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Sustainability and manufacturing

Future of Manufacturing Project: Evidence Paper 35

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Sustainability and manufacturing

By

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Contents

Executive summary

The aim of this report is to outline the challenges and opportunities available to UK manufacturing in a future world that is projected to be resource- and carbon-constrained.

This report describes the world in 2050 through the lenses of four key drivers: population growth, climate change, material availability and water supply. These drivers will present challenges globally, but concomitant economic opportunities will arise. Opportunities in the transportation, aviation, construction and the food sectors are presented here alongside the UK manufacturing sector's response. Finally new business models that may have a role to play in creating value as the sectors move further towards novel sustainability solutions are described.

Methodology

This paper is a synthesis of secondary and some primary literature. Where possible well-regarded sources have been used, including government documents, consultancy reports and opinions from manufacturer trade associations. All the work otherwise presented is my interpretation of the literature.

Caveats

The political construction of the climate change debate is such that historical focus has been predominantly on the emissions of greenhouse gases (GHGs) that result from human activities. A large amount of data related to GHGs is thus available. A focus on these however does not reflect the full sustainability impacts of products or services. Data on water and ecosystem impacts is extensive in some sectors and sparse or non-existent in others. Social impact data is both sparse and difficult to both quantify and qualify. As such this paper is necessarily missing important data that is not available for collection, but this could be remedied with extensive research effort. Coupled with the task itself, projecting impacts into the future and drawing inferences from those related to the UK manufacturing sector in the context of global competitiveness, all data and interpretations should be considered best informed guesses *that are open to revision* as they contain significant uncertainty as the time horizons extent further into the future.

1. Introduction: the world in 2050

By 2050 it is likely that there will be profound changes in the environment and the way people live and work as the global population rises, greenhouse gases continue to be emitted and materials used in a similar way as today. Driven by an increasing population, resource use and concomitant carbon dioxide emissions will grow under a business-as-usual trajectory, pushing the world over 2°C average warming and possibly up to 4°C – 6°C, with predicted catastrophic effects at the extreme.

Material resources are likely to be scarce, posing significant problems for manufacturers. Although not physically scarce prices will rise as easily-exploitable sources are depleted. Compounding this demand for land and water for agriculture and industry will grow, leading to conflict as natural resources are prioritised to society's basic needs over industry.

An increase in the incidence of extreme weather events may render large areas of landmass uninhabitable for much or all of the year, concentrating the population and industry into ever-growing urban areas that are less resilient to unpredictable shocks and risking supply chains. This lack of resilience may increase the risk of supply chain disruption with consequences for manufacturers globally.

These projections take historical growth and efficiency trends into account and infer that business-as-usual, in this case a drive to efficiency is a necessary, but not sufficient response to future sustainability challenges. There are opportunities for UK manufacturing to capture significant short-term and long-term value if they embrace both efficiency initiatives and radical innovation. This, however, will require appropriate policy support, which is currently lacking.

Uncertainties in impacts

Projections presented in this paper are a result of extensive modelling efforts and, as models, are simplified representations of the world; they contain inherent uncertainty. While a scientific consensus position is held on the anthropogenic nature of climate change there is little data quantifying the impacts and estimates of these impacts range on average from -4.8% to +2.3% of global GDP (Tol, 2012). Advances in probabilistic modelling are improving these estimates, but many measurable data are currently scarce or unknown. Using such a model on previously reported impacts of climate change on social welfare Tol (2012) estimates that if global temperatures rise by 2°C there will be a 37% chance of a net negative impact on global GDP, rising to 93% at 3°C. By analogy the data presented on market share for the UK manufacturing sector into a highly volatile future are highly uncertain, with unknown error bounds.

2. "Megaforces" will drive future direction

A number of environmental "megaforces" will be key drivers for business change to 2035 and beyond (KPMG International, 2012). These include climate change, population growth, energy and fuel, material resource scarcity, water scarcity, urbanization, wealth, food security, ecosystem decline and deforestation. Each of these *individually* is predicted to have a significant impact on the way we do and can do business, but it is critical to understand that the drivers are *irreducibly* inter-related. They influence each other in complex, unpredictable ways and cannot be disentangled to elucidate determinate cause-and-effect relationships. This has implications in that industry will have to conceive of business propositions and technologies that satisfy multiple constraints simultaneously.

