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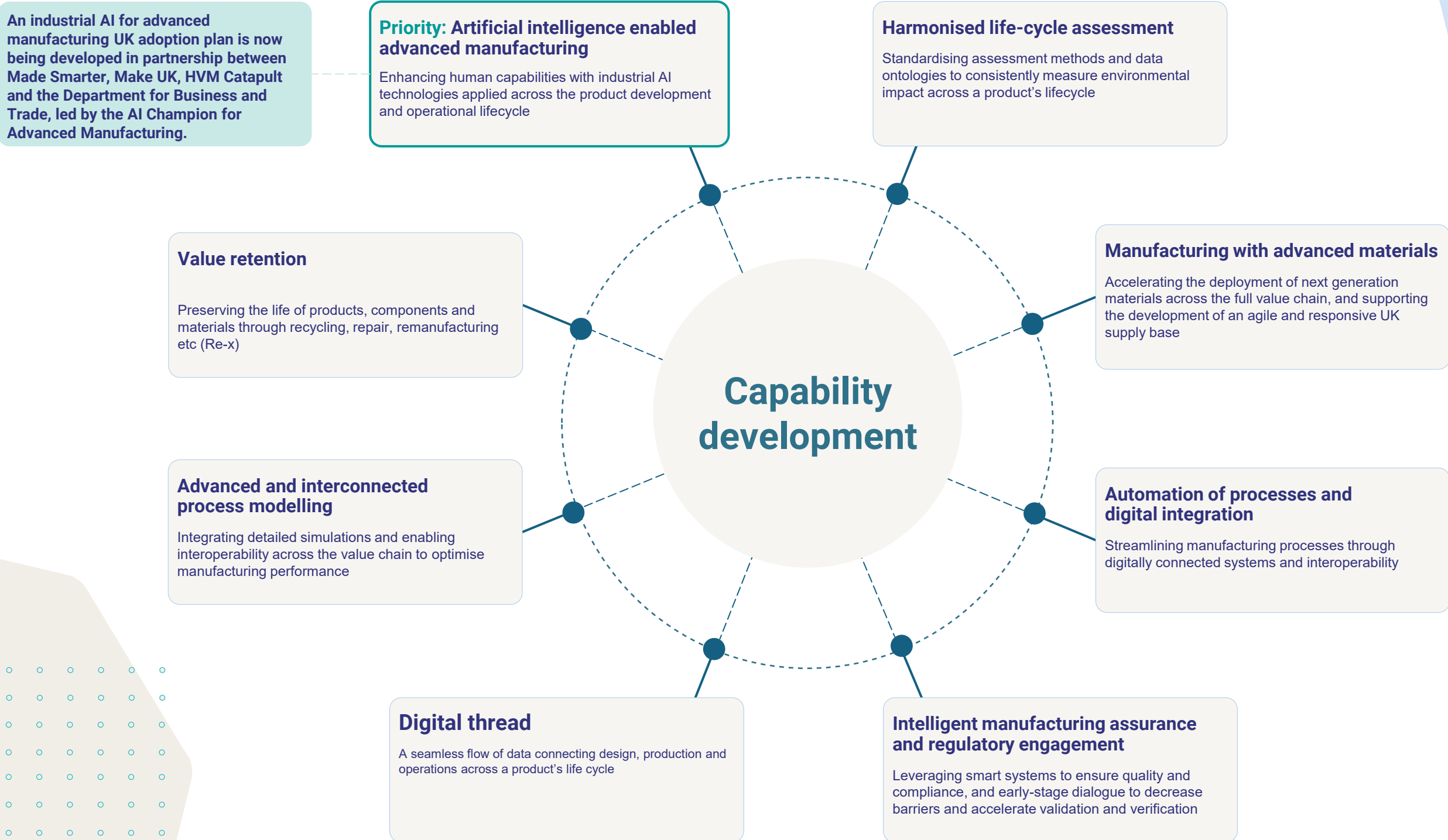
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Connected technology platforms

Through cross-domain analysis, eight connected technology platforms have been identified. They underpin both the core advanced manufacturing process technologies and the cross-cutting enabling technologies set out in this strategy.

They provide a shared foundation of insight and collective capability, showing where coordinated effort across our domains can best strengthen, connect and accelerate the technologies that matter most to UK industry.



Interpreting our roadmaps

The strategy structure

Why: Demand drivers

External pressures or opportunities that create the need for new or improved manufacturing capabilities.

What: Industry capability needs and priorities

The practical abilities industry must have to remain competitive in the future and the priorities for HVM Catapult.



