

Technology Strategy Consultation

28.01.26



Scope and distribution

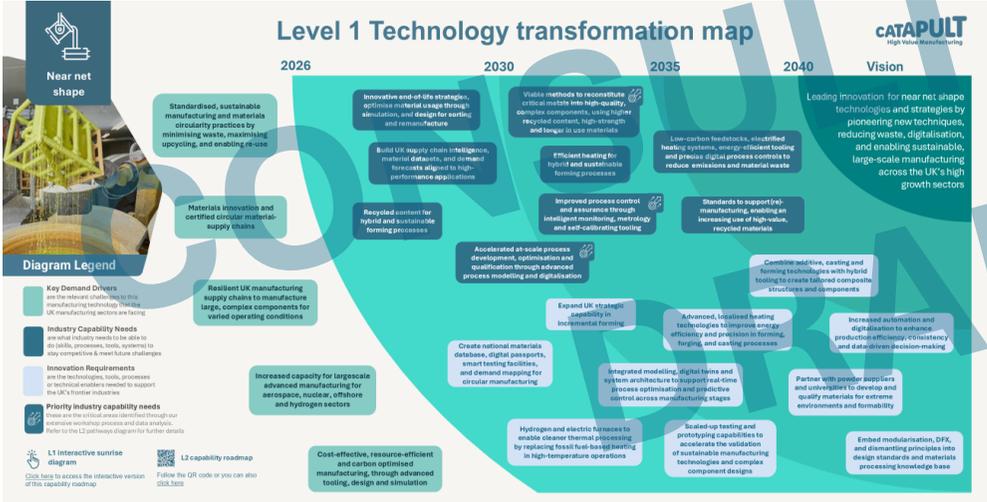
This document has been produced solely for consultation purposes and does not represent an official strategy of the HVM Catapult.

The document is a working draft issued ahead of wider industrial consultation and should be treated accordingly. It will be updated in the coming weeks as feedback is gathered and incorporated into the strategy framework ahead of formal publication.



Technology transformation map

transformation maps support industrialists and researchers to understand when various technology capabilities will emerge and reach maturity so they can navigate the complexities of the innovation landscape.



Level 1 – Inspire HVMC Technology transformation map

Mid-level overview mapping priority technology vision, connecting industry challenges to long-term innovation goals for strategic direction and collaboration.

Designed to provide a concise summary and positioning of technology domain.

- Chief Technology officers & other executive functions
- Government officials
- Industry leaders
- Chief & Principal Engineers
- Academics

Timelines

Each time horizon is separated by colour strands and helps illustrate when technologies and capabilities will reach maturity ready for industry adoption



Priority industry capability needs

these are the critical areas identified through our extensive workshop process and data analysis. Refer to the L2 pathways diagram for further details

Key demand drivers

are the relevant challenges to this manufacturing technology that the UK manufacturing sectors are facing



Near net shape

Key demand drivers: industry challenges and opportunities



Standardised, sustainable manufacturing and materials circularity practices by minimising waste, maximising upcycling, and enabling re-use

Process efficiency through iterative forming. Near net shape techniques reduce machining allowances, material waste, and embodied carbon by producing components closer to final geometry.

Closed-loop material systems
Enhanced scrap recovery and alloy re-melting practices enable circular use of high-value metals such as titanium, aluminium, and nickel superalloys.

Digital twins for lifecycle optimisation
Data-driven modelling of forming and forging processes supports predictive control of yield, recyclability, and material flow.

Cross-sector knowledge transfer
Lessons from aerospace, defence, and energy sectors drive scalable, sustainable near net shape solutions for wider UK manufacturing adoption.

Increased capacity for large-scale advanced manufacturing for aerospace, nuclear, offshore and hydrogen sectors

Scalable near net shape processes development at high volumes for forging, forming, casting capabilities to produce larger, more complex structures in a range and repeatably.

Integration of digital manufacturing technologies
Use of advanced simulation, in-process monitoring, and adaptive control to ensure dimensional accuracy and traceability in large scale components.

Investment in advanced infrastructure
Expansion of national facilities and testbeds across HVMC centres to support industrial applications and qualification of large components.

Cross-sector design and material innovation
Shared R&D in alloys, coatings, and forming methods to meet demanding performance and safety standards across aerospace, energy, and offshore sectors.

Resilient UK manufacturing supply chains to manufacture large, complex components for varied operating conditions

Diversified near net shape capacity
Building regional manufacturing hubs, supported for casting, forging, and forming to strengthen domestic capacity and reduce reliance on imports.

Material and process agility
Developing flexible near net shape processes that can accommodate multiple alloys and component geometries across sectors.

Digital connectivity and transparency
Implementing and benchmarking twin, data standards to ensure transparency, quality assurance, and rapid response to supply chain disruptions.

Sustainable and secure sourcing
Promoting the use of recycled feedstocks, UK sourced material supply, and strategic economy priorities to enhance capacity resilience and sovereignty.

Cost-effective, resource-efficient and carbon optimised manufacturing, through advanced tooling, design and simulation

Optimised process design
Using advanced simulation and digital twins to minimise trial-and-error, reduce material use, and optimise forming sequences for cost and carbon savings.

Innovative tooling solutions
Developing adaptive, long-life tooling and dies that improve process accuracy, extend service life, and reduce waste.

Integrative design for manufacturability
Embedding near net shape principles early in product design to reduce machining, energy use, and product on loss.

Data-driven performance monitoring
Leveraging in-process sensing and analysis to continually improve yield, efficiency, and sustainability metrics.

Materials innovation and certified circular material-supply chains

Advanced alloy development
Designing new high-performance alloys optimised for near net shape forming, improving formability, strength, and recyclability.

Recycling and re-melting innovations
Establishing efficient routes and reuse pathways and standards for high-value metals such as titanium, nickel, and aluminium to close the materials loop.

Design for circularity
Embedding circular economy principles in component and tooling design to enable easier recovery, repair, and re-use of materials.

Process-material co-optimisation
Linking simulation and data-driven control to match materials and forming processes for maximum yield and minimum waste.

Sustainable feedstock sourcing
Expanding use of secondary and certified low-carbon materials to reduce embodied emissions and support UK supply chain resilience.

Strategic summary

There is a strong and growing demand for low-carbon, energy-efficient production, expanded large-scale manufacturing capabilities, and resilient domestic supply chains across the UK's high-growth sectors. To achieve sustainable and scalable growth, it is essential to position and support the UK's advanced manufacturing sector as a leader in high-value, circular, and precision-engineered manufacturing for NNS.

Dr Evgenia Yakushina, NMIS



Strategic Imperatives

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



Level 2 – Influence Key demand drives

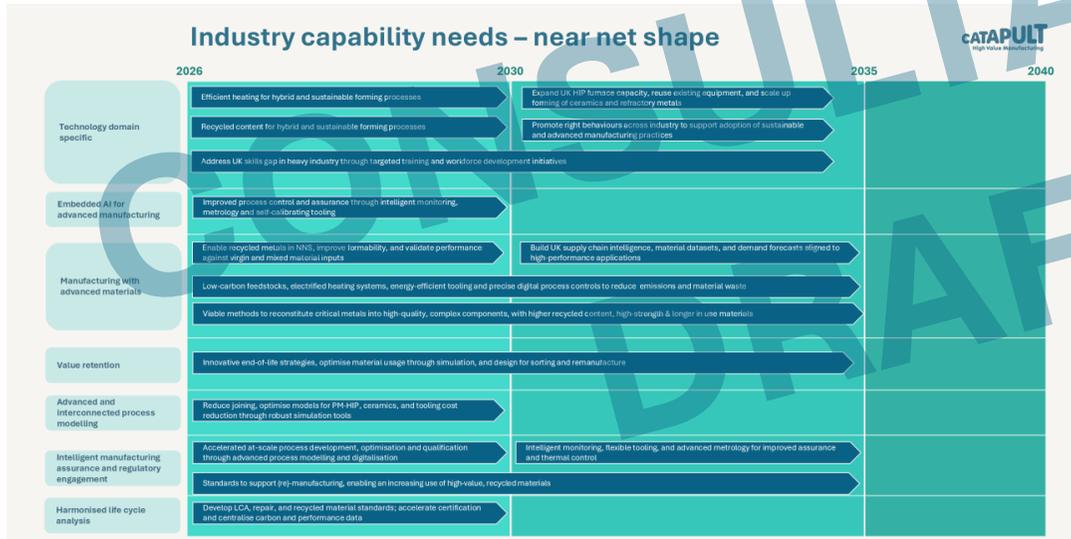
A comprehensive and detailed breakdown of industry challenges and opportunities within this technology domain.

Designed to provide social, economic, political, environmental and legal direction to our technology roadmaps.

- Chief Technology officers
- Strategy focussed executives
- Chief & Principal Engineers
- Industry Leaders
- Academics

Industrial capability needs

are what industry needs to be able to do (skills, processes, tools, systems) to stay competitive & meet future challenges



Level 2 – Influence HVMC technology domain roadmap

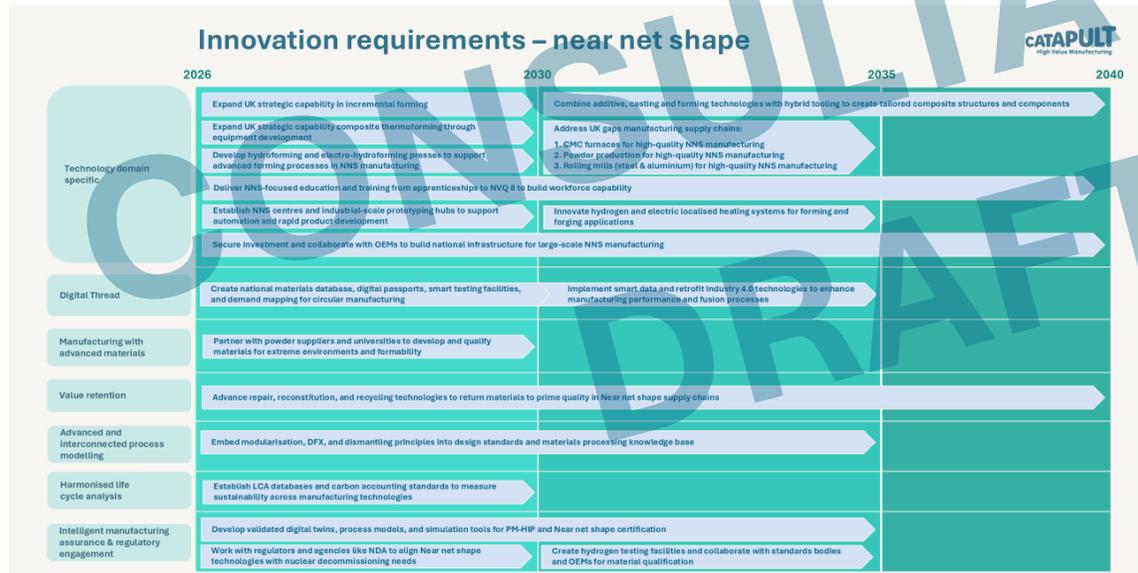
Detailed view mapping connected innovation areas & providing a clear review.

Designed to guide organisations with the development of internal technology and product roadmaps.

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Innovation requirements

are the technologies, tools, processes or technical enablers needed to support the UK's frontier industries



Level 2 – Influence

HVMC technology domain roadmap

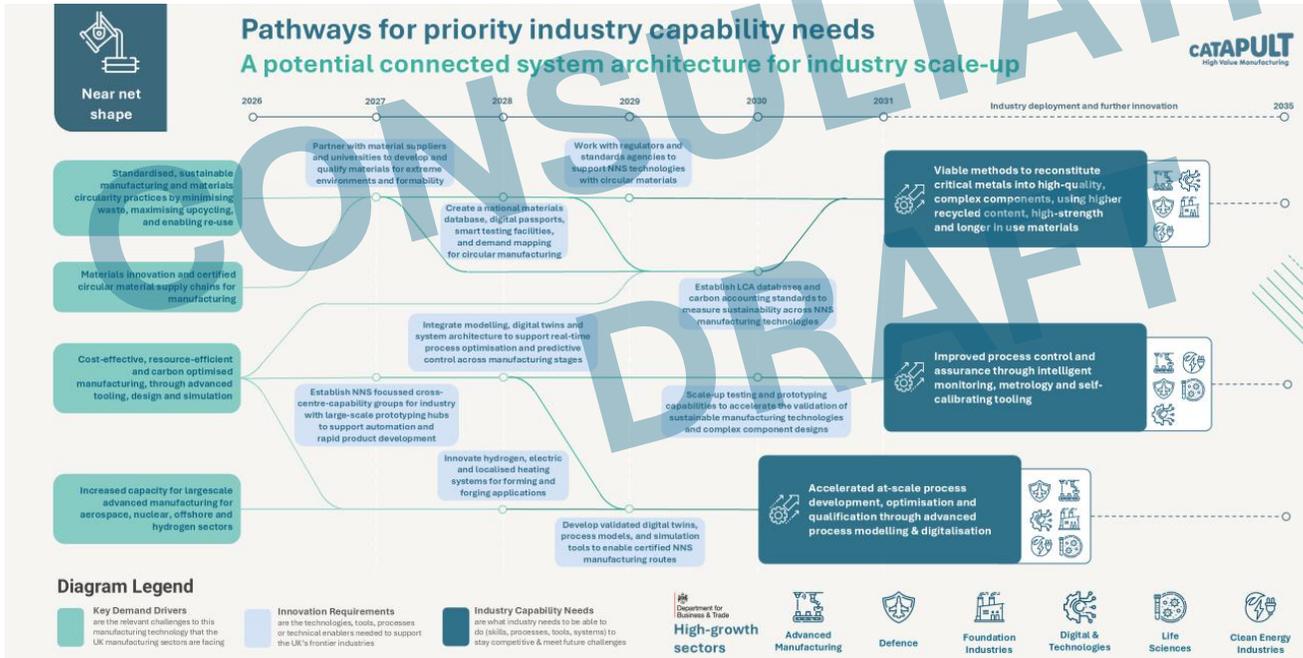
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Pathways for priority industry capability needs

This view lays out a potential connected system architecture for industry scale-up supported by our network of specialist centres



- Technology domain innovation priorities as highlighted by our TSPGs
- Large scale industrial capability development opportunities
- Networked innovation pathways
- Potential impact mapped to UK high growth sectors



**Near net
shape**



Near net shape



Diagram Legend

Key Demand Drivers

are the relevant challenges to this manufacturing technology that the UK manufacturing sectors are facing

Industry Capability Needs

are what industry needs to be able to do (skills, processes, tools, systems) to stay competitive & meet future challenges

Innovation Requirements

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L1 interactive sunrise diagram



L2 capability roadmap

[Click here](#) to access the interactive version of this capability roadmap

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Level 1 Technology transformation map

2026

2030

2035

2040

Vision

Standardised, sustainable manufacturing and materials circularity practices by minimising waste, maximising upcycling, and enabling re-use

Materials innovation and certified circular material-supply chains

Resilient UK manufacturing supply chains to manufacture large, complex components for varied operating conditions

Increased capacity for largescale advanced manufacturing for aerospace, nuclear, offshore and hydrogen sectors

Cost-effective, resource-efficient and carbon optimised manufacturing, through advanced tooling, design and simulation

Innovative end-of-life strategies, optimise material usage through simulation, and design for sorting and remanufacture

Build UK supply chain intelligence, material datasets, and demand forecasts aligned to high-performance applications

Recycled content for hybrid and sustainable forming processes

Accelerated at-scale process development, optimisation and qualification through advanced process modelling and digitalisation

Create national materials database, digital passports, smart testing facilities, and demand mapping for circular manufacturing

Hydrogen and electric furnaces to enable cleaner thermal processing by replacing fossil fuel-based heating in high-temperature heating

Viable methods to reconstitute critical metals into high-quality, complex components, using higher recycled content, high-strength and longer in use materials

Efficient heating for hybrid and sustainable forming processes

Improved process control and assurance through intelligent monitoring, metrology and self-calibrating tooling

Expand UK strategic capability in incremental forming

Integrated modelling, digital twins and system architecture to support real-time process optimisation and predictive control across manufacturing stages

Low-carbon feedstocks, electrified heating systems, energy-efficient tooling and precise digital process controls to reduce emissions and material waste

Standards to support (re-)manufacturing, enabling an increasing use of high-value, recycled materials

Advanced, localised heating technologies to improve energy efficiency and precision in forming, forging, and casting processes

Scaled-up testing and prototyping capabilities to accelerate the validation of sustainable manufacturing technologies and complex component designs

Combine additive, casting and forming technologies with hybrid tooling to create tailored composite structures and components

Increased automation and digitalisation to enhance production efficiency, consistency and data-driven decision-making

Partner with powder suppliers and universities to develop and qualify materials for extreme environments and formability

Embed modularisation, DFX, and dismantling principles into design standards and materials processing knowledge base

Leading innovation for near net shape technologies and strategies by pioneering new techniques, reducing waste, digitalisation, and enabling sustainable, large-scale manufacturing across the UK's high growth sectors





Near net shape

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Cross-sector knowledge transfer
Lessons from aerospace, defence, and energy sectors drive scalable, sustainable near net shape solutions for wider UK manufacturing adoption.

