



China-Britain
Business Council
英中贸易协会

CHINA-UK GREEN MANUFACTURING REPORT



Department for
International Trade





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FOREWORD



In today's world, resources and environmental issues are common challenges facing mankind. Realising green development has become a global consensus. The 2030 Agenda for Sustainable Development and the Paris Agreement have laid the basic pattern for countries across the world to widely participate in green development and provided valuable opportunities for global green transformation and development.

The Chinese government attaches great importance to green development and takes the construction of ecological civilisation as the millennium plan for the sustainable development of the Chinese nation. The "Two Mountains" theory, "beautiful China" and the 3060 double carbon goal are some of China's vivid practices of green development. At the same time, we will vigorously promote international cooperation in green development and take the initiative to collaborate with relevant countries, international organisations and institutions to build a green community of common destiny. As a pioneer of green development and one of the first countries to advocate the development concept of "green economy", Britain is at the forefront of the world in dealing with climate change, circular economy, green technology, and green finance, leading the global green development.

In recent years, under the guidance of the Chinese and British governments, the International Economic and Technological Cooperation Center of the Ministry of Industry and Information Technology, in conjunction with the British Federation of Industry and Commerce, the UK China Trade Association, Jaguar, Land Rover and other institutions and enterprises, has promoted the construction of the "China-UK modern industrial partnership", deepened practical cooperation between China and the UK in green manufacturing and other fields, and made positive progress. Meanwhile, the Center, together with the Department of International Trade of the United Kingdom, British China Trade Association, Manchester University, University of Liverpool and Exeter University, has jointly prepared the report on the development of green manufacturing between China and the United Kingdom, studied and sorted out the policy progress, industrial status and enterprise practice of China and the United Kingdom in the field of green manufacturing, analysed the potential of industrial cooperation between the two countries, and put forward specific cooperation suggestions. It can provide reference for the cooperation between the two governments, industry associations and enterprises.

The Center looks forward to carrying out more in-depth and pragmatic cooperation with the British business association, enterprises, research institutions and universities, promoting exchanges and cooperation between China and the UK in the fields of green manufacturing policy, industry, technology and standards, and making its due contribution to the construction of a beautiful "global village".

ZHENG Hong



Director of the International Economic and Technological Cooperation Center of the Ministry of Industry and Information Technology



The UK was the first major economy to pass an economy-wide net zero emissions law. This will see the UK reduce all greenhouse gas emissions to net zero by 2050. Green manufacturing and clean growth is at the heart of UK's Industrial Strategy. China is the world's largest manufacturing economy, and set the goal to peak carbon emissions by 2030 and achieve carbon neutrality by 2060.

The development of green supply chains is therefore high on the agenda of both countries. Rebuilding global industrial supply chains after the COVID-19 pandemic provides opportunities for green manufacturing. I am pleased to see the UK and Chinese governments, academics, industrial associations, and businesses working together to deepen international cooperation and boost bilateral trade & investment. The Department for International Trade commissioned this Green Manufacturing report to take collaboration to the next level. I would like to thank the Ministry of Industry and Information Technology, Centre for International Economic and Technological Cooperation, China Britain Business Council, University of Liverpool, University of Manchester and University of Exeter for their outstanding contributions.

This report helps UK and Chinese policy makers, researchers and industry professionals to understand relevant market trends, government policies, standards and regulatory regimes. An overview of the British and Chinese green manufacturing sectors and fields is also highlighted. I hope the cooperation mechanisms and case studies shared in this report will accelerate the future development of the green manufacturing industry and intensify international cooperation.

As the UK and China recover from the COVID-19 pandemic and transform to a greener future, there are tremendous opportunities to work together. I encourage businesses to leverage government support and all the resources available to deliver innovation and improve green manufacturing. I hope to see the UK and China ensure relevant policies evolve in a coordinated and mutually beneficial way. The Department for International Trade will share best practices, support business networks and promote green manufacturing collaborations in both countries.

Working together we can build a green, sustainable future for us all!

John Edwards,

A handwritten signature in black ink, appearing to read 'John Edwards', with a long horizontal flourish extending to the right.

Her Majesty's Trade Commissioner for China
Department for International Trade

1. EXECUTIVE SUMMARY

China and the UK are the largest and ninth largest manufacturing countries in the world, respectively. Despite both countries having made great efforts in developing the green manufacturing sector, there remains a lot of potential for cooperation. This report aims to explore the scope, attributes, and strengths of green manufacturing in both countries, identify opportunities, and make recommendations for governments, industries, and researchers in order to boost trade, investment, and international cooperation between China and the UK.

1.1 GREEN MANUFACTURING IN THE UK

Green manufacturing in the UK is not just about the goods it makes or the way in which they are produced, but also about the people that make them and the spaces, regions, and ecosystems in which they are made. The UK values quality, innovation, place-based agenda, and the life cycle impact of products.

The UK manufacturing industry excels in areas such as clean technologies, energy efficiency, eco-design, and new and sustainable business models. UK green manufacturing companies are quickly embracing the challenge of de-carbonising at scale, and their products aim to deliver economic, social, and environmental benefits. They have been working towards a circular economy by utilising strategies for maximising value from material resources, trying to avoid adverse effects on biodiversity or human health and wellbeing. Through this process, they seek external independent validation of their progress by way of acquiring certification of their plants and operations, their energy, carbon, and resource footprint, or of their labelling of products.

The UK government has made great efforts to support green manufacturing geared towards a circular economy. A combination of government strategies, foresight, planning, and market instruments are introduced in this report, including the UK Government's 2017 White Paper, the Future of Manufacturing Report, the Clean Growth Strategy Report, and the Net Zero Emissions Law. In addition to the investment on innovation and research projects led by UK companies, UK governmental funding plays a vital role in fundamental research and postgraduate training in the UK, represented by the Engineering and Physical Sciences Research Council (EPSRC), a major UK Research and Innovation (UKRI) council.

30 world-class UK green manufacturing companies are identified and summarised in this report to serve as examples, based on government funding, national awards, documented progress on sustainability, or widely cited in the industrial community. They cover a wide range of manufacturing industries from food to furniture and aerospace to consultancy. 11 UK world-leading companies are listed as examples in the areas of clean technology, energy efficiency, the creative sector, and business model innovation.

Three cases have been studied in this report to illustrate various ways of achieving green manufacturing in the UK: Riversimple, SGMA, and Notpla. Riversimple works on developing hydrogen-powered fuel cell electric vehicles, SGMA specialises in sol-gel coatings and advanced materials, and Notpla is dedicated to innovative sustainable packaging.

1.2 GREEN MANUFACTURING IN CHINA

China became the world's biggest manufacturing economy since 2010 when it surpassed the manufacturing output of the United States. Today, China is the only nation that meets all the industrial categories in the United Nation's International Standard Industrial Classification for All Economic Activities (ISIC). Although its manufacturing industry generates great wealth, it also leads to substantial ecological and environmental problems with ever-expanding demand for energy and resources and increasing pollutant emissions. In China, resource and environmental constraints have become a major bottleneck restricting China's economic and social development in the long term, and it is necessary to promote green industrial development in order to ensure the country's sustainable development.

In China, green manufacturing is seen as a modern manufacturing model that considers environmental impact and resource benefits. Its goal is to minimise damage to the environment while maximising the utilisation of resources and coordinate the economic and social benefits for manufacturing companies across their product's life cycle from the perspectives of design, manufacturing, packaging, transportation, utilisation, and disposal.

The main areas of green manufacturing in China include water and energy conservation, clean production, and the comprehensive utilisation of resources, working in tandem with three foci: the green transformation of traditional industries; the development of green industries such as energy and environment conservation, and new energy-efficient technologies; and the development of green manufacturing services. Key aspects of China's green manufacturing cover green factories, green production, green industrial parks, and green supply chains.

In China, the Ministry of Industry and Information Technology (MIIT) takes the lead in green manufacturing while other ministries and commissions cooperate with MIIT in specific work in related fields. Within MIIT, the Department of Energy Conservation and Comprehensive Utilisation specifically promotes work related to green manufacturing.

The Plan of Industrial Green Development (2016-2020) is the guiding national policy to promote green industrial development in China, centring on the five development concepts of innovation, coordination, green development, openness, and sharing. Under the guidance of MIIT, numerous research projects have been implemented by industrial associations and research institutes to make and revise standards in the fields of energy conservation, water conservation, comprehensive utilisation, and green manufacturing.

China actively works together with other countries in the field of green industrial development. Remarkable results have been made under an innovative and flexible approach to programmatic cooperation. Bilateral exchange mechanisms, including those focused on Sino-EU, Sino-France, Sino-Italy, and Sino-South Korea exchanges, run smoothly with regular communication on policies, standards, technologies, and industries. Dialogues with Spain, Greece, the Czech Republic, and many other countries are also being actively carried out.

2. GREEN MANUFACTURING IN THE UK

2.1 UK GREEN MANUFACTURING OVERVIEW

2.1.1 THE CONTEXT OF GREEN MANUFACTURING IN THE UK

With an output value of £396.6 billion in 2019, the UK is the ninth largest manufacturing nation in the world. The UK manufacturing industry accounts for two thirds of the country's overall R&D, 45% of exports, 15% of business investment, and the creation of 2.7 million high value jobs that pay higher than average.[1]

The basic principles of green manufacturing are well-known throughout the UK. However, for the purposes of this report, 'sustainable manufacturing', is used interchangeably with 'green manufacturing', throughout this report, with the former term generally preferred. Other descriptions such as 'low carbon manufacturing', and 'materials and resources efficiency' are almost synonymous with 'green manufacturing'.

Early appreciation of green manufacturing dates back to the 1960s, and the awareness was heightened when the Limits to Growth report was published in 1972.[2] At about the same time, the first life cycle assessment (LCA) was made by Coca Cola in 1969. Further interests culminated in the publication of ISO14000 series which fully defined the process of LCA.

The importance of industrial sustainability has since been recognised by the manufacturing industry: for instance, Shell published its first sustainability report in 1997. Since April 2013, all large companies are required to report on how they integrate sustainability into their business strategies.

Realising the importance of the concept of sustainable development, the Royal Academy of Engineering launched a nationwide initiative in 1998: the Visiting Professorship in Engineering Design for Sustainable Development. It was instrumental in promoting the idea of sustainability and LCA in the training of young engineers. Such principles have become an essential part of the engineering syllabus as required by the Chartered Engineering Institutions.

Another major landmark in the development of industrial sustainability was the announcement of the 17 Sustainable Development Goals (SDGs) by the United Nations General Assembly in 2015. While the concept of a circular economy started to emerge in the 1960s, it was not until 2016 that a thematic research programme –Towards Circular Economy – was launched by the Engineering and Physical Sciences Research Council (EPSRC). It is notable that a non-profit organisation, the Ellen MacArthur Foundation, set its mission as being "to accelerate the transition to a circular economy", and is actively engaged in propagating this idea to industry. An overview of the circular economy is well represented by Figure 1.[3] In fact, industrial leaders in the UK have adopted the idea of sustainable development in the 1980s. As an example, British Sugar's (now AB Sugar) Wissington Factory is regarded as a world-class example of a circular economy.[4]

The world's first product carbon footprint standard, PAS 2050, was developed by the UK. It aims to make the carbon footprints of goods, services, and products comparable, so that businesses can have a much better understanding of their supply chain efficiencies, and consumers can be more informed about the associated carbon emissions of their purchases.[5]

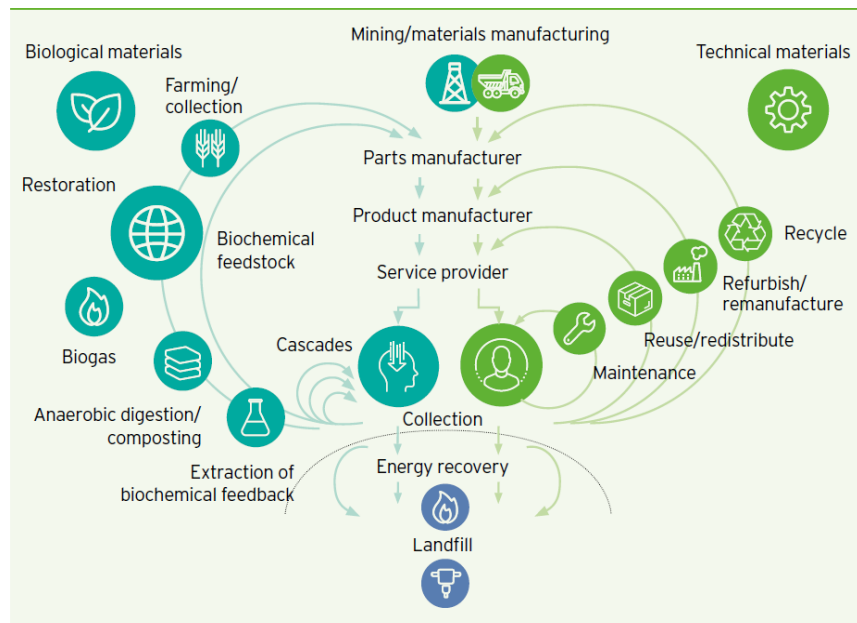


Figure 1. Traditional linear economy model (centre) and a circular economy model separated into biological and technical cycles [3]

2.1.2 AN OVERVIEW ON GREEN MANUFACTURING IN THE UK

Green manufacturing in the UK is not just about the goods made or the way in which they are produced, but the people that make them and the spaces, regions, and ecosystems in which the goods are made. It is these factors and their interactions that make the UK's green manufacturing — low carbon and sustainable manufacturing — unique and distinctive. The UK places great importance on the quality, innovation, and the life cycle impact of products.

There are a number of attributes that can be used to characterise or strategise green manufacturing. A non-exhaustive list is provided below:

1. Green manufacturing companies embrace the challenge of de-carbonising at scale; they are committed to a zero carbon or carbon neutral pathway and target.
2. Green manufactured products deliver economic, social, and environmental benefits.
3. Green manufacturing companies embrace the circular economy and other strategies for maximising value from material resources, getting more from less.
4. Green manufacturing companies and products do not have adverse effects on biodiversity or human health and wellbeing.
5. Green manufacturing companies seek external independent validation of their progress through certification of their plants and operations (ISO 14001, ISO 45001, and ISO 50001), their energy, carbon, and resource footprint, or their labelling of products.

Green manufacturing is a journey and not a destination, meaning companies are at different stages of this journey. Companies' progress on this journey can be seen through the green maturity index, which requires independent validation of product, facility, or service metrics in relation to sustainability. Examples of the standards that are relevant and used in the UK for green or sustainable manufacturing companies are shown below:

- » ISO 14025-2006 - Type III eco labels for Environmental Product Declarations;
- » PAS2050 – British publicly-available standard for product carbon foot printing;
- » The Green House Gas Protocol – Assessment of company green-house gas emissions.

Green manufacturing companies understand their progress in terms of emissions and are committed to reducing emissions. Based on PAS 2050:2011, product, process, and service footprinting, the Greenhouse Gas (GHG) Protocol reports emissions into Scopes 1, 2, and 3. Scope 1 represents direct operations, Scope 2 covers emissions from purchased energy, and Scope 3 includes the remainder of the supply chain emissions. It should be noted that lead innovators and many organisations that have taken up the challenge are on zero or carbon-neutral pathways to a defined year based on Scope 1 and 2 emissions.

2.1.3 UK LOW CARBON MANUFACTURING AND INDUSTRIAL STRATEGY

The UK approach to green manufacturing may be viewed in the context of the UK Industrial Strategy and the Clean Growth Strategy, as well as other supporting and related regional strategies and instruments.[6][7] The term ‘green manufacturing’ does not exist in the UK Industrial Strategy, the focus is on ‘low carbon’ which is referred to 21 times. The key areas identified which can drive green manufacturing include eco-innovation and low carbon technologies, low carbon bio-based products and processes, the low carbon economy, low carbon energy, low carbon hydrogen, low carbon industrial processes, low carbon industry, low carbon infrastructure systems, low carbon innovation, low carbon power now and into the future, low carbon technologies, low carbon transport, a resource efficient economy, and smart technologies.

2.1.4 UK INDUSTRIAL STRATEGY AND THE CIRCULAR ECONOMY

The UK Industrial Strategy is committed to moving towards a regenerative circular economy that replaces extraction and waste with restoration and regeneration. Products, components, and materials are reused in ways that retain their utility and value as they move through biological and technical cycles. This means that in a circular economy, resources are kept in use for as long as possible, extracting the maximum value and then recovering and regenerating products and materials at the end of each service life, hence manufacturers should expand their manufacturing system boundaries and influence in order to capture and utilise the circular economy’s benefits. Within the UK Industrial Strategy, the following support is recommended for manufacturing:

- » An approach to infrastructure investment that aims to regenerate natural capital;
- » Promotion of recycling and strong secondary materials markets where products are designed with efficiency and recyclability in mind;
- » The Courtauld Commitment to deliver a 20% per capita reduction in food waste by 2025;
- » A new bioeconomy strategy that will set out a framework for growth in the sector to develop new low carbon bio-based products and processes;
- » Policies in line with national ambitions of zero avoidable waste and a doubling of resource productivity by 2050;
- » A new strategy for resources and waste.

2.1.5 STRIKING THE BALANCE – THE ECONOMIC, ENVIRONMENTAL, AND SOCIAL SUSTAINABILITY TRILEMMA

It goes without saying that green manufacturing companies pursue sustainable development through the balancing of the sustainability trilemma as shown in Figure 2. Sustainable development can be defined as the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable development has three pillars: economic, environmental, and social sustainability. The aim is to strike a synergy between the three sustainability pillars.

