HM Government

Pro-Innovation Regulation of Technologies Review

Advanced Manufacturing

November 2023

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This report was presented by Professor Dame Angela McLean, the Government Chief Scientific Adviser, to the Chancellor of the Exchequer and to HM Government, as part of the Pro-Innovation Regulation of Technologies Review.

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Context

The UK's advanced manufacturing sector is of critical importance to our future prosperity, our global competitiveness, and our ability to drive the sustainable economic growth required for the UK to fulfil its ambition to become a global science superpower and to deliver on our net zero commitments by 2050. Manufacturers drive innovation and technological breakthroughs by pushing the boundaries of technology and process optimisation, and through the adoption of more intelligent, automated and data-driven processes that boost productivity and product quality and accelerate speed to market.

In the absence of a universally agreed definition of advanced manufacturing that applies across all sectors, we have defined it in this report as being production processes (and not exclusively end products) that integrate cutting-edge science and technology into manufacturing. This report considers challenges and opportunities from a technology and sector-specific standpoint, including the use of technological innovation such as advanced automation underpinned by data and AI, the use of digital twins, the development of materials such as composites, and advanced recycling technologies. The government has a key role to play in accelerating the adoption of next-generation telecoms technologies, including 5G (the value of which was highlighted in this Review's Creative Industries report[1]), This is crucial for the digitisation of advanced manufacturing which relies on a strong digital infrastructure.

The UK has a strong foundation in the advanced manufacturing sector, with initiatives such as Made Smarter[2] which aims to accelerate the development and adoption of advanced technologies in the manufacturing sector, and the High Value Manufacturing Catapult[3], a network of technology and innovation centres seeking to bridge the gap between the UK's world leading research and successful commercialisation. However, recent international developments including supply chain pressures caused by Russia's invasion of Ukraine and the focus on advanced manufacturing in the USA's Inflation Reduction Act (IRA) have highlighted the importance of a dynamic national manufacturing capability. A thriving advanced manufacturing sector is key to the UK's economic growth, stability and security, and ensuring that we have the right regulatory framework that removes or reduces market access barriers without compromising on safety will be central to the sector's continued development.

[1] https://www.gov.uk/government/publications/pro-innovation-regulation-of-technologies-review-creative-industries
[2] https://www.madesmarter.uk
[3] https://hvm.catapult.org.uk

Scope of the Review

This report follows others on Digital Technologies[4], Green Industries[5], Life Sciences[6] and Creative Industries[7] as part of the Pro-Innovation Regulation of Technologies Review[8]. As in those reports, this review focuses on regulatory opportunities and challenges where action can be taken within 6-18 months. We have engaged with government, regulators, industry and academic experts to identify actionable recommendations.

The advanced manufacturing sector is broad in scope, since it encompasses technologies applied in a wide range of sectors. This review does not seek to provide an exhaustive view of every sub-sector. We have instead focussed our recommendations on areas where we have heard about specific regulatory challenges or opportunities from industry stakeholders. For instance, there are challenges to driving uptake of advanced manufacturing techniques in the food and drink sector such as automated processing, packaging and quality control. We hear from industry that they are not regulatory in nature. Other sectors where advanced manufacturing technologies are deployed have been discussed in previous reports in this series.

The recommendations herein build on those from previous reports (for example, those on drones and autonomous vehicles in the Digital Technologies report, waste and the circular economy, and use of hydrogen in the Green Industries report, and novel foods in the Life Sciences report). Some recommendations made here, such as those on recycling, could well have been included in other reports, underscoring the importance of considering the reports in this series together as a set.

Per the Terms of Reference[9] of this review, this report focuses on the role that regulation and standards can play in driving pro-innovation growth by safely and ethically accelerating the development, testing, and uptake of new technologies. Regulation and standards are a key strand of the government's Science and Technology Framework, adopted in March 2023[10]. As the former Government Chief Scientific Adviser Sir Patrick Vallance set out in a letter to the Chancellor[11], regulating applications of technology which are close to being commercialised can help to create a market framework for safe deployment. We have heard from industry stakeholders that the UK's advanced manufacturing sector is generally well regulated, and that in many cases the industry benefits from alignment with major trading partners such as the EU, given the ease of market access. Industry stakeholders have highlighted that regulation and standards are only part of a whole system approach needed to drive innovation and growth in the sector. We have heard that further R&D investment is required, as well as the development of a skilled