Increased capacity for largescale advanced manufacturing for aerospace, nuclear, offshore and hydrogen sectors

Scalable near net shape processes
Development of high-tonnage forging, forming, & casting capabilities to produce larger, more complex structures efficiently and repeatedly.

Integration of digital manufacturing technologies: Use of advanced simulation, in-process monitoring, and adaptive control to ensure dimensional accuracy and traceability in large-scale components

Investment in advanced infrastructure
Expansion of national facilities and testbeds across HVMC centres to support industrial-scale trials and qualification of large components.

Cross-sector design and material innovation: Shared R&D in alloys, coatings, and forming methods to meet demanding performance and safety standards across aerospace, energy, and offshore sectors.

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Material and process agility
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Digital connectivity and traceability
Implementing end-to-end digital twins & data standards to ensure transparency, quality assurance, and rapid response to supply chain disruptions.

Sustainable and secure sourcing
Promoting the use of recycled feedstocks, UK-based material supply, and circular economy principles to enhance long-term resilience and sovereignty.

Cost-effective, resource-efficient and carbon optimised manufacturing, through advanced tooling, design and simulation

Optimised process design
Using advanced simulation and digital twins to minimise trial-and-error, reduce material use, and optimise forming sequences for cost and carbon savings.

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Design for circularity: Embedding circular economy principles in component and tooling design to enable easier recovery, repair, and re-use of materials.

Process-material co-optimisation: Using simulation and data-driven control to match materials and forming processes for maximum yield and minimum waste.

Sustainable feedstock sourcing: Expanding use of secondary and certified low-carbon materials to reduce embodied emissions and support UK supply chain resilience.



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Dr Evgenia Yakushina, NMIS



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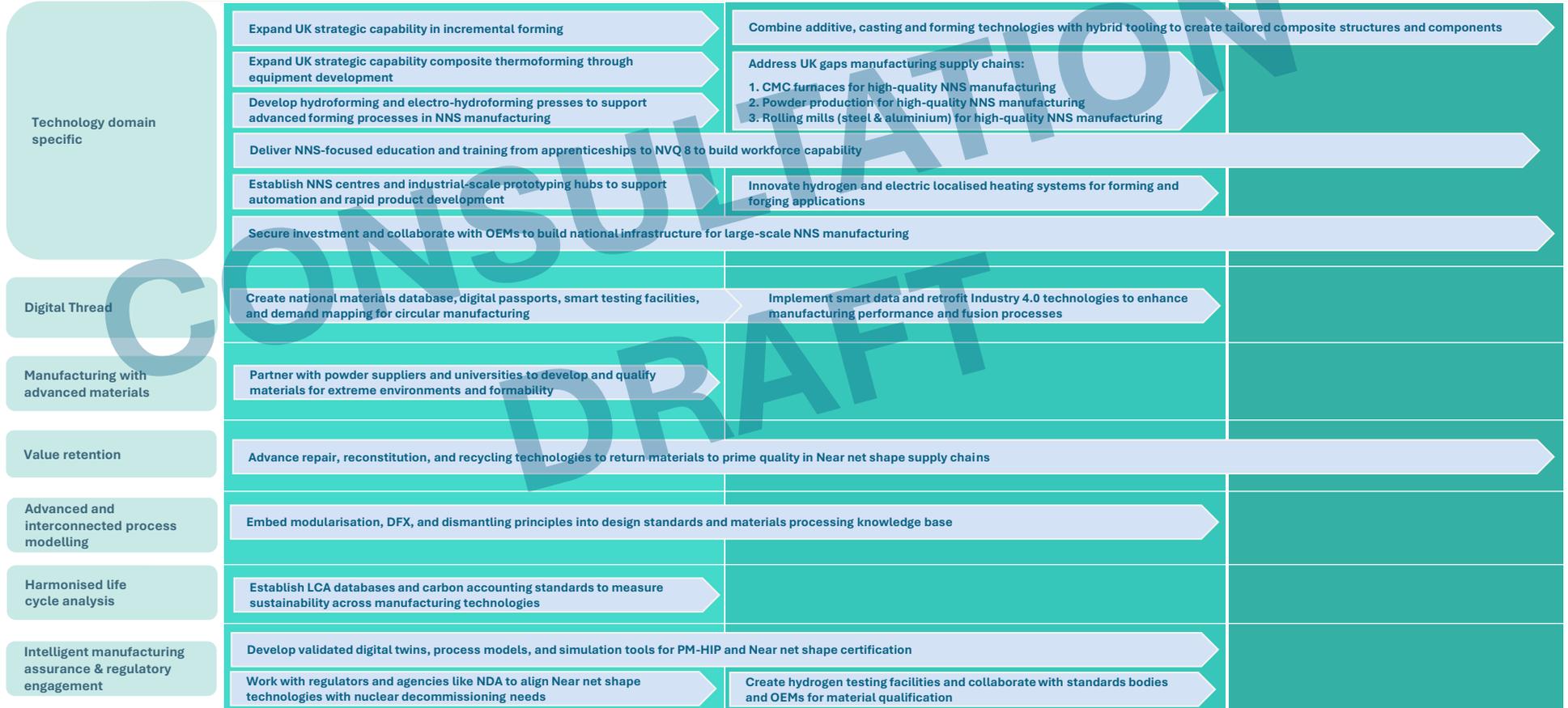
Innovation requirements – near net shape

2026

2030

2035

2040



Industry capability needs – near net shape





Near net shape

Pathways for priority industry capability needs

A potential connected system architecture for industry scale-up

2026 2027 2028 2029 2030 2031 Industry deployment and further innovation 2035

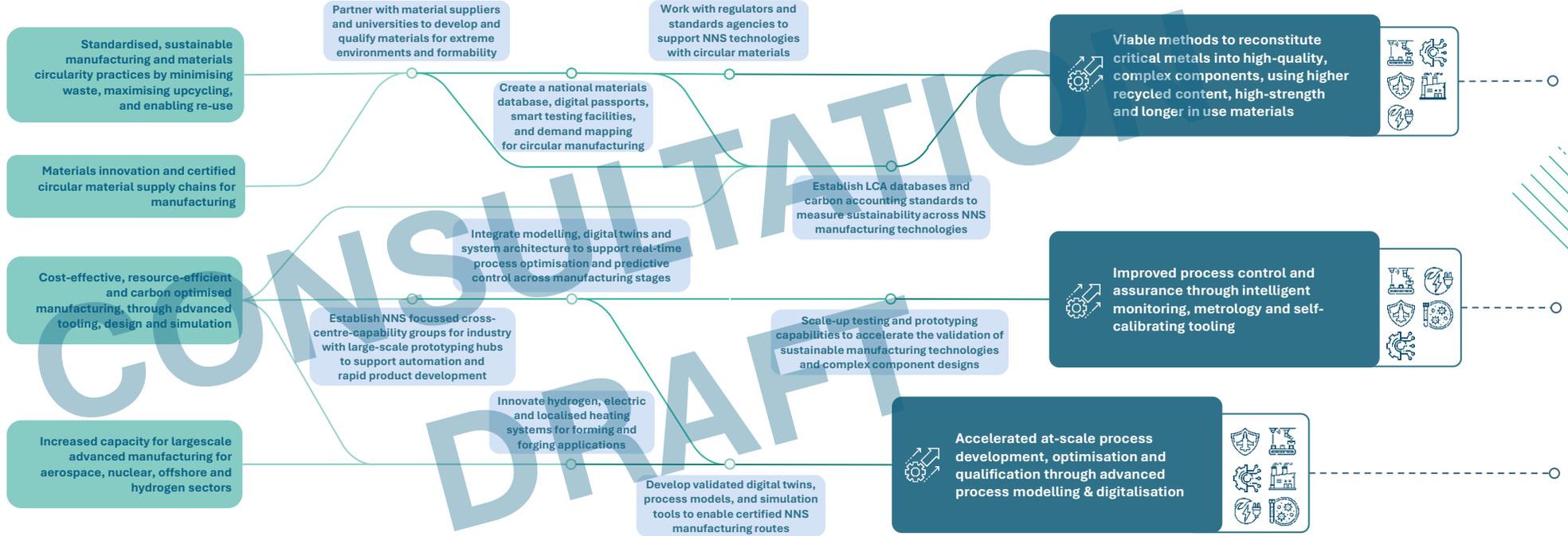


Diagram Legend

Key Demand Drivers are the relevant challenges to this manufacturing technology that the UK manufacturing sectors are facing

Innovation Requirements are the technologies, tools, processes or technical enablers needed to support the UK's frontier industries

Industry Capability Needs are what industry needs to be able to do (skills, processes, tools, systems) to stay competitive & meet future challenges

Department for Business & Trade
High-growth sectors

Advanced Manufacturing

Defence

Foundation Industries

Digital & Technologies

Life Sciences

Clean Energy Industries

Additive manufacturing



Additive manufacturing



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L1 interactive sunrise diagram



L2 capability roadmap

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Technology transformation map

2026

2030

2035

2040

Vision

Improved designs of next-generation components with better performance and value

Advanced digital tools and end to end manufacturing data processing frameworks

Sustainable manufacturing through reduced material waste and energy usage

Extend component life and value across the lifecycle (e.g., through remanufacturing)

Reduced cost of manufacturing through a more efficient and flexible manufacturing process

Improve designs of next-generation components with lower through-life cost

Advanced design, materials and manufacturing concepts to enable large complex assemblies with lower part-count

Circular metals strategy supported by efficient recycling loops and material recovery driven by government policy

Adoption of circularity principles by UK industry, specifically supply chains

Support pull-through of emerging technology developments to integrate into the AM process and to exist in the supply chain

Partner with powder suppliers and universities to develop and qualify new and recycled materials

Demonstrate an effective design workflow and digital thread, supported by material data, process simulation and process data capture

Digital tools that enable an effective design workflow and digital thread

Mature, reconfigurable additive and hybrid manufacturing systems

Standards and best practice guidance for manufacturing and certification of AM components

Improved cost, rate, scale and quality of AM processing to enable economic and sustainable applications

Develop and apply priority AM technologies to process materials and create components to enable new applications and life extension

Develop end-to-end process chain that integrates with the AM processes

A mature, robust and flexible UK supply chain with a capable workforce, manufacturing equipment and material

Fast validation of product performance and shorten development cycle

Automate design workflow for high-complexity geometries supported by process modelling

AI-supported part inspection and predictive quality

Improve efficiency and efficacy of part inspection for QA, creating routes to rapid qualification

Lead the UK's advancement in additive manufacturing, drive innovation, AM standards and insight to accelerate adoption, strengthen industrial capability and unlock sustainable economic growth through developing accessible world-class expertise, technical leadership and technology foresighting

Automate design workflow for high-complexity geometry supported by process modelling

Implement technical and commercial training programmes, including apprenticeships and upskilling of existing roles



Additive manufacturing

Key demand drivers: industry challenges and opportunities

CATAPULT
High Value Manufacturing

Improved designs of next-generation components with better performance and value

Advanced design for AM enables complex geometries impossible with traditional methods, improving component functionality and system performance

Lightweight lattice structures reduce mass while maintaining strength, enabling higher-efficiency designs for demanding applications.

Integrated multi-material printing provides tailored properties, enhancing durability, thermal management, and in-service reliability.

AM-enabled part consolidation will reduce assembly steps and improving operational robustness across product lifecycles.

Digital design workflows link simulation and AM processes, accelerating innovation and reducing development time for advanced components

Reduced cost of manufacturing through a more efficient and flexible manufacturing process

On-demand, distributed manufacturing reduces inventory, tooling expense, and long supply-chain reliance.

Rapid iteration cycles minimise rework and development lead times, delivering faster, more cost-effective product refinement.

Tool-less production enables economical low-volume and customised manufacturing compared with traditional forming or machining.

Automated AM workflows improve process repeatability and reduce labour-intensive steps, lowering total cost per part

Advanced Design for AM reduces material use by building only required geometry, lowering waste and production costs.

Sustainable manufacturing through reduced material waste and energy usage

Near-net-shape AM reduces machining operations and associated energy consumption across production lines

Recycled metal powders and polymers extend material life and reduce environmental impact of feedstock sourcing

Digital monitoring optimises build parameters to reduce energy demand and minimise process variability

AM enabled localised production supply chains, decreasing transport emissions and improving environmental performance across supply chains

Process optimisation minimises scrap generation, supporting circular economy goals and resource efficiency

Advanced digital tools and end to end manufacturing data processing frameworks

Integrate sensor-rich AM equipment with real-time monitoring systems to capture detailed build data for improved control

Develop interoperable data standards enabling seamless communication between design software, AM machines, and downstream inspection processes

Implement automated analytic pipelines that convert raw AM process data into actionable insights for quality assurance

Use digital twins and predictive modelling frameworks to optimise AM workflows, reduce variability, and enhance production efficiency

Create digital warehouse to enable on demand manufacturing of replacement components without the requirement of a physical inventory

Extend component life and value across the lifecycle (e.g. through remanufacturing)

AM repair techniques restore high-value components, reducing replacement needs and extending operational asset life.

Precision deposition enables targeted refurbishment of worn features, improving component performance and durability.

Digital twins support predictive maintenance and AM-enabled repair planning across complex industrial assets.

Customised AM overlays enhance surface properties for improved wear, corrosion, and thermal resistance.

On-site AM repair capabilities reduce downtime and cost, strengthening resilience of critical systems and infrastructure.



Strategic summary

Additive manufacturing is transforming UK industry through innovative component design, efficient digital production, and sustainable, low-waste processes. It extends asset life, reduces costs, and strengthens supply-chain resilience. By enabling advanced materials, rapid iteration, and distributed manufacturing, AM underpins a more competitive, adaptable, and future-ready high-value manufacturing economy.