2.1 Megaforce: population growth & urbanisation

In 2050, there will be 3 billion more people in the world. The population will be older, richer and predominantly urban, providing an opportunity for UK export-driven growth. Unsustainable population growth is considered to be a key driver that put societies at considerable risks (World Economic Forum, 2012a) and if consumption levels are positively correlated with population growth this will place an unprecedented burden on the environment and on society. For industry, this is an exogenous factor that has to be adapted to, but will provide significant growth opportunities.

Pressures

The global population is predicted to rise to over 9 billion by 2050 (UN, 2011). Major increases in population will be seen in Africa, South Asia and the Middle East (OECD, 2012). Without intervention a growing population will require 2.1 planets' worth of resources by 2030 and 2.9 planets by 2050 (WWF, 2012) equivalent to an increase in demand in water by 140% and land by 250% by 2030 (McKinsey Global Institute, 2011).

There will be extra demands on agricultural land for cereal crops and for animal products. The increased population will require 55% more water to meet its needs. Manufacturing will draw 400% more water, thermal electricity 140% more and domestic use 130% more. This will result in groundwater depletion in some areas and may be a threat to agriculture and urban water supplies, with 6.5bn living in water-stressed areas. Meeting this demand will put food production in competition with other sectors, including industry, biofuels and infrastructure development.

It is projected that over 6 billion people will live in urban areas and 0.6 billion fewer in rural areas by 2050 (UNCSD, 2012a), accounting for 70% of the global population (OECD, 2012). The energy demanded by the increased population is projected to increase by 80%, with fossil fuels providing 85% of the energy mix, further exacerbating climate change as more greenhouse gases are released into the environment (OECD, 2012). Although urbanisation should allow for better management of scarce resources an increasingly urban population will experience a warming world with increased competition for land, food and natural resources, water stress, traffic congestion and health issues. Extreme weather events, as a consequence of global warming, will result in increased vulnerability in urban areas due to concentration of people and assets, especially transportation and infrastructure that is located near coastal regions. This may have significant indirect effects on UK manufacturing if supply chains are disrupted (UNISDR, 2013).

Localised urban heat waves and air pollution from transport and cooling will increase death rates especially in, but not limited to, the elderly (IPCC, 2012). As the rate of urbanisation and pollution increases, premature deaths will double to 3.6 million per annum, predominantly in Asia. The OECD is likely to have the second highest rate of premature deaths due to pollutants after India.

Compared to 12% today, by 2030 33% of the global population is predicted to be over the age of 60 years, rising to 38% in 2050 (UNCSD, 2012b). In the UK it is projected that by 2033 there will be 2.8 people of working age for every pensioner, down from 3.2 in 2008 (Cracknell, 2010). Countries with a higher proportion of younger people will have a comparative advantage of a more active workforce and the UK's shrinking workforce could impact manufacturers that do not adapt.

World GDP is projected to quadruple by 2050, with the fastest rises seen in Africa and in BRICS countries. Growth in GDP between 2010 – 2030 will be driven by an increase in buildings, machines and infrastructure, which implies an increase in energy and resource demand. Industry will grow faster in non-OECD countries than OECD, while services will grow faster in OECD countries. The WBCSD (2008) estimates that there will be approximately 4 billion middle-income consumers in the world by 2030. This could be seen as an unprecedented opportunity for business growth, but may come at a cost if Western consumption habits are duplicated in developing countries. Under a business as usual scenario, where energy and material efficiency increase in line with population there is the chance of likely and significant impacts to the planet that could act to reduce average world consumption per capita by 14% by 2050 (OECD, 2012).