[4] https://www.gov.uk/government/publications/pro-innovation-regulation-of-technologies-review-digital-technologies
[5] https://www.gov.uk/government/publications/pro-innovation-regulation-of-technologies-review-green-industries
[6] https://www.gov.uk/government/publications/pro-innovation-regulation-of-technologies-review-life-sciences
[7] https://www.gov.uk/government/publications/pro-innovation-regulation-of-technologies-review-creative-industries
[8] https://www.gov.uk/government/collections/pro-innovation-regulation-of-technologies-review
[9] https://www.gov.uk/government/publications/terms-of-reference-for-the-review-of-regulation-for-emerging-technologies
[10] https://www.gov.uk/government/publications/uk-science-and-technology-framework
[11] https://www.gov.uk/government/publications/introductory-letter-about-pro-innovation-regulation-of-technologies-review

workforce, including through apprenticeship programmes. The Science and Technology Framework takes just such a whole systems approach and includes strands in support for R&D, a skilled workforce and pro-innovation regulation.

Section 1: Global leadership in the safe deployment of new tech

Standards

Standards often serve as a foundation for innovation and the safe adoption of cutting-edge technologies, particularly in the advanced manufacturing sector. The development of clear technical standards can help unlock regulatory flexibility and drive commercialisation. Standards can help establish performance criteria, testing methodologies and quality assurance measures. As a result, standards are often incorporated into regulatory frameworks. The recommendations in this paper on standards could help unlock innovation and lay the groundwork for proportionate, agile regulation once technologies reach an appropriate maturity level.

The government recognises the importance of an agile approach to standards in a world of rapid technological change and has agreed a joint action plan on Standards for the Fourth Industrial Revolution[12] with the UK National Quality Infrastructure (NQI)[13]. We have heard from industry that the UK should continue to play a role in the development of technical standards through a number of Standards Development Organisations (SDOs) such as the International Organisation for Standardisation (ISO). The UK's continued international influence enables the uptake of innovative approaches to emerging and advanced technologies. Technologies such as the Internet of Things (IoT) and cloud computing rely on global technical standards to ensure interoperability. These technologies are critical to the UK's advanced manufacturing sector, which is underpinned by strong IT and its interaction with process technology. However, this can also make these businesses a target. In 2022, manufacturing was the sector most targeted globally by cybercriminals for extortion attempts, such as ransomware[14]. Technical standards can play an important role here in safeguarding against future attacks.

Recommendation 1: The government should work with the UK NQI and UK industry and academia, to shape global technical standards to achieve interoperability in key technologies, with a particular focus on cyber security.

Case study: Standards driving the uptake of innovative technology – the BSI's involvement in the Faraday Battery Challenge

In 2019 the British Standards Institution (BSI), sponsored by Innovate UK through the Faraday Battery Challenge, launched a standards programme to develop and

[12] https://www.gov.uk/government/publications/standards-for-the-fourth-industrial-revolution-action-plan
[13] https://www.gov.uk/guidance/the-uks-national-quality-infrastructure
[14] https://www.ibm.com/reports/threat-intelligence

codify good practice and build public confidence in batteries and electric vehicles (EVs). The Standards for the Fourth Industrial Revolution Action Plan cites “targeted engagement, in-depth knowledge gathering activities, and BSI’s fast-track standards creation process" as helping to create three new standards covering health, safety and environmental considerations in battery manufacturing, design and use, and a roadmap for future standards uptake. These standards have contributed to a significant increase in the number of EVs on UK roads. A total of 712,000 zero-emission Battery Electric Vehicles (cars) were registered in 2022, compared to just over 100,000 in 2019[15].

Safety in industrial robotics and automation

Businesses globally are embracing the benefits provided by industrial robotics and automation. These technologies offer significant opportunities, including speed, increased productivity and product quality, and enhanced worker safety. Advanced automation systems can collect vast amounts of data which can be used to identify inefficiencies and deliver cost savings by optimising resource utilisation. The Made Smarter review[16] estimated that automation and robotics could add £183bn to the industrial sector over the next decade. These systems can optimise workflow to minimise waste and energy consumption, driving more streamlined and sustainable processes, and can be reprogrammed or reconfigured to adapt to changing needs. The UK should seize the opportunity to drive adoption of these technologies while using its global leadership in standard-setting to ensure that productivity gains go hand in hand with safety. With regard to industrial robots, China, Japan and Germany are among the leading nations in terms of annual installations. The UK, however, is behind its international competitors and is currently 24th in the world robot density rankings, making it the only G7 country to sit outside the top 20[17].