Dr Hoda Amel, MTC



Innovate UK

Strategic Imperatives

➤ Skilled and empowered

➤ Resilient and responsive

➤ Resource efficient and regenerative

➤ Innovative and Digital



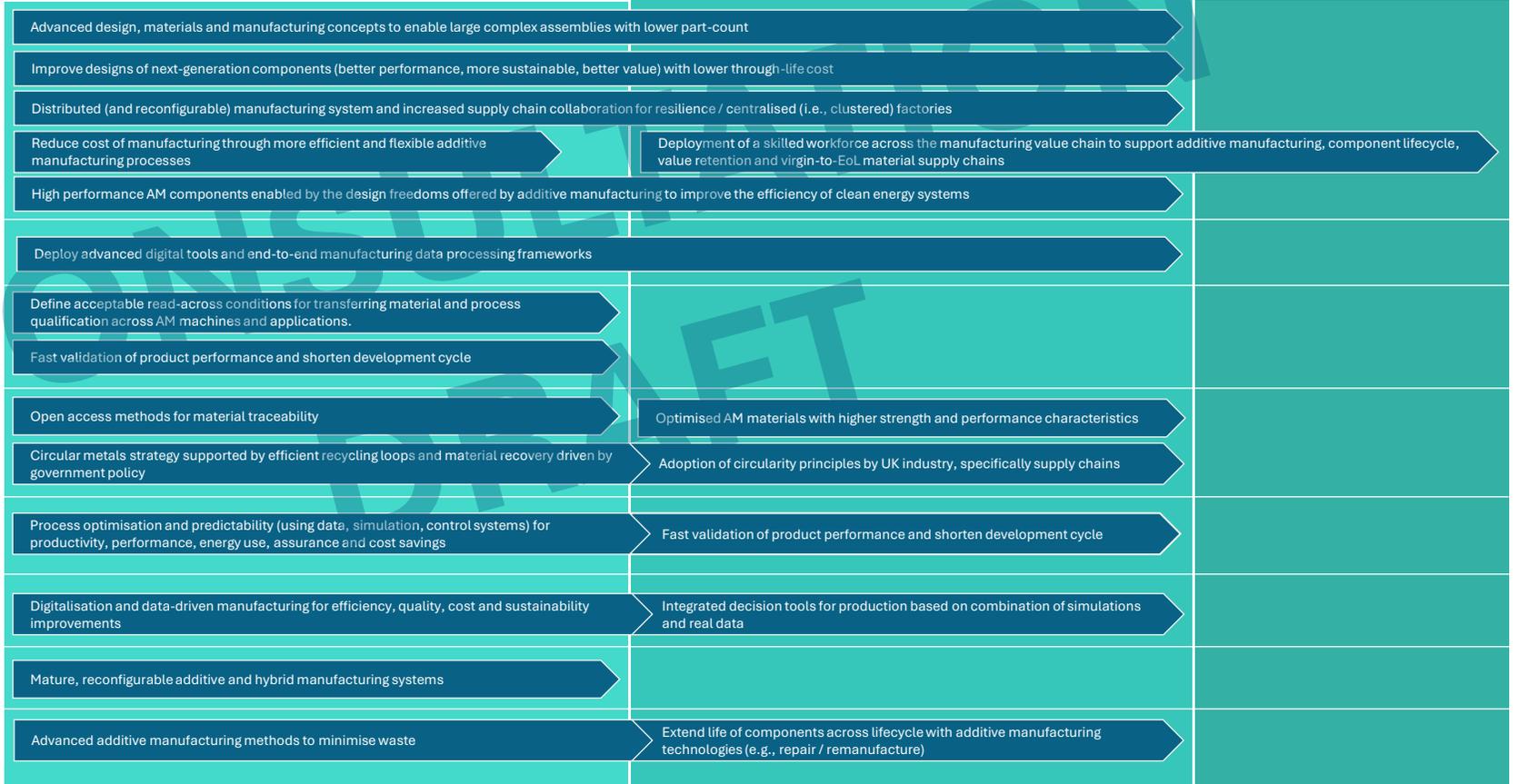
Industry capability needs – additive manufacturing

2026

2030

2035

2040



Innovation requirements – additive manufacturing

	2026	2030	2035	2040
Technology domain specific	<ul style="list-style-type: none"> Drive market demand by proving AM's superiority through cost models that highlight value-add and hidden savings overlooked by conventional methods Identify areas of strength and weaknesses for UK considering scale-up predictions for key sectors Post-process development for improving part performance and manufacturing efficiency Implement AM-focused technical and commercial training programmes, apprenticeships, and skills pipelines to develop a highly capable, future-ready manufacturing workforce 	<ul style="list-style-type: none"> Explore "digital warehouse" concept for spare parts qualified for AM Achieve mature, scalable additive manufacturing processes capable of producing larger, high-quality components with consistent reliability 		<ul style="list-style-type: none"> Pull-through AM technology developments providing step changes in rate/scale/quality
Digital Thread		<ul style="list-style-type: none"> Demonstrate end-to-end digital thread Establish HVM Catapult data sharing and ability to share externally, adopting data management structures in line with existing standards 		
		<ul style="list-style-type: none"> Ensure trustworthy, application-ready material property data generated from real additive manufacturing builds Increase digitalisation and process control towards closed-loop for improved quality 		
Intelligent manufacturing assurance & regulatory engagement	<ul style="list-style-type: none"> Improve efficiency and efficacy of part inspection for QA, creating routes to rapid qualification Clarify current AM standards, certification routes and regulatory for priority sectors and applications, and create practical user guide Identify where standards are lacking and need support for development 	<ul style="list-style-type: none"> Encourage adoption of standardised guidelines across industry 		<ul style="list-style-type: none"> Continuous improvement of the standards / data sets to keep up with technology developments
Manufacturing with advanced materials	<ul style="list-style-type: none"> Partner with powder suppliers and universities to develop and qualify new and recycled materials Focus on materials to enable priority industrial applications and support development of emerging high-potential materials 	<ul style="list-style-type: none"> Unlock next-generation higher-value applications through multi-material, functionally graded components & establishing linked design workflows 		
Advanced and interconnected process modelling	<ul style="list-style-type: none"> Automate design workflow for high-complexity geometry supported by process modelling AM process Modelling for improved performance and reliability for priority applications 	<ul style="list-style-type: none"> Embed modularisation, DFX, and dismantling principles into design standards 		
Embedded AI for advanced manufacturing	<ul style="list-style-type: none"> Develop intelligent in-situ process monitoring using AI to analyse build behaviour and detect deviations instantly 	<ul style="list-style-type: none"> Validate AI-optimised adaptive control systems that autonomously adjust parameters to ensure consistent, high-quality AM production AI-supported part inspection and predictive quality 		
Automation of processes and digital integration	<ul style="list-style-type: none"> Establish rapid build strategies in powder bed systems for increased productivity and cost reduction 	<ul style="list-style-type: none"> Demonstrate automation for scaled-up production, particularly focusing on downstream process steps 		
Value retention	<ul style="list-style-type: none"> Mature the reuse and recycling of raw materials Advance repair, reconstitution, and recycling technologies to return materials to prime quality 			<ul style="list-style-type: none"> Encourage adoption of interchangeable AM processes & interoperable process chain steps
Harmonised Life Cycle Analysis	<ul style="list-style-type: none"> Fill data gaps in lifecycle assessment databases for priority equipment & materials Support improvement of standards/data sets to measure environmental impact 	<ul style="list-style-type: none"> Establish LCA databases and carbon accounting standards to measure sustainability across AM 		





Additive manufacturing

Pathways for priority industry capability needs

A potential connected system architecture for industry scale-up

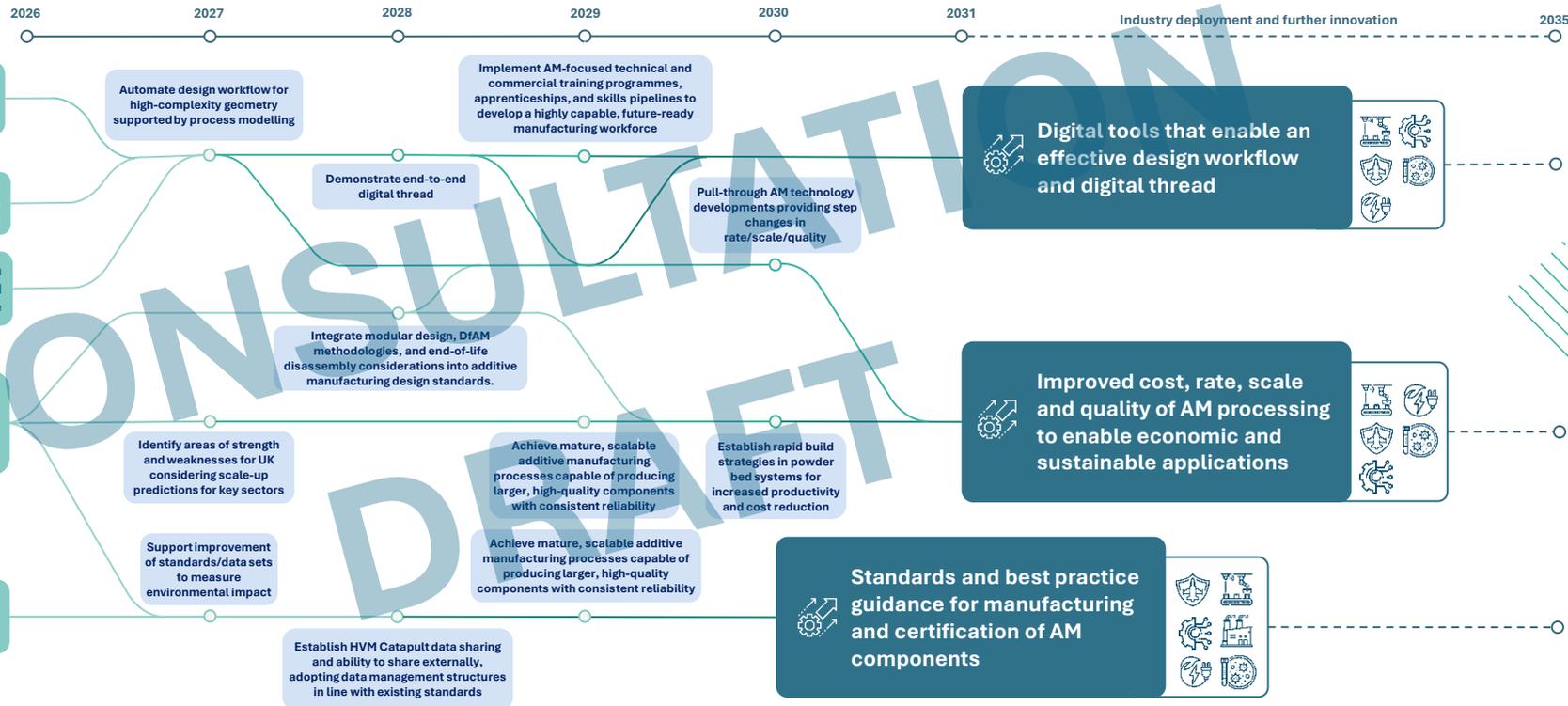


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High-growth sectors

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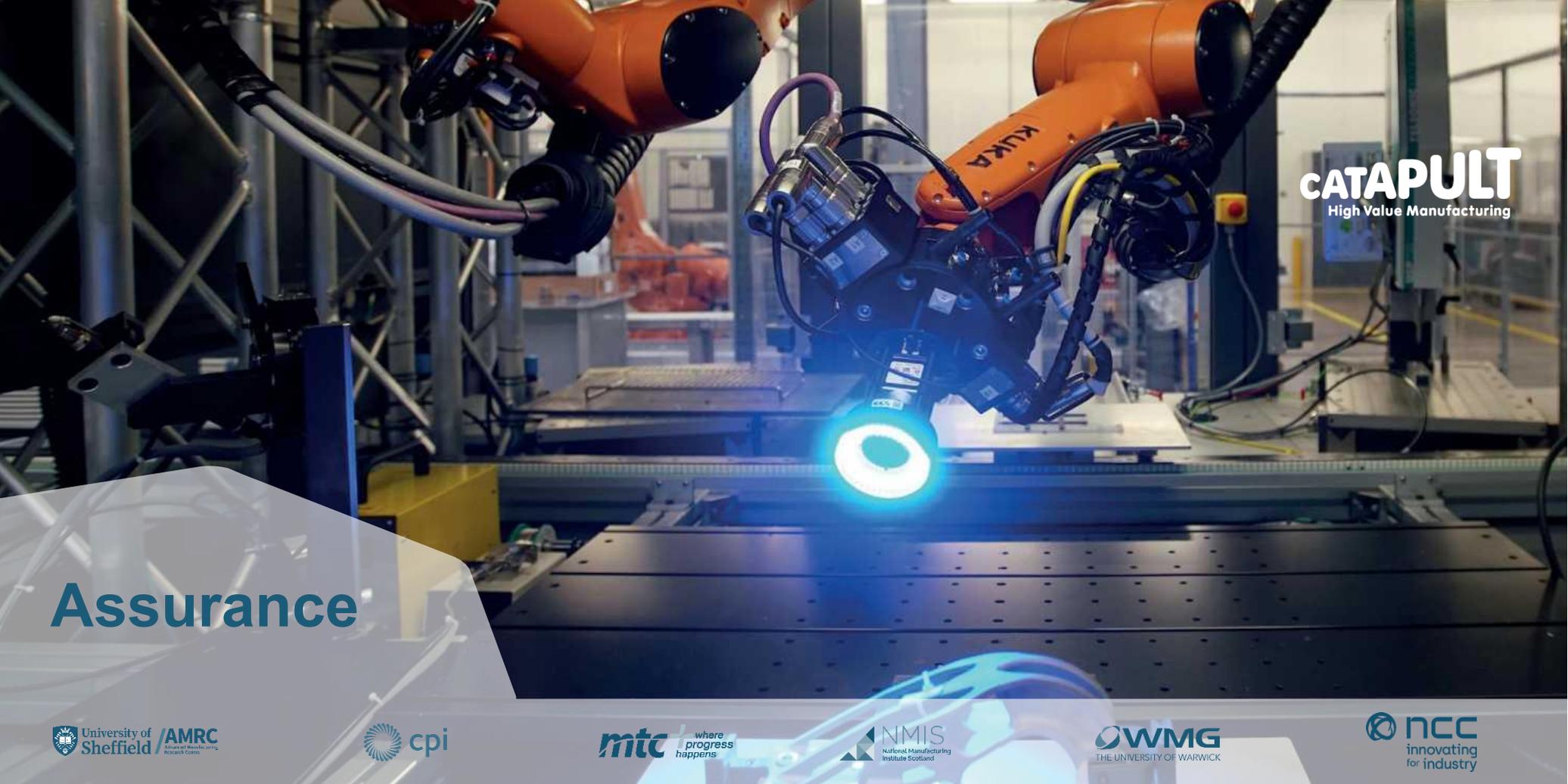
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CATAPULT
High Value Manufacturing

Assurance



Assurance



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Technology transformation map

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Vision



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Assurance

Key demand drivers: industry challenges and opportunities

Assurance Barriers to Adoption of Advanced & Flexible Manufacturing Technology

Process Optimisation:
Using trusted data-driven optimisation enhances productivity, improves energy efficiency, reduces cost, and strengthens quality across manufacturing systems.

Emerging Manufacturing Technologies:
Encouraging adoption of advanced and flexible manufacturing technologies that present unique assurance challenges which must be suitably addressed and enabling future products.

Emerging Inspection Technology:
Demonstration, standardisation and best practice of new and potentially disruptive inspection and measurement technology.

Integrating Digital Manufacturing and Assurance Data traceability

End-to-End Data Frameworks
Demonstrating and encouraging advanced digital tools (Model Based Design, Model Based Enterprise, Digital Product passport) to establish connected manufacturing data flows, allowing the transfer of assurance requirements, decision-making, and collaboration.

Digital Thread for Data Traceability:
Adoption of digital thread as the means of automating and strengthening traceability, driving quality improvements, lifecycle visibility, and demonstrating assurance across manufacturing operations and supply chain.

Control Systems Integration:
Demonstrating and setting assurance requirements for integrated sensing and control systems to enable responsive data driven closed loop control in support of high-performance manufacturing.

Advancing Assurance, Certification and Regulatory Pathways

Regulatory Compliance:
Evolving regulations demand rigorous assurance frameworks to deliver safe, certified products across nuclear, energy, and aerospace sectors as well as emerging new products and applications

Accelerated Certification:
Utilisation of existing and in-process data can streamline certification, reducing barriers, supporting new products, and enabling faster market entry.

Assurance Importance:
Advocating for and demonstrating the importance of investment in assurance and value of robust inspection, measurement and testing of products to industry, government and regulators.

Assurance Challenges for Circularity, Remanufacture and Maintenance

Circularity Systems:
Assurance techniques to support circularity and enable efficient material reuse. Thus enhancing sustainability, and reusable material pathways across manufacturing ecosystems.