Priority industry capability needs

The most critical capability gaps identified through industry consultation that must be addressed first to deliver impact.

How: Innovation requirements and priorities

The specific technologies, tools, processes, data, skills or system enablers that must be developed, improved or integrated to meet future industry capability needs, and the priorities for HVM Catapult.

Connected technology platforms

Highlight where coordinated effort across our domains can best strengthen, connect and accelerate the technologies that matter most to UK industry

Roadmap activity examples

Establish test beds to develop, integrate and validate novel inspection, measurement and test techniques and processes.

Demonstrated the trustworthy comparative robustness of emerging inspection, measurement and test technologies

The above 'what' items are linked and dependent – denoted by the overlapping boxes

Deployment of increased mechanization to remove variability and increase standardization linked to respective process specifications

Standardised digital weld procedures, reusable qualification libraries, harmonised standards

The above 'how' discrete items that are not linked and occur in different time horizons

IUK Strategic imperatives



Alignment with the Innovate UK vision

Each demand driver is colour-coded to align with the four imperatives of the Innovate UK materials and manufacturing vision 2050.

Innovative and digital

Businesses drive continuous and transformative innovation and create, adopt and export advanced digital technologies

Resource-efficient and regenerative

Sectors maximise circularity of materials, energy and water and aim for a net positive impact on the environment

Resilient and responsive

Mitigating risks from supply chain disruptions, national/global crises, and climate change.

Skilled and empowered

Workforces are highly skilled in executing advanced tasks and are empowered by configurable, open technology stacks

Joining engineering



Further details of the demand drivers, industry capability needs and innovation requirements are available online. Follow the QR code or [click here](#).

Vision

HVM Catapult, alongside industry, academia and partner RTOs, will champion innovation in sustainable joining technologies to enable modular, repairable and recyclable structures through advanced design, digital integration and workforce upskilling to secure UK manufacturing global competitiveness.



2026

2030

2035

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Advanced design practices that improve sustainability and circularity

Through-life assurance that leverages data-driven technologies

Accessibility to skills – from technicians to engineers

Process automation to boost productivity and reduce manufacturing costs

Digitalisation technologies for predicting and optimising manufacturing processes

Capabilities for dissimilar materials and recycled materials

Advanced design practices to support through-life and end-of-life disassembly and recycling

Modular architecture and agile tooling

Remote and portable robotic joining and inspecting systems in standard and specialised habitats

Advanced automation integrating digital twins, modelling and in-situ monitoring to capture and control joining integrity in real time

Standardised high-fidelity design models enabling a whole life cycle engineering ethos – sustainability, repair, maintenance repair and overhaul optimisation, and disassembly

Robust certification, qualification and standardisation processes to support adoption of recycled materials and end-of-life product responsibility

In-process monitoring and real-time assurance

Develop AI as a strategic tool for optimisation

High-integrity joining and certification by analysis

Accelerating transfer of cross-sector joining technology

High-fidelity data capture, simulation and AI-assisted validation, leveraging large-scale digital twin models for optimisation of joining processes

Integrated in-process monitoring and inspection systems for enhanced manufacturing reliability and efficiency

Creation of a central processing repository for dissimilar material joining and respective procedures to optimise performance

Developing and validating advanced design and simulation techniques – including digital twins, predictive and life cycle assessment models

Characterisation of joining performance in advanced, recycled and dissimilar materials

Integrated cost estimation, sustainability assessments and data governance for environmentally and economically sustainable joining practices

Technology-enhanced training and haptics

Standardising and creating a data infrastructure for cross-sector interoperability

Designing and proving of advanced consumables to facilitate joining dissimilar and recycled materials

Key

Demand drivers

Why change is needed.

Industry capability needs

What capabilities industry needs to respond to these changes.

Innovation requirements

How capabilities must develop.

Priority industry capability needs

The most critical capability gaps identified through industry consultation that must be addressed first to deliver impact.

Joining engineering – demand drivers

Through life assurance that leverages data-driven technologies

In-Process Monitoring & Real-Time Assurance to reduce lead times and in-sequence rectification through immediate data loops capable of tracking volumetric integrity and thermally induced dimensional deviations

Modular Repair & Through-Life Monitoring Systems that positions this theme as a priority path, treating assets as live data-generators ensuring long-term integrity through constant data gathering

High-Integrity Joining & Certification by Analysis to reduce the reliance on physical testing through lowering adoption barriers for new technologies through advanced modelling

Digital Thread & Product Passports that establishes a 'service digital thread' linking joining parameters directly to NDT results to ensure supply-chain

Digitalisation technologies for predicting and optimising manufacturing processes

AI as a Strategic Tool for Optimisation for data mining of large-scale information to optimize joint designs and process inputs

Standardising and creating a Data Infrastructure for Cross-Sector Interoperability to create a common language for joining data and the establishing of framework for sharing of sovereign data. This also includes ownership of digital product data.