Robotics technology evolves rapidly and as it changes new safety issues arise, particularly where robots interact with or assist humans in their work. These are commonly known as collaborative robots or cobots and present entirely new safety challenges compared to traditional industrial robots. For example, restricted and safety zones, which prevent humans getting too close to the robot, can no longer exist as the lack of barrier is inherent to the function of cobots. A lack of clear safety standards has been highlighted by manufacturers as a barrier to the widespread adoption and deployment of innovative robotics technology. Businesses are keen to see government and regulators, notably the Health and Safety Executive (HSE), engaging with industry to develop standards in this area.

[15] RAC, The road to electric - in charts and data, 2023: https://www.rac.co.uk/drive/electric-cars/choosing/road-to-electric/

[16] https://www.gov.uk/government/publications/made-smarter-review

[17] https://ifr.org/downloads/press2018/2022_WR_extended_version.pdf

Recommendation 2: The government should work with the BSI and the HSE to launch a standards programme to establish clear principles for the deployment of cobots in manufacturing that cover issues such as risk assessments and liability. To support foreign investment, this standards programme should look to influence the development of international best practice in this area.

In line with many other regulators, the HSE reports challenges in attracting tech skills and talent for which it competes with the private sector. This impacts its ability to regulate and develop standards for emerging technology. Secondments between industry and the regulator would facilitate greater knowledge exchange, support horizon scanning within the regulator and foster greater collaboration. This should help the HSE to deliver practical and proportionate action on standards to drive the deployment of robotics. We consider that secondments can be mutually beneficial, providing that arrangements can be put in place to mitigate conflicts of interest, commercial sensitivities and the potential for regulatory capture. Secondments should be undertaken as part of a wider programme of engagement with industry and trade associations, including knowledge sharing workshops, events and their ongoing regulatory service. The below recommendation should be considered alongside recommendations on secondments between regulators and industry made in this Review's upcoming report on cross-cutting issues.

Recommendation 3: HSE should explore secondments where manufacturing staff in industry and/or trade association representatives are placed within the regulator, and regulatory staff within industry. The secondments should seek to drive innovation and address knowledge gaps.

Automation in agriculture

This Review's report on Digital Technologies considered the role of Artificial Intelligence (AI) and automation in enhancing productivity and growth while also providing wider societal benefits. Cutting edge automation relies on the application of technologies such as AI, computer vision and sensors. This enables machines to perceive, interpret and respond to the environment, making decisions and executing actions autonomously. One area of the economy facing acute challenges which automation could help address is agriculture. While some sub- sectors such as dairy farming tend to be heavily automated, there is a need to unleash opportunities in others, including weed identification, crop data collection, targeted pesticides and soft fruit and vegetable picking. £22m worth of fruit and vegetables[18] were wasted in 2022 due to staff shortages and low productivity. Research shows that in the USA, the introduction of autonomous robots on corn farms could save $15 to $20 per acre, potentially unlocking up to $1.5bn in value[19].

The challenge for the UK is that the regulations in force were designed for industrial robots in traditional manufacturing settings. UK regulations derive from the Supply of Machinery (Safety) Regulations 2008 as they apply in GB. A more flexible regulatory approach that keeps pace with technological change is required, and divergence

[18] https://www.nfuonline.com/media-centre/releases/millions-of-pounds-of-fruit-and-veg-wasted-due-to-workforce-shortages

[19] https://www.mckinsey.com/industries/agriculture/our-insights/trends-driving-automation-on-the-farm

here would set the UK out as a leader in developing proportionate and well-adapted regulation without sacrificing safety. This would be likely to help enable the manufacture and rollout of robotics at scale in agricultural settings and promote more R&D.

Recommendation 4: The government should review the Supply of Machinery (Safety) Regulations 2008 as they apply in Great Britain, as part of its future thinking on product safety, with the aim of putting in place an up to date, proportionate regulatory regime that supports early-stage innovation and automation in agriculture.

Section 2: Clean Transport and Future Mobility

The future of transport will involve adopting new sources of energy, smarter modes of transport and innovative physical and technological infrastructure. This Review's report on Digital Technologies set out the need to bring forward the Future of Transport bill to unlock opportunities for connected and autonomous vehicles. Technological innovation will be key to enabling the safe uptake of these new forms of transport. Innovative transport also relies on technology enabling the development of clean fuels such as battery power and hydrogen, as the UK advances towards meeting its net zero targets.

The future of air mobility

The UK is a world leader in civil aerospace, with strengths in the most technologically advanced and highest value parts of aircraft (wings, aero engines and advanced systems such as landing gear)[20]. The sector has a key role to play in achieving Net Zero by 2050 and is building capability in emerging zero emissions technology, including through a record £685m of R&D funding[21] over the next three years, made available via the Aerospace Technology Institute (ATI). Beyond maintaining and building upon existing strengths, the UK should seize opportunities in advanced air mobility (AAM) and applications of drones.