Assurance for Life Extension:
Approaches to enhance the value of lifecycle data, ensuring performance through-use and enabling re-certification of in-service legacy equipment.

Recovery and Remanufacturing
Optimised MRO strategies ensuring safety and compliance while allowing recovery of parts with retained value, extending part life, minimising MRO cycles and improving sustainability outcomes.

Assurance Skills Gaps and Pathways

Assurance Skills & Knowledge Sharing:
Collaborative platforms, documentation and best practice to accelerate the exchange of assurance expertise and thus enabling consistent and sustainable methods.

Available Assurance Skills:
Availability of assurance practitioners to support industry across the range of assurance related inspection techniques.

Accredited Assurance Skills:
Formal accreditation and recognised training pathways to strengthen competency and ensure trust of inspection and measurement results and outcomes.

Strategic summary

Assurance is fundamental to the credibility of the work carried out within HVM Catapult. Through advancement of in-process measurement, traceability and the exploitation of data, HVMC is helping position the UK as a global leader in the adoption and exploitation of novel assurance methods. This work supports UK manufacturers in ensuring robust product-assurance approaches, while reducing cost and development lead times.

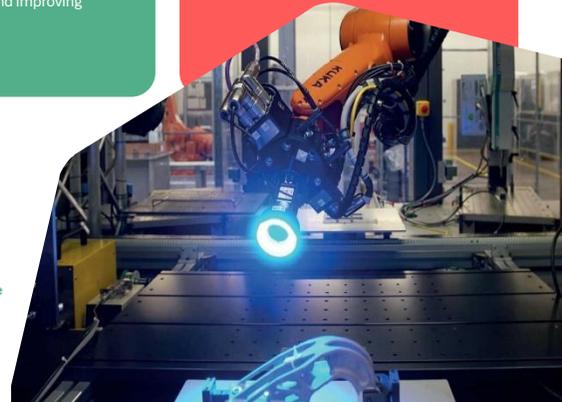
Graeme Bisland CEng, NMIS



Strategic Imperatives

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Industry capability needs - assurance

2026

2030

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2040

Technology domain specific

- Training frameworks and delivery mechanism for assurance skillsets and digital upskilling of existing assurance workforce
- Integrated frameworks and maturity grids for assessment and adoption of assurance processes
- Establish test facilities supporting the testing of emerging products and applications
- Secure investment to encourage adoption and research in digital and emerging assurance technologies
- Cross sector transferable inspection, measurement and certification best practice
- Co-ordinated sectorial collaboration to drive regulatory advancements and development of new standards
- Adoption of developed new product & process assurance standards
- 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

Digital Thread

- Accepted methods and frameworks to ensure single source of truth for assurance data
- Encourage adoption of digital sharing of assurance data among supply chain
- Developed best practice and cyber security for certification and quality data

Embedded AI for advanced manufacturing

- Adoption of machine learning to enable adaptive/risk based inspection and measurement strategies
- Simplified approaches, software, and AI to address complex uncertainty quantification

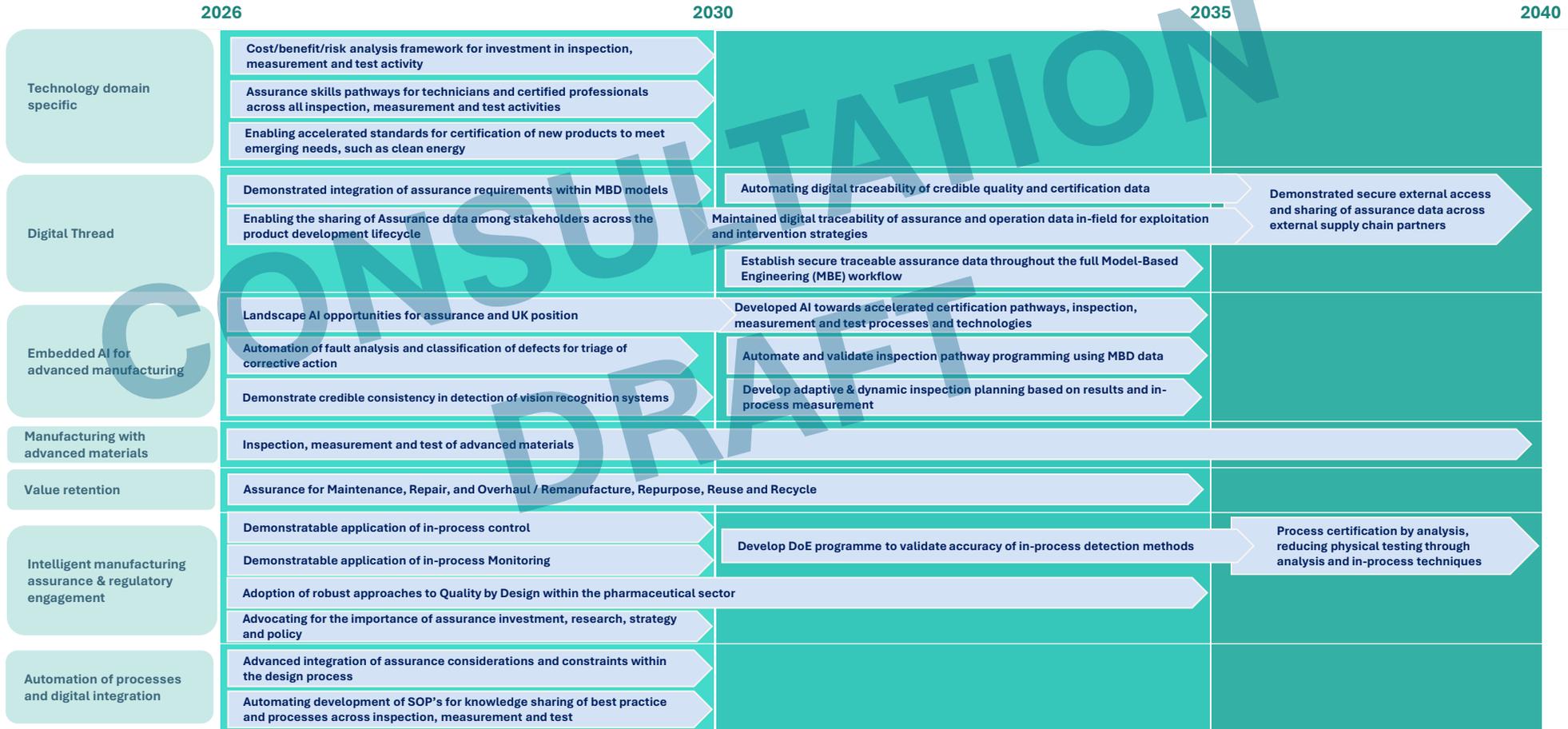
Value retention

- Certification, ensured quality and reliability of products that are Remanufactured, Repurposed, Reused and Recycled

Intelligent manufacturing assurance and regulatory engagement

- Advanced use of data and simulation across quality and certification activities
- Demonstration of data driven quality/fault prognosis, decision making and control
- Acceptance of in-process practices as definitive and credible sources of inspection and measurement

Innovation requirements - assurance





Assurance

Pathways for priority industry capability needs

A potential connected system architecture for industry scale-up



Advanced Assurance Certification and Regulatory Pathways

Increased pressure on manufacturing to reduce cost and lead times without compromising quality and reliability of product is driving consideration of new approaches and exploiting opportunities throughout product development and production, including inspection, measurement, test and certification.

Integrated Digital Manufacturing and Assurance Data Traceability

Traditional approaches of demonstrating traceability and communicating assurance data throughout manufacturing are time consuming, labour intensive and subject to human error. Alternative means of demonstrating and communicating inspection, measurement, test and certification data would not only satisfy existing needs but offer improvements and opportunities to increase efficiency.

Demonstrated integration of assurance requirements within MBD models

Demonstratable application of in-process monitoring

Landscape AI opportunities for assurance and UK position

Establish secure traceability of assurance data throughout the full Model-Based Enterprise (MBE) workflow

Demonstratable application of in-process control

Automate and validate inspection pathway programming using MBD data

Demonstrate credible consistency in detection of vision recognition systems

Demonstrated secure external access and sharing of assurance data across external supply chain partners

Develop DoE programme to validate accuracy of detection methods

Develop adaptive & dynamic inspection planning based on results and in-process measurement

Automation of fault analysis and classification of defects for triage of corrective action

Accepted methods and frameworks to ensure single source of truth for assurance data

Advanced use of data and simulation across quality and certification activities

Simplified approaches, software, and AI to address assurance challenges

Diagram Legend

Key Demand Drivers are the relevant challenges to this manufacturing technology that the UK manufacturing sectors are facing

Innovation Requirements are the technologies, tools, processes or technical enablers needed to support the UK's frontier industries

Industry Capability Needs are what industry needs to be able to do (skills, processes, tools, systems) to stay competitive & meet future challenges



Bio- manufacturing



Bio-manufacturing



Diagram Legend

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Priority industry capability needs these are the critical areas identified through our extensive workshop process and data analysis. Refer to the L2 pathways diagram for further details

L1 interactive sunrise diagram



L2 capability roadmap

Click [here](#) to access the interactive version of this capability roadmap

Follow the QR code or you can also [click here](#)

Technology transformation map

2026

2030

2035

2040

Vision

Next generation therapeutics require innovative biological production methods

Biomanufacturing processes seek optimisation for efficiency and sustainability

Global food systems need sustainable and secure production solutions

Industries are transitioning to sustainable biobased materials and chemicals

Healthcare diagnostics require bio-manufactured components for reliable and innovative detection and monitoring

Manufacturing skills and workforce development across the value chain

Early detection & diagnostic standardisation to developing reliable, standardised diagnostic workflows and reagents to enable earlier disease detection and intervention

Establish agreed quality standards and consistent laboratory methods to ensure reliability and reproducibility in biomanufacturing.

Food and feed production for sustainable agriculture and secure, resilient supplies supporting human and animal nutritional needs

Scaling cost-effective, GMP-compliant manufacturing for complex biologics and personalised medicines to meet growing demand

Sustainable and cost-effective biomanufacturing advancing greener production methods to replace traditional processes and reduce environmental impact

Support cutting-edge biomanufacturing facilities and capabilities underpinning public health and strategic priority response

Develop novel biomanufacturing capabilities including new modalities, bioreactors, analytics and formulation

Accelerating safe, ethical therapeutic approval through standardised regulations, virtualised manufacturing, and robust data governance

Alternative antimicrobials enabling innovative biological approaches to combat resistance and protect global health across diverse applications

Develop integrated multi-omic analytical capabilities and harmonised data systems for genomics, proteomics, and metabolomics insights.

Develop scalable drying, purification, and formulation technologies - including bioprinting - to enable efficient production of alternative proteins and advanced materials.

Circular material systems using waste as feedstocks to develop next generation green materials in localised ecosystems

Leverage digital capabilities including digital twins, integrated analytics and automated process control to enhance biomanufacturing efficiency

Develop standardised digital models, in-line analytics, and fast computational tools to optimise biomanufacturing quality

Build UK resilience through sustainable biomanufacturing that delivers chemicals, materials and therapeutic products via efficient, low-impact processes, scalable technologies, and fossil-free feedstocks - ensuring cost competitiveness, food security, and health innovation while supporting economic growth and environmental sustainability



Bio-manufacturing

Key demand drivers: industry challenges and opportunities



Next generation therapeutics require innovative biological production methods

- Growth in phage, microbiome, RNA, oligonucleotide, and gene therapies demands advanced, flexible clinical manufacturing platforms.
- Personalised medicines and theragnostics require small-batch, high-precision biomanufacturing with rapid scale-out capability.
- Synthetic biology and cell-free expression enable novel drug development and complex therapeutic delivery systems.
- Nano-system delivery technologies increase manufacturing complexity and require new process innovations.
- Antimicrobial resistance drives adoption of phage technologies and microbiome-based therapeutics.

Biomanufacturing processes seek optimisation for efficiency and sustainability

- Process intensification and automation reduce energy, cost, and resource use while improving productivity.
- Transition from single-use plastics to circular, certified second-life materials supports sustainability goals.
- Standardised LCA and carbon accounting frameworks enable transparent sustainability measurement and compliance.
- Energy-efficient organisms and biocatalysis methods support greener, low-impact production pathways.
- Defossilisation and sustainable feedstocks reduce reliance on petrochemicals and improve supply chain resilience.

Global food systems need sustainable and secure production solutions

- Alternative proteins and cellular agriculture improve food security and reduce environmental impact.
- Gas fermentation and vertical farming enable scalable, controlled production of food and pharma ingredients
- Bio-derived agri-stimulants and animal health solutions meet growing population and climate resilience needs.
- Novel bioproducts for space travel and planetary colonisation highlight strategic biomanufacturing importance.
- Food safety standards and traceability systems ensure consumer trust and regulatory compliance.

Industries are transitioning to sustainable biobased materials and chemicals

- Bio-based feedstocks and defossilisation strategies reduce petrochemical dependency and emissions.
- High-performance biopolymers and bio-recovery technologies enable circular economy adoption.
- Hydrogen and carbon as building blocks support advanced materials and sustainable fuels.
- Certification frameworks ensure trust and scalability for recycled and bio-derived materials.
- Sustainable packaging and standardised metrics drive eco-friendly manufacturing practices.

Healthcare & diagnostics require biomanufactured components for reliable and innovative detection and monitoring

- Early disease detection drives demand for diagnostic reagents and biologically derived components.
- Animal-free testing and ethical in vitro models accelerate innovation and regulatory acceptance.
- Data science and real-time release technologies enable rapid certification and deployment of diagnostics.
- Virtualised manufacturing supports smart design and faster regulatory approval processes.
- Regulatory clarity for microbiome and phage therapies remains critical for market adoption.

Strategic summary

UK biomanufacturing must advance agile, sustainable platforms to meet healthcare, food, and industrial demands. Innovations in therapeutics, diagnostics, and bio-based materials, coupled with circular processes and ethical standards, will drive resilience and global competitiveness. Regulatory clarity, automation, and scalable design underpin a future-ready, low-impact biomanufacturing ecosystem.

Suzanne Robb, CPI



Strategic Imperatives

- Skilled and empowered
- Resilient and responsive

- Resource efficient and regenerative
- Innovative and Digital



Innovation requirements – bio-manufacturing

2026

2030

2035

2040

	2026	2030	2035	2040
Technology domain specific	Access to pilot scale infrastructure, that is either specific or flexible, to support the needs across biomanufacturing sectors			
	Personalised therapy supply, generating products for small numbers of patients in localised institutes			
	Sustainable and cost-effective biomanufacturing advancing greener production methods to replace traditional processes and reduce environmental impact			
	Food and feed production for sustainable agriculture and secure, resilient supplies supporting human and animal nutritional needs			
	Optimised and available bioproduction hosts (chassis) for engineering biology			
	Alternative antimicrobials enabling innovative biological approaches to combat resistance and protect global health across diverse applications			
	Access to sustainable and consistent feedstocks			
Digital Thread	Intensified manufacturing to increase efficiency, and sustainability and costs of bio manufactured products			
Manufacturing with advanced materials	Circular material systems using waste as feedstocks to develop next generation green materials			
Value retention	Cost effective biomanufacturing enabling position in competitive chemicals and materials sectors			
Advanced and interconnected process modelling				
Harmonised life cycle analysis	Standard LCA across biomanufacturing sectors			
Intelligent manufacturing assurance & regulatory engagement	Real-time release to enable manufactured products to be rapidly deployed at the point of manufacture			
	Legislative support prioritising the use of sustainable biobased alternatives across all sectors			

CONSULTATION DRAFT

Technology capabilities – bio-manufacturing

2026

2030

2035

2040

Technology domain specific

Expand analytical technologies for phage characterization, potency, stability, and microbiome CQAs.

Establish 100–1000 L drying, extrusion, purification and formulation capabilities for productization.

Understand capability and capacity gaps for large and novel biomanufacturing approaches across the UK

Develop novel biomanufacturing reactors and processes including access to pilot facilities

Digital Thread

Implement integrated LIMS/MES with equipment connectivity, robust metadata, and compliant data governance.