It is unlikely that the planet can support the level of exploitation associated with a rising population consuming at the same level as occurs in post-industrialised countries today. National GDP is predicated on consumption-led growth and there is little appetite in the West to consume differently. UK manufacturers, and business in general, need to find ways of deliver the same products with vastly reduced impacts and also to shift to different modes of consumption, including selling performance and service provision instead of goods. Consumer behaviour change is a critical dimension in this debate and effective programmes for change will require that social scientists be given equal footing with scientists and engineers so that the issues can be tackled in an informed manner.

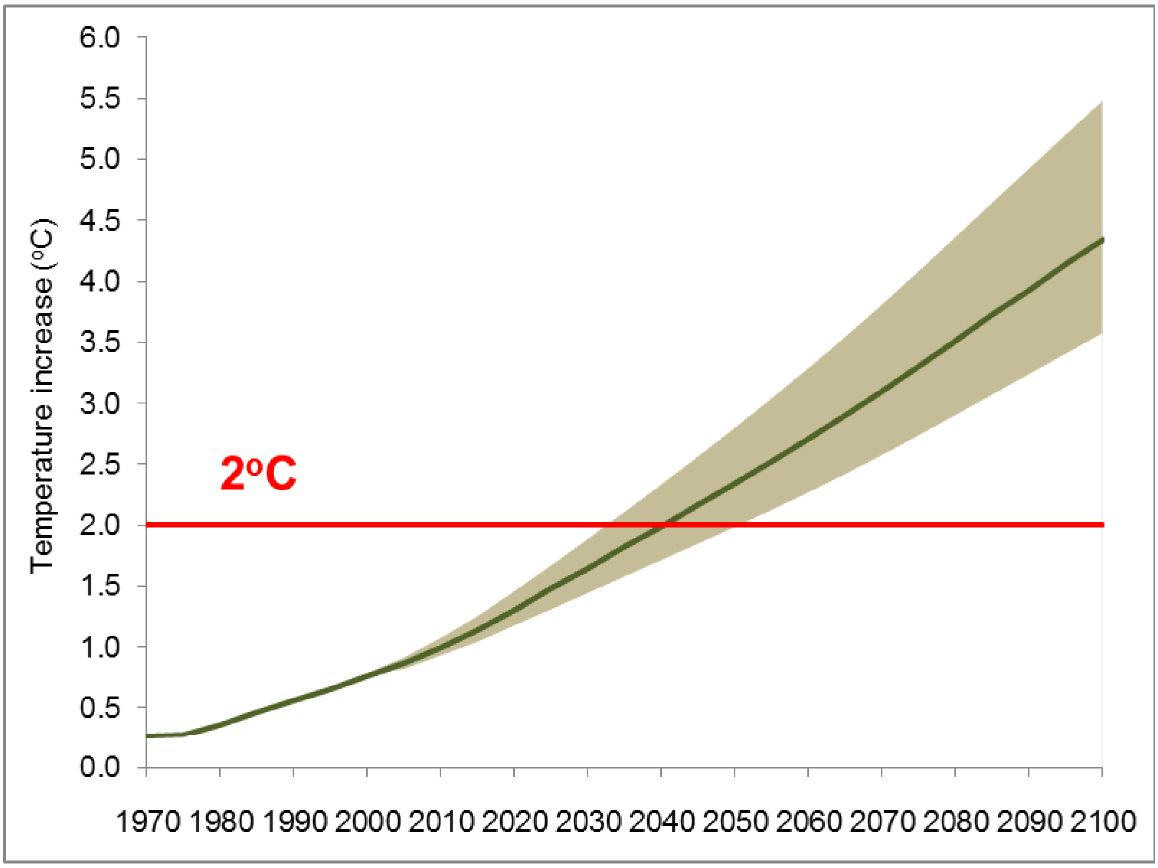
2.2 Megaforce: climate change

Climate change is projected to result in an increase in average global temperatures, extreme weather events and a disruption of water availability, with potentially significant implications for manufacturing if resources are diverted to maintain the basic needs of the human population. Manufacturers will need to develop ultra-efficient processes and products that emit far fewer greenhouse gases as well as manage for potentially unpredictable supply chain risks.