Drone technologies are used widely in the energy, agriculture, construction and transport sectors. Estimates suggest that by 2030 drones could add up to £45bn to the UK economy and over 600,000 jobs "could be associated with an economy that fully adopts drones"[22]. This Review's report on Digital Technologies emphasised the need to unlock the innovation potential of the drone sector by empowering regulators and improving the regulatory landscape, including by building on the Civil Aviation Authority's (CAA) efforts to establish sandbox capabilities with options for experimental aviation.

AAM encompasses flight technologies and transformational designs such as electric Vertical Take-off and Landing (eVTOL) aircraft. eVTOL aircraft have the capability to take off and land without a runway. In theory, they can be deployed in areas with more limited infrastructure, urban environments and confined spaces, (though they will still require infrastructure such as vertiports and electric charging points), can be subject to noise restrictions and need to integrate with the existing aviation system. eVTOL could be particularly useful where deployment of aircraft is needed flexibly and quickly, such as in disaster zones, search and rescue operations, time-critical deliveries, national security operations or for emergency medical services. They could also be used to provide air taxi services. Further, eVTOL technology encourages innovative aircraft design, opening up opportunities including for

[20] https://www.gov.uk/government/publications/aerospace-sector-deal
[21] https://www.gov.uk/government/news/green-aerospace-tech-to-receive-record-government-funding
[22] https://www.pwc.co.uk/issues/emerging-technologies/drones/the-impact-of-drones-on-the-uk-economy.html

improved manoeuvrability and payload capacity. With investments growing and prototypes in development, major AAM providers could potentially be similar in size to the largest airlines in the world by 2030[23]. AAM flights are expected to be much shorter and more frequent than commercial airline travel today, involving smaller craft with fewer passengers. eVTOL also have the potential to be more environmentally friendly than traditional aircraft, with lower carbon emissions and reduced noise pollution. The main challenge is in evolving the existing regulatory framework to support the safe deployment and testing of eVTOL. At present, we have heard that early-stage testing of eVTOL requires disproportionate permissions. A proportionate, risk-based approach should be used to determine the level of regulatory oversight required.

Recommendation 5: The government should evolve the existing regulatory framework to enable the safe testing and rollout of eVTOL. The government should work with industry, regulators and local authorities to consider opportunities to clarify and simplify consenting processes to enable testing of eVTOL.

Additive manufacturing

The defence sector has the potential to act as a key enabler of innovative technologies for civilian use. The Ministry of Defence has committed to spending over £186bn on equipment and equipment support between 2018 and 2028[24]. Defence procurement policies and investment decisions therefore have significant implications for the UK industrial technology base, helping to create market opportunities for higher-risk, early-stage innovative products and technologies.

One example where defence procurement can leverage a powerful technology which has been revolutionising manufacturing is additive manufacturing, more commonly known as 3D printing. Additive manufacturing has disrupted traditional manufacturing processes across various industries including aerospace, maritime and automotive with widespread application in the defence sector. The global aerospace and defence additive manufacturing market is projected to grow from $3.73bn in 2021 to $13.01bn in 2028[25]. Some of the applications of 3D printing in defence include the ability to produce complex and intricate parts that would be challenging or impossible to manufacture using traditional methods as well as monolithic (one-piece) hulls for combat vehicles and 3D printed runways.

The UK should harness this opportunity by agreeing a national approach and regulatory framework governing the use of additive manufacturing in defence which keeps pace with the technological advances. Specifically, a focus on certifying the manufacturing process rather than certifying each individual part would, as well as lowering costs for manufacturing businesses, accelerate the pace at which parts could be produced for the defence inventory, and enable the upscaling of advanced manufacturing methods in the defence sector. This would increase investor confidence in the development and deployment of this technology in the wider

[23] https://www.mckinsey.com/featured-insights/the-next-normal/air-taxis
[24] https://committees.parliament.uk/writtenevidence/6501/default/
[25] https://www.fortunebusinessinsights.com/aerospace-defense-additive-manufacturing-market-106550

economy. Further, the UK could show international leadership by influencing global standards in this area through engagement with the ISO and American Society for Testing and Materials (ASTM) standards.

Recommendation 6: The NQI and The Welding Institute (TWI) should develop 3D printing standards to enable the certification of the entire production process, rather than individual parts. This would bring 3D printing standards in line with traditional manufacturing standards.

Innovation and safety in the auto sector

For the UK to shift the dial on innovation, sustainability, safety and productivity in this sector, it is important to look at technologies that can have a significant impact across the whole manufacturing process. The government has recognised the importance of digital twins and is working with industry and academia through its National Digital Twin Programme[26] to better understand and develop the standards, frameworks, guidance, processes and tools needed around digital twins.