Creation of models and digital twins of fermentation and cellular processes for prediction, optimisation and troubleshooting

Embedded AI for advanced manufacturing

Multiohmics integration through converging genomics, proteomics, transcriptomics, metabolomics data with agreed standards and formats

Computational 'Omics' tooling developing scalable computational pipelines, fast analysis tools, and harmonized outputs for interoperability

Manufacturing with advanced materials

Engineer extracellular matrix mimics, tuneable biostability polymers, and structured culture materials improving yields for alternative proteins

Value retention

Influence and enable funding and investment incentives through partnerships with IUK, UKRI and other groups such as BIA and BBIA

Advanced and interconnected process modelling

Deploy model predictive control in in line process analytical technologies (PAT) for critical quality attributes (CQAs) and critical process parameters (CPPs)

Intelligent manufacturing assurance and regulatory engagement

Agree data, quality, and lab method standards to ensure comparability and regulatory confidence in non-pharma sectors including developing open source engineered strains



Bio-manufacturing

Pathways for priority industry capability needs

A potential connected system architecture for industry scale-up

2026 2027 2028 2029 2030 2031 Industry deployment and further innovation 2035

To achieve UK net zero and food security, scalable alternative proteins, biobased agrichemicals, and functional ingredients are needed—replacing harmful chemicals and supporting sustainable agriculture, animal feed, and nutritional quality for a healthy population.

Formulation and stability of bio-actives for long term storage / application including encapsulation

Process intensification / novel process creation for efficient / cost effective production

Food and feed production for sustainable agriculture and secure, resilient supplies supporting human and animal nutritional needs

Legislative support to push towards alternative pesticides / stimulants

Addressing antimicrobial resistance requires UK capability to develop and scale microbiome and phage therapies for human health, agriculture, and crop protection—enabling clinical adoption and strengthening resilience against global public health threats.

Analytical characterisation of multispecies microbiome products and phage therapies

Incentivised adoption and integration into the NHS as viable alternatives to antibiotics

Alternative antimicrobials enabling innovative biological approaches to combat resistance and protect global health across diverse applications

Regulatory guidance on alternative antimicrobials further developed across sectors

Phage production for human compassionate use in the UK

Biomanufacturing must integrate automation, digitalisation, and modular approaches to reduce costs, energy use, and timelines—optimising supply chains and delivering scalable, sustainable alternatives across chemicals, materials, and pharmaceuticals to compete with fossil-based systems.

Sustainable and consistent feedstock, standardised feedstock testing to understand process efficiencies

Development of modular biomanufacturing to ensure adaptability and flexibility of UK capabilities

Sustainable and cost-effective biomanufacturing advancing greener production methods to replace traditional processes and reduce environmental impact

Increased technologies (PAT) improving process monitoring, modelling and development of digital twins

Chemical processing integration for feedstock generation / product formulation

Diagram Legend

Key Demand Drivers
are the relevant challenges to this manufacturing technology that the UK manufacturing sectors are facing

Innovation Requirements
are the technologies, tools, processes or technical enablers needed to support the UK's frontier industries

Industry Capability Needs
are what industry needs to be able to do (skills, processes, tools, systems) to stay competitive & meet future challenges

Department for Business & Trade
High-growth sectors

Advanced Manufacturing

Defence

Foundation Industries

Digital & Technologies

Life Sciences

Clean Energy Industries

Composites engineering



Composites Engineering



Diagram Legend

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L1 interactive sunrise diagram

L2 capability roadmap

[Click here](#) to access the interactive version of this capability roadmap

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Level 1 Technology transformation map

2026

2030

2035

2040

Vision



DRAFT



Key demand drivers: industry challenges and opportunities

Enhanced UK supply chain resilience and reconfigurability in critical materials and products

Dynamic supply chain adaptability:
Building flexible networks that can rapidly respond to disruptions and changing market demands.

Strategic material security:
Ensuring access to critical raw materials through diversified sourcing and robust domestic capabilities.

Collaborative innovation ecosystems:
Creating integrated partnerships across industry, academia, and government to accelerate technology adoption and resilience.

Materials and products tailored for harsher environments

Extreme-condition performance:
Designing composites that maintain strength, durability, and functionality in severe operating environments.

Advanced material engineering:
Developing fibres, matrices, and coatings to resist high temperatures, corrosion, and mechanical stress.

Adaptive structural concepts:
Creating innovative composite architectures that deliver reliability and efficiency under unpredictable conditions.

Improved productivity through enhanced quality, rate and cost of manufacture

High-speed, high-quality production:
Industrialise advanced composite manufacturing for rapid throughput without compromising precision.

Smart process optimisation:
Harness automation, data-driven control, and adaptive tooling to cut cost and cycle time.

Scalable manufacturing systems:
Deploy flexible, next-generation factories capable of meeting future demand at global scale.

Reduced embodied carbon of materials and products and reducing waste

Resource-efficient production:
Minimising material wastage and energy usage to improve manufacturing productivity.

Design for sustainability:
Using relevant, detailed and shareable lifecycle information to drive ongoing improvement of products and systems, including approaches that lead to a net positive environmental impact.

Closed-loop material systems:
Restoring and retaining the value of materials so they can be reused multiple times without losing performance, supporting business models built around a circular economy.

Increased size and complexity of products

Large-scale structural capability:
Develop composite solutions that enable bigger, more complex components without compromising performance.

Advanced design and manufacturing methods:
Introduce innovative processes and tooling to handle intricate geometries and integrated systems.

High-assurance testing and validation:
Establish rigorous, accelerated certification and reliability approaches for oversized, complex composite structures.

Strategic summary

The UK holds a leading global position in the design, production and use of products made with composite materials – across transport, defence and energy. HVM Catapult’s role is to maintain that, and propel it towards resilient productivity through rapid production, sustainable materials, and brand-new markets.

Matt Scott CEng, NCC



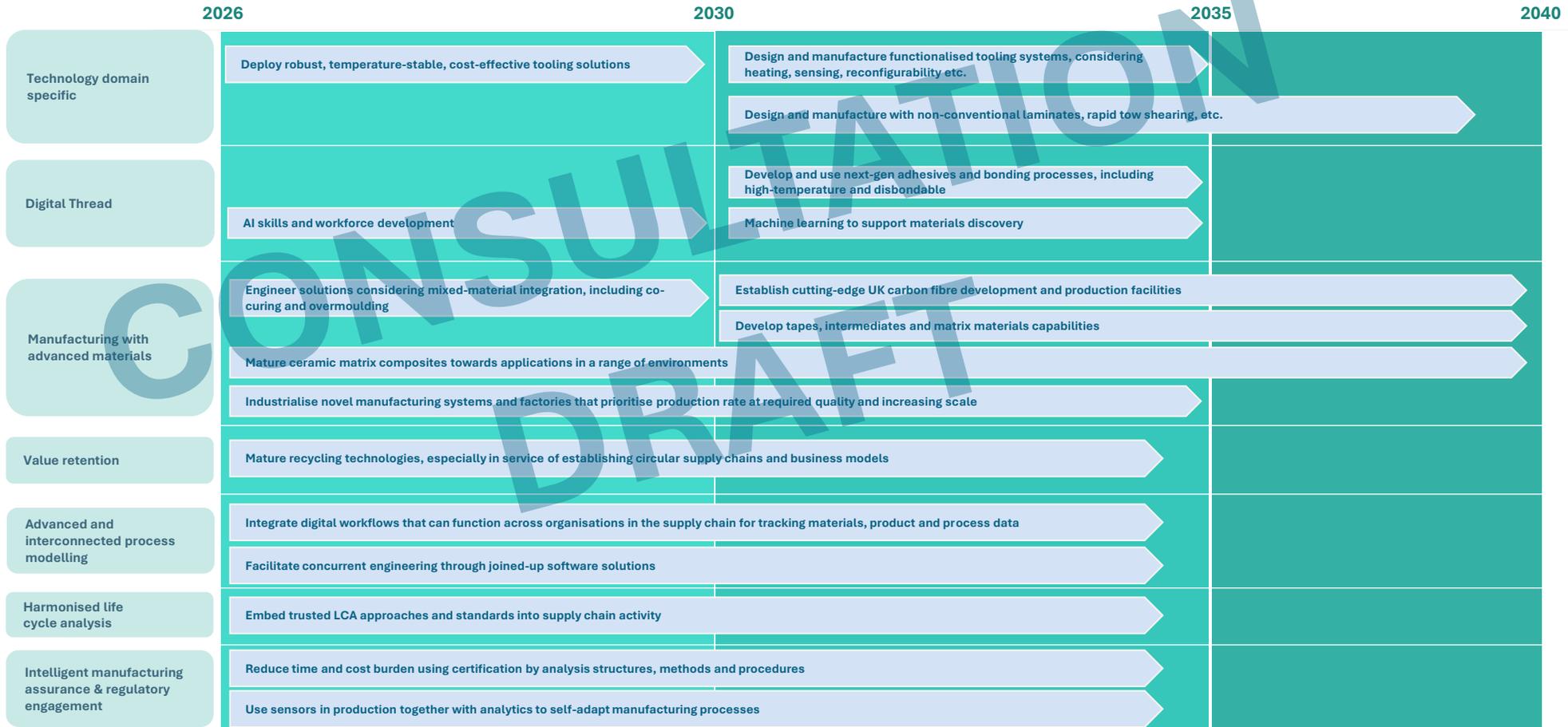
- Skilled and empowered
- Resilient and responsive

Strategic Imperatives

- Resource efficient and regenerative
- Innovative and Digital



Innovation requirements – composites



Industry capability needs – composites engineering





Composites Engineering

Pathways for priority industry capability needs

A potential connected system architecture for industry scale-up

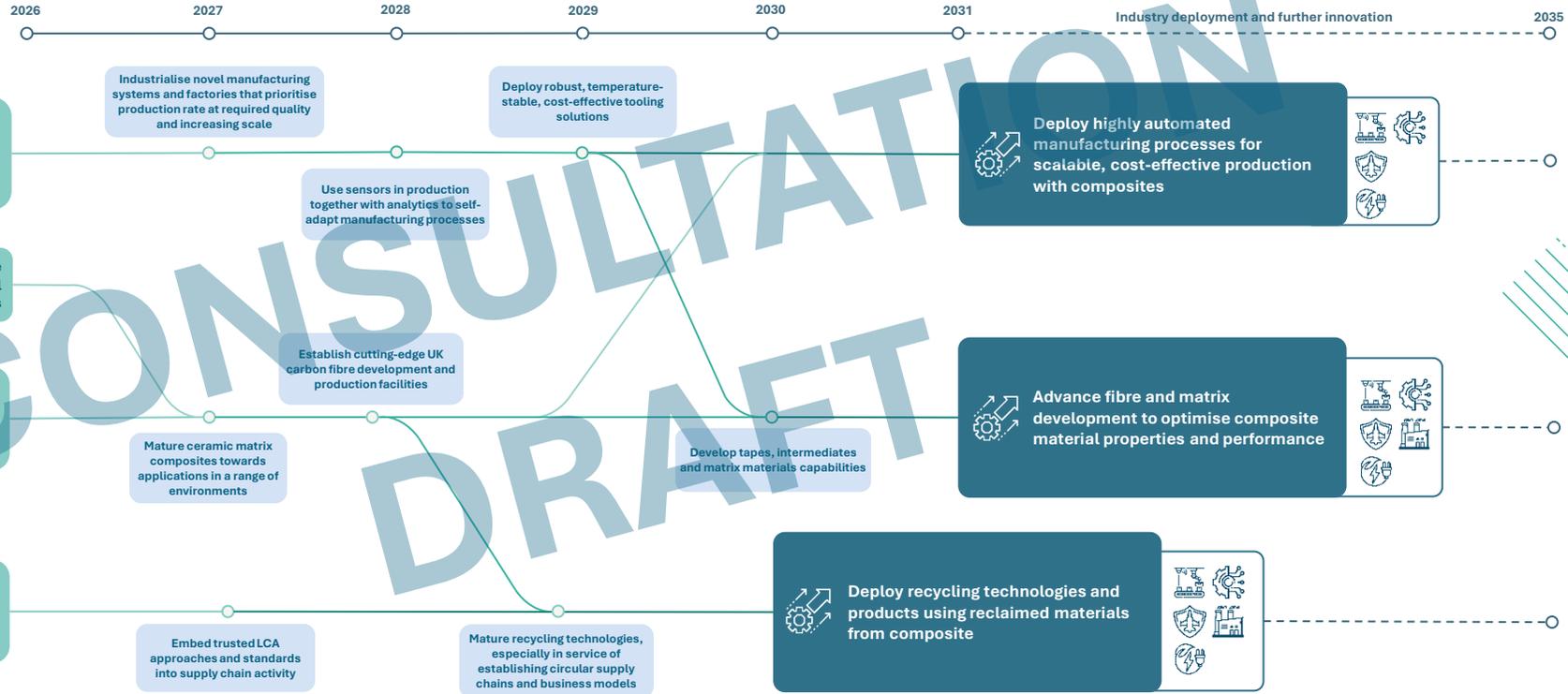


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Department for Business & Trade
High-growth sectors

Advanced Manufacturing

Defence

Foundation Industries

Digital & Technologies

Life Sciences

Clean Energy Industries



CATAPULT

High Value Manufacturing

Digital manufacturing





Digital Manufacturing



Diagram Legend

Key Demand Drivers

are the relevant challenges to this manufacturing technology that the UK manufacturing sectors are facing

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Priority industry capability needs

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L1 interactive sunrise diagram



L2 capability roadmap

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Technology transformation map

2026

2030

2035

2040

Vision

Advanced, data-driven and digitalised manufacturing to improve productivity and competitiveness

Address knowledge capture and retention challenges through digital technologies

Robust data governance and management frameworks ensure secure, decentralised, and effective use of manufacturing data

Increase digital literacy, trust and industry-wide data sharing to drive effective digitalisation and meet rising user expectations

Circularity, sustainability, and future-proofing through advanced analytics, LCA, and resilient supply chains are essential

Agile, connected, manufacturing through interoperable reference architectures, digital threads and distributed supply chains

Industrial cybersecurity frameworks and digital resilience solutions for secure, authorised, and standards-compliant manufacturing operations.

Sustainable design and digitalisation to minimise waste and maximise resource recovery

Digital platforms for knowledge capture, traceability, and skills frameworks supporting assurance and lifelong engineering development

Fostering collaborative innovation ecosystems and upskilling the workforce for human-centric manufacturing

Autonomous and remotely operated systems to support predictive maintenance and real-time monitoring for extending component life

Demonstrators and testbeds for interoperable, secure and governed data management and sharing platforms advocating industry standards

Integrated process optimisation linking automation, digital twins and connected enterprise systems

Unified digital demonstrators, automation, sensors, and robotics for efficient, traceable, and sustainable manufacturing adoption.

Comprehensive data and AI governance frameworks ensuring secure, FAIR, and quality-driven manufacturing data management

Integrated process optimisation linking automation, digital twins and connected enterprise systems

Development of ontologies, interoperable frameworks, data sharing platforms, digital passports and collaborative platforms to establish robust data and knowledge management

Validated AI models enabling optimisation, transparency, and advanced analytics for manufacturing

AI-driven modelling, simulation, and analytics for process optimisation, validation, and productivity improvement.

AI-powered personalisation, generative models, and automation for enhanced manufacturing efficiency and learning.

Drive widespread adoption of digital manufacturing across UK industry, we can unlock transformative gains in productivity, efficiency and global competitiveness. These advancements will not only strengthen supply chains and sustainability but also create high-quality jobs, elevate skills and deliver long-term prosperity for the nation



Digital
Manufacturing

Key demand drivers: industry challenges and opportunities

CATAPULT
High Value Manufacturing

Advanced, data-driven and digitalised manufacturing to improve productivity and competitiveness

Data-driven process control and simulation models increase productivity, performance, and energy efficiency.

Robotics, automation, and control systems enable scalable, flexible manufacturing for diverse applications.

Digital twins and lean manufacturing principles support continuous improvement and process intensification.