Products should be designed with their whole life cycle in mind: this comprises production, distribution, usage, and disposal with minimum to zero environmental burden, with maximum social value, and in line with business objectives.

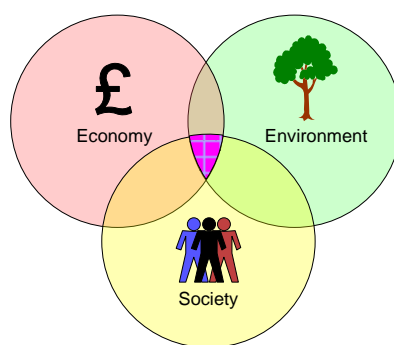


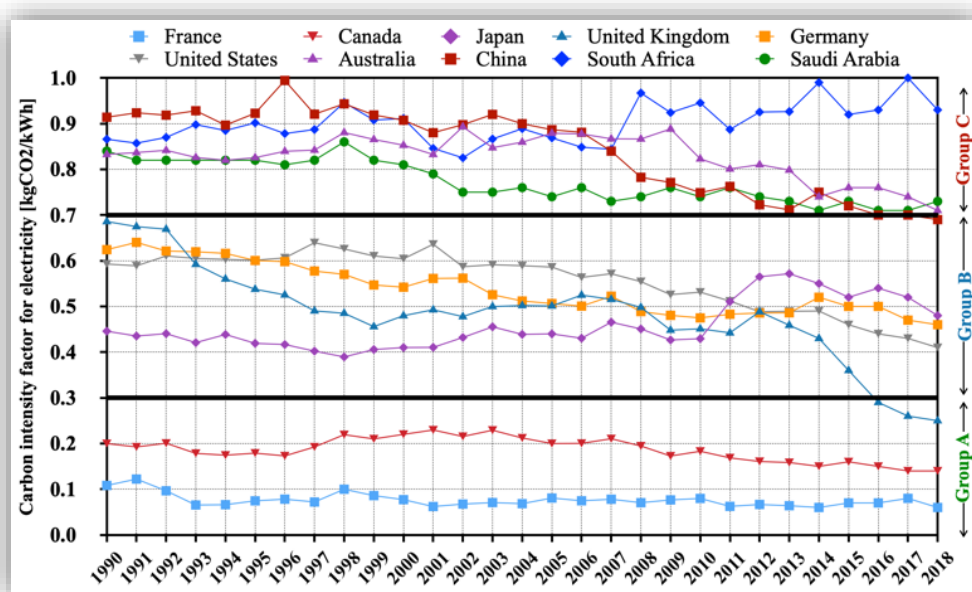
Figure 2. The sustainability trilemma

2.1.6 LOW CARBON MANUFACTURING PATHWAY

Green manufacturing companies are committed to pursuing a pathway towards low carbon manufacturing driven by a defined carbon neutral or carbon zero milestone. There are strong social and legislative drivers for this transition in the UK. The UK pioneered legislation to drive this transition with the 2008 Climate Change Act which set legally binding ‘carbon budgets’, with a target to cut UK’s emissions by at least 80% by 2050 compared to the 2008 baseline.[8] A number of organisations have subsequently set carbon neutral or zero targets for 2028, 2038, 2040, 2048, and 2050.

A key challenge for green manufacturing is to manufacture and add value while simultaneously reducing emissions and adhering to a de-carbonisation pathway. In manufacturing, in addition to the carbon dioxide (CO₂) directly emitted using fossil fuel on the manufacturing site, the electricity used to work the production equipment is a key driver of CO₂ emissions. Considering the slow rate of decarbonisation, it is essential for green manufacturers to reduce the energy intensity used in the manufacturing process. Manufacturing plants demand power and consume energy in the entirety of their operation for processes that keep machines, offices and services running, amongst others. For machines and manufacturing plants, this is called basic energy and lowering its usage is important for sustainability. The design of equipment, machine tools, and manufacturing plants plays a significant role in influencing basic energy consumption and operational emissions, especially Scope 2 emissions. Thus, green design and products can focus on energy rated (best available in class) equipment and facilities. Trading of such equipment and capabilities for green design and products could form part of the collaboration between the UK and China within green manufacturing.

To evaluate the carbon emissions from electricity consumption, the direct energy consumed, E , is multiplied by the carbon intensity, e_{CO_2} , as shown in Equation (1). The carbon emission is measured in $kgCO_2$, the direct energy consumed in manufacturing in kWh , and carbon intensity in $kgCO_2/kWh$. The carbon intensity is influenced by the proportion of carbon-rich primary energy resources¹ used in power generation, which are mainly fossil fuels. Based on the data presented by the International Energy Agency in 2018, the carbon intensities of electricity generation in the UK and China were 0.25 and 0.69 $kgCO_2/kWh$, respectively. Figure 3 shows the carbon intensity of electricity generation [2] in several countries in the 1990-2018 period.



$$\text{Carbon Emissions} = E \times e_{CO_2} \text{ Equation (1)}$$

Figure 3. Carbon intensity of electricity generation in different countries adapted from IEA data

Based on the carbon intensity of electricity production, countries can be classified into three main groups: Group A, with carbon intensity up to 0.29 $kgCO_2/kWh$ (the green area: Tier C); Group B, from 0.30 to 0.69 $kgCO_2/kWh$ (the blue area: Tier B); and Group C, upwards of 0.70 $kgCO_2/kWh$ (the red area: Tier A). Based on this classification, the UK is in Group A and China is in Group B. It should be noted that both countries have significantly improved their positions in reducing the CO_2 intensity of their electricity generation; each moving to a lower group in terms of clean energy for manufacturing. Green manufacturing companies should not be complacent with their current energy supply but should pursue further comprehensive and effective measures to decarbonising their energy, such as through investing in onsite renewable energy or switching to more greener suppliers. This implies that companies can be greener both in the UK and China depending on how they source their energy.

① ¹ Primary energy resources include coal, petroleum and natural gas as fossil fuels and biofuel, hydro, solar, wind, geothermal, earth, wave and tidal as green energy resources.

In China, this reduction in carbon emissions is driven by the increasing use of renewable energy, especially hydroelectricity (67% of its renewable energy). In the UK, CO₂ reduction is largely attributed to the significant decrease in the country's coal energy share as well as its increasing use of wind and biomass energy (82% of its renewable energy).

To reduce carbon emissions, it is highly recommended that companies incorporate energy demand reduction strategies alongside energy smart manufacturing. Energy efficiency can also be achieved by way of green equipment, facilities, and plants. As indicated in Figure 4, the aforementioned actions will not be sufficient without the removal or minimisation of carbon in the energy sources. This means that the third and biggest factor to be considered for de-carbonisation is the use of renewable energy, or low or zero carbon emission energy.

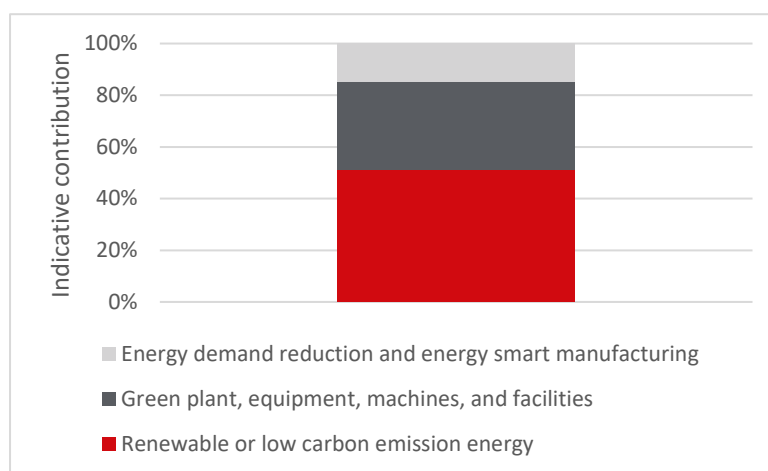


Figure 4. Indicative relative challenges and focus for decarbonising manufacturing industries to support clean growth

2.1.7 BUSINESS MODELS FOR GREEN MANUFACTURING

The 2017 UK Industrial Strategy White Paper notes that business models will be transformed by the following factors:

- » New industries in their own right, like artificial intelligence (AI), machine learning, and data analytics, will transform business models across many sectors as vast datasets are deployed. This can be layered onto green manufacturing and smart manufacturing.
- » Future mobility, when identified in the UK as a driver for green manufacturing. New market entrants and new mobility business models will present fresh opportunities for green products and services.
- » A rethink of business models to support the circular economy that companies are now embracing, and the related transformed business objectives and systems.

2.1.8 UK GREEN MANUFACTURING MARKET

A UK parliamentary report stated that a more circular UK economy could be worth £9 billion to £29 billion a year and would create 10,000-175,000 jobs across different skill levels by 2030.[10] Concomitantly, a survey conducted by the Office for National Statistics revealed that the low carbon manufacturing industry was

estimated to be worth £15 billion and employed a total of 83,600 people in 2018. It also reported a healthy growth of the green economy at a rate of 5% in 2018.[11]

The Manufacturing Technologies Association (MTA) in the UK is the trade representative association for companies in the manufacturing technology sector. In their 2020 report Decarbonisation: Future Growth for Manufacturing, a similar and consistent picture was given.[12] The new investment in green technologies that will be needed to underpin the net-zero target, as estimated by the Commission on Climate Change, are in the order of 1-2% of GDP per year up to 2050. The impact of new investment on GDP will see a projected rise from £8 billion to £20 billion in output for UK manufacturing and its supply chains. The resulting effect on jobs will also be substantial, creating:

- » 400,000 to 1 million jobs in the economy as a whole;
- » 37,000 to 90,000 jobs in UK manufacturing sector;
- » 34,000 to 83,000 further jobs in the supply chain.

2.1.9 STAKEHOLDERS IN GREEN MANUFACTURING

Due to the significant impact that the manufacturing industry has on available resources, energy, and carbon emissions, numerous bodies have taken to formulating policies, programmes, and activities in support of research and development (R&D), knowledge transfer, and the implementation of green manufacturing. Key stakeholders in green manufacturing are identified below:

- a. Government departments: the Department for Business, Energy and Industrial Strategy; the Department for Environment, Food and Rural Affairs; the All-Party Parliamentary Manufacturing Group; and the Government Office for Science and Regional Governments;
- b. Research and technology organisations: universities; the High Value Manufacturing Catapult (including seven centres); and the Scottish Institute for Remanufacturing;
- c. Funding bodies: the Engineering and Physical Sciences Research Council (EPSRC); Innovate UK; and The Carbon Trust;
- d. Professional institutions: the Royal Academy of Engineering; the Manufacturing Technologies Association; Unite; and the Institute of Directors;
- e. Charitable organisations: the Ellen MacArthur Foundation and the Waste and Resources Action Programme (WRAP).

Within the context of sustainability and green manufacturing, any stakeholder analysis must consider present, future, direct, and indirect stakeholders, as well as impacts, ideally guided by a process of responsible innovation and assessment and mitigation of rebound effects.

A general illustration of the green manufacturing primary stakeholders is illustrated in Figure 5. Each of these primary stakeholders has its own current and future network of interconnected stakeholders. Any primary and secondary network analysis needs to be developed for a particular industry, product, and company considering the specific conditions and local context.

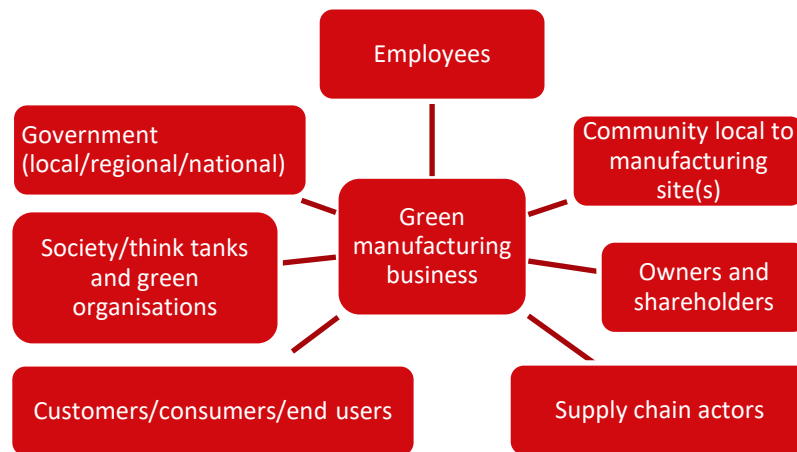


Figure 5. Primary stakeholders for green manufacturing

In the UK, in addition to the Department for Business, Energy and Industrial Strategy, organisations such as the Ellen MacArthur Foundation, the Forum for the Future, the Green Alliance, the Waste and Resources Action Programme (WRAP), Zero Waste Scotland, the High Speed Sustainable Manufacturing Institute (HSSMI), RSA (The Great Recovery), the Royal Academy of Engineering, universities, the Advanced Manufacturing Centres (AMRCs), and Catapults provide the underpinning research base and technology and sometimes advocacy to support green manufacturing businesses.

2.1.10 THE IMPACT OF INDUSTRY 4.0 ON GREEN MANUFACTURING

There is excitement and anticipation that the development of Industry 4.0 will provide opportunities for realising clean and green manufacturing goals. The scope of Industry 4.0 is characterised by:

- a. Horizontal integration across the entire green manufacturing value creation network;
- b. End-to-end engineering across the entire product life cycle;
- c. Vertical integration and networked manufacturing systems.

Horizontal integration across the entire green manufacturing value creation network provides an opportunity for visibility, modelling and process chain optimisation of material and energy resources. End-to-end engineering across the entire product life cycle will not only enable green product management, but also provide the necessary knowledge framework and feedback to drive improvements to regenerate products, evolve product families and improve innovation. Vertical integration and networked manufacturing systems are essential for support, for example, the transition to zero carbon manufacturing facilities will require a fully integrated manufacturing system within a digitalisation framework.

Industry 4.0 can help extend the system boundary for realising green manufacturing, enabling real-time metrics monitoring and utilising the power of big data and artificial intelligence (AI) algorithms to drive innovation and green manufacturing excellence.

2.2 UK GOVERNMENT POLICY AND PLAN

2.2.1 UK GOVERNMENT POLICY FOR INDUSTRY

The UK Government's 2017 Industrial Strategy White Paper is the primary policy instrument within which the growth of green manufacturing is to be realised. The report entitled The Future of Manufacturing also helps to define the timeline of progress.[14] Complementary to these are several policy instruments, examples of which are shown in Table 1 below to demonstrate how strategy, foresight, and market instruments are combined.

Table 1: Summary of the UK government policy on green manufacturing issues

Relevant UK Policy Document	Policy Focus
2010 to 2015 government policy: energy demand reduction in industry, business and the public sector. https://www.gov.uk/government/publications/2010-to-2015-government-policy-energy-demand-reduction-in-industry-business-and-the-public-sector	To support the Carbon Plan for the UK to cut its greenhouse gas emissions. This requires energy efficiency increases across all sectors. This policy helps achieve this by supporting industry, businesses, and the public sector to use less energy, which will reduce the impact of rising energy prices.
Policy paper: Clean Growth Strategy - An ambitious blueprint for Britain's low carbon future. https://www.gov.uk/government/publications/clean-growth-strategy/clean-growth-strategy-executive-summary	This strategy sets out a comprehensive set of policies and proposals that aim to accelerate the pace of clean growth, i.e. deliver increased economic growth and decreased emissions.
The Green Investment Bank: policy and finance context. https://www.gov.uk/government/publications/green-investment-bank-policy-and-finance	The Department for Business, Innovation & Skills (BIS) commissioned this report to look at the shape of a UK green economy and the funding it would need. The report makes the high-level case for Green Investment Bank (GIB) intervention along market economy investor principles.
Policy paper: Green finance strategy. https://www.gov.uk/government/publications/green-finance-strategy	Sets out the proposals for green finance at the heart of delivering the UK's Clean Growth Strategy, 25 Year Environment Plan, and Industrial Strategy, and how the proposals support the UK's economic policy for strong, sustainable, and balanced growth.

Policy paper: Circular Economy Package policy statement.

<https://www.gov.uk/government/publications/circular-economy-package-policy-statement>

The Circular Economy Package (CEP) introduces a revised legislative framework, identifying steps for the reduction of waste and establishing an ambitious and credible long-term path for waste management and recycling.

Policy paper: Resources and waste strategy for England.

<https://www.gov.uk/government/publications/resources-and-waste-strategy-for-england>

This strategy sets out how the UK will preserve material resources by minimising waste, promoting resource efficiency, and moving towards a circular economy in England.

Strategy/plan - Making Things Last: A circular economy strategy for Scotland.

<https://www.gov.scot/publications/making-things-last-circular-economy-strategy-scotland/>

The Scottish Government's circular economy strategy, 'Making Things Last', published in 2016, sets out a clear vision and priorities for action to move towards a more circular economy; and Scotland set a series of ambitious targets to drive circularity.

2.2.2 THE UK CLEAN GROWTH STRATEGY

The Clean Growth Strategy Report notes that since 1990, UK emissions from business and industry have almost halved. This is mainly due to efficiency gains and a shift in manufacturing to cleaner fuels, as well as changes to the industrial structure of the UK economy. This emphasises the need to consider productivity, structure, and intensity in the pathway to green growth. There are several factors that could affect the energy consumption or carbon footprint of an industry, sector, company, or production line with an example of such factors is shown in Table 2. In the context of a green manufacturing industry, the factors highlighted in Table 2 are the production output of an industry and its sectors, the changes in the composition of the industry (its structure), and the changes in the energy or carbon intensity of the sectors.