A digital twin is an extension into a virtual model of a real-world entity, environment or process. The digital twin mimics its real-world counterpart and can be used to assess functionality, degradation and impact. The use of digital twins in the advanced manufacturing sector enables companies to create accurate digital replicas of the full manufacturing process, from the movement of human employees within a factory to the status of physical machinery and the design and performance of end products. By using IoT devices such as sensors to capture right time data (data delivered at the point where it will have the greatest impact), businesses can identify and optimise inefficiencies, supporting sustainability by reducing waste and lowering the cost of production.

Used across a range of sectors, digital twins have seen significant uptake in the automotive sector where they offer a transformative approach to product development, manufacturing and maintenance. A digital twin can be made of the whole car, including vehicle software, mechanical components, the electrical system and can model physical behaviour of the car. Digital twins can be used to replicate the planned production process, enabling process failures to be identified before production is commenced. Further, once the vehicle is produced and deployed, the performance and operation data produced by connected cars can be integrated into the twins. The insights produced can be used to update vehicle software, enable predictive maintenance and conduct remote diagnostics. McKinsey estimates that the adoption of digital twins can support a decrease in the time to market for a product by 50% and improve product quality by 25%. The digital twins market in Europe alone is expected to be worth €7bn by 2025, with an annual growth rate of 30-45%[27].

[26] https://www.gov.uk/government/consultations/enabling-a-national-cyber-physical-infrastructure-to-catalyse-innovation/outcome/enabling-a-cyber-physical-infrastructure-to-catalyse-innovation-government-response-html

[27] https://www.mckinsey.com/capabilities/operations/our-insights/digital-twins-the-art-of-the-possible-in-product-development-and-beyond

Regulators and standards bodies can dramatically improve the overall efficiency and sustainability of the manufacturing process by facilitating more innovative testing routes using digital twins and reducing reliance on physical demonstrations. This should be informed by existing work exploring how certification can be achieved through the use of digital tools being carried out by the High Value Manufacturing Catapult. Further, the UK has demonstrated international leadership in setting out innovation best practice in similar technologies, namely through the BEIS (now DBT) Building Information Modelling (BIM) programme and the standards that BEIS produced with BSI. These standards directly shaped the ISO approach[28]. The UK should seek to play a similarly influential role when it comes to digital twins.

Case study: UK Ventilator Challenge - digital twins deployed to deliver ventilators during the pandemic

In response to the COVID-19 pandemic, the Prime Minister issued a challenge to UK industry to supply thousands of additional ventilators. A consortium of businesses from the healthcare, technology, automotive and logistics sectors and research centres formed to meet the challenge. To deliver the ventilators safely, at the necessary pace and scale, digital twinning technology was deployed to create and test digital models of the production system. This allowed for the rapid design and installation of a new production line based on the 3D model taking into consideration ergonomic and social-distancing concerns. The model also enabled potential bottlenecks in production to be identified and optimised.

Using these digital tools contributed to the delivery of an increase in production from 30 to 3000 units a week, a 50% reduction in floorspace and build benches, and an 85% overall improvement in production time of the ventilator compared to the original production facility, while maintaining safe working practices.

Recommendation 7: The government, through its National Digital Twin Programme, should work with BSI to convene a group of relevant stakeholders, including regulators, to determine and develop the standards needed to accelerate the deployment of digital twins. This should build on the success of BIM and ensure use of the technology is safe, secure, trustworthy, ethical, sustainable, adaptable and, where required, interoperable.

Clean Fuels

Clean fuels in the automotive and maritime sectors are areas where regulatory frameworks can play a key role in facilitating the safe deployment and uptake of technological innovation. The Green Industries report sets out the opportunities presented by hydrogen, particularly as part of the energy system, as well as highlighting the need to support hydrogen production.

[28] https://www.bsigroup.com/en-GB/iso-19650-BIM/

Hydrogen

Building on our recommendation in the Green Industries report to establish an effective regulatory system for hydrogen, hydrogen internal combustion engines offer an alternative to petrol and diesel engines for certain applications, namely where batteries or fuel cells are not suitable, as hydrogen combustion is less efficient than both. Further, current hydrogen combustion technology is not zero emissions at the exhaust due to its nitrogen oxide emissions, so opportunities in this space are most likely to apply to non-road mobile machinery (NRMM), where hydrogen combustion offers infrequent and rapid refuelling compared to electric vehicle recharging. Further, hydrogen has a high energy density and can store a large amount of energy per unit mass (if not per unit volume), and so can provide high power with low weight. Hydrogen internal combustion engines offer similar opportunities in the maritime and aviation sectors although these are at a less advanced stage of development. Should the technology develop further such that nitrogen oxide emissions are eliminated, hydrogen combustion could offer opportunities for wider application. We note that significant investments are being made in support of this aim.