Adoption of digitalisation enhances quality, cost savings, and sustainability across manufacturing operations.

Address knowledge capture and retention challenges through digital technologies

Workforce development initiatives build digital skills across the entire manufacturing value chain.

Addressing the knowledge cliff ensures continuity as experienced workers retire from the sector.

Digital capabilities support compliance with cCMP and advanced manufacturing requirements.

Upskilling enables adaptation to new technologies and evolving industry standards.

Robust data governance and management frameworks ensure secure, decentralised, and effective use of manufacturing data

Implementing data management systems supports ownership, security, and decentralised data access.

Knowledge management frameworks enable effective sharing and utilisation of manufacturing information.

Data governance ensures compliance with regulations and industry standards for data protection.

Decentralised data strategies enhance collaboration and innovation across manufacturing networks.

Increase digital literacy, trust and industry-wide data sharing to drive effective digitalisation and meet rising user expectations

Promoting digital literacy and awareness fosters organisational readiness for digital transformation.

Ethical frameworks and trust-building support responsible adoption of digital technologies.

Flexible working models and automation complement human roles in manufacturing environments.

Industry-wide collaboration on data sharing and security drives sector-wide innovation and resilience.

Circularity, sustainability, and future-proofing through advanced analytics, LCA, and resilient supply chains are essential

Standardised LCA and carbon accounting frameworks quantify sustainability benefits and ecological impact.

Circularity principles drive resource efficiency, waste reduction, and sustainable manufacturing practices.

Advanced analytics and digital threads enhance traceability and transparency in supply chains.

Future-proofing strategies include agile development and resilient, sustainable design methods and tools.



Strategic summary

Digitalisation and automation are driving productivity and sustainability across manufacturing. Secure data governance combined with a skilled workforce enables transformation and innovation. Circularity and resilient supply chains ensure the industry remains future-proof and competitive.

Dr Nandini Chakravorti, MTC



Strategic Imperatives

- Skilled and empowered
- Resilient and responsive

- Resource efficient and regenerative
- Innovative and Digital



Industry capability needs – digital manufacturing

2026 2030 2035 2040



Innovation requirement – digital manufacturing





Digital manufacturing

Pathways for priority industry capability needs

A potential connected system architecture for industry scale-up

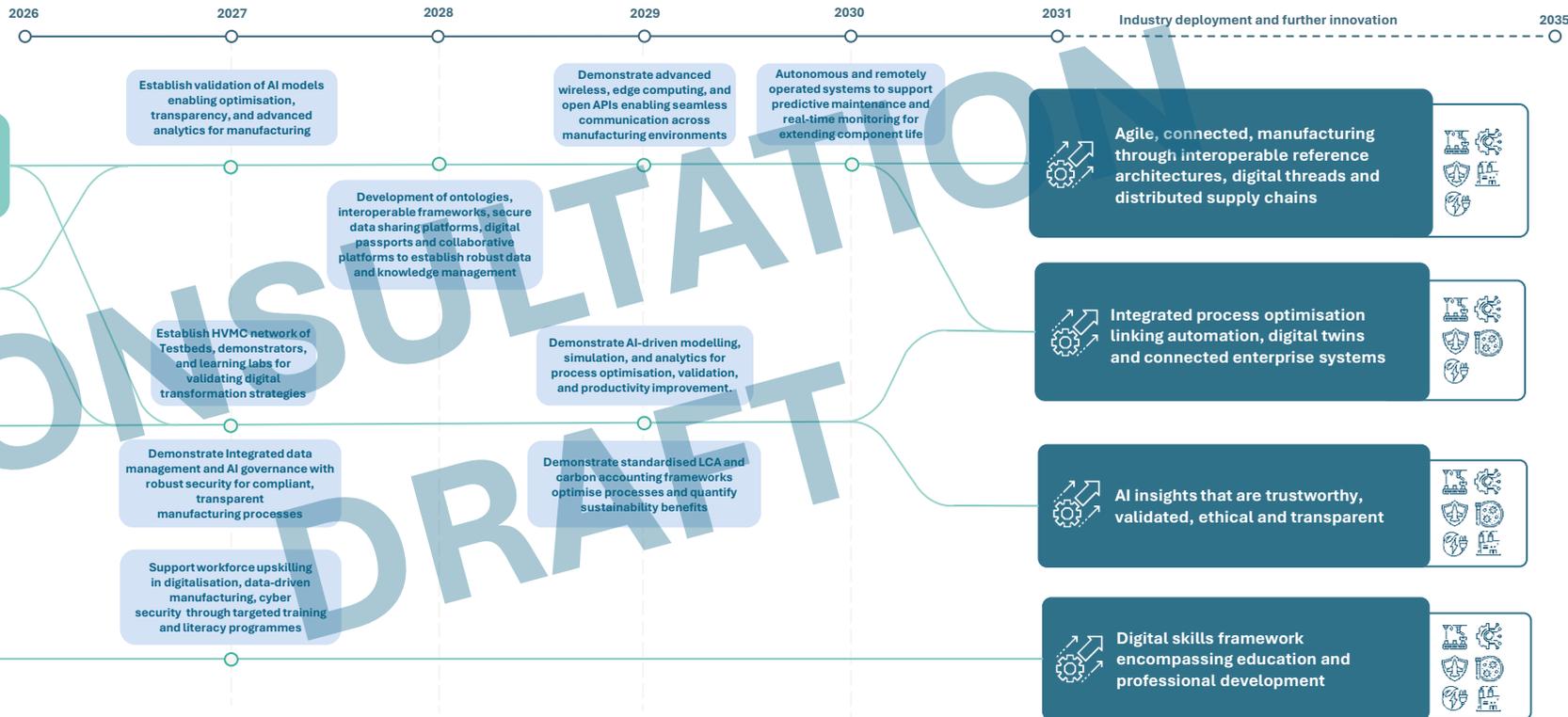


Diagram Legend

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Joining engineering



Joining engineering



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L1 interactive sunrise diagram



L2 capability roadmap

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[Click here](#) to access the interactive version of this capability roadmap

Technology Transformation Map

2026

2030

2035

2040

Vision

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

Hybrid manufacturing techniques to enable joining of next-generation materials for harsh environments

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

Advanced, automated and scalable joining technologies which improve integrity, reduce variance and enable high throughput manufacturing of next generation products

The use of hybrid technologies to engineer joint performance

Autogenous fusion, and solid-state joining at scale

Joining techniques to promote modular construction enabling higher performance and sustainable energy systems

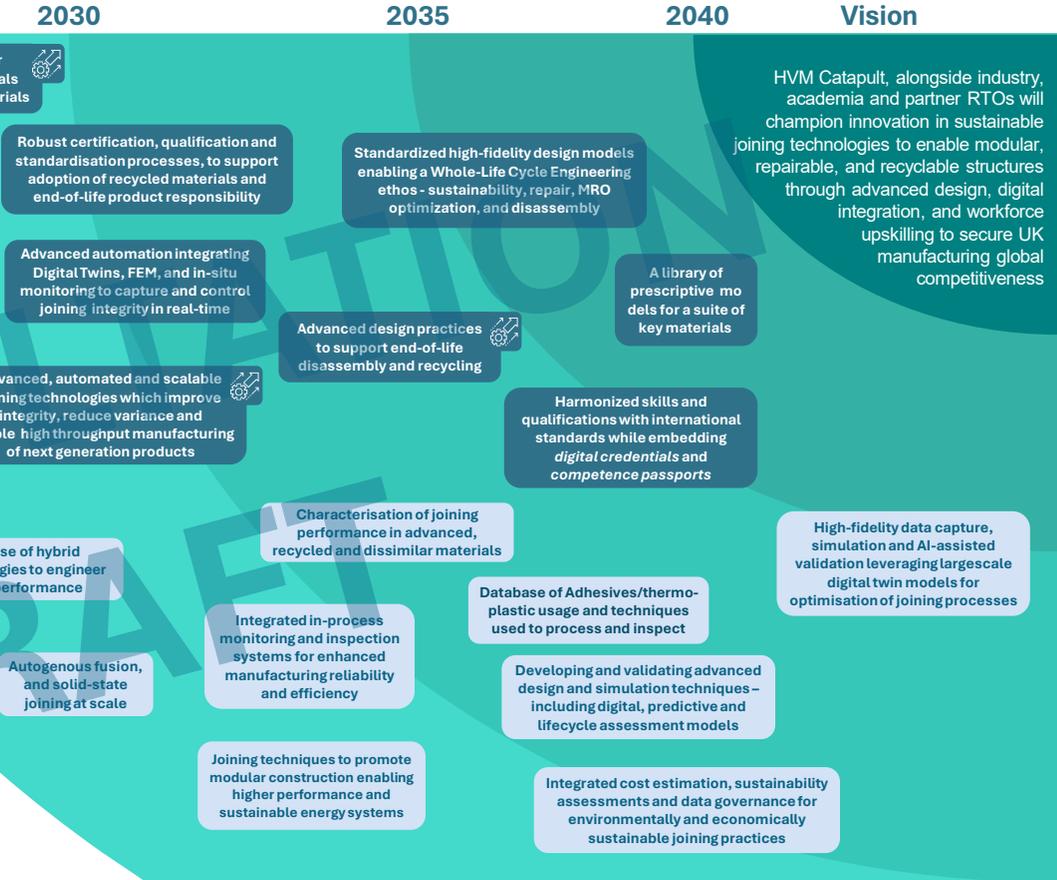
Robust certification, qualification and standardisation processes, to support adoption of recycled materials and end-of-life product responsibility

Standardized high-fidelity design models enabling a Whole-Life Cycle Engineering ethos - sustainability, repair, MRO optimization, and disassembly

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

Characterisation of joining performance in advance, recycled and dissimilar materials

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



A library of prescriptive models for a suite of key materials

Harmonized skills and qualifications with international standards while embedding digital credentials and competence passports

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

Database of Adhesives/thermo-plastic usage and techniques used to process and inspect

Developing and validating advanced design and simulation techniques – including digital, predictive and lifecycle assessment models

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

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



Joining engineering

Key demand drivers: industry challenges and opportunities

Process automation to boost productivity and reduce manufacturing costs

Closed-loop process control using Machine Learning to define processing limits and automatically adjust processing conditions within those approved qualification limits

Process passports enabling the automated generation of process specification procedures providing direct capture of essential, and supplementary essential parameters to formulate a 'True' qualification record related to material, component, structure.

Increased deployment of high-speed, high-energy density, and photonic joining technologies to enhance dissimilar joining capability and minimise disruption of substrate properties

Agile, quick-change intelligent tooling linked to implementing standardized modular construction to maximise utilisation and match demand in high volume production environments

Through life assurance that leverages data-driven technologies

In-line volumetric inspection to reduce lead-times, waste and energy, whilst concurrently improving productivity

The use of advanced tactile and remote sensing technologies to monitor dimensional deviations during joining to improve FEA models to predict residual stress and improve structural integrity

Real-time dimensional inspection to enable translation of product and process information to be incorporated into digital systems to highlight and prevent in-sequence rectification of products

Modularised Portable Repair Systems that enable reconfigurable and integrated joining and inspection methods to be applied to a variety of conditions and environments.

The application of closed loop thermal management systems linked to material specifications to improve productivity

Accessibility to skills – from technicians to engineers

Targeted Training Pathways – Develop structured programs for technicians and engineers to master advanced joining technologies and digital tools.

Industry-Academia Partnerships – Collaborate with universities and employers to deliver practical, accredited courses aligned with emerging joining innovations.

Demonstrator Access – Provide real-world facilities for skill application, ensuring workforce readiness for complex joining processes.

Flexible Learning Platforms – Offer online and blended learning options to reach diverse roles across the manufacturing supply chain.

Continuous Professional Development – Create lifelong learning frameworks to keep technicians and engineers updated on evolving joining standards and practices.

Advanced design practices to improve sustainability and circularity

Design for Disassembly to enable the efficient separation of joined components, simplifying reuse and recycling processes

Material Compatibility Analysis to ensure joints use compatible materials, reducing contamination and improving recyclability

Lightweight Hybrid Structures to combine advanced materials to minimize resource use while maintaining structural integrity

Digital Twin Integration to simulate joint performance and lifecycle impacts, optimizing sustainable design decisions

Modular Joint Design to create adaptable joints for easy repair, upgrade, and extended product life

Designing of advanced consumables for improved joining performance and longevity for applications in welding, brazing, soldering and adhesive joining.

Digitalisation technologies for predicting and optimising manufacturing processes

AI integration of joining conditions to enable data collection, mining and sharing of large-scale information to process optimised joint designs for efficiency and performance.

The creation and deployment of Digital Technologies that advance high-fidelity joining simulations to underpin Design and Certify by Analysis philosophies

Human-Centric Life Cycle Design principles to ensure safe, efficient assembly, maintenance, and re-manufacturing throughout product life

Digital product passports that captures and links material property data, joint geometry and process inputs at the component level to the resulting residual stress and microstructural predictions

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.