Table 2: Factors influencing the clean growth path of consumption in industries

Contributing Effect	Inference
Production	When the output of a sector increases, and more goods are produced, the total energy and carbon footprint used invariably increases.
Structure	The composition of the manufacturing sector can change from one period to another. When the industry shifts towards less energy demanding processes or less carbon intensive and sectors, energy use and carbon emissions decrease. In this case, the overall energy efficiency or carbon intensity might seem to have improved when in fact a structural change has occurred. The opposite can also be true.

Energy intensity

This is the unit of energy consumed to produce a unit of output or the carbon footprint of an output. When technology and manufacturing systems change, more or less energy and a larger or smaller carbon footprint may be used to produce the same output.

If there is no apparent change in the industry or company structure, then intensity improvements have to outpace productivity improvements for the transition to cleaner manufacturing to be sustained.

The UK Clean Growth Strategy focuses on improving business and industry efficiency. This is supported through:

1. The development of world-leading green finance capabilities, including the Green Finance Taskforce, voluntary green and sustainable finance management standards, a clean technology early-stage investment fund, and green mortgages;
2. A package of measures that support businesses to improve their energy productivity by at least 20% by 2030;
3. An Industrial Energy Efficiency scheme that helps large companies incorporate measures to cut their energy use and bills;
4. A joint industrial decarbonisation and energy efficiency action plan with seven of the most energy intensive industrial sectors;
5. The investment of £100 million in leading edge carbon capture usage and storage (CCUS) and industrial innovation by the international leadership on CCUS, in collaborating with global partners to drive down costs;
6. The partnership with industry through a new CCUS Council to directly meet the UK's ambition of having the option of deploying CCUS at scale in the UK, and to maximising its industrial opportunity;
7. A strategic approach to greenhouse gas removal technologies, building on the Government's programme of research and development and addressing the barriers to their long-term deployment;
8. Phasing out of the installation of high carbon forms of fossil fuel heating in new and existing businesses off the gas grid during the 2020s, starting with new build;
9. The recycling of heat produced in industrial processes, to reduce business energy bills and benefit local communities;
10. The innovation and investment of public funds for research and innovation in energy, resource, and process efficiency, thereby encouraging the use of lower carbon fuels.

2.2.3 UK NET ZERO EMISSIONS LAW AND COP26

In June 2019, the UK became the first major economy to pass a Net Zero Emissions law. This legal commitment requires the UK to bring all greenhouse gas emissions to net zero by 2050, a more ambitious and demanding target when compared to the 2008 Climate Change Act, which set the goal at 80% of reduction in greenhouse gas emissions by 2050. Momentum and action towards net zero emissions are further supported by the COP26 United Nations Climate Change Conference which will be hosted by the UK in Glasgow in 2021. This momentum and focus was captured by the UK government by Alok Sharma, COP26 President and Secretary of State for Business, Energy and Industrial Strategy:

“While we rightly focus on fighting the immediate crisis of the Coronavirus, we must not lose sight of the huge challenges of climate change. With the new dates for COP26 now agreed we are working with our international partners on an ambitious roadmap for global climate action between now and November 2021. The steps we take to rebuild our economies will have a profound impact on our societies’ future sustainability, resilience and wellbeing and COP26 can be a moment where the world unites behind a clean resilient recovery”.

2.2.4 UK GOVERNMENT PLAN

UK manufacturing plays an important role in achieving the net zero target by 2050 and moving the nation towards a truly circular economy. The government has launched various plans providing direction to support research and industrial activities for cleaner growth within UK manufacturing, and Figure 6 provides an overview of the strategic plan of sustainable manufacturing in the UK. To move UK manufacturing towards sustainability, the key stakeholders, as discussed in Section 2.1.9, need to work in partnership with each other to create the best possible environment for research, innovation, and business to flourish.

In 2013, the Government Office for Science proposed a Foresight report entitled The Future of Manufacturing: A New Era of Opportunity and Challenge for the UK, which took a strategic look at the manufacturing sector through to 2050. Over £200 million has been invested into research and innovation in the areas of sustainable manufacturing and the circular economy. According to experts, the shift of UK manufacturing towards sustainability needs transformation on three-levels:

1. Eco-efficient manufacturing (factory level): This level focuses on the development of new technologies and adoption of methods to maximise the efficiency of materials, energy, and water; for instance, through the identification of waste and modelling of factory resource flows.
2. Sustainable business innovation (firm level): This level focuses on the designing of sustainable business models which create and capture new value in new ways. Despite being the world pioneer in manufacturing servitisation (e.g., Rolls Royce’s ‘power-by-the-power’ model), UK manufacturing is still largely dominated by the traditional business model of making and selling products. Sustainable manufacturing requires UK manufacturers to re-think their business models and develop new ones that can profit from the concepts of a circular economy, such as recycling, remanufacturing, and reducing.
3. Industrial system transformation (industrial level): This level uses a systematic approach to model, map, and design future UK industrial systems in which value is maximised.

The UK’s sustainable manufacturing approach is still primarily focused on tackling the eco-efficiency challenges at the factory level, and this is predicted to continue to be the case in the period 2020-2030 as a strategy to hedge against increasingly vulnerable supply chains.[15] While the firm and industrial levels are essential, they tend to pose more challenging as they require the involvement of more stakeholders and not many studies exist on this topic. The situation thus indicates that there might be a need to put more effort into these two levels.

In 2015, the Manufacturing Commission of the All-Party Parliamentary Manufacturing Group (APMG) launched a report entitled Industrial Evolution: Making British Manufacturing Sustainable, outlining the vital measures and plans that government and industry should take to make UK manufacturing more sustainable. The report proposes 24 specific recommendations in five key areas for the UK government to make strategic plans (Figure 6): leadership, resilience, innovation, collaboration, and system change.

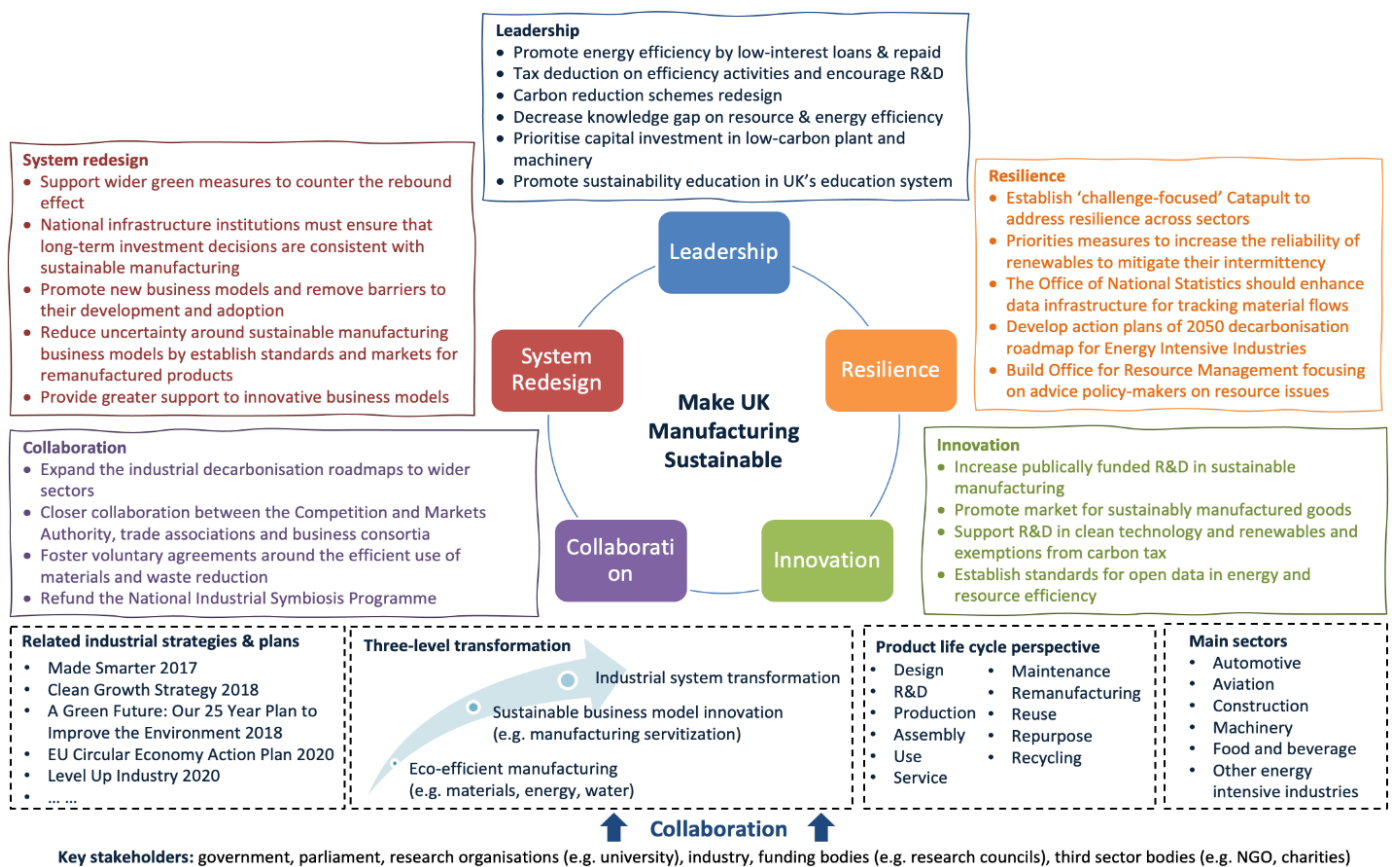


Figure 6. An overview of the strategic plan for UK sustainable manufacturing (sources: APGM report 2015; EPSRC Innovative Manufacturing Centre for Industrial Sustainability; Foresight, The Future of Manufacturing, 2013; Sustainability and Manufacturing evidence paper 2013; The Next Manufacturing Revolution 2013)

2.3 UK GREEN MANUFACTURING RESEARCH CAPACITY

2.3.1 CHARACTERISTICS OF THE UK GREEN MANUFACTURING SECTOR

Since the financial crisis in 2008, the manufacturing sector has received increasing political and public attention in the UK. Manufacturing has been placed back into the centre of the economy and contributed around 10% of the UK's total GDP in 2018. UK manufacturing is currently the world leader in areas such as clean technologies, eco-design, and new sustainable business models [16], and it is predicted that there are increasing opportunities for the UK due to the growing global markets for more sustainable products. The characteristics of UK sustainable manufacturing are as follows [16]:

1. UK sustainable manufacturing is the world leader in four aspects:
 - » Clean technology: The UK has strong technical and managerial knowledge of clean production and has significant opportunities for growth in areas such as new materials, automation, and fuel cells.
 - » Energy efficiency: The UK has some of the most efficient individual factories in the world.
 - » Creative sector: The UK's creative sector is well placed to play a role in addressing the challenges of sustainable manufacturing through system design thinking.
 - » Business model innovation: UK manufacturing is a world leader in exploring and achieving sustainable manufacturing through new business models.
2. UK sustainable manufacturing activities are predominantly implemented by SMEs and start-ups. However, SMEs often lack the internal skills to take advantage of opportunities outside of their core business, or the scale to make external assistance (e.g., through a consultant) worthwhile. The UK government plays a critical role in helping smaller firms experiment and innovate in sustainable manufacturing.
3. Many UK manufacturers see sustainability as an essential element of their business. Most of them have a strong social responsibility to embed sustainability into their business and are motivated to look for innovative ways to make their manufacturing more sustainable. 90% of UK manufacturers are aware of the 2050 Net Zero target and 50% of them are committed to following through with concrete actions. Before COVID-19, 30% of UK manufacturers had invested in energy efficiency and have seen an increase in profits as a result.
4. Various stakeholders, e.g., government, parliament, manufacturers, and even NGOs, all play important roles in moving UK manufacturing towards sustainability. For instance, the Ellen MacArthur Foundation is a globally influential charity in the UK within the circular economy space, and has impacted a large number of researchers, policymakers, and businesses worldwide. Elsewhere, the High Value Manufacturing Catapult, established by Innovate UK and aiming to bridge the gap between business and academia, is leading the UK's green manufacturing revolution and bridge.
5. UK manufacturing tackles sustainability challenges from the perspective of the entire product life cycle, focusing especially on high-value activities such as R&D, design, services, and end-of-life strategies. The production is still largely outsourced to other countries, despite a recent attempt to move it back to the UK. In this context, it is vital for UK manufacturers to develop sustainable business models that

create and capture value in new ways, and build supply chains that minimise greenhouse gas emissions.

6. The UK has seen the adoption of digital technologies as an important approach for sustainable manufacturing. Significant investment has been put into research and industrial activities to explore the use of additive manufacturing, the internet of things, data science, and other areas, combined with innovations in business models and supply chains.
7. Achieving sustainability in UK manufacturing requires collaboration between every sector. Despite a shortage in materials, energy, and manufacturing skills for a number of years, the UK now has the correct mix of skills, workforce, and industry to benefit from a transition towards a circular economy.[17] UK manufacturers do not work alone and are intensively collaborating with other sectors such as retailers, distributors, and finance. There is also strong collaboration between academics, the government, and manufacturers.

Table 3: Examples of UK world leading companies in four areas of sustainable manufacturing

Company	Industry	Clean technology	Energy efficiency	Creative sector	Business Model Innovation
Riversimple	Automotive	*	*		*
Toyota UK	Automotive	*	*		
Johnson Matthey	Chemicals and sustainable technologies	*			
Tata Steel UK	Steel	*	*		
Jaguar Land Rover	Automotive		*		
Elvis and Kresse	Fashion				*
Adnams	Drinks	*	*		
Vitsoe	Furniture		*	*	*
AB Sugar	Food	*	*		*

2.3.2 MAJOR RESEARCH PROGRAMMES IN GREEN MANUFACTURING

As one of the major UK Research and Innovation (UKRI) councils, the Engineering and Physical Sciences Research Council (EPSRC) is the main funding body for fundamental research and postgraduate training for engineering and physical science research in the UK. At the EPSRC, £341.4 million (6.56% of the whole portfolio) has been allocated to fund 266 research projects held by 46 research organisations under the theme of 'Manufacturing the Future since 2010'. Sustainable manufacturing research is funded across various research areas, such as resource efficiency, manufacturing technologies, materials engineering, operational research, and engineering design. Table 4 shows some examples of the fundamental research projects related to sustainable manufacturing funded by the EPSRC in recent years, and Table 5 lists funded collaborative projects between the UK and China in sustainable manufacturing. These projects are research-orientated and led by the universities in collaboration with industrial partners.

Table 4: Sustainable manufacturing-related research projects funded by the EPSRC

Project code	Project title	Year(s)	Educational institution	Value
EP/N011368/1	Uncovering Fundamental Mechanisms to Enable Sustainable Steel Manufacturing	2016-2021	University of Warwick	£1.16m
EP/P027393/1	High Performance Discontinuous Fibre Composites - a sustainable route to the next generation of composites	2017-2020	University of Bristol	£1m
EP/P027490/1	Advanced Manufacturing for Sustainable Biodegradable Microbeads - BIOBEADS	2017-2021	University of Bath	£1.1m
EP/R011168/1	Investigation on Sustainable Refractory Systems for Investment Casting Manufacturing of Titanium Alloys	2018-2021	University of Birmingham	£450k
EP/R01213X/1	New Manufacturing Processes for More Sustainable Commodity Chemicals	2018-2023	University of Durham	£877k
EP/R022518/1	Soft Processing to Enable the Low Impact, Sustainable Manufacture of Inorganic Materials and Advanced Inorganic Semiconductor Composites	2018-2021	University of Manchester	£474k
EP/R027129/1	Hub 'Science' 3: Catalysis for the Circular Economy and Sustainable Manufacturing	2018-2023	University of Bath	£4m
EP/R031401/1	Sustainable and industrially scalable ultrasonic liquid phase exfoliation technologies for manufacturing 2D advanced functional materials (EcoUltra2D)	2018-2022	Oxford Brookes University	£261k
EP/R031665/1	Sustainable and industrially scalable ultrasonic liquid phase exfoliation technologies for manufacturing 2D advanced functional materials (EcoUltra2D)	2018-2022	Brunel University London	£411k
EP/R031819/1	Sustainable and industrially scalable ultrasonic liquid phase exfoliation technologies for manufacturing 2D	2018-2021	University of Hull	£331k

	advanced functional materials (EcoUltra2D)			
EP/R032041/2	Circular 4.0: Data Driven Intelligence for a Circular Economy	2019-2022	University of Exeter	£728k
EP/P012272/1	Energy Resilient Manufacturing 2: Small is Beautiful Phase 2 (SIB2)	2017-2021	Cranfield University	£756k
EP/R025983/1	Design and green manufacturing of functional nanomaterials	2018-2023	University of Sheffield	£1m
EP/R027129/1	Hub 'Science' 3: Catalysis for the Circular Economy and Sustainable Manufacturing	2018-2023	University of Bath	£4m
EP/P008917/2	REBUILD - REgenerative BUILDings and products for a circular economy	2017-2021	University of Exeter	£922k
EP/P027121/1	Through-life performance: From science to instrumentation	2017-2022	Cranfield University	£1.2m
EP/R001715/1	LightForm: Embedding Materials Engineering in Manufacturing with Light Alloys	2017-2022	University of Manchester	£4.8m
EP/R004226/1	Design the Future 2: Enabling Design Re-use through Predictive CAD	2017-2022	University of Strathclyde	£587k
EP/R013179/1	Designing the Future: Resilient Trans-Disciplinary Design Engineers	2017-2023	University of Bath	£1.8m
EP/S036091/1	UK Manufacturing Symbiosis NetworkPlus (UKMSN+)	2019-2022	Aston University	£893k
EP/N018427/1	Autonomous Inspection in Manufacturing & Remanufacturing (AIMaReM)	2016-2020	University of Strathclyde	£2m
EP/N018524/1	Robotic disassembly technology as a key enabler of autonomous remanufacturing	2016-2021	University of Birmingham	£2m

EP/L016389/1	EPSRC Centre for Doctoral Training in Sustainable Materials and Manufacturing	2014-2022	University of Warwick	£3.3m
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Table 5: UK-China research collaboration in sustainable manufacturing

Project code	Project title	Year(s)	Educational institution	Value
EP/J007870/1	Sustainable global manufacturing network between the UK and China	2012-2015	University of Liverpool	£133k
EP/S018190/1	Research on the theory and key technology of laser processing and system optimisation for low carbon manufacturing (LASER-BEAMS)	2019-2022	University of Manchester	£813k
EP/S018573/1	High efficiency value-added bulk recycling of polymers by solid state shear milling	2019-2021	University of Bradford	£804k
EP/S018204/1	Sustainable Processing of Energy Materials from Waste	2019-2022	Queen Mary University of London	£813k
EP/S018352/1	Green Recycling And re-manufacturing of Carbon fibre composites for a circular Economy (GRACE)	2019-2022	University of Manchester	£784k
EP/S018204/2	Sustainable Processing of Energy Materials from Waste	2019-2022	Imperial College London	£813k

2.3.3 MAJOR BUSINESS INNOVATION PROGRAMMES IN GREEN MANUFACTURING

In addition to the fundamental research funded by the EPSRC for Technology Readiness Level 1-3 (TRL), the UK government also invests in innovation and research projects led by the UK companies. These business-driven projects for TRL 3-5 are mostly funded by Innovate UK, part of UK Research and Innovation. Since 2007, Innovate UK has invested around £2.5 billion to help UK businesses to innovate. Normally, the businesses need to provide a certain amount of match funding and collaborate with universities. Innovate UK's projects have successfully created a large number of jobs (around 70,000) and accelerated the transfer of research outcomes into commercial impact. Table 6 shows some examples of the Innovate UK programmes in sustainable manufacturing in the past three years.