Pressures

A consequence of an increasing population burning fossil fuels on a business-as-usual trajectory is that atmospheric greenhouse gas emissions (GHG) will continue to rise despite overwhelming scientific evidence that suggests that inaction to abate emissions will have potentially catastrophic consequences on the biosphere and on humanity's' ability to adapt to a warmer planet (Figure 1). It is considered "extremely likely (>95%)" that human activities are responsible for this warming (IPCC, 2007) and this is reflected in by an overwhelming expert consensus supporting the position in peer reviewed literature (Cook et al., 2013). Although there are still uncertainties in climate models (see e.g. Deser et al., 2012) past predictions have been largely borne out by present evidence (Allen et al., 2013).

Figure 1: Projected future temperature increases as a consequence of increasing GHG emissions

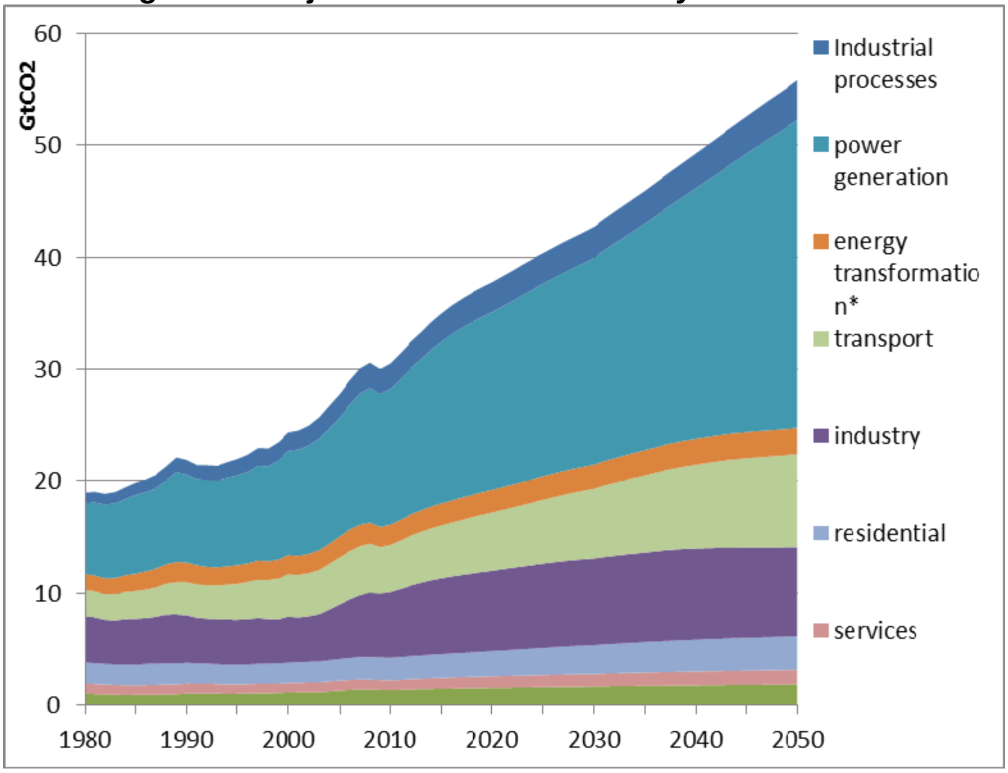


Uncertainty in predictions is represented by the shaded regions. Source: replotted from OECD 2012 Figure 3.9B

The average annual rate of decarbonisation since 2000 has been 0.8%, with carbon emission increases tightly coupled to increases in GDP (PwC, 2012b). The 2050 global energy mix is predicted to be similar to that today and 85% of the power supply will be derived from fossil fuels (IEA, 2012). If national GHG reduction pledges are not met then the amount of carbon dioxide that can be emitted into the atmosphere to limit warming to less than 2°C will be locked in mainly through capital expenditure by 2017. In order to avoid 2°C warming the rate of decarbonisation needs to improve from 0.8% per annum to 5.1% per annum until 2050, which means consuming only 1/3 of our proven reserves of fossil fuels up to 2050. If decarbonising takes place at only twice the current average rate, 1.6%, it is estimated that the planet may warm to 3°C-6°C by 2100. Adaptations designed to respond to 2°C warming may fail (World Bank, 2012).