Prof Steve Jones, AMRC

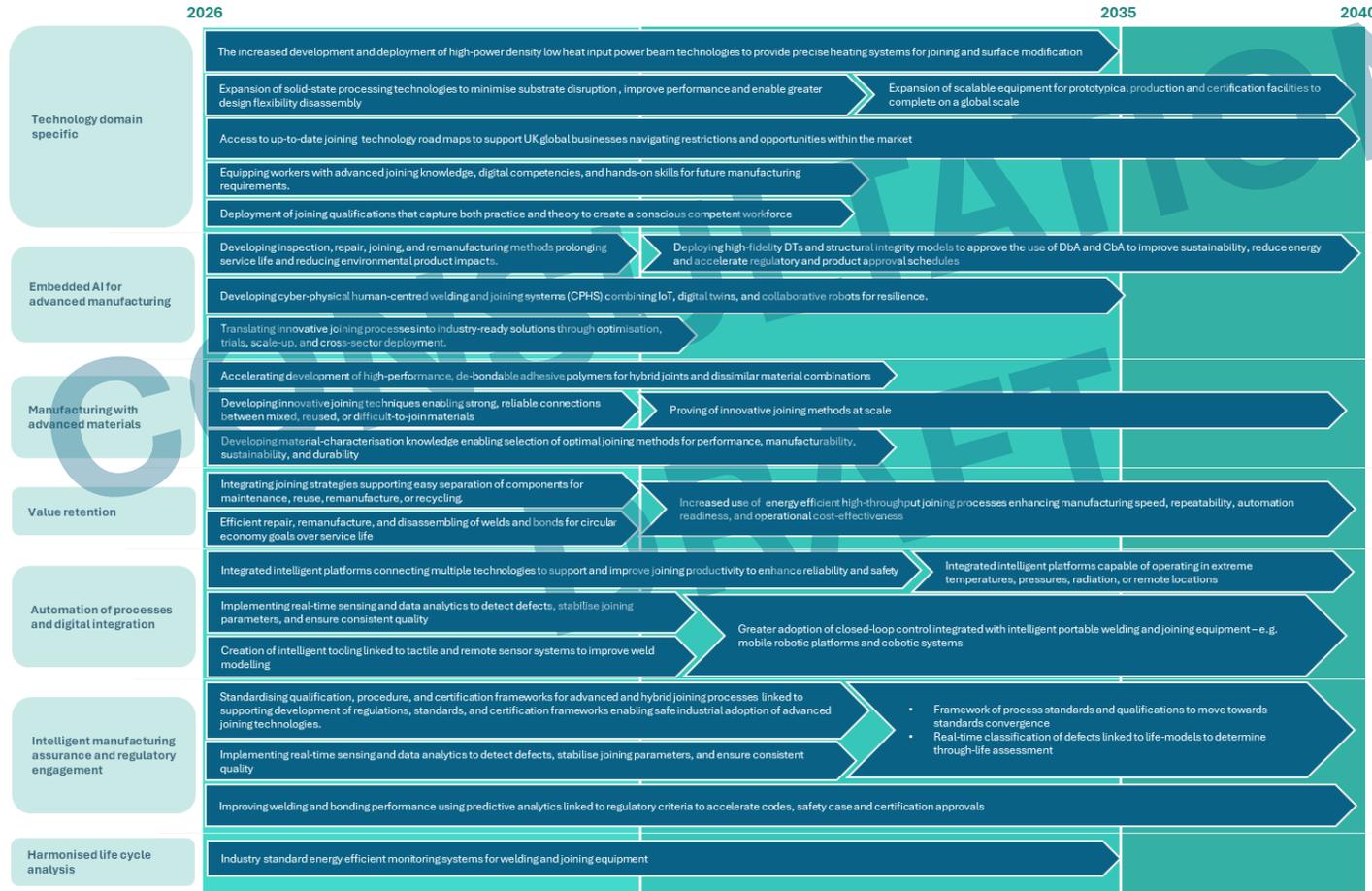


Strategic Imperatives

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



Industry capability needs – joining engineering



Innovation requirements – joining engineering

	2026	2030	2035	2040
Technology domain specific	Development and validation of advanced joining techniques for thick section metallics (50mm+)	Increased deployment of autogenous fusion, and solid-state joining at scale using modified filler materials and atmospheres		
	Joining of dissimilar materials – within genre and across the material spectrum, e.g. metallics to ceramics, a metallics to composites	Characterisation of joining performance in advanced, recycled and dissimilar materials		
	Developing workforce capabilities through training and knowledge sharing to implement advanced joining technologies effectively and safely.			
	Development of next generation of joining engineering modules capturing technology developments linked to improve regulatory control	Flexible Learning Platforms from RQF 3 to RQF 8		
	Reliable mechanical joining solutions for structural components, ensuring performance, durability, and efficient assembly across industries.			
Digital Thread	Traceable digital records of materials and components for quality assurance and end-of-life circularity in joining	Digital twins and physical separation methods to safely process materials and components for precision joining.		
	Centralized digital repository providing comprehensive material properties, standards, and sourcing information to support manufacturing decisions.	Deployment of advanced digital design software to simulate, optimize, and validate joining processes before physical implementation.		
Manufacturing with advanced materials	Data collection and collation of generic materials to generate joining design and performance taxonomy for virgin and recycled materials	Comprehensive database of material properties to support informed joining decisions, simulation, and design optimization.		
	Working with academia and materials producing suppliers to develop the next generation of joining consumables	Creation of a central processing repository for dissimilar material joining and respective procedures to optimize performance		
		Partner with industry in the development of novel filler materials for dissimilar materials joining		
Value retention	Promotion of modular construction enabling higher performance and sustainability	Innovative design practices building on modularization to recover, reuse and recycle critical materials		
Advanced and interconnected process modelling	Interconnected loop between modelling and real-world manufacturing – leading to design and certification by analysis			
Harmonised life cycle analysis	Standardization of primary data and collection methods to generate 'Trustworthy' information to improve processing and data transfer			
	Establishing technical and regulatory standards for joining processes to ensure interoperability, safety, and consistent quality globally.			
	Establish LCA databases and carbon accounting standards to measure sustainability across joining technologies			
Intelligent manufacturing assurance & regulatory engagement	Integrated in-process monitoring and inspection systems for enhanced manufacturing reliability and efficiency	Integrating joining and inspection techniques directly within manufacturing processes to improve efficiency, monitoring, and high-quality production outcomes.		
	Deployment of increased mechanization to remove variability and increase standardization linked to respective process specifications			





Joining engineering

Pathways for priority industry capability needs

A potential connected system architecture for industry scale-up

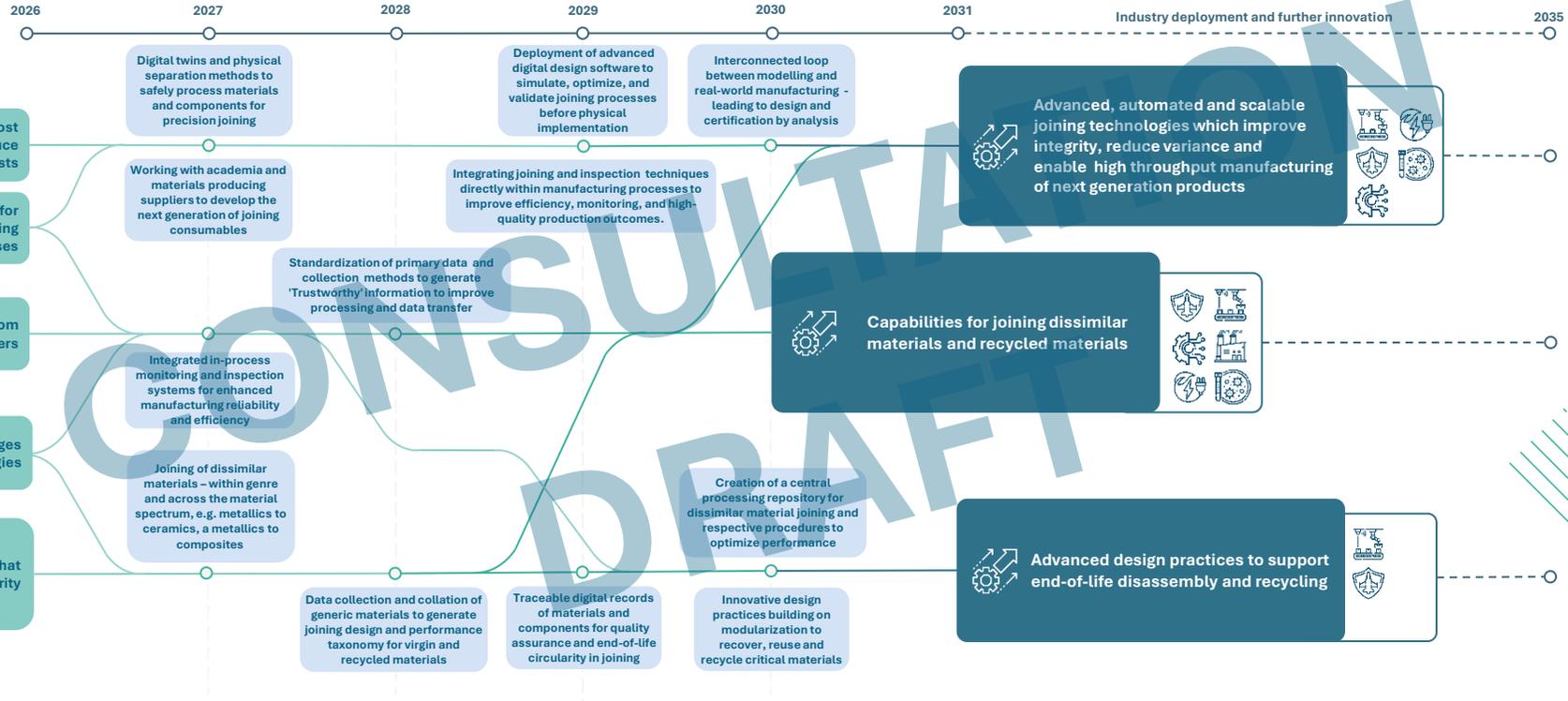


Diagram Legend

Key Demand Drivers are the relevant challenges to this manufacturing technology that the UK manufacturing sectors are facing

Innovation Requirements are the technologies, tools, processes or technical enablers needed to support the UK's frontier industries

Industry Capability Needs are what industry needs to be able to do (skills, processes, tools, systems) to stay competitive & meet future challenges

Department for Business & Trade
High-growth sectors

Advanced Manufacturing

Defence

Foundation Industries

Digital & Technologies

Life Sciences

Clean Energy Industries

Robotics and automation



Robotics and automation



Diagram Legend

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L1 interactive sunrise diagram

[Click here](#) to access the interactive version of this capability roadmap



L2 capability roadmap

Follow the QR code or you can also [click here](#)

Technology transformation map

2026

2030

2035

2040

Vision

Maximise the value from the compliant use of data, digital threads and digital product passports

Strengthened workforce skills for business continuity and long-term capability

Integration of Human-Robot Collaboration

Resource and energy efficient manufacturing through advanced design, virtualisation and innovative materials

Proven technology and validated business models

Trustworthy, transparent autonomous systems for productivity

Delivering mass customisation manufacturing through scalable, flexible and reconfigurable automation solutions

A capable UK based, Automation supply chain

Training and upskilling for widespread automation adoption

Data-driven manufacturing using digital twins, real-time verification and cloud platforms for smart decision-making

User-friendly, plug-and-play systems with AI-enabled robotics to lower adoption barriers

Sensor-integrated automation for process control, defect detection and quality

Accessible training and low-code tools for automation adoption and development

Intelligent and adaptable automation and robotics solutions for sorting, segregation, disassembly and remanufacturing.

Automation and robotics operating in an unstructured and dynamic environment

Widespread adoption of Automation, with responsive UK based supply chain with global recognition

Flexible automation, mobile robots and dexterous grippers

AI embedded in robot controller systems, faster processors, smart network of sensors, application driven sensing response

Agile, intelligent, AI-powered automation systems for diverse and custom production with integrated quality control

Physical process optimised by product performance through life via Data

Modular digital platforms for data, AI, digital twins and design components

Automation and Robotics adoption in UK manufacturing will significantly boost productivity and competitiveness, Leading to higher living standards and more high-quality jobs.



Robotics and automation

Key demand drivers: industry challenges and opportunities



Mass customisation manufacturing through scalable, flexible and reconfigurable automation solutions

Reconfigurable robotic cells – Modular robotic stations can be rapidly retooled to accommodate frequent product variations seamlessly.

Flexible production lines – Automation enables real-time adaptation to shifting batch sizes and up-stream quality without interrupting manufacturing flow or efficiency.

Scalable automation architectures – Systems expand or contract capacity easily, supporting demand fluctuations and customised order requirements.

Integrated AI-driven planning – Intelligent scheduling optimises robot tasks for high-mix, low-volume personalised manufacturing environments

Rapid changeover technologies – Smart tooling and automated setup transitions significantly reduce downtime when switching between customised products

Strengthened workforce skills for business continuity and long-term capability

Upskill staff to operate, monitor, and optimize automated robotic systems ensuring reliable production performance during organizational disruptions.

Developed cross-functional automation competencies enabling employees to build robust business models and cases.

Implement structured training programs that build long-term robotics proficiency reducing reliance on external technical support resources.

Enhance digital literacy and human-robot collaboration skills strengthening workforce resilience across evolving automation-driven manufacturing environments.

Embed continuous learning pathways for advanced robotics technologies, ensuring sustainable capability growth and future-ready operational expertise.

Maximise the value from the compliant use of data, digital threads and digital product passports

Digital threads for traceability enables seamless data connectivity across design, production, and lifecycle improving efficiency and decision-making accuracy.

Product passports for compliance supports structured digital records ensure regulatory adherence while facilitating product lifecycle management and sustainability reporting.

Data-driven optimisation – Collected operational data enables AI and automation systems to enhance process performance and reduce waste.

Secure, compliant data sharing ensuring sensitive information is safely exchanged across supply chains without violating privacy or regulations.

Lifecycle insights for innovation – Analytics from digital product data supports continuous product improvement and informed strategic planning.

Resource & energy efficiency through advanced design, virtualisation and innovative materials

Optimised energy use – Digital twins and simulations streamline robotic workflows, reducing energy consumption and material waste across production cycles.

Virtualised process simulations – Simulation-driven layout and workflow design enable efficient automation, minimising resource use and operational downtime.

Innovative materials – Lightweight, advanced materials reduce robotic handling loads, improving system efficiency and lowering energy requirements.

Precision and low-waste production – Advanced design tools guide robots to minimise scrap generation and maximise resource utilisation consistently.

Sustainable product development – Integrated eco-design and virtual modelling support environmentally conscious manufacturing with intelligent, energy-efficient robotic system

Integration of Human-Robot Collaboration (Cobotics)

Safe collaborative workflows – Cobots support operators, enhancing productivity while maintaining ergonomics and safety within flexible manufacturing environments.

Adaptive assistance – Intelligent robots respond to human movement, reducing strain and supporting complex, precise assembly operations efficiently.

Accuracy and consistency – Sensor-enabled cobots improve task quality, allowing workers to focus on higher-value decision-making activities.

Agile production – Reconfigurable cobotic stations enable rapid task changeovers, supporting efficient small-batch and personalised manufacturing processes.

Workforce capability – Training in cobot interaction builds skills and confidence, ensuring safe, effective adoption across automated operations.

Strategic summary

The future of UK manufacturing depends on scalable, flexible automation enabling mass customisation, a automation skilled workforce to ensure long-term capability, and the compliant use of data through digital threads and product passports. Advanced design, virtualisation and innovative materials will further drive resource-efficient, low-energy, resilient production.

Prof Harry Burroughes, AMRC



Strategic Imperatives

- Skilled and empowered
- Resilient and responsive

- Resource efficient and regenerative
- Innovative and Digital



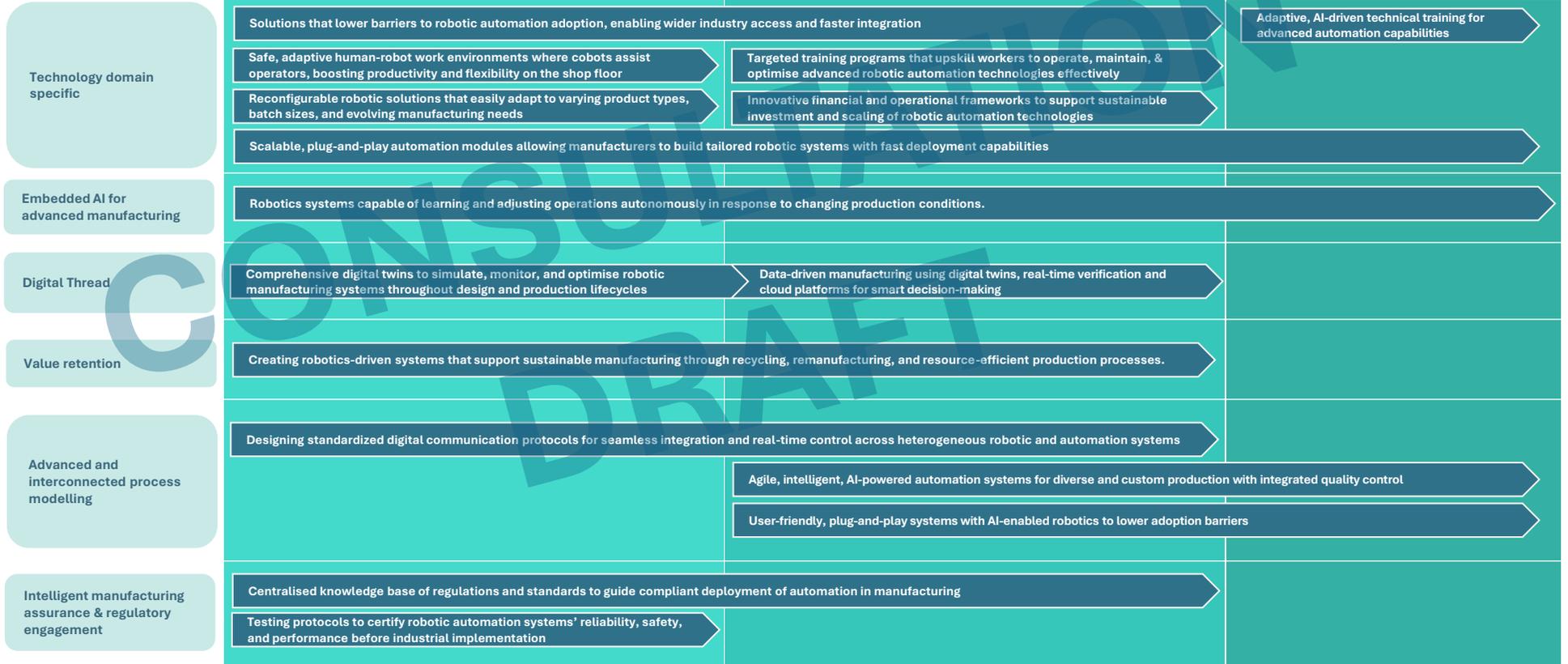
Industry capability needs – robotics and automation