High-fidelity data capture, simulation and AI-assisted validation leveraging largescale digital twin models for optimisation of joining processes to underpin Design and Certify by Analysis philosophies whilst tracking a component's evolution from COS through to final assembly.

Digital Product Passports & Century-Scale Integrity linking material data to long-term asset health via Long-term (100-year) data storage solutions.

Advanced design practices to improve sustainability and circularity

Design for Disassembly & Repair to ensure assets can be recovered, repaired, and reused. This includes designing and proving of consumables that facilitate joining of advanced and recycled materials

Dissimilar Material Joining & Mechanical Fastening to exploit hybrid structures that permit the design and use of advanced coatings and thermal treatments in parallel with surface engineering concepts.

Digital Twins for Lifecycle Impact to simulate joint performance and lifecycle impacts and enable designers to predict a repair or replacement.

Systems Engineering & Joining Optioneering enabling joining to become a primary driver of the design ensuring scalability and production efficiency are baked into the initial blueprints.

Accessibility to Skills – From Technicians to Engineers

Technology-Enhanced Training & Haptics to capture nuanced physical interactions of expert welders thereby accelerating the learning curve using AR, AI, and human-machine interaction.

Targeted Sills Pathways to Address Skill Shortages through educationally structured programs for technicians and engineers to master advanced joining and digital tools through improved industry, FE, and university alignment.

Supply Chain & SME Integration to strengthen support via trade associations to include service providers and in-training ecosystems.

Advanced CPD & Active Skills Research to create lifelong learning frameworks whilst concurrently conducting 'Active Research' on skills identification to proactively map out the roles needed for 2030 and beyond.

Process automation to boost productivity and reduce manufacturing costs

Accelerating Transfer of Cross-Sector Joining Technology to improve agility and deployment of high-speed, high integrity fixing mechanisms to improve dissimilar joining, minimise substrate disruption, whilst increasing production rates.

Development of remote, and Portable Robotic Joining and Inspecting Systems for standard and specialised habitats permitting a dedicated focus on repair welding as a productivity driver.

Modular architecture and Agile Tooling permitting maximising utilisation in high-volume environments focused on market-ready productivity tools.

Production Ready Closed-Loop & Adaptive Control Systems using evolutionary Machine Learning to define processing limits to manage in-situ residual stress and distortion within approved qualification envelopes.



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Strategic summary

The increasing demand for joining engineering will see the adoption of advanced design practices for circularity, prioritizing disassembly through modularisation to improve sustainability and recover valuable materials whilst maintaining the need for high structural integrity. Such a challenge will require engineers to leverage a compendium of AI systems incorporating material evolution data, and in-process sensing, through to certified digital twins, capable of orchestrating high-fidelity simulation systems needed to balance through-life assurance, and end-of-life recovery.

IUK Strategic imperatives

- Innovative and digital
- Resource-efficient and regenerative
- Resilient and responsive
- Skilled and empowered



Joining engineering – Industry capability needs

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Technology domain specific

Joining techniques for thick section metallics (50mm+)

Capabilities for dissimilar materials and recycled materials

Advanced design practices to support through life and end-of-life disassembly and recycling

Remote and Portable Robotic Joining and Inspecting systems for standard and specialised habitats

Strategic R&D and Financial Readiness Assessments incorporated into the design process

Advanced consumables to facilitate joining dissimilar and recycled materials

Dissimilar Material Joining & Mechanical Fastening

Joining qualifications - practice and theory for a conscious competent workforce

Digital Thread & Product Passports

Targeted Skills Pathways to Address Skill Shortages

Technology-Enhanced Training & Haptics

Cyber-physical human-centred welding and joining systems (CPHS) combining IoT, digital twins, and collaborative robots for resilience.

Design database for Disassembly & Repair

Develop AI as a Strategic Tool for Optimisation

Human-Centric Design & Digital capability

Systems Engineering & Joining Optioneering

Manufacturing with advanced materials

Accelerating development of high-performance, de-bondable adhesive polymers for hybrid joints and dissimilar material combinations

Surface Engineering and Consumable Development for complex material combinations

Value retention

Joining strategies supporting easy separation of components for maintenance, reuse, remanufacture, or recycling.