GHG emissions from all sectors are projected to grow significantly if growth follows a trajectory based on this historical efficiency gain (Figure 2).

Figure 2: Projected GHG emissions by sector to 2050



**includes emissions from oil refineries, coal and gas liquefaction. Source: replotted from OECD 2012 figure 3.7*

An increase in global temperature will have effects on agricultural yield; an increase in human deaths due to excessive heat and pollution; shifting weather patterns; more frequent and extreme weather events, including heat waves, droughts and floods; ocean acidification; land-use change; and biodiversity loss (IPCC, 2007). Warming will increase the level of urban air pollution, which will become the most significant cause of premature mortality. Biodiversity, including species and primary forests loss, is projected to decrease by 10% by 2050, impacting those who depend on the land for a living and agricultural supply chains. For example, the lost value associated with deforestation is estimated to be between US$2trn – US$5trn per year. (OECD, 2012).

2.3 Megaforce: material security

Raw materials used for the manufacturing process, including ores, minerals and liquid fossil deposits, are unlikely to run out in the near future, but their extraction is predicted to become economically unattractive as easily-exploited and high quality sources are depleted. Manufacturers will need to develop material-efficient processes and manage for supply chain disruptions in order to remain competitive.

Pressures

Global demand for engineering materials and rare earth elements has quadrupled in the past 50 years. Demand for metals will increase by 30%-50% by 2020 and by up to 90% for steel and 60% for copper by 2030, compared to 2010 (Chatham House, 2012). Based on predictions of population growth and increasing wealth demand is projected to at least double based on current levels by 2050 (Allwood et al., 2011). China will consume up to 50% of global metals in 2020, much of this coming from imports (Chatham House, 2012).

Rare earth elements are important in renewable energy and clean efficiency technologies, including photovoltaic films, magnets used in wind turbines, batteries used in electric vehicles and phosphors used in low energy lighting. They have been identified as very high risk materials based on a number of criteria, including scarcity, production concentration, reserve distribution, recycling rate, substitutability and governance.

The depletion of economic reserves of materials and significant environmental and monetary cost associated with the exploitation of lower grade minerals will act to place further pressure on materials that are strategically important (Allwood et al., 2011) and force the adoption of conservation and substitution measures. A failure to respond to "peak metal" could put US$2trillion of economic output at risk in 2030 (World Economic Forum, 2012b). As globalisation increases it seems likely that competition for resources will be fierce and protectionism is possible as the few countries that are exporters of the rarer metals put them to their own uses.

A "peak oil" scenario, estimated to occur before 2030 (Sorrell et al., 2010), will reduce supply of conventionally extracted oil and increase difficulty of discovery and extraction. This will likely result in an increase in the price of oil-based commodities and suppressing demand (Allwood et al., 2011).

Materials based on renewable feedstocks, including wood, paper and bio-plastics, rely on availability of favourable land. The trends in competition for land to 2050 show an increase in land for bio-energy, crops and livestock, with forest and other land decreasing. The exceptions are scenarios implementing a carbon tax and a lower meat diet where more land is converted back to unmanaged forest (Smith et al., 2010). The opportunity to significantly expand renewable materials production is therefore considered to be limited, which impacts the amount of biofuels that can be produced and thus the penetration of less carbon intensive fuels as a strategy for decarbonisation of the energy supply.

The by-products of some extraction processes can be deleterious to local ecosystems if not properly controlled and waste impacts may grow as ores are depleted (Norgate et al., 2007), often requiring remediation to restore local eco-systems. However it is noted that well run mines can be beneficial to local communities and ecosystems providing employment and improving biodiversity (IIED, 2002).