2026

2030

2035

2040



Innovation requirements – robotics and automation

	2026	2030	2035	2040
Technology domain specific	Secure cloud platforms to enable remote control, monitoring, and collaborative operation across sites	Modular, adaptable robotic hardware platforms that can be rapidly reconfigured to suit changing production requirements		
	Modular robot systems that scale flexibly with production needs, enabling rapid deployment and reconfiguration	Intuitive, accessible human-machine interfaces that simplify robot programming, monitoring, and interaction for diverse users		
	Scalable automation business frameworks that lower investment risks and enhance return on robotic technology adoption.			
Embedded AI for advanced manufacturing	Real-time sensor data streams for immediate process adjustments and enhanced robotic system performance	Control architectures enabling robots to autonomously adapt to real-time manufacturing changes and unexpected conditions		
	Advanced real-time simulation models and communication protocols to support precise, coordinated robot motion and control.	AI algorithms to assist operators and robots with predictive maintenance, quality control, and process optimisation		
	Robotic systems capable of independent decision-making, adapting dynamically to complex manufacturing environments without human intervention			
Digital thread	Detailed digital replicas of manufacturing systems to simulate, monitor, and optimise robotic operations in real time			
Value retention	Tools for continuous monitoring, updating, and maintenance of robotic systems to extend operational lifetime.	Energy-efficient and resource-saving principles within automation design to support net-zero manufacturing targets		
Intelligent manufacturing assurance and regulatory engagement	Accessible software libraries that accelerate development, integration, and reuse of robotic automation components and algorithms			
	Ergonomic, safety-conscious automation solutions that enhance operator wellbeing and seamless human-robot collaboration	Standards to verify safety, reliability, and performance across robotic automation technologies.		
	Robust cybersecurity measures to protect automated manufacturing systems from cyber threats and operational disruptions	Open platform protocols to enable interoperability and seamless integration of heterogeneous automation and robotic components		
Advanced and interconnected process modelling	Collaboration between software, hardware, and process engineers to accelerate integrated robotics innovation and deployment	Augmented and virtual reality tools for simulation, operator training, and remote robot monitoring and control		
	Connected automation systems that improve supply chain responsiveness and enable synchronized manufacturing across distributed sites			
	Collaborative, open-source digital design frameworks that enable faster, modular development of automated robotic manufacturing systems			



Robotics and automation

Pathways for priority industry capability needs

A potential connected system architecture for industry scale-up



Maximise the value from the compliant use of data, digital threads and digital product passports

Resource and energy efficient manufacturing through advanced design, virtualisation and innovative materials

Delivering mass customisation manufacturing through scalable, flexible and reconfigurable automation solutions

Agile, intelligent, AI-powered automation systems for diverse and custom production with integrated quality control

AI embedded in robot controller systems, faster processors, smart network of sensors, application driven sensing response

Sensor-integrated automation for process control, defect detection and quality

User-friendly, plug-and-play systems with AI-enabled robotics to lower adoption barriers

Modular digital platforms for data, AI, digital twins and design components

Physical process optimised by product performance through life via Data

Agile, intelligent, AI-powered automation systems for diverse and custom production with integrated quality control (part 1 reaches maturity)

Data-driven manufacturing using digital twins, real-time verification and cloud platforms for smart decision-making

User-friendly, plug-and-play systems with AI-enabled robotics to lower adoption barriers



Diagram Legend

Key Demand Drivers are the relevant challenges to this manufacturing technology that the UK manufacturing sectors are facing

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Subtractive manufacturing



Subtractive manufacturing



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Technology transformation map

2026

2030

2035

2040

Vision

Addressing the digital deficit in manufacturing process optimisation

Mitigating supply chain fragility and securing strategic investment

Overcoming barriers in advanced material development and qualification

Transitioning to sustainable and circular subtractive manufacturing models

Scaling industrial infrastructure to support national energy systems

Capability for design for subtractive manufacture, repair and component re-use

Development of educational frameworks for next generation subtractive manufacturing engineers and machinists

Implementation of digital autonomy and digital twins for intelligent process planning

Deployment of reconfigurable subtractive systems within connected and responsive future supply chains

Realisation of zero-defect subtractive processes and precision finishing of complex near net shape routes

Harmonisation of physical autonomy with human-in-the-loop for robust subtractive operations

Deploying embedded 3D metrology and sensors to drive real-time adaptive control for zero-defect production

Establishing a centralised national database to validate properties and accelerate new material introduction

Creating modelling toolkits that prioritise energy efficiency and carbon reduction in process parameter selection

Implementing standard data protocols to enable secure sharing and performance benchmarking across supply chains

Establishment of data-centric subtractive frameworks and digital passports for lifecycle transparency

Development of disruptive and non-traditional material removal processes for challenging environments

Advanced subtractive processing capabilities for next generation materials and future complex components

Embedding sustainable subtractive principles and energy efficient machine tools for circular operations

Defining robust cutting strategies and tooling parameters for novel alloys and difficult-to-machine materials

Designing application-oriented training programmes to upskill the workforce in human-centric automation and digital skills

Engineering technologies to capture, separate, and reprocess swarf and fluids for circular resource recovery

Prototyping scalable hybrid systems and reconfigurable robotics for large-envelope in-situ machining operations

Leading innovation for subtractive manufacturing processes and technologies by pioneering autonomous precision, digitalisation, and circularity, enabling resilient, high-integrity production across the UK's critical supply chains

Formalising partnerships between research centres and industry to facilitate knowledge exchange and de-risk R&D

Creating AI-driven tools to assess manufacturability and verify processes via high-fidelity digital thread simulations



Subtractive manufacturing

Key demand drivers: industry challenges and opportunities

Mitigating supply chain fragility and securing strategic investment

The subtractive manufacturing sector faces volatile raw material availability and high capital costs for advanced equipment that stifle growth.

Strategic supply chain mapping: lack of visibility requires mapping to foresight high-priority sectors facing critical feedstock and tooling shortages.

De-risking capital investment: high capital costs demand new mechanisms to de-risk investment in high-capacity, multi-axis CNC machinery.

Strengthening local ecosystems: global disruption risks necessitate distributed, reconfigurable subtractive manufacturing networks and clustered factories to ensure national resilience.

Securing critical component supply: sovereign capability is essential to secure the supply of complex critical components.

Addressing the digital deficit in manufacturing process optimisation

A reliance on disconnected legacy machine tools hinders the sector's ability to adopt precision, data-driven manufacturing.

End-to-end connectivity: siloed legacy assets require end-to-end connectivity to ensure seamless data flow from computer aided methods to inspection.

Scalable flexible manufacturing: static production lines must become reconfigurable cells to adapt to varying complex part geometries.

Predictive process control: unpredictable tool wear demands in-process sensing to optimise surface finish, quality and dimensional accuracy.

Virtualising smart machining: legacy equipment limitations require virtualisation to enable smart design, process verification and automated correction.

Overcoming barriers in advanced material development and qualification

Innovation is bottlenecked by the difficulty of processing next-generation materials and the slow pace of regulatory validation.

Next-generation material machinability: unknown cutting characteristics of next-generation materials hinder applications in hydrogen, nuclear and high value sectors.

Accelerating product validation: slow certification speeds require rapid verification of processed surface integrity to accelerate manufacturing readiness.

Agile standardisation methods: rigid specifications necessitate agile standards and open access data to enable wider material re-use.

Prototypic material research: high innovation risks demand joint research to de-risk subtractive manufacturing of novel materials and protect intellectual property.

Transitioning to sustainable and circular subtractive manufacturing models

Subtractive processes inherently generate waste; the industry must urgently pivot to reclamation and energy efficiency to meet net zero.

Material reclamation systems: high material waste necessitates systems for swarf recovery and separation to improve material security.

Circular lifecycle design: linear consumption models require designing components for efficiency, remanufacturing and sustainable decommissioning strategies.

Energy efficient machining: rising energy costs demand optimised toolpaths and plant operations to drive manufacturing cost reduction.

Sustainable process inputs: environmental impact must be lowered by developing sustainable coolants and extending tooling life.

Scaling industrial infrastructure to support national energy systems

The UK currently lacks the large-scale subtractive manufacturing capacity required to deliver heavy energy infrastructure and grid modernisation.

Grid modernisation strategy: grid expansion demands defined supply chain options and capabilities to manufacture future component configurations.

Clean energy scale-up: capacity gaps require developing heavy subtractive manufacturing skills specifically for hydrogen production and nuclear decommissioning.

Strategic sector foresighting: strategic gaps necessitate foresighting applications that support the industrialisation of large-scale critical structures.

Decommissioning and compliance: regulatory pressures demand compliant processes for sustainable decommissioning of offshore structures and nuclear waste.

Strategic summary

There is a critical demand for resilient supply chains, scalable energy infrastructure, and resource-efficient production. To secure this future, we must position the UK as a global leader in data-driven subtractive manufacturing and circular value recovery, enabled by a skilled and empowered workforce capable of delivering these complex, critical systems.

Prof David Curtis, Advanced Manufacturing Research Centre



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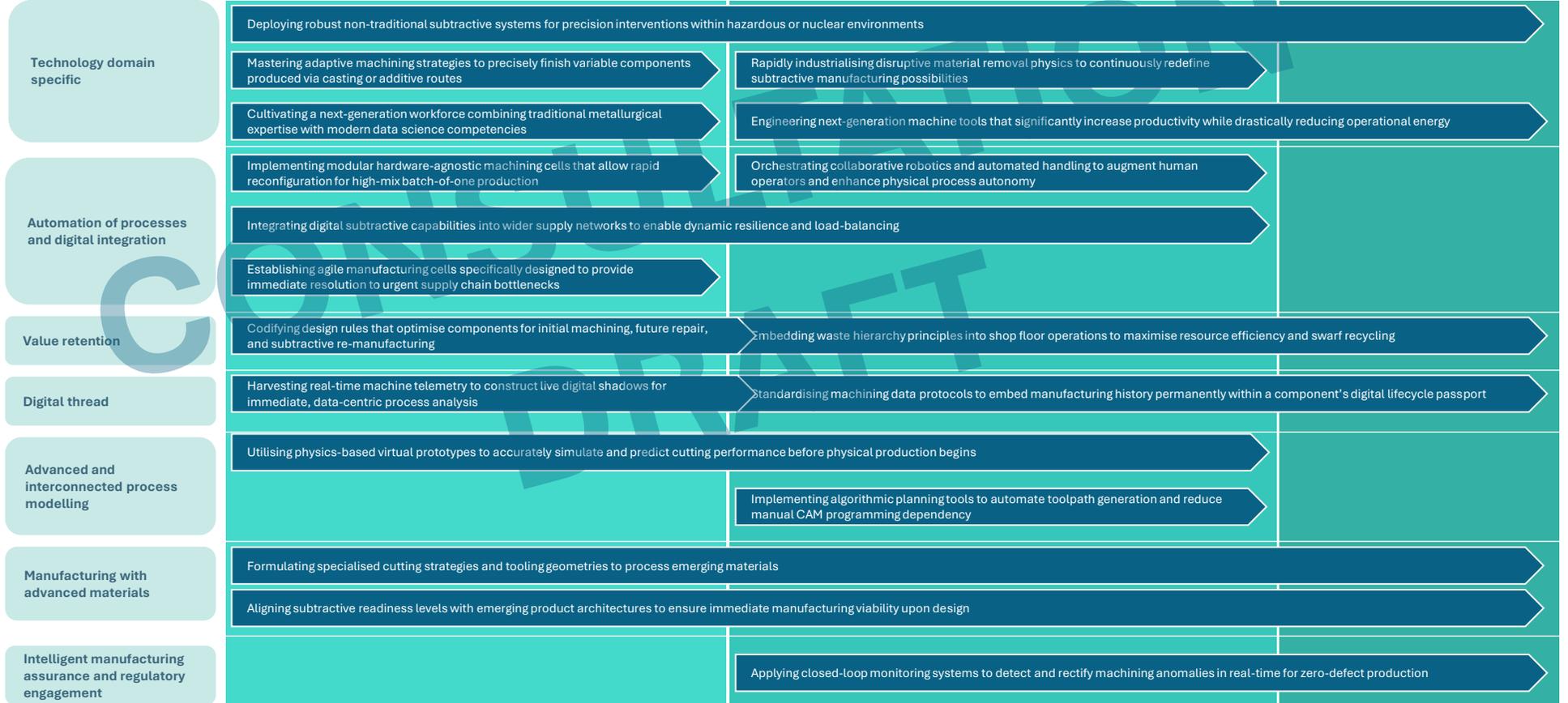
Industry capability needs – subtractive manufacturing

2026

2030

2035

2040



Innovation requirements – subtractive manufacturing

	2026	2030	2035	2040
Technology domain specific		Developing optimisation mechanisms to enhance the resilience and efficiency of subtractive manufacturing supply chains		
		Fostering an enhanced R&D ecosystem that bridges the gap between academic research and industry		
		Building a cohesive partner ecosystem to accelerate the development and adoption of subtractive technologies		
		Creating a dedicated platform to facilitate the exchange of technical knowledge and best practices		
Automation of processes and digital integration		Validating scalable hybrid manufacturing systems that combine additive deposition with subtractive finishing processes	Developing flexible robotic manufacturing cells capable of performing precision in-situ subtractive machining operations	
			Designing human-centric automation workflows that augment operator capabilities rather than replacing the workforce	
Digital Thread		Establishing data-centric shop floors that securely capture and share real-time process performance analytics		
		Implementing integrated management systems for validating and distributing critical material and process capability data		
Manufacturing with advanced materials		Defining robust machining strategies and tooling parameters for novel alloys and advanced hybrid materials		
		Establishing collaborative networks to streamline the validation and route-to-market for emerging raw materials		
Value retention		Implementing industrial symbiosis technologies to convert subtractive manufacturing waste streams into reusable resources		
		Engineering integrated systems for the efficient recovery, separation, and reprocessing of coolants and swarf		
Embedded artificial intelligence for advanced manufacturing		Deploying AI-driven design analysis tools to automatically assess component geometry for subtractive manufacturability		
		Utilising machine learning algorithms to enable adaptable manufacturing systems driven by historic data pools		
		Establishing open-access data frameworks to accelerate artificial intelligence research within the subtractive domain		
Advanced and interconnected process modelling		Integrating low-cost sensor networks for real-time monitoring of machining stability and vibration dynamics		
		Developing high-fidelity physics-based simulations to accurately predict subtractive process outcomes and behaviour		
		Creating multi-objective process models that prioritise energy efficiency and carbon reduction alongside productivity		
		Developing optimisation toolkits to balance productivity rates against environmental impact and resource consumption		
Intelligent manufacturing assurance & regulatory engagement		Embedding integrated 3D metrology systems within machine tools to enable zero-defect closed-loop verification		



Subtractive manufacturing

Pathways for priority industry capability needs

A potential connected system architecture for industry scale-up



Addressing the digital deficit in manufacturing process optimisation

Establishing data-centric shop floors that securely capture and share real-time process performance analytics

Deploying AI-driven design analysis tools to automatically assess component geometry for subtractive manufacturability

Establishing open-access data frameworks to accelerate artificial intelligence research within the subtractive domain

Developing optimisation mechanisms to enhance the resilience and efficiency of subtractive manufacturing supply chains

Developing high-fidelity physics-based simulations to accurately predict subtractive process outcomes and behaviour.

Implementation of digital autonomy and digital twins for intelligent process planning



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How can you help?

The HVM Catapult technology strategy will be informed by this consultation. We invite inputs from a broad range of UK manufacturing to shape the roadmaps and the relevant innovation priorities.

Follow the link to take part in the consultation and help shape the technology innovation priorities for UK industry:

https://forms.office.com/Pages/ResponsePage.aspx?id=T6cm_jmD3kW8K62j72hTmHeXx2S1YQhLhagbXdKDmPVUOUM...

The HVM Catapult technology strategy will be published following the consultation period.