Table 6: A selection of the programmes of Innovate UK's projects in sustainable manufacturing since 2018

Programme of Innovate UK projects	Successful projects
ISCF Smart Sustainable Plastic Packaging: Feasibility Studies and Industrial Research, £1 million, 2020	Link
The Sustainable Innovation Fund: Round 1, £75 million, 2020	Link
The Sustainable Innovation Fund: SBRI Phase 1, £10 million, 2020	Link
APC 12: Advancing the UK's Low Carbon Automotive Capability, £25 million, 2019	Link
IDP15: The Road to Zero Emission Vehicles, Feasibility Studies, £2 million, 2019	Link
Clean Growth Innovation Fund: Round 1, £4 million, 2019	Link
APC 10: Advancing the UK's Low Carbon Automotive Capability, £30 million, 2018	Link
APC 11: Advancing the UK's Low Carbon Automotive Capability, £20 million, 2018	Link
Plastics Innovation: Towards Zero Waste, £3 million, 2018	Link

The following table shows some successful examples of the Innovate UK funded projects in sustainable manufacturing in the past three years.

Table 7: Examples of successful Innovate UK funded projects

Title: Zero Emission Tata hydrogen Engine (ZETE)

Project organisations: TATA Motors European Technical Centre plc, Johnson Matthey Plc, Revolve Technologies Ltd, Ulemco Ltd, University of Brighton

Description: This project addresses the challenge of dramatically reducing carbon and air quality emissions in heavy goods vehicles (HGV). The market opportunity is to address this critical global energy and environmental requirement to reduce emissions by delivering practical, cost effective solutions for truck and fleet operators, as the costs of vehicle ownership are acutely important for business operation success in this sector. [Link](#)

Title: EV-LIFT (Electric Vehicle Light-weighting Integrated Future-proof Traction)

Project organisations: YASA Ltd, HSSMI Ltd, Lotus Car Ltd, Coventry University

Description: The project aims to produce a best-in-class electronic drive unit (EDU) for next generation battery electric vehicles (BEVs). The project will utilise best-in-class motor, SiC inverter, and gearbox technology that enables significant light-weighting and efficiency improvements for next-generation BEVs. [Link](#)

Title: Using aviation based reclaimed carbon fibres for BMC

Project organisations: Toyota Tsusho UK Ltd, Fiba Tech Industries Ltd, NCC Operations Ltd

Description: The project aims to research and develop a range of composite materials (known as bulk moulding compounds) using recycled carbon fibres reclaimed from end-of-life (EOL) aircraft and aerospace production waste. The material will be suitable for large-scale volume production of lightweight automotive components, using material that is currently sent to landfill or burned. This approach will reduce the environmental impact of the vehicle through reduced energy usage in manufacturing when compared to the production of virgin carbon fibres. All the consortium members are UK based but the output has large-scale export potential and job creation possibilities. GKN can supply aviation waste CFRP and process the developed material giving a circular supply chain. FTI Group will develop the BMC materials and TTUK will supply the reclaimed fibres. [Link](#)

Title: Zero Emissions capable Ready for Autonomous Urban Deliveries (ZERAUD)

Project organisations: Clairvaux Ltd, Tetra Design Services Ltd

Description: The project will add an electric drive axle to a conventional diesel driven truck, storing the electrical energy on the trailer in the space that is often left empty at the front of the lower deck of a double deck trailer. Urban step frame double deck trailers are already relatively expensive (compared to the full-length alternative). Project ZERAUD intends to offer an alternative to the high cost of a typical low floor independent suspension (typically £10,000-12,000 more than a pair of standard axles) by redesigning either the axle or the chassis frame to allow sufficient wheel movement without needing independent wheel ends. This will help to offset the cost of the hybridisation. [Link](#)

Title: Tucana

Project organisations: Jaguar Land Rover Ltd, Broetje-automation UK Ltd, CCP Gransden Ltd, Expert Tooling & Automation Ltd, Magna International Holding UK Ltd, Toral International UK Ltd, University of Warwick

Description: In Project Tucana, Jaguar Land Rover leads a consortium of world-leading academic and industry partners spanning the entire supply chain to introduce large composite assemblies and realise world-leading lightweight body structures. The consortium will leverage globally cutting-edge industrialised materials, design, and manufacturing concepts to integrate much higher quantities of affordable lightweight carbon-fibre composites into premium volume automotive applications, while also increasing the knowledge of these global businesses and the UK research base. As an enabler for a zero-emission electrified vehicle platform, Project Tucana has potential to reduce vehicle CO₂ emissions and improve range and air quality. The project will deliver inward investment

opportunities and strengthen the UK's capability by integrating existing automotive lightweight technologies and developing knowledge to deliver a new UK supply chain at a globally significant scale for cost competitive carbon-fibre-composites. [Link](#)

Title: Building UK Tier 1 Supply of Powertrains for Zero Emission Buses and Commercial Vehicles

Project organisations: Arcola Energy Ltd, AVID Technology Ltd, Eaton Ltd, Terragenic Ltd

Description: This project will accelerate development and market readiness of zero emission powertrains and components and strengthen UK Tier 1 supply for a wide range of commercial vehicles and buses.

It will bring to market complete fuel cell electric powertrains, develop a best-in-class highly integrated motor drive unit, strengthen UK capability in supply of power-led battery packs, and demonstrate a game-changing hydrogen storage technology on a commercial vehicle for the first time. Two zero-emission vehicles will be developed to production prototype stage, a double deck bus and a 12t truck, demonstrating the capability and performance of the whole powertrain and the key components for a wide range of commercial vehicles. [Link](#)

2.3.4 RESEARCH CENTRES IN GREEN MANUFACTURING

Since 2010, UK Research and Innovation has been investing in establishing research centres and national hubs focusing on research into making UK manufacturing more sustainable. In 2011-2016, £5.3 million was invested to build the EPSRC Centre for Innovative Manufacturing in Industrial Sustainability:

EPSRC Centre for Innovative Manufacturing in Industrial Sustainability (EP/I033351/1, 07.2011-12.2016, £ 5,233,278)

Lead organisation: University of Cambridge

Project Partners: Adnams, Carbon Trust, EEF, General Motors Company, IBM, Marks & Spencer plc, Riversimple, Shearline Precision Engineering, Toyota, Trades Union Congress, Unilever, Vitsoe.

Project summary: The centre works closely with leading companies of all sizes and from all sectors who are already actively preparing for this challenge. The centre mainly works on two fronts: rapidly reducing the resource and energy-intensity in the production of existing goods while simultaneously investigating options for a radical redesign of the industrial system.

After 2016, the UK government further invested to build manufacturing hubs, one of which is focused on sustainable manufacturing in the steel industry (£10.5 million).

SUSTAIN Manufacturing Hub (EP/S018107/1, 2019-2026, £10.5m)

Lead organisation: National Steel Innovation Centre, Swansea University

Project Partners: ADS Group Limited; The Manufacturing Technology Centre Ltd; Construction Products Association; British Steel Ltd; Sheffield Forgemasters Engineering Ltd; Tata Steel UK Limited; Liberty Steel UK; Henry Royce Institute; Kubal Wraith; SPECIFIC Innovation and Knowledge Ctr; Subcoal International BV; Primetals Technologies Ltd (UK); UK Steel; Knowledge Transfer Network Ltd; High Value Manufacturing (HVM) Catapult; Celsa Steel UK; British Constructional Steelwork Assoc; Welsh Government.

Project summary: SUSTAIN Manufacturing Hub aims to transform the productivity, product diversity, and environmental performance of the steel supply chain in the UK. The hub will lead grand challenge research projects of carbon neutral steel and ironmaking and smart steel processing.

In 2020, to further assist the UK transition towards a circular economy, UK Research and Innovation invested £30 million across various research councils to fund a National Interdisciplinary Circular Economy Hub and five Circular Economy Centres. Each of the centres will conduct interdisciplinary research to accelerate the understanding of, and solutions to, enabling circularity of a resource flow (materials, material systems, products, and/or services), and reuse waste materials in the construction, textiles, chemical, and metal industries.

UKRI National Circular Economy Hub

Lead organisation: University of Exeter

Project summary: The development of the UK's first Circular Economy Observatory will provide a digital system view of national resource flows as a foundation for modelling and quantifying potential benefits, opportunities, and interventions to inform and influence national leadership and industrial decision-making. It is the first national research hub of its kind to lead support for practices of a circular economy; track materials and waste; develop novel and innovative approaches to feed legacy materials, by-products, and waste into value-creating activities; and engage stakeholder communities through compelling narratives for improved understanding of the principles of a circular economy.

2.4 UK GREEN MANUFACTURING INDUSTRY AND BUSINESS OPPORTUNITIES

2.4.1 GREEN MANUFACTURING ROADMAP

The UK does not have a top-down green manufacturing roadmap set by the government. Instead, government policies in this area can be extracted from relevant formal papers. In particular, the following papers are highly relevant to the core principles of green manufacturing:

1. Industrial Strategy White Paper, November 2017 – four industrial grand challenges are proposed: growing the AI & data-driven economy, clean growth, the future of mobility, and the ageing society. Clean growth is directly relevant to green manufacturing.

2. Made Smarter, October 2017 – this report is entirely focused on the barriers of, benefits of, and progress towards digitalisation.
3. A green future: Our 25 Year Plan to Improve the Environment, January 2018.
4. Clean Growth Strategy, April 2018.

Apart from government reports on the future of manufacturing, a few related studies were also published by an industrial body (British Glass), a research centre, and a trade union.[18-20]

An overarching goal in relation to green manufacturing is the Climate Change Act 2008, which is the UK's approach to tackling and responding to climate change. The original target of reducing greenhouse gas emissions by at least 80% relative to 1990 levels was replaced by 100% in the 2019 Net Zero Legislation (Section 2.2.3). As a major user of energy, the manufacturing sector is therefore directly involved in the drive for energy efficiency. From the various policy documents, only a few high-level targets are published:

- » Develop a package of measures to support businesses to improve their energy productivity by at least 20% by 2030;[7]
- » Work towards eliminating all avoidable waste by 2050 and all avoidable plastic waste by end of 2042.[21]

Generally, the UK takes a holistic approach to energy efficiency instead of specific focus on manufacturing technology alone. For instance, the Industrial Energy Transformation Fund set up for 2018-24 cover the following areas:

- » Improved process control;
- » More efficient heat exchange;
- » More efficient drying;
- » Energy recovery from waste heat;
- » Energy recovery from waste pressure;
- » Resource process optimisation.

For the next five years, and possibly beyond, the focus on green manufacturing principles, i.e., energy, materials, and life efficiencies, will cover the following topics:

- a. The circular economy;
- b. Energy efficiency;
- c. Climate change and environmental sustainability;
- d. Decarbonisation, low carbon industry, and clean growth (grand challenge).

It is expected that imaginative and innovative ideas will emerge from academia, research organisations, and industry in response to the initiatives set up by the government. In terms of technical topics directly related to green manufacturing, it is envisaged that the UK will continue to spearhead their research strengths in the following areas:

- a. Packaging materials and technology;
- b. Advanced materials and lightweighting;
- c. Additive and hybrid manufacturing;
- d. Business modelling and digitalisation;
- e. Innovative manufacturing processes.

2.4.2 WORLD CLASS GREEN MANUFACTURING COMPANIES IN THE UK

A total of 30 world-class green manufacturing companies are identified and summarised in Table 8. Their selection is based on winning government funding, national awards, documented progress on sustainability or being widely cited in the industrial community. They cover a wide spectrum of industries, including food, furniture, automotive, aerospace, consultancy, and others. The list not only includes long-established companies but also very recent innovative start-ups. It should be noted this list is not exhaustive as there are far more than 30 top companies in green manufacturing in the UK. More companies can be identified and classified appropriately with further effort.

Table 8: Summary of 30 world class green manufacturing companies in the UK

Company Name / Website / Location	Nature of Business	Applicable Industry	Competency in Green Manufacturing
AB Sugar www.absugar.com Peterborough PE7 8QJ	Sugar and circular economy	Agriculture and sugar	World leader in green manufacturing of sugar, produces only 200gm of waste for every tonne of sugar produced.
Alvant www.alvant.com Basingstoke RG24 8GT	Materials and lightweighting	Aerospace, healthcare, transport, and performance products	Aluminium metal matrix composite materials for lightweighting, an alternative to titanium and carbon composites, and new gravity die casting process for AMC-reinforced components.
Autocraft Solutions Ltd www.autocraftsg.com Grantham NG32 2LY	Engine remanufacturing	Automotive	Europe's largest independent engine remanufacturer, specialised in plasma transfer wire arc/rotating single wire cylinder bore spray process. Winner of the 2018 APRA Remanufacturer of the Year (Best Process Optimization) Award.
Carbon Footprint Ltd http://www.carbonfootprint.com	Consultancy	Manufacturing, logistics and multi-sectors	Specialised in carbon footprinting analysis for companies, product, services,

Basingstoke RG21 4HG			and Carbon Neutral+ standards.
Carwood carwood.co.uk Coventry CV3 2RQ	Diesel fuel injection remanufacturing	Automotive	Specialised remanufacturer of diesel fuel injectors and diesel fuel pumps. Winner of the 2018 APRA Most Sustainable Business Model Award.
David Luke Ltd www.davidluke.com Manchester M12 6LB	School uniforms and reuse	Clothing	Convert single-use plastics from litter, landfill, and the oceans by remanufacturing them into school uniforms. A winner of Queen's Award for enterprise in sustainable development 2020.
Elvis and Kresse www.elvisandkresse.com Kent ME9 9AP	Reuse	Fashion	Use decommissioned fire hose from the British Fire Brigades for design and creation of luxury bags, giftable wallets, and stylish belts.
Grainger & Worrall www.gwcast.com Bridgnorth WV15 5HP	Casting	Automotive, engines, and marine	Next generation casting for aluminium and non-ferrous metal, sand casting design and simulation, digital sand printing, and integrity validation, Queen's Award for Enterprise: Innovation in 2020, owns largest industrial CT scanner in the UK.
Graphene Composites graphenecomposites.com Stockton-on-Tees TS21 3FD	Nanomaterials technology	Aerospace, armour, and power	Combining graphene, aerogels and other materials to form composites amongst the strongest, lightest, and most resilient materials. Light-weighting applications.