Hydrogen fuel cell electric vehicles (FCEVs) combine hydrogen and oxygen to produce electricity in an electrochemical cell, which powers electric motors, and is zero emission at the exhaust. FCEVs have longer driving ranges and shorter refuelling times than battery electric vehicles, although they are less efficient. At present, the primary challenges to FCEVs are their high cost and the lack of both hydrogen refuelling infrastructure and low-carbon hydrogen production. However, this technology offers significant opportunities including for on road, aviation, heavy duty and maritime transportation.

Case study: JCB's hydrogen-powered internal combustion engine

JCB's hydrogen engine programme aims to decarbonise heavy machinery for the construction and agricultural industries, using hydrogen combustion technology which produce zero carbon emissions and represents a practical and high-performing alternative to batteries for equipment with high power demands. Electric vehicle charging infrastructure is unlikely to be available in more remote construction sites. The government has given special dispensation, under a vehicle special order, that allows JCB to test and use its world-first hydrogen- powered backhoe loader on UK roads. JCB has also designed and built a mobile hydrogen refueller to allow the delivery of hydrogen to on-site machines. The JCB hydrogen engine utilises existing technologies, cost base, and supply chains.

Last year, the government announced the launch of a £20 million competition for industry to harness the power of hydrogen in new transport projects including through hydrogen internal combustion engines for off-road construction machinery. Part of the work in the Tees Valley Hub will seek to address challenges such as providing refuelling infrastructure at scale and integrating that within a wider decarbonised energy network.

Recommendation 8: The government's forthcoming strategy on decarbonising NRMM should make clear how a regulatory framework could support the use of hydrogen combustion for NRMM.

Clean fuels in maritime

In 2021, international shipping accounted for approximately 2% of global energy related CO_2 emissions[29]. The ambition to decarbonise shipping and to develop clean marine propulsion and associated technologies is rapidly gathering pace. At COP26, 14 countries signed the Declaration on Zero Emission Shipping by 2050, pledging to push the International Maritime Organisation (IMO) to adopt a goal of full decarbonisation of international shipping by 2050[30]. In July 2023, the International Maritime Organization (IMO) adopted a target of net zero greenhouse gas emissions from international shipping close to 2050, with indicative checkpoints of 20-30% by 2030 and 70-80% by 2040. A shift towards decarbonisation, technological advancement, and the digital revolution are transforming ship construction, navigation, fuel management, vessel maintenance and end-of-life recycling. Innovation in this sector is likely to involve the adoption of entirely new carbon-neutral and zero-carbon fuels and the handling, storage and propulsion technologies that accompany them.

The UK has the capability to become a leading player in clean maritime technologies given its strengths in advanced engineering, high quality design and manufacturing, expertise in services and ports and the ability to adapt and innovate.

However, there are currently regulatory barriers to the deployment of new zero-emission fuels such as hydrogen and ammonia in the UK. Specific challenges reported by industry include differences in risk-based evaluations between regulators and classification societies (shipping standards bodies) and a lack of a clear regulatory pathway for the safe operation of zero-emission fuelled vessels. Regulation may also be needed for portside infrastructure to enable alternative fuel storage, as well as regulation enabling battery charging facilities. The current regulatory framework provides limited incentives for operators to take up zero emission fuels. As a result, the sector is facing a lack of demand mainly due to the price differential between zero emission fuels and traditional maritime fuels.

Recommendation 9: The government should use its upcoming Clean Maritime Plan to send a clear signal to industry of its support for zero emission fuels and set out plans to stimulate demand in the sector.

[29] https://www.iea.org/energy-system/transport/international-shipping
[30] https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx

Section 3: Driving a circular economy

The circular economy is a model of production and consumption which involves sharing, leasing, reusing, repairing, remanufacturing, refurbishing and recycling existing materials and products for as long as possible, to reduce or eliminate the need for new materials. Improved resource efficiency would contribute towards achieving the UK's commitments to the Aichi Biodiversity Targets[31]. It could also improve economic security, create new markets and jobs, drive innovation in manufacturing and speed the adoption of new technologies[32]. The Energy Efficiency Taskforce (EETF) demonstrates the government's commitment to taking action across a number of sectors and areas, including examining where regulatory frameworks can reduce demand for energy. Ensuring that the built environment supports energy efficiency and carbon reduction will be key to achieving this aim.