Energy efficient high-throughput joining processes enhancing manufacturing speed, repeatability, automation readiness, and operational cost-effectiveness

Automation of processes and digital integration

Automated Process Passports & Resource Integration

Advanced automation integrating Digital Twins, modelling, and in-situ monitoring to capture and control joining integrity in real-time.

Standardised high-fidelity design models enabling a Whole-Life Cycle Engineering ethos - MRO optimisation, and disassembly

High-Integrity Joining & Certification by Analysis

Robust certification, qualification and standardisation processes, to support adoption of recycled materials and end-of-life disposal

Standardising and creating a Data Infrastructure for Cross-Sector Interoperability

Digital Product Passports & Century-Scale Integrity

Intelligent manufacturing assurance and regulatory engagement

In-Process Monitoring & Real-Time Assurance

Production Ready Closed-Loop & Adaptive Control Systems

Intelligent platforms connecting multiple technologies to support and improve joining productivity to enhance reliability and safety

Framework of standards and qualifications convergence

Harmonised life cycle analysis

Intelligent platforms connecting multiple technologies to support and improve joining productivity to enhance reliability and safety

Joining engineering – Innovation requirements

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Technology domain specific

Characterisation of joining performance in advanced, recycled and dissimilar materials assessing, effects from impurities, interfacial chemistry, corrosive response and mechanical stress distribution etc.

Accelerating transfer of Cross-Sector Joining Technology through Cross-Sector Gap Analysis, DfM & DfD, Semantic Search and AI Scouting etc.

Development and validation of advanced joining techniques for thick section metallics (50mm+) e.g. the use of Power Beam and advanced arc welding.

Development of heterogeneous joining technologies for next gen materials

Proven advancements and increased deployment of autogenous fusion and solid-state joining at scale.

Competitive deployment of advanced arc welding using next generation consumables

Joining of dissimilar materials – within genre and across the material spectrum, e.g. metallics to ceramics, a metallics to composites

Development of next generation of joining engineering modules capturing technology developments linked to improve regulatory control

Advanced CPD & Active Skills Research to create lifelong learning frameworks conducting 'Active Research' on skills identification

Flexible Learning Platforms from RQF 3 to RQF 8

Digital Thread

Technology-Enhanced Training & Haptics to address the skills shortage and accelerate capability

High-fidelity data capture, simulation and AI-assisted validation leveraging largescale digital twin models for optimisation of joining processes using, e.g., Multi-Modal Data Fusion, Multi-Physics Simulation & Reduced Order Modelling, Closed loop Validation and Twin-to-Physical feedback etc.

Developing and validating advanced design and simulation techniques – including digital twins, predictive and lifecycle assessment models using MSM-Microstructure to Macro-Structure, LCA integrated into the design loop, and Uncertainty Quantification

Standardising and creating a Data Infrastructure for Cross-Sector Interoperability

Manufacturing with advanced materials

Data collection and collation of generic materials to generate joining design and performance taxonomy for virgin and recycled materials

Creation of a central processing repository for dissimilar material joining and respective procedures to optimize performance

Working with academia and materials producing suppliers to develop the next generation of joining consumables

Designing and proving of advanced consumables to facilitate joining dissimilar and recycled materials

Traceable digital records of materials and components for quality assurance and end-of-life circularity in joining

Value retention

Modular construction enabling higher performance and sustainability

Integrated cost estimation, sustainability assessments and data governance for environmentally and economically sustainable joining practices, e.g., Activity-Based Costing, Multi-Criteria Decision Analysis, Digital Product Passports etc.

Innovative inspection, repair, and remanufacturing methods that prolong service life and reducing environmental product impacts using -autonomous inspection and disassembly techniques, etc.

Intelligent manufacturing assurance & regulatory engagement

Integrated in-process monitoring and inspection systems for enhanced manufacturing reliability and efficiency to improve efficiency, monitoring, and high-quality production outcomes.

Establishing technical and regulatory standards for joining processes to ensure interoperability, safety, and consistent quality globally.

Deployment of increased mechanization to remove variability and increase standardization linked to respective process specifications

Standardised digital weld procedures, reusable qualification libraries, harmonised standards

Supply Chain & SME Integration to strengthen support via trade associations to include service providers and in-training ecosystems.