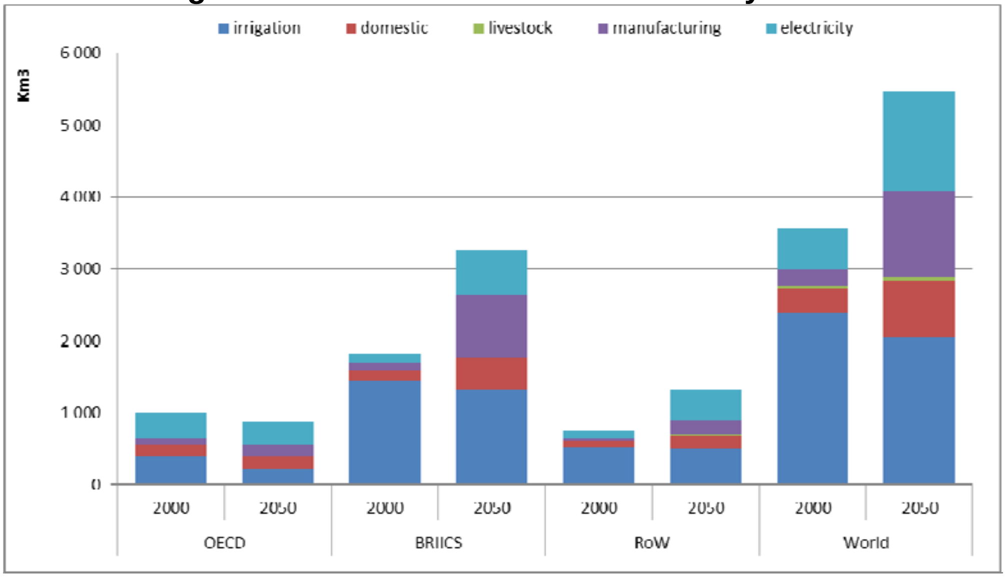
2.4 Megaforce: water

The use of water is closely coupled with energy, food production and environmental integrity. As water is a finite resource future competition may put the manufacturing sector in direct competition with food production and the basic needs of society, with ensuing political implications. Industry needs to develop processes that use far less fresh water in order to mitigate against this possibility.

Pressures

An increased demand for water will be driven by population growth, urbanisation and demographic shifts that result in greater levels of consumption. By 2050 it is estimated that global water demand will increase by 55% compared to 2000, with a 400% increased demand from manufacturing and 140% from electricity generation (OECD, 2012) (Figure 3). There is a high likelihood (3.8/5.0) of high impact (4.0/5.0) water supply crises over the next decade (World Economic Forum, 2012a), resulting in groundwater depletion and impacts being felt in competing food and energy production sectors.

Figure 3: Blue water demand to 2050 by sector



Source: re-plotted from OECD, 2012

70% of global water is extracted for agricultural use and 19% for industrial use (Royal Society, 2012). In India agriculture accounts for 90% of the water abstraction, whilst in the UK public water supply accounts for 30% of the total, electricity supply 55% and industry 9% (ICE, 2012). UK consumption relies heavily on “virtual water” imported and embedded in goods that are produced from water drawn in their countries of origin. Of the total consumptive water used in the UK, three-quarters of the total is met by water resources from other nations (ICE, 2012).

Energy is used in the cleaning and movement of water and it is estimated that as much as 19% of electricity and 33% of natural gas in California is used in water-related activities (Royal Academy of Engineering, 2012). As groundwater sources become depleted due to population growth more energy will be required to extract the same amount of water, which will have a significant impact on greenhouse gas emissions if the energy is produced using fossil fuels (McKinsey Global Institute, 2011). Similarly, the water requirements for fuels can be significant, with biodiesel having a water footprint 60,000 times greater than the fossil fuel equivalent (Berger et al., 2012).

As the global population becomes increasingly middle-class changes in diet will put added pressure on water supply as more meat and vegetable oils are consumed in place of grains and pulses. One kilogram of beef requires 15,500 litres of water to produce, while the equivalent amount of wheat requires only 1,300 litres (UNESCO, 2009).

Increasing urbanisation will lead to 60% of the global population living in cities by 2030. While urbanisation can make managing water easier it can place growing pressure on local water resources, exacerbated by climate change which is predicted to affect the patterns of the hydrological cycle in uncertain ways across the globe (OECD, 2012).