<p>Impact Recycling impact-recycling.com</p> <p>Newcastle NE28 6HH</p>	<p>Materials recycling</p>	<p>Plastics, carpet, and fishing</p>	<p>Recycling of mixed rigid plastic, laminate and multi-layer plastic film, fishing net and carpet fibres, CryoCut for plastic size reduction, pipe relining technology manufactured from plastic waste recyclates, and use of hard-to-recycle plastics in rotomoulded applications.</p>
<p>Keronite www.keronite.com</p> <p>Haverhill CB9 8PJ</p>	<p>Surface treatment</p>	<p>Aerospace, automotive, electronic and consumer technology, medical, oil and gas, and sports equipment</p>	<p>Use of plasma electrolytic oxidation coating for life extension and weight reduction of magnesium, aluminium, titanium, and lightweight aluminium brakes for vehicles.</p>
<p>Lucideon Ltd. www.lucideon.com</p> <p>Stoke-on-Trent ST4 7LQ</p>	<p>Materials technology and consultancy</p>	<p>Ceramics</p>	<p>Formerly British Ceramic Research Association. Field enhanced sintering for making solid oxide fuel cell ceramics with time and energy reduction, and inorganic sustainable alternatives to plastic microbeads.</p>
<p>National Composites Centre www.nccuk.com</p> <p>Bristol BS16 7FS</p>	<p>Research and technology organisation, lightweighting, and reuse</p>	<p>Aerospace, car, ship, and wind turbine</p>	<p>Sustainable composites for light-weighting, wind turbine blades, and product life extension. Reuse of composite via new technology for disbanding joints.</p>
<p>Notpla www.notpla.com</p> <p>London E9 5EN</p>	<p>Packaging materials</p>	<p>Food</p>	<p>Innovative digestible seaweed packaging material, biodegradable packaging, packaging for water, and zero-waste packaging.</p>

<p>Oakdene Hollins</p> <p>www.oakdenehollins.com</p> <p>Aylesbury</p> <p>HP19 8HT</p>	<p>Consultancy</p>	<p>Aerospace, automotive, mattress, and hydraulics</p>	<p>This company also hosts the Centre for Remanufacturing and Reuse, specialised in remanufacturing, and circular economy projects.</p>
<p>Pavegen</p> <p>pavegen.com</p> <p>London</p> <p>WC1H 8LS</p>	<p>Pavement system</p>	<p>Renewable energy and smart city</p>	<p>Special paving tiles that convert footsteps into kinetic energy through electromagnetic generators.</p>
<p>Perceptive Engineering</p> <p>www.perceptiveapc.com</p> <p>Daresbury</p> <p>WA4 4AB</p>	<p>Consultancy</p>	<p>Pharmaceutical, formulated products, water, pulp, and paper</p>	<p>Process monitoring and optimisation, integrated diagnostics, and analytics, intelligent continuous biomanufacturing.</p>
<p>PVOH Polymers Ltd</p> <p>www.pvohpolymers.co.uk</p> <p>Cirencester</p> <p>GL7 1YZ</p>	<p>Polymer</p>	<p>Medical, agricultural, chemical, fisheries, and pharmaceutical</p>	<p>Biodegradable and water-soluble polymers, reduction of protective packaging, and ease of recycling of complex multilayer containers/films.</p>
<p>Recoturbo</p> <p>www.recoturbo.co.uk</p> <p>Doncaster</p> <p>DN5 8PT</p>	<p>Turbocharger Remanufacturing</p>	<p>Marine, rail, automotive, and agriculture</p>	<p>Specialist turbocharger remanufacturing to OEM specifications, seven-step Recoturbo remanufacturing process.</p>
<p>Riversimple</p> <p>www.riversimple.com</p> <p>Llandrindod</p>	<p>Sustainable car design</p>	<p>Automotive</p>	<p>Sustainable design of a lightweight car of 580kg powered by hydrogen fuel cell and distributed manufacturing.</p>

Wells LD1 6DF			
Rype Office www.rypeoffice.com London NW10 7SU	Remanufacturing and circular economy	Office furniture	Remanufacturing high quality used furniture and creating furniture from plastic waste.
Scottish Institute for Remanufacturing www.scot-reman.ac.uk Glasgow G1 1XJ	Remanufacturing and circular economy	Automotive, power and inkjet printer	Glass and carbon fibre reinforced polymer composites, cleaning technologies for diesel particulate filters, and cylinder head casings.
SGMA sol-gel.co.uk Gillingham ME7 1RZ	Paper coating technology	Replacement of single-use plastics, food, and drink packaging	Sol gel coating for fibre-based material with biodegradable, compostable and recyclable properties. A winner of the 2019 Innovate UK Women in Innovation award.
Spinko Ltd t/a Harrison Spinks www.harrisonspinks.co.uk Leeds LS11 5SB	Mattress manufacturing	Furnishing	The most sustainable, innovative and vertically integrated mattress and comfort component manufacturer in the world. A winner of the Queen's Award for Sustainable Development 2019.
Teer Coatings Ltd www.teercoatings.co.uk Droitwich WR9 9AS	Surface coating and coating systems	Cutting tool, energy, materials, and nanotechnology	Life extension and reuse of micro-tooling, nano-composite coating for improved wear resistance, and new coatings for bipolar plates for producing hydrogen.
W.H. Tildesley	Forging	Aerospace, automotive,	Part of a Field Assisted Sintering Technology

www.whtildesley.com Willenhall WV13 2AN		marine, power, oil, and gas	(consortium) for Ti-6Al-4V machining swarf into engine components. Near net shape sustainable manufacturing.
TRB Lightweight Structures trbls.com Huntingdon PE29 7EN	Panel Manufacturing and lightweighting	Aerospace, automotive, defence, marine, and rail	Composites with carbon, glass, aramid fabrics in woven and unidirectional formats and bio-based materials. Sandwich panel with fibre-faced skins and aluminium honeycomb core.
TWI www.twi-global.com Cambridge CB21 6AL	Research and Technology Organisation, welding, joining, coating, and remanufacturing	Aerospace and automotive	Compositionally complex materials (CCM) coating for resistance to H2 embrittlement, CO2 corrosion, stability at high temperatures, wear resistance in the production of clean energy, and laser cladding for remanufacturing.
Worn Again Technologies https://wornagain.co.uk/ Nottingham NG1 1GF	Waste recycling	Textile and circular economy	Regenerative technology for the polyester and polycotton blended textiles, and PET plastic.
Xtrac Ltd http://www.xtrac.com/ Thatcham RG19 4ZA	Motorsport and lightweight electric vehicle	Hyper car and transmission	Integrated lightweight electric vehicle gearbox family developed for the growing single speed Electric Vehicle market. A winner of the Queen's Award for Enterprise 2020

2.4.3 SELECTED CASE STUDIES

Case 1: Riversimple Ltd

Company website: <https://www.riversimple.com/>

Riversimple is a UK car manufacturing start-up for hydrogen-powered fuel cell electric vehicles, founded by former motorsport engineer and racing driver Hugo Spowers. This company is developing revolutionary technologies for next-generation cars, which are lightweight, fast, and sustainable. Riversimple's car design is radically different from traditional designs; their design makes for much lighter and smaller cars.

The company follows a unique value proposal since the start of their business, which is "systematic elimination of the environmental impact of personal transport". The company believes that technological innovation is not sufficient to achieving sustainability. It requires a system change, for instance, and innovations in business models to make car manufacturing more sustainable. Riversimple puts a substantial amount of effort into developing sustainable business models. It is a car company, but it does not sell cars; instead of selling cars, the company sells mobility as a service (e.g., the use of cars and customer use of mileage). The car user would be charged for the miles travelled plus a monthly fee, or be given a fixed price three-year leasing fee covering all services, such as maintenance, road tax, insurance and, importantly, fuel. Retaining the ownership of the cars, the company has higher incentive to design a car which lasts longer and is easier to be reused, remanufactured, and recycled. Riversimple is one of the pioneers in green manufacturing in car industry with the aim to "provide mobility at zero cost to the planet".

Case 2: SGMA

Company website: <https://sol-gel.co.uk/>

A key part of the UK and Innovate UK strategy and investment is concurrent support for equality, diversity, inclusion, and access in innovation; an exemplar scheme is the Women in Innovation Awards. There are many women innovators, one of whom has been selected and highlighted for this case study due to her associations with green manufacturing. The Innovate UK winners of the Woman in Innovation awards are pioneers of timely and transformative innovations to tackle the Grand Challenges we face as a society.

Dr Fanya Ismail is the founder and CEO of SGMA which specialises in sol-gel coatings and advanced materials. SGMA applies a chemical process called 'sol-gel' to make disposable coffee cups waterproof without the need to use plastic. This process addresses the challenge of single-use plastic, plastic materials, and other products that are difficult to recycle. This innovation promotes green products, manufacturing, and sustainable futures by exploiting advanced research development to allow people to eat and drink safely with minimum negative impact on living organisms and the environment.

Case 3: Notpla

Company website: <https://www.notpla.com/>

Notpla is an innovative sustainable packaging company which was cofounded by Rodrigo Garcia Gonzalez and Pierre Paslier in 2013 under the name of Skipping Rocks Lab while studying innovation design engineering at Imperial College London and the Royal College of Art.

Instead of transporting and drinking water via plastic bottles, a breakthrough idea of 'edible water' was invented. In simple terms, a small volume of water is 'packed' inside an edible packaging: this is produced by a known cooking process called spherification. Water is contained inside a double membrane which is based on two ingredients: sodium alginate, a natural thickener (E-401) from algae, and calcium chloride (E-

509). Both compounds combine to form a transparent gel wall which is strong enough to conserve liquid inside, as shown in Figure 7.[22]

Each sphere, manufactured through dipping ice cubes into the membrane solution for encapsulation, contains 20-150 ml of water and the production cost is about 1.5 pence each. The machine will be available for lease in 2021. This new approach will replace PET bottles, which can take up to 1,000 years to biodegrade. The impact to the environment is enormous as it is estimated that about 60 million plastic bottles are sent to landfills every day.[23] Presently, the company is developing new ideas for packaging, including sachets, nets, and takeaway boxes.



Figure 7: Edible water bubble/sachet

3. GREEN MANUFACTURING IN CHINA

3.1 DEFINITION AND STRUCTURE OF GREEN MANUFACTURING

3.1.1 DEFINITION OF GREEN MANUFACTURING

Green manufacturing is a modern manufacturing model that considers environmental impact and resource benefits. Its goal is to minimise damage to the environment while maximising the utilisation of resources and coordinate the economic and social benefits for manufacturing companies across their product's life cycle from design, manufacturing packaging, and transportation to utilisation and disposal.

3.1.2 MAIN CONTENTS OF GREEN MANUFACTURING

- » Main tasks: The main tasks for green manufacturing are to promote water and energy conservation, clean production, the comprehensive utilisation of resources, and other green development goals within the industry.
- » Industry directions: Comprising the green transformation of traditional industries; the development of green industries that adhere to proper energy conservation practices, the observation of policies for environmental protection, and new energy-efficient technologies; and the development of a green manufacturing service industry.
- » Key contents: The key contents focus on the construction of a green manufacturing system, including the development of green factories, green production, green industrial parks, and green supply chains. Each of these has its own requirements which needs coordinated advancement. Green factories are the production unit of the manufacturing industry and the main body of green manufacturing. They are the core supporting unit of the green manufacturing system that focus on the process of the green production. Green products embody the conversion of the supply chain to green manufacturing, focusing on the greening of the whole life cycle of a product. Green industrial parks are a platform for manufacturing enterprises and infrastructure. They characterise the concept and requirements of greening, as well as focusing on the overall management and collaborative links between factories in the park. Green supply chains will be the result of combining green manufacturing theory and supply chain management technology, which concentrates on the coordination and cooperation of enterprises on the supply chain nodes.

3.2 CHINA GREEN MANUFACTURING OVERVIEW

3.2.1 MARKET OVERVIEW

Since the start of the Reform and Opening period, China's manufacturing industry has developed rapidly and is continually expanding in scale, surpassing the manufacturing output of the United States in 2010 and becoming the world's biggest manufacturing economy in that year. China has since maintained this position for the past decade, with 28.1% of the world's total manufacturing output in 2019. Today, China is the only nation that meets all the industrial categories in the United Nation's International Standard Industrial Classification for All Economic Activities (ISIC). Of over 500 major industrial products, China ranks first globally for 220 of them.

Although industrial processes generate wealth, they also bring substantial ecological and environmental problems. Industry is the main battleground of energy consumption and pollutant emissions.

Industrialisation means the demand for energy and resources is ever-expanding, in turn increasing the emissions of pollutants. The carrying capacity of resources and the environment is approaching a limit, and regional environmental pollution and ecological damage are occurring more frequently, with resource and environmental constraints having become the main bottleneck restricting the development of a green manufacturing industry. In order to ensure sustainable development of the manufacturing industry going forward, it is necessary to promote green industrial development.

3.2.2 INDUSTRY-RELATED INSTITUTIONS

Green manufacturing in China adopts the management model of utilising the skills and abilities of one department to meet the requirements of another. The Ministry of Industry and Information Technology (MIIT) takes the lead in green manufacturing and the other ministries and commissions cooperate in specific work-related fields. Within MIIT, the Department of Energy Conservation and Comprehensive Utilisation specifically promotes the work related to green manufacturing. The main issues include:

- » Formulating and organising the implementation of the relevant policies, namely energy conservation and the comprehensive utilisation of resources;
- » The promotion of clean production in the manufacturing and communication industries;
- » Organising and coordinating relevant major demonstration projects;
- » The promotion and application of new products, technologies, equipment, and materials.

Numerous institutes participated in researching and formulating green manufacturing standards, including the MIIT's International Economic and Technological Cooperation Centre, the China Electronic Information Industry Development Research Institute, the Fifth Electronic Research Institute of MIIT, and the China Electronic Technology Standardisation Research Institute. Furthermore, the China Green Supply Chain Alliance and the China Green Manufacturing Alliance have built an exchange and cooperation platform by gathering industry resources to carry out the implementation of policies and standards, along with project docking and publicity.

3.3 GOVERNMENT POLICY AND PLAN

3.3.1 GOVERNMENT POLICY

Since 1978, China began paying attention to the issues arising from resources and environment that have accompanied industrial development. With the maturation of China's legal practice, the relevant provisions have become stricter and more practical, promoting the development of industrial green transformation.

Stage 1: The exploration period of green legal policies (1978-2000)

In September 1979, the Environmental Protection Law (for trial implementation) passed a number of provisions concerning the prevention and control of industrial pollution. This acknowledged the fact that China's industrial development had entered a new stage and attention needed to be paid to the environmental impact of production activities. Subsequently, a series of laws such as the Law of Water Pollution Prevention and Control (1984), the Mineral Resources Law (1984), and the Law of Air Pollution Prevention and Control (1987) were issued, all of which contain a large number of provisions relating to green industrial development. In this period, the focus of the relevant green laws and policies was on pollution prevention and control but not enough attention was paid to the utilisation of energy resources; administrative measures were mainly used, market-orientated measures were lacking, and the focus was on terminal control.

Stage 2: The development period of green legal policies (2001-2011)

After China's accession to the World Trade Organization (WTO) in 2001, the pace of integration between China's manufacturing industry and international markets accelerated, and legislation for environmental protection sped up significantly. This legislation included the Environmental Impact Assessment Law (2002), the Clean Production Promotion Law (2002), and the Regulations on the Collection and Use of Sewage Charges (2002). The Law on the Prevention and Control of Environmental Pollution by Solid Waste (1995) was revised, and relevant standards were issued. Green laws and policies shifted from focusing on controlling and preventing pollution to giving full attention to the wider ecological and environmental impact brought on by industrial development. Legislation related to energy utilisation has also been significantly strengthened, shifting from an initial focus solely on end treatment to paying equal attention to prevention of pollution at the source of production, process control, and end treatment. Legislation also shifted from focusing on administrative control to paying equal attention to administrative and market control. During this period, the pace of transformation of Chinese enterprises visibly accelerated, and many green industrial products broke through foreign trade barriers and gained a share of the international market.

Stage 3: The mature period of green legal policies (from 2012 to now)

Since 2012, the construction of an ecologically friendly society has risen to the level of national strategy, and China's industrial development has entered a new period of comprehensive green transformation. In 2015, with the implementation of the Manufacturing Power Strategy, green industrial development was promoted to new heights, and green manufacturing was regarded as one of the five key national projects. The Environmental Protection Law, the Law of Prevention and Control of Water Pollution, and other important laws have been revised, and the legal protection system has been improved greatly. Policies implemented include the Manufacturing Power Strategy and the Plan of Green Industrial Development (2016–2020), and the Guide for Green Manufacturing Engineering Implementation (2016-2020).

Standards implemented include the General Principles of Green Product Evaluation, the General Principles of Green Factory Evaluation, and the Guidelines for Green Industrial Park Evaluation and Green Manufacturing. The green supply chain management guidelines for manufacturing enterprises and other standards have allowed for the integration of the green manufacturing system, green manufacturing demonstration model projects, and other support projects, creating a beneficial atmosphere for green transformation of enterprises. In this period, the issue of environmental protection received unprecedented attention. The relevant, green-orientated laws and policies reflect the necessary requirements for the construction of an ecological society, with an increasing number policies being proposed to match these new laws. Meanwhile, more attention is now paid to the application of market-orientated methods, especially the implementation in numerous fields of an environmental protection tax. The implementation of green laws and policies has been effectively promoted by the supervision of environmental protection and energy conservation. More enterprises are beginning to pay attention to and participate in the practice of green development, and the pace of industrial green transformation is speeding up.

3.3.2 GOVERNMENT PLAN

In terms of promoting green manufacturing, the Plan of Industrial Green Development (2016-2020) — a special plan to guide green industrial development during the 13th Five-Year Plan — has raised the banner of green industrial development and accelerated the formation of a work pattern for promoting green development. Centring on the five development concepts (innovation, coordination, green development, openness, and sharing), the plan puts forward 10 major tasks from both horizontal and vertical dimensions.

In order to implement the concept of green development, with due consideration for the inheritance and deepening of energy conservation and emissions reduction, four of the proposed tasks focus on:

- » Saving;
- » Cleaning;
- » Recycling;
- » Low carbon.

These, combined with several major national strategies and implementation of the five development concepts, led to the proposition of six tasks from the viewpoint of enhancing science and technology support capability, the construction of a green manufacturing system, regional green coordinated development, green manufacturing and the Internet, service platform construction, international exchanges, and cooperation.

The 10 tasks are not only important measures and powerful guarantees for implementing the concept of green development and promoting green industrial development. They are also the concrete embodiment of the five development concepts (innovation, coordination, green development, opening, and sharing).