Harmonised life cycle analysis

Optimise heat input and consumable efficiency, low-energy joining, Integrate carbon modelling

Establish LCA databases and carbon accounting standards to measure sustainability across joining technologies

Joining engineering: Priority pathways

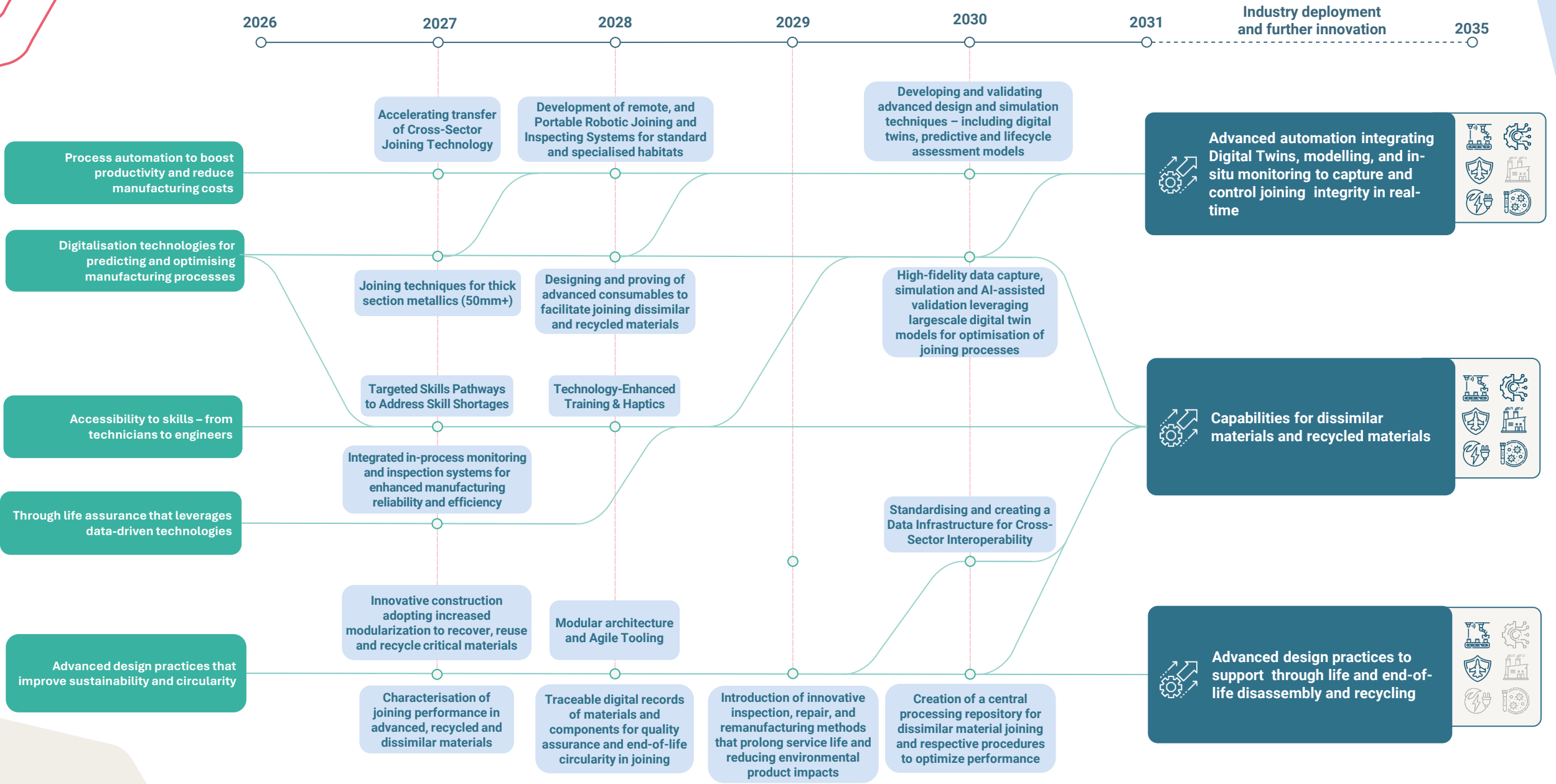


Diagram Legend

- Demand drivers**
Why change is needed
- Innovation requirements**
How capabilities must develop
- Industry capability needs**
What capabilities industry needs to respond to these challenges
- Priority industry capability needs**
The most critical capability gaps identified through industry consultation that be addressed first to deliver impact

Industrial strategy growth-driving sectors

- Foundation Industries
- Clean Energy Industries
- Digital & Technologies
- Life Sciences
- Advanced Manufacturing
- Defence