Extreme weather events

An increase in average global temperature is predicted to affect weather patterns over the 21st century, including the frequency and severity of extreme events. An increase may increase risks of damage to infrastructure and power supplies, especially around coastal regions. The global nature of production means that disruptions in other parts of the globe can significantly affect the supply chain. An intense monsoon in Thailand in 2011 flooded over 1000 factories that supplied 804 international companies. Computer hard-driver supply chains were disrupted, reducing revenue projections of leading computer manufacturers by 5% - 10% (PwC, 2012a). Nissan's and Toyota's supply chains were likewise disrupted, resulting in those companies suspending car production at a cost of US$1.25bn and US$1.4bn respectively (UNISDR, 2013).

The direct disruptions faced by the UK are likely to be less severe, but regions of the UK are likely to face extended periods of water stress, with droughts and heavier floods affecting power generation and transmission, transportation, infrastructure, ICT and agriculture (HM Government, 2011a).

Drawing these two aspects of extreme weather together it is likely that UK manufacturing will have to prepare for the potential of some disruption along its entire value chain. This preparation may require the development of ultra-efficient processes and reconfiguration of supply chains for resilience rather than efficiency.

2.5 Megaforces and supply chain vulnerability

Megaforces threaten to increase the vulnerability of the supply chain as increases in extreme weather events, shifting weather patterns and environmental damage may result in supply volatility of raw materials, land-use change or disruption of critical infrastructure, especially pertinent for operations located on coastal areas. In addition supply chain vulnerability has increased as a consequence of globalisation. Businesses have prioritised short-term cost efficiency, including offshoring and outsourcing manufacturing; reduced inventory capacities and come to rely on single sourcing rather than having alternative suppliers from which to draw from (SCR, 2003). The most significant impacts of disruption are reported as loss of orders and revenue, followed by a delayed cash flow.

Due to cost and lack of capability most UK manufacturers have part of their supply chain located overseas and 20% have half of their suppliers outside of the UK, with Asia supplying over half of manufacturers. Asia and Pacific countries supply materials crucial to the UK manufacturing sector, including iron ores, copper, aluminium and industrial minerals (Deloitte, 2012).

UK manufacturers have responded to the challenge of supply chain vulnerability by increasing collaboration; sourcing from multiple suppliers despite quality control issues and increased transaction costs; and on-shoring and increasing their use of local suppliers (EEF, 2012a). However, it is likely that a majority of businesses, in particular SMEs, do not have any contingency plans to manage for disruption (UNISDR, 2013).

A resilient supply chain will have a number of characteristics that allow it to adapt to disturbances with minimal financial impact (Deloitte, 2012). *Redundancy* (UNESCAP, 2012), having alternative distribution networks, including modes of transport and alternative suppliers, is an important characteristic. However, redundancy is ostensibly at odds with efficiency, where buffering capacity is removed to save costs. New ways of thinking about supply chains redundancy that act to minimise and spread risk and also reduce cost will be necessary. However, in the long term and in the face of significant disruption from the effects of climate change and increasing population growth, these costs may be seen as negligible compared to the cost of inflexibility.

2.6 Megaforces: the challenge for the manufacturing sector

A confluence of megaforces begs two questions: how will society mitigate current and future damage? How will it adapt to a changed world? The role that the manufacturing sector can aspire to will necessarily address both of these questions. The first, mitigation, will require that impacts on the environment be reduced substantially. Industrial and agricultural processes will need to be made ultra-efficient across multiple dimensions. End-products, including vehicles and infrastructure, will have to emit very few pollutants throughout their life cycles and be widely deployed. Some technology to address these challenges is already available, but much has to be developed. Effective skills, business models and policy will be needed to deliver appropriate outcomes. The second, adaptation, will require that the way we do things is reconceptualised, requiring shifts in expectations and behaviour across society and demanding the cooperation of scientists, engineers, social scientists and the public. Modal shifts in transportation, moving away from cars to mass transit solutions; the engineering of crops that thrive in harsher environments; and radical infrastructure design may be appropriate responses, but these will require significant policy support to enable the long-term thinking required.