Promoting energy efficiency

For this task, work is carried out from three aspects:

- » Structural energy saving;
- » Technical energy saving;
- » Management energy saving.

The work will focus on:

- » Promoting energy saving technological transformation;
- » Eliminating backward production capacity and equipment;
- » Promoting high-efficiency energy-saving products;
- » Carrying out energy efficiency benchmarking in key industries;
- » Improving energy saving regulatory system and market-oriented mechanisms;
- » Building a long-term energy saving development mechanism with orderly participation of government, enterprises, and social organisations.

Promoting clean production

For this aspect, the following actions should be carried out:

- » Technically transform clean production of the main pollutants to decrease key pollutant levels;
- » Organise and implement the demonstration and promotion of clean production technology;
- » Vigorously promote the green design of industrial products;
- » Carry out the substitution of toxic and harmful raw materials (products);
- » Innovate by way of policy guidance;
- » Increase policy support;
- » Improve the level of industrial clean production from the dimensions of point, line, and surface.

Strengthening the comprehensive utilisation of resources

In this area, the following actions should be carried out:

- » Promote the utilisation of industrial solid waste;
- » Promote the efficient utilisation of renewable resources and the standardised development of the industry;
- » Actively develop remanufacturing;
- » Comprehensively implement a circular mode of production;
- » Promote linkage, symbiosis, and collaborative utilisation among enterprises, industrial parks, industries, and regions;
- » Cultivate new energy for green development.

Reducing greenhouse gas emissions

Industrial emissions are a substantial contributor to climate change, meaning curtailing them is essential in order to make the transfer to lower carbon emissions. To this end, a pilot demonstration of industrial low-carbon development should be carried out to promote industrial low-carbon development.

Constructing a green manufacturing system

The following steps are necessary to establish and consolidate a green manufacturing industry:

- » Research and development of green products;
- » Transformation and upgrading of green factories;
- » The creation of green industrial parks;
- » The establishment of a green supply chain.

Furthermore, model green factories will be constructed to demonstrate the green manufacturing process. This will aid the construction of a 3D green manufacturing system with high efficiency that engages in recycling and emits clean, low carbon emissions. 100 green industrial parks and 1,000 green demonstration factories will be created to promote 10,000 kinds of green products and form a market-orientated promotion mechanism for green manufacturing.

Enhancing the supporting ability of science and technology

The government should promote green technological innovation by nurturing the green transformation of traditional industries and encouraging breakthroughs in key common technologies within the green manufacturing industries and increase the effective supply of green scientific and technological achievements. They should also promote the application of any green scientific and technological achievements, and actively organise the implementation of integrated and systematic green solutions that can coordinate energy conservation, consumption reduction, emission reduction, and pollution control. The green upgrading of industry by relying on scientific, technological, managerial, and business model innovation should be promoted. This will improve the manufacturing industry's international competitiveness and break trade barriers.

Fully embracing regional comparative advantages

In the process of regional industrial development, the following steps should occur:

- » Implement green standards;
- » Exploit regional comparative advantages to the full;
- » Strengthen regional cooperation;

- » Promote the green development of the regional industry.

For example, the Beijing-Tianjin-Hebei region and its surrounding area's Industrial Resources Comprehensive Utilisation and Industrial Collaborative Development Action Plan (2015-2017) was issued to promote the coordinated green development of the Beijing-Tianjin-Hebei region. It aims to build a system for the comprehensive utilisation of regional resources and for collaborative regional development, to improve the efficiency of utilising regional resources and energy, and to reduce pollutant emissions.

Further integrating green manufacturing with the Internet of Things

The aim is to improve the levels of intelligent management for energy, resources, and environmental protection, and promote the digitalisation of green manufacturing.

One goal is to promote intelligent energy management. Enterprises are encouraged to implement dynamic monitoring, control, and optimal management of energy consumption. This is especially the case for enterprises with equipment that consumes large amounts of energy through the application of the Internet of Things, big data, cloud computing, advanced process control, and other technologies. Promoting intelligent energy analysis will improve energy analysis, quota forecasts, and balanced scheduling, and refine an organisation's energy management. MIIT has carried out trial runs of online monitoring of levels of industrial energy consumption and promoted the construction of a platform for monitoring savings in industry energy levels nationwide.

Another aspect is to promote innovation in resource recycling, making use of the Internet of Things and big data to carry out information collection, data analysis and flow monitoring. The use of electronic tags will be encouraged, along with 2D codes and other technologies that rely on the Internet of Things, so as to track the flow of electrical waste and discarded electronic products.

Strengthen standards

Standards to create a green manufacturing system for products, factories, industrial parks, and the supply chain will be established. The formulation and revision of green standards in numerous fields, including energy and water consumption, industrial development, carbon emission, and clean production, will be sped up. MIIT has already issued its Guidelines for the Construction of a Standardised Green Manufacturing System, alongside an action plan, Standardisation of Energy Conservation and Green Development in Industry, and has also established a comprehensive standardisation system for green manufacturing.

Carry out international exchange and cooperation

Policies of cooperation between China and the EU, France, Italy and the US will strengthen interaction and exchange between bilateral and multilateral government departments, think tanks, guilds, and other relevant enterprises to strengthen international cooperation, carry out exchange training regarding advanced emission reduction technologies, policies and regulations, and explore effective mechanisms to encourage technology transfer and promotion. China-EU cooperation has carried out policy research on green ecological product design, while MIIT has cooperated with the Italian Ministry of the Environment to implement the Sino-Italy Industrial Energy Efficiency Training project and MIIT has held three consecutive sessions of dialogue on remanufacturing with the US Department of Commerce. Furthermore, in-depth exchanges on the remanufacturing trade, the market access regulatory environment, remanufacturing technology and standards, and remanufacturing industrial policies have been carried out. In projects involving extensive international cooperation, such as the Belt and Road Initiative, the concept of green development should be implemented and focus on global sourcing. Overseas green manufacturing and

green service rates through overseas investment, engineering contracting, technical cooperation, and equipment export should be promoted.

3.3.3 KEY STANDARDS FOR CHINESE GREEN MANUFACTURING

According to the Guidelines for the Construction of a Standardised Green Manufacturing System, focusing on key links of energy conservation and emission reduction within key areas of industrial manufacturing has already started, and nearly 1,000 standards within the field have been issued or are being formulated in China. Among them, under the guidance of think tanks and industry associations including MIIT, numerous standard research projects have been implemented to promote standards in the fields of energy conservation, water conservation, comprehensive utilisation, and green manufacturing. For example:

- » The General Principles of Green Factory Evaluation;
- » The General Principles of Green Product Evaluation;
- » The General Principles of Green Industrial Park Evaluation;
- » The Guidelines for Green Supply Chain Management of Green Manufacturing Enterprises.

The above are mostly recommended standards, which complement standards of pollution emission and energy efficiency, and together forming a standard system to promote industrial development. In turn, this system provides a necessary reference model for enterprises to carry out green industrial development.

3.3.4 THE REGULATORY SYSTEMS FOR GREEN MANUFACTURING IN CHINA

Environmental Impact Assessment

This refers to predicting and analysing the environmental impact that may be caused by the implementation of planning and construction projects. It also evaluates the methods and systems in place for putting forward measures for the prevention or reduction of adverse environmental impacts, along with tracking and monitoring these impacts. The system implements the relevant risk prevention requirements and is widely used to reduce damage caused to the environment by specialised planning and construction projects.

In China, there is specialised planning related to industry. The relevant departments of the State Council and local district governments at or above the municipal level shall assess the environmental impact of the special plans before the draft of the special plans are submitted to MIIT for approval. The report shall include forecasts and assessments of the possible environmental impacts of the special plan, and will lay out what prevention measures should be taken if there is any adverse impact.

As well as specialised planning related to industry, there are construction projects related to industrial development, and classification system has been adopted according to the environmental impact of industrial construction projects. If construction is likely to have a major environmental impact, a report shall be prepared to evaluate this impact. If it is likely to have a minor environmental impact, a report shall be prepared to analyse the environmental impact. If the impact is small there is no need for an assessment, a registration form of environmental impact shall be filled in. The environmental impact report includes the following content:

- » An overview of the construction project;
- » The current situation of the surrounding environment of the construction project;
- » Analysis and forecasts of the possible impact of the construction project on the environment;
- » The environmental protection measures in place for the construction project and its technical and economic demonstration;

- » The economic profit and loss analysis of the impact of the construction project on the environment;
- » The suggestions for the implementation of environmental monitoring of the construction project;
- » The environmental protection measures conclusion of impact assessment;

Professional institutions need to be entrusted for any assessments of environmental impact.

The Three Simultaneities system

The Three Simultaneities system oversees all newly built, reconstructed, or expanded basic construction projects, including small-scale construction projects, technological transformation projects, and all engineering construction and natural development projects that may cause pollution and environmental damage. It requires that such projects strictly implement measures to prevent pollution and ecological damage, and they must be designed, constructed, and put into operation in tandem with the main project. Meanwhile, these pollution prevention and control facilities shall meet the requirements of the approved environmental impact assessment documents and shall not be dismantled or left idle without authorisation.

Licences

This refers to the legal system in which the relevant environmental and resource authorities issue a qualification certificate or licence to units and individuals applying according to the Environmental Protection Law and other relevant laws and regulations. This licence allows them to engage in certain activities that have adverse effects on the ecological environment. Through the licence system the pollutant discharge behaviour of organisations within the industry is brought to the attention of the national management system, which aims to control the pollution discharge prevalent across the country and carry out targeted environmental management. In the field of industry, units that do the following must apply for a licence:

- » Discharge industrial waste gasses or any air pollutants stipulated by the state to be toxic or harmful;
- » Directly or indirectly discharge industrial wastewater into water bodies;
- » Operate central heating facilities;
- » Carry out centralised treatment of industrial sewage;
- » Carry out centralised treatment and disposal of refuse;
- » Carry out treatment and disposal of any hazardous wastes.

Permitted items include:

- » A quota for the type, concentration, and total amount of pollutants that can be discharged by pollutant discharging units;
- » A listing of the prescribed discharge mode, time, and location;
- » The environmental management requirements for pollutant discharging units.

According to the law, pollutant discharging units must obtain a pollutant discharge licence, and only discharge pollutants as stipulated by this licence. Those that fail to obtain a pollutant discharge licence and those that exceed the scope of the licence are deemed as illegal polluters.

Full disclosure of environmental information

Environmental information includes any sources of information from both the government and enterprises. Government environmental information refers to any recorded information produced by or obtained by environmental protection departments while performing their duties. Enterprise environmental information refers to the information recorded by and preserved by enterprises and related to the environmental impact

and behaviour of enterprises. The relevant laws and regulations (the Environmental Protection Law, Measures for Environmental Information Disclosure (trial), Measures for Environmental Information Disclosure of Enterprises and Institutions, Guidelines on Strengthening the Construction of Enterprise Environmental Credit System, and the Evaluation Report on Environmental Responsibility Information Disclosure of China's Listed Companies) all stipulate the issue of enterprise environmental information disclosure, and must be followed. As far as industrial enterprises are concerned, the main institutions required to disclose environmental information are enterprises with large amounts of emission and public companies.

The contents that should be disclosed are:

- » The name of the emission;
- » The company's emission mode;
- » Emission concentration and total amount;
- » Emission exceeding the prescribed limit.

In addition to the above mandatory environmental information disclosure, China also encourages enterprises to disclose the following environmental information:

- » Their environmental protection policy;
- » Annual environmental protection objectives and results;
- » Annual total resource consumption;
- » Any investments in environmental protection and environmental technology development;
- » Construction and operation of environmental protection facilities;
- » Treatment and disposal of wastes generated during the production process;
- » The company's recycling situation and whether or not they are attempting to utilise all waste products.
- » The voluntary agreement signed with the relevant environmental protection department to improve environmental behaviour;
- » The nature and extent of enterprises' social responsibility;
- » Any other environmental information voluntarily disclosed by enterprises.

Encouraging enterprises to disclose environmental information ensures that freedoms of information are protected for citizens, legal representatives, and other organisations, and strengthens the supervision of government and society on their pollutant discharge enterprises.

Eliminate outdated manufacturing technology and output

Technology must be improved to boost the efficiency of energy resources and reduce the emission of pollutants. At present, China mainly eliminates two types of outdated technology and equipment:

- » Technology and equipment that seriously pollutes the environment;
- » Article 46 of the Environmental Protection Law (Reviewed 2015) clearly stipulates that, "the state shall implement the elimination system for processes, equipment, and products that seriously pollute the environment. No institution or individual may produce, sell, transfer or use processes, equipment or products that seriously pollute the environment."
- » Technical equipment with high energy consumption;

- » The Law of Energy Conservation (Reviewed 2018) clearly stipulates that the state shall implement the elimination system for outdated energy-consuming products, equipment, and production processes. It prohibits the production, importing, and sale of energy consuming products and equipment that are officially eliminated by the state or do not meet the mandatory energy efficiency standards. It prohibits the use of energy consuming equipment and production processes that are explicitly eliminated by the state.

The eliminated technology and equipment are clearly defined by the above legal provision and the following catalogues issued by MIIT

- » The Catalogue of Obsolete or High-energy Consuming Mechanical and Electrical Equipment or Products;
- » The Catalogue of Obsolete High-energy Consuming Telecommunication Equipment.

Environmental protection supervision

In 2016, the Central Committee of the Communist Party of China and the State Council launched the Central Environmental Protection Supervision, now the Central Ecological Environmental Protection Inspection. They also carried out environmental protection inspection into the relevant departments of provincial party committees and governments, and promoted local party committees and governments to implement the main responsibilities of environmental protection. The parties under supervision are:

- » All party committees and governments of provinces, autonomous regions, and municipalities directly under the central government, and can be transferred to the relevant municipal party committees and their relevant departments;
- » The relevant departments of the State Council that undertake important ecological and environmental protection responsibilities;
- » The relevant central enterprises that are engaged in production and business activities that have a greater environmental impact;
- » Any other units that require supervision by the central government.

The contents of the inspection are:

- » Studying and implementing the policies of Xi Jinping Thought regarding ecological civilisation and implementing the new development concept, as well as promoting high quality;
- » Implementing the policies of the Central Committee of the Communist Party of China and the State Council on ecological civilisation construction and environmental protection;
- » Implementing the laws, regulations, policies, standards, and plans of the state's environmental protection;
- » Protecting the party of the ecological environment;
- » Implementing policy while assigning equal responsibilities of the party and government and the construction of a long-term mechanism for environmental protection;
- » Treatment of outstanding environmental problems;
- » The environmental deterioration of regional river basins and their improvement;
- » The legislation and reform of environmental problems as reflected by public sentiment;
- » Illegal interventions in the process of alleviating environmental issues, and ecological and environmental protection misdemeanours not being brought to justice.

Energy Conservation Supervision

This refers to the supervision and inspection of energy production, operation, and utilisation of companies and any other relevant enterprises. This will be for the implementation of energy conservation laws, regulations, rules, and mandatory energy conservation standards, to properly handle any illegal energy usage, and to put forward suggestions on energy use in accordance with the law. The contents of energy conservation supervision mainly include:

- » The establishment and implementation of an energy conservation target responsibility system, along with an energy conservation plan, management system, and technical measures;
- » The implementation of energy conservation evaluation and a review system for fixed assets investment projects, including the implementation of energy conservation evaluation and review, and the implementation of energy conservation review opinions;
- » The implementation of an elimination system for energy consumption in manufacturing equipment and the production process;
- » The implementation of mandatory energy conservation.

Supervision includes the following aspects:

- » The implementation of standards;
- » The implementation of an energy statistics, utilisation analysis, and reporting system;
- » The implementation of relevant systems such as the establishment of energy management posts and the appointment of energy management directors;
- » The implementation of an energy efficiency labelling system for energy using products;
- » The procurement and use of energy-saving products and equipment by public institutions and the development of an energy audit;
- » Engagement in energy-saving consulting, design, and evaluation of the energy-saving requirements and the authenticity of information given by institutions providing services such as assessment, testing, auditing, and certification;
- » Other matters that should be subject to energy-saving supervision as stipulated in energy-saving laws, regulations, and rules.

MIIT organises and implements the energy conservation supervision for national major industrial special projects in the field of industry and manufacturing.

3.4 KEY GREEN MANUFACTURING SECTORS AND COMPANIES

3.4.1 KEY SECTORS

3.4.1.1 ENERGY-SAVING AND CARBON-REDUCING TECHNOLOGY

Energy-saving industrial boilers

China produces and uses the largest number of boilers in the world. Industrial boilers can be divided into hot water boilers and steam boilers, according to their purposes. Based on the performance of the product, industrial boilers can be divided into steel industrial boilers, condensing industrial boilers, and vacuum boilers. At present, the China market needs energy-saving and low-pollution industrial boilers, that use clean fuel and clean combustion technology, with thermal efficiency exceeding 94% and that attain a Grade 1 energy efficiency standard.

Energy-saving transformers

The electronic transformer is a new type of electrical energy converter. It adopts the basic functions of traditional power transformers, like voltage conversion, electrical isolation, and energy transfer. Furthermore, it can regulate power quality, control the power flow within an electrical system, reactive capacity compensation, and carry out other additional functions. The rapid development of China's economy means an increased demand for electricity. As the main equipment in the power transmission and transformation system, transformer technology has developed significantly in China. The China market requires energy-saving transformers that have a high storage capacity and that are high-voltage, noise controllable, degradable, and recyclable, that meet Grade 1 energy efficiency standards, and decrease electrical wastage.