Bio-based materials are made up of substances derived from plant or living matter (biomass) and either occur naturally or are synthesised. Bio-based products have numerous applications in various sectors and can make the economy more sustainable, lower its dependence on fossil fuels and prevent the depletion of non-renewable resources. The global market for bio-based materials is growing rapidly and the UK is well placed to become a world leader by harnessing its world-class science base. However, current economic and regulatory frameworks incentivise linear models of production and consumption, particularly regarding the effective management of chemicals, plastics and other composite materials used in advanced manufacturing. We consider that top-down targets to encourage recycling can also be a driver for innovation and advanced manufacturing processes while standardisation, public procurement, awareness raising and labelling can all help to improve uptake.

We have heard from industry that sustainable feedstocks (raw materials used in industrial processes) such as hemp could present opportunities in the manufacturing sector. This includes the use of hemp in sustainable construction materials, as a biofuel, as an alternative to plastic and to produce lightweight materials for automotive and aerospace vehicles, or in the future, for wind turbines[33]. We understand that barriers to the increased use of industrial hemp are primarily not regulatory but are related to the lack of necessary manufacturing and process infrastructure.

Composites, plastics and chemical recycling

Some of the materials used in technologies key to the transition to net zero are not yet widely recycled. While composite materials can make a positive impact on

[31] https://www.cbd.int/kb/record/decision/12268

[32] https://www.oecd.org/cfe/regionaldevelopment/Ekins-2019-Circular-Economy-What-Why-How-Where.pdf

[33] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1089680/Phase_1_report_-_University_of_York_-_HEMP-30_catalysing_a_step_change_in_the_production.pdf

energy efficiency, durability and weight reduction in vehicles, aircraft and wind turbines, their end-of-life treatment is challenging and costly. Furthermore, not all recycling techniques are accessible or cost effective, and the value extracted from the recyclate can vary. In addition, recycling requirements for composites are currently sector-specific and definitions of recycling are not aligned. There is also a lack of agreed standards including inconsistency in recycling processes, quality, performance and safety, as well as testing methodologies and traceability. While UK legislation more broadly supports the move away from landfill, as yet there is no regulatory requirement limiting the landfill disposal of composite materials (other than in the automotive, construction and electrical sectors). The government should aim to introduce restrictions on sending composite materials to landfill as soon as is practicable, taking into consideration current recycling capabilities.

Recycling of composite materials presents a significant opportunity in the wind sector, notably composite turbine blades. Many of the first generation of UK wind farms are reaching the end of their 25-year life cycle, with approximately 325,000 blades ready for recycling by 2050[34]. For many companies, the easiest and cheapest way to deal with spent turbine parts is to bury them in landfills. In aerospace, significant volumes of composite aircraft parts will also need to be recycled in the same timeframe. Similarly, in the automotive sector, the transition to electric vehicles necessitates the acceleration of the light-weighting of structures to compensate for heavy battery packs.

A similar, long-standing problem relates to vehicle tyres, which were banned from UK landfill sites in 2002 but which remain difficult to recycle. Large numbers are therefore kept in storage or exported. Turning tyres into renewable carbon fuel through chemical recycling is an environmentally sound option, and measures to incentivise the take-up of this technology would benefit the circular economy. More broadly, there is also a need to focus on incentivising innovation at the product design phase. With wind turbine blades, for example, as much effort should be placed on making them recyclable as should go into developing innovative recycling techniques. The Green Industries report in this series recommended a regulatory framework for EV battery recycling. A similar approach is now required for a wide range of cross-sectoral challenges.

[34] https://ore.catapult.org.uk/wp-content/uploads/2021/03/Catapult_Summary_Blade_Report_web.pdf

Recommendation 10: The government should work with sectoral trade bodies, Catapult centres, sector councils and other relevant bodies to encourage the development of repair, reuse and recycling technology and capability for composites and other problematic waste streams, with a particular focus on how products can be made recyclable and to minimise waste.

Recommendation 11: The government should work with industry, academia and bodies such as UKRI to support innovation that embeds sustainable composites into the next generation of wind turbines and transport, through the creation of new fibres and matrices, sustainable design methods and new market dynamics that will encourage a circular materials ecosystem for composites.