Energy-saving motors

Electric motors convert electric energy into mechanical energy. They use an electrified coil (stator winding) to generate a rotating magnetic field and act on the rotor (such as a closed aluminium frame squirrel cage) to form the electromagnetic torque. Currently, most of the motors produced in the China market are inefficient and consume a lot of energy. New energy-saving motors are needed that are highly efficient, industry-specialised, integrate multiple functions, and are of smaller size.

Energy-saving pumps

Pumps are mainly used in manufacturing for transporting liquids: water, oil, acids and alkalis, emulsion, suspending emulsion, and liquid metal. Gear oil pumps can also transport liquid-gas mixtures and liquid-containing suspended solids. At present, the China market needs small, noise-controlled, energy-saving, portable, automatic, and energy-saving pumps.

Energy-saving Air Compressors

China is the world's biggest producer of air compressors, yet few enterprises can produce high-end air compressor products. At present, large-scale, systematic, and energy-saving air compressors are needed in the China market.

Energy saving fans

This is a kind of fluid-controlled machinery that uses mechanical energy to improve the gas pressure and gas discharge. At present, the China market needs energy-saving fans that are high-pressure, powerful, noise-controlled, able to withstand high temperatures, and small in size.

Green data centres

Green data centres are the IT system, refrigeration, lighting, and electrical equipment in data rooms. Such equipment can maximise energy efficiency and minimise environmental impact. At present, the China market needs large-scale and new green data centres with PUE < 1.3.

Carbon Dioxide capture and storage

China's Five-Year Plan prioritises carbon capture and storage. At present, the China market needs CCU's capture technology with high absorbing efficiency. Each unit must be non-corrosive, have low regeneration energy consumption, and utilise any by-products.

3.4.1.2 TECHNOLOGY OF INDUSTRIAL WATER CONSERVATION AND UNCONVENTIONAL WATER RESOURCES UTILISATION

Circulating water treatment

Traditional circulating water treatment enterprises in China are mainly based on traditional processes, but the market needs more advanced technologies, such as non-phosphorus/low phosphorus water treatment and biodegradable technologies.

Sewage treatment and reuse (reclaimed water)

Sewage reuse refers to waste water or sewage reused in a production system for domestic miscellaneous use after secondary and advanced treatment. China's reclaimed water (sewage reuse) industry started late and has entered a stage of steady development. At present, advanced sewage reuse technologies such as membrane separation and concentrated processing-adding dispersant, among other technologies, are needed in the China market.

Smart water management

The development of China's smart water industry is still in its growth and exploration stage, and the industry is maintaining a trend of steady growth. At present, merging internet technology and big data with water conservation is needed in China.

Seawater desalination

Fresh water crises are seriously threatening the survival and development of many countries. This means seawater desalination technology is receiving unprecedented attention. Seawater desalination technology mainly includes seawater desalination, surface brackish water desalination, and industrial water desalination. At present, there is large market demand in China for seawater membrane modules, energy recovery devices, high-pressure pumps and some related raw chemical materials, seawater corrosion-resistant pipes, and steam injection devices.

3.4.1.3 ENVIRONMENTAL PROTECTION TECHNOLOGY

Equipment for the control and prevention of water pollution

In recent years, equipment to prevent and control water pollution in China is in the stage of rapid development, and the overall technical level of water pollution prevention and control equipment has been greatly improved. Some equipment, such as separation equipment, oxidation disinfection equipment, and domestic treatment equipment for the main product can basically meet the treatment requirements of general industrial wastewater and domestic sewage. At present, the China market needs advanced membrane treatment technology that offers the properties of bio-augmentation, low energy consumption, and high efficiency.

Equipment for the prevention and control of air pollution

Driven by a series of national energy conservation and environmental protection policies, along with strong domestic market demand, China's air pollution prevention and control equipment industry has maintained steady and rapid growth. In the future, with the increase of industrial investment, technological breakthrough, and scale accumulation, the development of air pollution prevention and control equipment will be accelerated. At present, there is high demand in the China market for high-end ambient air and pollution source monitoring equipment, industrial ultra-low emissions technology, low emissions vehicle manufacturing technology, clean combustion technology and equipment, fixed source VOCs purification technology and equipment, and dust pollution control technology and equipment.

Soil pollution remediation equipment

The treatment of polluted land is one of the most urgent environmental issues. In China, soil pollution control and remediation started relatively late and at present, there is high demand for thermal desorption, chemical leaching, and redox technologies for contaminated soil remediation.

Solid waste disposal

China's solid waste disposal industry started late with a relatively low degree of marketisation, and is still in the early stage of development. However, with the continuous improvement of environmental protection policies, the market size of the solid waste disposal industry in China has grown rapidly in recent years. The technology of solid waste treatment and disposal equipment in China needs to be improved, and there is high demand for sludge treatment technology and efficient anaerobic digestion technology.

Noise and vibration control equipment

With the revision of the Law on Prevention and Control of Environmental Noise Pollution (2018), the field of noise and vibration control has made further progress. At present, rail transit vibration isolation technology and equipment are the key directions of development.

Specialised instruments and meters for monitoring the environment

With the promulgation of the 13th Five-Year Plan for environmental protection and under the guidance of various new environmental policies, China's industry for instruments monitoring the environment has been developing steadily, and the industry concentration is gradually increasing. In the future, China's specialised instruments and meters for environmental monitoring will develop towards units that offer high quality, multi-functionality, small-scale integration, automation, systematisation, and intelligence. There is high demand in the market for high-quality analysers, special monitoring instruments, and automatic monitoring systems.

3.4.1.4 UTILISATION AND RESOURCE MANAGEMENT TECHNOLOGY

Manufacturing resource-recycling equipment

In recent years, the scale of China's renewable resources industry has continued to expand, and many renewable resources enterprises have developed and expanded, with industrial clusters forming in some areas. In the future, China plans to promote green standards, along with bolstering recycling services and collaborative development, as well as improving quality and specialisation, and the clustered development of the renewable resources industry. There is high demand within the market for harmless, refined, and high-value recycling technologies.

Equipment for the comprehensive utilisation of industrial solid waste

With the goals and related policies of promoting national green economic development, China's industrial solid waste utilisation industry is developing rapidly. The scale of the industry is gradually expanding, and the rate of utilisation is increasing year by year. High-tech processing, high performance, and high value are the main development directions for the future. Technology that integrates physics, chemistry, biology, and other disciplines of composite industrial solid waste comprehensive utilisation, as well as high-value technology for industrial solid waste comprehensive utilisation products, is needed in the China market.

Equipment for the comprehensive utilisation of mineral resources

In recent years, the intensity of mineral resources development and utilisation in China has increased rapidly. Mining and processing technology and equipment have been continuously improved, as has the utilisation level. It is worth noting that the renewable non-ferrous metal industry has seen rapid development. The scale of the industry has been expanding, and has entered a transition period towards recycling mineral

resources. At present, China needs high efficiency and low-consumption metallurgical processing technology and equipment.

Remanufacturing equipment

The remanufacturing industry developed relatively late in China, though it is now displaying a trend of further development. China has become one of the most important remanufacturing centres in the world, and is at the global forefront in basic theory research and technology application development. At present, China has had a number of remanufacturing technology achievements with independent intellectual property rights and has begun to carry out demonstration and pilot applications in the remanufacturing enterprises. In the future, China's remanufacturing industry aims to develop in a way which requires key technologies such as plasma, electron beam additive manufacturing, and 3D printing remanufacturing.

Kitchen waste utilisation equipment

With the rapid development of the catering sector and the corresponding growth in kitchen waste, there is huge market demand for the utilisation of emission-free kitchen waste. However, the size of China's kitchen waste utilisation industry is relatively small, and the gap between production and capacity is rather large. There is high demand in the China market for core technology and high-end supporting equipment for kitchen waste fertiliser.

Equipment for the recycling of packaging waste

As China is a nation with substantial levels of manufacturing and consumption of packaging, the packaging waste recycling industry in China has great development potential. There is high demand in the Chinese market for large-scale, efficient, and complete sets of wastepaper recycling technology and equipment.

3.5 EFFECTIVE COOPERATION MECHANISMS AND CASE STUDIES IN GREEN MANUFACTURING

In recent years, international cooperation in the field of green industrial development has continued to deepen in China. The exchange and cooperation mechanism has gradually improved, with Sino-EU, Sino-France, Sino-Italy, and Sino-South Korea bilateral exchange mechanisms have been running smoothly and regular docking in terms of policies, standards, technologies, and industries carried out. Dialogue with Spain, Greece, the Czech Republic, and many other countries is also being actively carried out. Meanwhile, through the green manufacturing partnership initiative, the global climate conference, and other activities, China is interacting with the world's top 500 enterprises and global stakeholders by constantly enriching the diversified and multi-level international exchange system. Pragmatic cooperation has also been steadily promoted. Relying on the positive interaction of multiple subjects, innovation, and flexibility in cooperation methods, and the focus and pragmatism of cooperation contents, international cooperation in the field of green industrial development has achieved remarkable results, forming several replicable cases and experiences.

3.5.1 EFFECTIVE MECHANISMS OF INTERNATIONAL COOPERATION

3.5.1.1 GRADUAL ESTABLISHMENT OF MECHANISMS FOR BILATERAL POLICY EXCHANGE

Taking bilateral cooperation between China and South Korea by way of example, in July 2014, Miao Wei (the Chinese Minister of Industry and Information Technology), and Yin Xiangzhi (윤상직) (the South Korean Minister of Industry, Trade, and Resources), signed a memorandum of understanding on industrial cooperation between the two ministries, and established a ministerial dialogue mechanism. The cooperation

areas included industrial policy, energy conservation and emission reduction, automobile manufacturing, machinery, new materials, petrochemicals, and IT. At present, three ministerial dialogues on industrial cooperation between China and South Korea have been held, and relevant industrial exchanges are deepening. In December 2017, MIIT and the Ministry of Industry, Trade, and Resources of South Korea signed the memorandum of understanding on strategic cooperation in the field of green ecological industry development, which made it clear that the two countries would strengthen cooperation in green ecological parks and other fields, and the two sides would strengthen cooperation in green industrial parks, clean production, energy efficiency, and other fields, so as to jointly promote the sustainable development of industries of the two sides. The signing of the memorandum will promote mutually beneficial cooperation in industrial energy conservation and green development, along with facilitating great interaction and jointly promoting win-win development. Under the framework of this cooperation, the two sides have held three green industrial development cooperation and exchange meetings and conducted extensive exchanges and discussions on topics such as the progress of green manufacturing policies, the implementation of green platform construction, industrial cooperation, a green supply chain, exhibition and training in green policies, and green industrial parks. The two sides agreed to jointly create a Sino-South Korea Green Industrial Park in Yancheng, Jiangsu province and Feicheng, Shandong province.

On the part of Sino-EU, during the Sino-EU Summit in November 2009, a memorandum of understanding was signed between MIIT and the EU General Department of Enterprises and Industry on the establishment of a consultation mechanism for the China-EU Industrial dialogue. This formally established a dialogue mechanism at the vice-ministerial level between the relevant government departments on both sides. Under the mechanism, five working groups have been established on small and medium-sized enterprises, industrial energy efficiency and emission reduction, raw materials, automobile manufacturing, and shipbuilding. Among them, the working group on industrial energy efficiency and emission reduction is co-hosted by MIIT and the EU Internal Market, Industry, Entrepreneurship and SMEs Department. It conducts policy exchanges in every year, with the location alternating between China and Belgium. It has successfully held 11 conferences, mainly focused on the latest green industrial policy and circular economy action plan issued by China and Europe. The key issues discussed in the conferences have included industrial development in areas of energy efficiency improvement, the recycling of power batteries for new energy vehicles, plastic recycling strategy, green design, waste management, and the remanufacturing of mechanical and electrical products. In 2013-2014, the ecological design and product policy project was jointly held by China and the EU; in 2017, at the eighth working group meeting, it was decided to jointly carry out an industrial product ecological design training course project, with a total of three phases.

In terms of cooperation between China and France, on 30th December 2009, during his visit to China, French Prime Minister François Fillon and Chinese Premier Wen Jiabao witnessed the signing of a memorandum of understanding on cooperation between MIIT and the former French Ministry of Economy, Industry, and Employment. This paved the way for the establishment of a Sino-French industrial, communication, and information cooperation mechanism. The two sides agreed to establish three working groups under the mechanism, surrounding small and medium-sized enterprises, industrial energy efficiency and emission reduction, and automobile manufacturing. As one of the three working groups, the working group on industrial energy efficiency and emission reduction is co-hosted by MIIT and the General Administration of Enterprises for the French Ministry of Economy and Finance. It conducts policy exchanges in turn in China and France every year. It has successfully held seven meetings, mainly focusing on the latest green industrial policies of China and France. The meetings also covered the practice of ecological design policies, the creation of green factories, and industrial waste investment. In-depth exchanges were conducted on issues

such as resource reuse and green supply chain management. At the sixth round of Sino-French high-level economic and financial dialogue held on 7th December 2018, the two sides reached a consensus on the development of green industry and proposed that under the framework of the green manufacturing working group established by the MIIT of China and the French Ministry of Economy and Finance, the two sides would encourage enterprises and scientific research institutions to standardise green manufacturing equipment, as well as the construction of green industrial parks, and green factories. Both sides welcome and support strategic cooperation between the international economic and technological cooperation centre of MIIT and Schneider Electric in the field of green and intelligent manufacturing.

In terms of China and Italy, in order to implement the memorandum of understanding on industrial energy efficiency cooperation signed by MIIT and the Ministry for the Environment, Land, and Sea of the Republic of Italy, the first meeting of the steering committee for Sino-Italian industrial energy efficiency cooperation was held in Beijing on 7th April 2016. In order to strengthen policy exchange and technical cooperation in the field of industrial energy conservation and green development between the two countries, the two sides held two Sino-Italian green industrial development forums in Beijing, China, in November 2017 and Milan, Italy in November 2018, respectively. Topics the forums focused on included:

- » Energy efficiency promotion policies;
- » Development trends and technical demands within the photovoltaic and automotive industry;
- » Experiences and comprehensive solutions on advanced energy conservation and environmental protection technology;
- » Energy conservation;
- » Financial service mechanisms.

According to the memorandum of understanding signed by the two sides, MIIT organised local relevant departments, scientific research institutes, relevant institutions, and enterprises responsible for industrial energy conservation and emission reduction to attend the Sino-Italian industrial energy efficiency training courses held in China and Italy.

In terms of China and the UK, Article 57 of the results of the Ninth Sino-British Economic and Financial Dialogue (released in December 2017) clearly states that MIIT and the UK's Department for Business, Energy and Industrial Strategy should cooperate to encourage exchanges and dialogue between the two sides. At present, both sides are exchanging views on the establishment of a mechanism. At the same time, industry discussions between the two sides are also being actively carried out. By taking advantage of the Sino-British Green Manufacturing and Remanufacturing Industry Development Summit held in China and the Sino-British Future Manufacturing Seminar and Remanufacturing Seminar held in the UK, the two governments' relevant departments, research institutions, industry associations, and enterprises had beneficial exchanges.

In addition to the above mechanism exchanges, dialogues on green industry and low-carbon development are also being carried out with the US, Spain, Greece, the Czech Republic, and other countries.

3.5.1.2 UNDERTAKING BILATERAL AND MULTILATERAL EXCHANGES AND COOPERATION

In terms of international implementation, China earnestly implements the UN Convention Framework on Climate Change, the Stockholm Convention, the Minamata Convention on Mercury, and other international conventions. The 23rd and 24th United Nations Climate Conferences and other multilateral exchange platforms were actively used to hold activities like China Corner, and beneficial exchanges were conducted with representatives of participating international institutions and organisations on the practice of

promoting high-quality development of the industrial economy through green industry and low-carbon transformation.

In terms of communication in various fields, in industrial energy efficiency, China has hosted and participated in relevant conferences and forums. It has conducted extensive exchanges with Italy, the US, Brazil, the United Kingdom, Germany, Chile, and other countries on industrial energy efficiency, motor system energy efficiency, automobile industry energy efficiency, and green data centres. In the field of the comprehensive utilisation of resources, China has actively participated in international recycling conferences in the US and the Middle East, where China conducted discussions on the extension of manufacturer responsibilities, recycling resources in the automotive industry, and recycling renewable resources with a list of countries which includes the UK, France, the Netherlands, Sweden, Belgium, Finland, South Korea, and Japan. In the field of remanufacturing, China carried out policy and technical exchanges on multilateral (APEC) and bilateral (Sino-British) platforms, while in the field of water conservation, China held in-depth exchanges and discussions with Australia, Singapore, and other countries concerning industrial water-conservation related issues.

3.5.1.3 THE ORDERLY IMPLEMENTATION OF INTERNATIONAL COOPERATION PROJECTS

China has actively engaged with international organisations advocating for sustainable development and jointly developed international cooperation projects, such as the Project of Promoting Energy-Efficient Electric Motors in Chinese Industries (PREMCI) with the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF). Through policy research, pilot demonstration, training, and other project activities, PREMCI improves China's high-efficiency motor production capacity, speeds up the promotion and application of high-efficiency motors in the industrial field, and boosts the green development of industry. At present, the project is under implementation. China has cooperated with the World Bank to conduct research on the innovation of government green manufacturing management mechanism of China's economic reform promotion and capacity enhancement project (TCC6). The project is being implemented in order to explore the innovation and development of the green manufacturing management mechanism through the government's mechanisms for management, market promotion, the development for merged Internet plus green manufacturing, and public service capability improvement. The South-South Cooperation Project for energy conservation and environmental protection industry is carried out with the United Nations' Industrial Development Organisation (UNIDO). China will promote the utilisation of waste heat from cement kilns and efficient refrigeration in the food industry to Indonesia and Thailand and other Belt and Road Initiative countries through seminars, enterprise docking, and other activities. It will contribute to the upgrading of the green development of industry in Belt and Road Initiative nations and the further development of the regional green industry.