Chemical recycling is an approach which breaks down polymeric substances into chemical building blocks. It enables plastic waste, including hard-to-recycle plastic products such as films and laminated plastics, to be converted into feedstock. Innovative chemical recycling technologies can produce high quality plastics which can safely be used for food packaging, which current (mechanical) recycling systems cannot do[35]. To promote wider uptake of chemical recycling, it is important that the benefits are shared among everyone involved in the recycling value chain. When producing plastics, 'mass balance' techniques can be used to track the proportion of a given product that is derived from sustainable (i.e. recycled or renewable) sources. Various methods can be used for certifying the extent to which a product is 'sustainable', and there is currently no commonly accepted standard. The development of industry standards or certification for mass balance products would help ensure that chemical recycling is supported and recognised in the same manner as traditional recycling. We hear from industry that this would particularly benefit the food and drink sector which relies on plastics to keep products fresh and safe for consumption, by reducing plastic waste and supporting the production of food grade plastics developed through chemical recycling technologies.

Recommendation 12: The government should work with BSI, industry, academics and end users to support the development of common standards around what constitutes a mass balance approach in chemical recycling, with the aim of decoupling value creation from the consumption of fossil resources.

Chemical safety

Chemicals regulation in the UK, in particular UK REACH, aims to ensure that the hazards and risks of chemicals manufactured and imported into the UK are understood and the risks to human health and the environment are minimised. We have heard a range of views from industry stakeholders on the merits of either being closely aligned with the EU REACH regime to enable continued market access, or conversely, developing a bespoke approach to some aspects of the chemicals framework to unlock innovation. However, the main issue raised is the potential cost to UK businesses of accessing data held by EU companies to enable UK REACH

[35] https://www.theconsumergoodsforum.com/wp-content/uploads/2022/04/PW-Chemical-Recycling-Vision-and-Principles-Paper-July-2022.pdf

transitional registrations. Defra has a programme of work in place to address this concern, including the legal extension of transitional registration deadlines to ensure industry does not incur nugatory costs while this work progresses.

It is not possible to fully understand the long-term impacts of the synthetic chemicals typically used in advanced manufacturing. By some estimates, there is no data on the environmental impacts of up to 95-98% of chemicals currently on the global market[36]. Certain synthetic chemicals are well known to be damaging, with specific health and environmental concerns around Poly-fluorinated Alkyl Substances (PFAS) which are commonly considered 'forever chemicals' due to their high persistence. In the context of a circular economy the risks around the use of these chemicals may be amplified, as they could remain in circulation for longer. For example, they are found in recyclable paper and cardboard food packaging in the UK[37].

The UK should encourage larger scale development and adoption of safe, sustainable chemicals as alternatives to PFAS where feasible. The use of bio-based chemicals could be explored as these may also enable cleaner production processes. Innovation in this area could help ensure that substances of very high concern are progressively replaced by less dangerous substances or technologies, where technically and economically feasible alternatives are available, in line with the UK's risk-based approach.

Recommendation 13: The government should consider with regulators, research institutions and industry how the design, manufacture and use of more efficient, safe and sustainable chemicals[38] can be facilitated. This could involve exploring bio-chemical alternatives to the most harmful PFAS. Where regulatory barriers to innovation are identified as part of this work, one option to consider might be the development of a regulatory sandbox in the north-east of England, given the density of chemicals manufacturing in this part of the UK.

Building materials and techniques

The built environment encompasses the construction of buildings in all forms including commercial, industrial and residential, as well as civil engineering infrastructure including roads, bridges and rail lines. Regulation has the potential to further drive innovation at scale to promote more sustainable manufacturing processes related to construction and greater productivity. Our engagement with industry points to two areas of innovation that can deliver this step change in efficiency and sustainability: Modern Methods of Construction (MMC) and the tracking of embodied carbon. MMC is a broad term that encompasses several innovative manufacturing techniques such as additive manufacturing (3D printing), modular construction and the use of off-site manufacturing, improving the speed and accuracy of construction projects and helping decarbonise the sector. According to the UK Green Building Council, 25% of UK emissions are directly attributable to the

[36] https://pubs.acs.org/doi/10.1021/es3002713
[37] https://www.pfasfree.org.uk/wp-content/uploads/Forever-Chemicals-in-the-Food-Aisle-Fidra-2020-.pdf
[38] https://www.oecd.org/chemicalsafety/risk-management/sustainable-chemistry/

built environment[39]. The calculation and tracking of embodied carbon supports builders to assess the amount of carbon emitted during a construction project, including the extraction of raw materials, manufacturing, transportation and installation.

Recommendation 14: The UK Green Building Council should convene industry and relevant members of the Catapult network to encourage greater testing and piloting of innovative solutions in the built environment, including advanced manufacturing solutions to support the transition to net zero.

[39] https://ukgbc.org/our-work/climate-change-mitigation/

This publication is also available on our website at www.gov.uk/government/publications

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