3.5.2 RELATED CASES

3.5.2.1 CREATING COOPERATIVE EXECUTION PLATFORMS AND THE INTEGRATION OF PRODUCTION, STUDY, RESEARCH, AND APPLICATION RESOURCES

Under the framework of the exchange mechanism of relevant government departments, the establishment of an industrial cooperation implementation platform by both sides is conducive to promoting the docking and cooperation of China and foreign industries. For China and South Korea, in May 2018, during the third ministerial dialogue on industrial cooperation between China and South Korea, witnessed by Minister Miao Wei of MIIT and Minister Bai Yunkui (수상) of the South Korean Ministry of Industry, Commerce and Resources, the heads of the Chinese International Economic and Technological Cooperation Centre of MIIT

and the National Clean Production Centre of South Korea signed a memorandum of understanding on cooperation. The two sides will jointly build a cooperation and implementation platform for green industry between China and South Korea, so as to strengthen practical cooperation in green industrial parks, clean production, and green manufacturing partnership. At present, the implementation platform of Sino-South Korean green industry cooperation is to actively promote the construction of the Sino-South Korean (Yancheng and Feicheng) Green Industrial Parks, and promote exchanges between research institutions, industry organisations, and enterprises of both sides.

In terms of China and France, according to the consensus reached by MIIT and the General Administration of Enterprises for the French Ministry of Economy and Finance, under the framework of the Sino-French cooperation mechanism joint committee, China and France have designated the International Economic and Technological Cooperation Centre of the MIIT and the Future Industry Alliance of France as the implementation platform of Sino-French industrial cooperation. This is responsible for coordinating resources from all walks of life, carrying out docking cooperation, and publicising achievements of Sino-French industrial cooperation. The Sino-French platform has successfully established a Sino-French modern industrial partnership, released three batches of Sino-French industrial cooperation demonstration projects in the fields of intelligent manufacturing, green manufacturing, education and training, and held a Sino-French industrial cooperation roundtable.

In order to implement the consensus reached by the leaders and industrial authorities of China and the UK, and to promote the strategic docking and practical cooperation of green industries between the two countries, the Centre for International Economic and Technological Cooperation (situated within the Chinese Ministry of Industry and Information Technology) and the British Federation of Industry and Commerce, jointly initiated a Sino-British modern industrial cooperation partnership. This aims to build a platform for modern industrial exchanges and cooperation between the two countries and achieve win-win development.

3.5.2.2 PROMOTING THE CONSTRUCTION OF GREEN INDUSTRIAL PARKS AND STRENGTHENING THE PLATFORMS FOR INDUSTRIAL COOPERATION

In order to implement the memorandum of understanding on strategic cooperation in the field of green ecological industry development signed by China and South Korea, MIIT and the South Korean Ministry of Industry, Commerce and Resources are promoting the establishment of green industrial parks in Yancheng, Jiangsu province and Feicheng, Shandong province. With the support of the competent departments of the two governments, a team of experts (from MIIT's Centre for International Economic and Technological Cooperation, the Chinese Academy of Social Sciences, Tsinghua University, the National Clean Production Centre of South Korea, Yushan University of South Korea, and the Yushan Ecological Industry Development Centre) have set up an expert group to actively promote the preparation of the construction plan for the Sino-South Korean green industrial parks in Yancheng and Feicheng. In July 2019, a group of experts from China and South Korea visited Yancheng and Feicheng to evaluate the development status of the parks, the characteristics of the industry and the basis of cooperation between China and South Korea and discussed the idea with local governments and relevant enterprises of creating a green industrial park. In November, China organised a visit to South Korea for the experts and responsible officials from Yancheng and Feicheng to visit the Korean Clean Production Centre, Yushan University, and the Yushan Eco-Industrial Park. On 11th–12th of November, experts from the Yushan Ecological Industry Development Centre of South Korea visited Feicheng to inspect two enterprises, Shiheng Special Steel and Yiteng New Material, and promoted the application of industrial symbiosis technology in the project of chemical oxygen demand carbon source

replacement and the utilisation of industrial wastewater, along with the project of silicon fertiliser transformation using slag from blast furnaces. In July 2019, China and South Korea organised an exchange seminar on the evaluation standards of green industrial parks between China and South Korea in Beijing. Experts from research institutions and universities of the two countries exchanged evaluation standards for green industrial parks and discussed the formulation of evaluation standards of green industrial parks between China and South Korea - four indicators were formed covering industrial park management performance, economic performance, environmental performance, and social performance.

3.5.2.3 IMPLEMENTING A SERIES OF TRAINING PROGRAMMES TO PROMOTE THE EXCHANGE OF KNOWLEDGE & TALENTS

The Sino-EU Industrial Product Eco-design Training Project is an important cooperation achievement of the Sino-EU industrial dialogue and consultation mechanism. Since the eighth meeting of the Sino-EU industrial dialogue, MIIT and the European Commission's Department of Internal Market, Industry, Entrepreneurship and SMEs have jointly carried out three training sessions. The first phase was held in Kunming in July 2019; the second in Brussels in September 2019; and the third carried out online due to the impact of Covid-19, with expert seminars and online training sessions held from October to November 2020. Lectures were designed for the three training programmes. Experts from China and Europe introduced the latest progress in ecological design policies and regulations, standard formulation, and market supervision measures, and shared the successful case studies of Lenovo, NAEs, Bosch, and other Chinese and European enterprises in ecological design. In the second and third training programmes, experts from both sides discussed the commonalities and differences in policies and methods between China and the EU, the regulation of the eco design/energy labelling market between China and the EU, and the potential for cooperation between the two sides.

The Sino-Italian industrial energy efficiency training project aims to strengthen exchange and cooperation in the field between China and Italy, to study and exchange the experience and best practice of industrial energy efficiency management in the EU and Italy, and improve the energy efficiency management level of Chinese industrial enterprises. The training course was held six times in China and Italy. Its contents included introducing trainees to:

- » Italian government practices in promoting industrial energy efficiency;
- » Italian government practices in implementing the EU's industrial energy efficiency policy;
- » The Italian professional energy manager system;
- » The management, technology, and methods behind Italy's industrial energy audit;
- » The application of zero energy consumption buildings in Italy;
- » The practical application of energy management system, energy saving projects, and financing based on Italy's practice of investment mechanism;
- » The technology of cogeneration and CCHP in the industrial field.

A case study on Leonardo S.p.A's energy conservation was carried out. Advanced enterprises in the field of energy conservation and emission reduction, (such as Dolomite Ceramic Sanitary Ware Factory and Dobden Co Ltd), were investigated. The training course helped Chinese representatives deepen their understanding of foreign energy efficiency management policies and advanced technologies, to broaden their international vision, improve their management ability, and create cooperation opportunities.

3.5.2.4 GATHERING THE CONSENSUS OF LEADING INDUSTRIAL ENTERPRISES TO BUILD A MODEL FOR GREEN MANUFACTURING

In July 2017, the Green Manufacturing Partnership initiative was launched in Beijing. It aimed to encourage leading enterprises with a strong green manufacturing capacity, a high degree of internationalisation, wide product coverage, and strong industry driving ability to issue their own statements or voluntary commitments, and also put forward specific goals and plans, for practicing social responsibility and accelerating green development. This initiative was received positively and has widely involved experienced leading industry enterprises with track records for significant achievements in the field of green development. On 5th July 2019, during the Sino-French Industry Roundtable - witnessed by Xin Guobin, Vice Minister of Industry and Information Technology, the Director of the General Administration of Enterprises of the French Ministry of Economy and Finance, Schneider Electric Group, and Dongfeng Motor Group - put forward the goal of accelerating the green development of enterprises, and it has become one of the first model enterprises responding to the Green Manufacturing Partnership initiative in the field of Sino-French cooperation. Both Schneider Electric Group and Dongfeng Motor promised to:

- » Apply the latest green design and manufacturing technology to all factories in China and implement the latest green manufacturing standards;
- » Actively play a leading role in promoting green supply chain management to drive upstream and downstream enterprises to achieve common green development;
- » Promote green international cooperation to boost the leading role of green manufacturing advanced technology and equipment.

The effective combination of import and export will realise the complementary advantages of green manufacturing concepts, technologies, standards, and management at home and abroad. Schneider Electric Group and Dongfeng Motor Group will strive to become the practitioners and leaders of green manufacturing and contribute to the green development of industry.

The Centre for International Economic and Technological Cooperation of MIIT and Schneider Electric signed a strategic cooperation in the field of green and intelligent manufacturing, which became one of the achievements of the sixth Sino-French financial dialogue. In 2018-2019, the two sides jointly held a seminar on leading sustainable development in green manufacturing and a training activity on the interpretation and implementation of green supply chain management policies and technological innovation between China and France. This seminar strengthened cooperation and the exchange of information and experience between Chinese and French enterprises, building a platform for further cooperation between enterprises from both sides. On 28th October 2019, in order to implement the Green Manufacturing Partnership initiative and strengthen Sino-French green manufacturing technology exchange and industrial cooperation, the Centre for International Economic and Technological Cooperation of MIIT and France's Schneider Electric Group jointly held the Green Manufacturing Partnership model experience exchange meeting in Beijing.

4. CONCLUSIONS

China is the largest manufacturing nation in the world. While making great achievements in its industrialisation, it faces tremendous challenges such as massive energy consumption, a deteriorating environment, and air, water, and soil pollution. Therefore, green manufacturing has been designated by China as a key route to enabling sustainable development in the country. China considers some areas to be key in the push towards green manufacturing: energy saving, carbon reduction, industrial water conservation, unconventional water resource utilisation, environmental protection, and the comprehensive utilisation of technology and resources. The UK, on the other hand, is the ninth largest manufacturing nation in the world. Looking at the entire product life cycle, the strengths of UK manufacturing are attributed to the early-stage strengths R&D, design, and technology, and also to later-stage strengths in areas such as servitisation, end-of-life innovation (e.g., repurposing and upcycling), and high value manufacturing. On the other hand, China's manufacturing strength is associated with the middle of the life cycle, such as the production and distribution, and also the benefits of low-cost and large-scale production, which leads to a larger carbon footprint. There is tremendous potential to leverage resources beyond governmental support and involve multiple stakeholders to work together to deliver innovation and improve sustainable manufacturing in China and the UK.

4.1 BUSINESS AND TECHNICAL COLLABORATION OPPORTUNITIES BETWEEN CHINA AND THE UK

4.1.1 INVESTMENT AND BUSINESS OPPORTUNITIES FOR CHINA AND THE UK

In the continuous strive towards green manufacturing, the combination of Chinese and British strengths could form a synergistic partnership which could accelerate the pathway to industrial sustainability and the elimination of waste. The following recommendations are made for business and investment opportunities in China and the UK:

1. The preparation of a directory of green manufacturing businesses in the UK: The directory will ease the search for required products, technologies, and services for interested parties from China. It will be highly beneficial for the Chinese side to provide information on the addressable market size and the priorities of demand.
2. Candidate companies: As a first step, 30 British companies listed in Section 2.4.2 could provide the first batch of green manufacturing businesses for trading or investment. Given the present issue of Covid-19, most companies will welcome investment to ensure short-term cash flow and long-term new product development. More attention could be given to newly-started innovative businesses where the need for investment is the strongest.
3. Business representation in China: A small number of companies outlined in Table 8 already have branch offices in China. For those without such a presence, the possibility of partnership or having a sole agent in China could be explored. With the right product, China could offer enormous market opportunities.
4. Business risks: Since the business environments in the UK and China are not identical, due to cultural and social differences, not every British green manufacturing company could be transplanted to China.

The issues of customer needs and business risks have to be fully considered during the investment phase.

4.1.2 TECHNICAL COLLABORATION OPPORTUNITIES FOR THE UK AND CHINA

The UK has a strong science and engineering base actively engaged at the frontier of new ideas and technologies. With a common interest in materials and energy efficiency, there are huge opportunities for technical collaboration between UK and China. Such collaboration could cover all aspects of green manufacturing but for practical reasons, a step-by-step approach is more realistic and achievable. A number of considerations need to be taken for such technical collaborations and they are outlined as follows:

1. Identification of green manufacturing topics: Green manufacturing has a very wide coverage from business model to servitisation, design to virtual reality, manufacturing to remanufacturing. With such a long list, it is advisable to select a small number of related technical, modelling or analysis topics for collaboration, for instance, design for green products, multi life cycle modelling and economics of green manufacturing.
2. Framework for collaboration: It is very likely that the nature of collaboration will be pre-competitive and hence at a lower technology readiness level. The unit of collaboration could be in the form of a joint project for two parties and a joint network for multi-parties. The parties involved could be a research centre, an RTO (research and technology organisation such as the Manufacturing Technology Centre), a university department, an industrial business or a combination of such bodies. A balanced approach to collaboration in the form of an equal number of projects led by the UK and China will provide a good starting point.
3. Compatibility, communication and co-ordination (3C): Technical collaboration is human-centred activities and compatibility between partners, i.e., forming a partnership with the right chemistry, is therefore essential. A high level of communication skills, most likely in English, is a pre-requisite. Use of modern IT support for co-ordination in a remote project environment for tracking exchanges, dynamic updating of documents, and informal communication will be highly beneficial.

4.2 RECOMMENDATIONS FOR POLICY MAKERS

4.2.1 TECHNICAL COLLABORATION OPPORTUNITIES FOR THE UK AND CHINA

1. Integrated strategy and policies: Developing a long-term strategic plan which integrates the different existing policies and supports an optimum system for delivery of green manufacturing vision. This will link industrial strategy, clean growth, and circular economy and other instruments. This aims to facilitate the consideration of resource nexus, capturing, and managing interdependencies.
2. Supporting international supply chains: Extend the idea of a country-wide circular economy to international circularity. The synergising of international policies and market instruments can help deliver green manufacturing, especially when considering scope 3 emissions and the embodied impacts of products and materials when they cross national boundaries. This also broadens the solution space and business opportunities when considering products in a circular economy.

3. Responsible innovation and the sustainability pillars: A truly sustainable policy framework has to consider the three pillars and how to progress them simultaneously while minimising the unintended impact outside the system being considered. It is recommended that policy frameworks and market instruments include a process of responsible innovation, reflection and assessment of the rebound effect considering the present and future needs, and the long-term vision for sustainable futures.
4. Supporting access, diversity, inclusion, and equality in innovation: Policy developers and market instruments have a role in promoting access, diversity, inclusion, and equality in innovation and in the economy. The development of green manufacturing and digitalisation presents timely opportunities for nation states to promote and support multidimensional diversity and a stronger base for social benefits of innovation. The Women in Innovation Awards established by Innovate UK is an exemplar which can be further expanded.

4.2.2 RECOMMENDATIONS FOR INDUSTRY

1. Comprehensive net zero targets: Commitment and development of zero carbon targets and pathways taking into account Scope 1 and 2 emissions and low carbon targets (near zero) based on Scope 1, 2, and 3 emissions.
2. The circular economy as the norm: The circular economy presents an opportunity for supporting green manufacturing as well as a platform for innovating products and services. Realisation of this vision will help companies make the most of the clean growth strategy.
3. The visible and invisible plastic waste challenge: One of the biggest challenges to the circular economy is the impact of plastic waste and invisible micro and nano plastics in our environment, water systems, and potentially food. In addition to focusing on net zero carbon transition, there is a strong need to consider plastic footprints and related innovations.

4.2.3 RECOMMENDATIONS FOR RESEARCHERS

1. Net zero carbon manufacturing and built environment science: Development of the underpinning science and roadmap to enable companies to transition from national targets or planetary boundaries to local targets and manufacturing systems for zero carbon manufacturing.
2. Metrics and standards: Development of metrics, consensus, and international standards for the evaluation and benchmarking of green products, services, supply chain, and factories.
3. A smart and resilient green industry: Development of the scientific base for smart and resilient green industry as the next step to Industry 5.0, new developments in AI, computing, and circular economy will be fully exploited across industry.
4. A focus on green design: The circular economy is a key area of focus for researchers. The design and assembly of products and vast range of materials present fundamental challenges for realising circularity. There is an urgent and timely need for researchers to consider design and manufacture for circularity to ensure that green products and green energy solutions are also optimised within a circular economy.

4.2.4 RECOMMENDATIONS OF CHINA-UK ACTION PLANS FOR THE NEXT YEARS

1. Set up an annual high-level government meeting for creating a three-year plan on trade/technical/educational issues in the area of smart, resilient and digitalised green manufacturing, and the circular economy within the context of a post-Covid-19 economy. New and co-ordinated initiatives will be formulated, implemented, and the impact of such initiatives will be measured and assessed for decisions on the second three-year plan.
2. Launch a virtual green manufacturing show with at least 50 companies from each country of UK and China. Each participating company will provide a video highlighting its latest and best product/services. In addition, a total of 20 presentations will be included in this virtual show. The sole purpose of this activity is to facilitate commercial and trade activities in all aspects of green manufacturing.
3. Prepare a virtual directory of green manufacturing covering products, technologies, services, education, and training aspects to will enhance the publicity and international promotion of British know-how in green manufacturing.
4. Hold a virtual forum on the UK/China green manufacturing for both academic and industrial researchers. The purpose of this forum is to promote research and development collaboration with British and Chinese enterprises/research and technical organisations/universities engaged in green manufacturing.

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