UK manufacturing has competencies in these areas and is a world leader in some sectors. However, as a nation the UK ranks towards the middle of the EU-27 eco-innovation index as it lacks structural support. Without support any advantages that we have over nations with support may be eradicated in the future.

3. Opportunities for creating value for sustainable manufacturing

The impacts described in the section above present opportunities for the UK manufacturing sector to 2050. Manufacturers that can develop ultra-efficient processes and products and design resilient supply chains will be in a good position to hedge against resource scarcity and rising commodity prices as well as capture economic value. Clean automotive and aviation technology will be desirable in congested and polluted cities. A new green revolution will be necessary to feed the rising population.

The annual value of global sustainability business operations in 2020 is reckoned to be US$1.5-4.5. trillion rising to US$3-$10 trillion in 2050. In 2050 natural resource sustainability opportunities, including water, energy and materials, are estimated to be worth an average of US$4.1 trillion and social sustainability, including health and education, on average US$2.1 trillion (WBCSD, 2010).

In 2010/2011 the global sales of low carbon and environmental goods and services were £3.3trillion. with the largest sectors being alternative fuels (16%), building technology (13%), wind power (12%), alternative fuel and vehicles (10%) and water supply and waste water treatment (8%) (HM Government, 2012a).

Using assumptions based on future energy demand, technology cost and policy implementation HSBC Global Research (2010) estimates that the world market for energy efficiency will be US$1.2trillion by 2020 (Table 1), with a growth of 13% CAGR. This will require capital investment of US$10trillion from 2010 to 2020. Similarly Akashi and Hanaoka (2012) estimate that worldwide cumulative investment in appropriate technology is estimated to be US$6.0 trillion in 2020 (0.7% GDP) and US$73trillion in 2050 (1.8% GDP).

Table 1: Global Market for Environmental Goods

Efficiency initiative	Global market, US$ billions, by 2020, range (most likely)	Growth opportunities for UK industry
Transportation, including low-carbon vehicles	312 – 731 (677) 151 – 473 (473)	Aviation[1]: alternative and composite materials; aviation fuel. Automotive: see Figure 8.
Buildings	194 – 308 (245)	heating: heat recovery, heat pumps and fuel cells; cooling innovations; lighting[2]
Industrial	154 – 217 (183)	process engineering, automation, systems modelling, miniaturisation[3]
Fuel cells	2 – 5 (3)	hydrogen storage and production[4]

Ranges estimated from conservative to optimistic scenarios. The perceived most likely scenario is bracketed. Sources: 1: (Materials & Structures National Technical Committee); 2: (Green Construction Board, 2013); 3: (Technology Strategy Board, 2012); 4: (EGSKTN, 2013)

In the EU on average 40% of manufacturer's costs are on raw materials and a further 10% on energy and water. Labour accounts for 20% of costs (Greennovatel, 2012). The cost savings associated with material savings is estimated to be 0.37% of GDP across the EU. If simple resource efficiency measures were adopted cost savings of €10bn could be achieved across the manufacturing sector in the EU-27 (EIO, 2012), with significant returns accruing to individual businesses with no- or low-investment (Table 2). However, in order to reduce material inputs significantly by 2050 ("Factor 5", or 80% reduction) 100% of companies across the EU would have to achieve average annual improvements of 10%.

Table 2: Savings as a result of resource efficiency programmes

Country	Savings	Initiatives
Globally	$3.7 trillion by 2030	resource productivity measures, including legislation
The EU	€10 billion – €50 billion across EU-27	material efficiency measures. Lower figure is based on 25% of companies implementing measures, higher on 100% of companies.
UK	£23bn - £33bn nationally (no/low investment - payback < 1 year) £19,000 – £52,000 per company (payback 0.06 – 3.45 years)	resource efficiency, including waste, energy and water
Germany	€210,000 per company €37bn – €48bn p.a. across manufacturing sector	material savings
Hungary	€134,000 - €180,000 per company (no investment - payback < 3 years) €412,000 per company (payback > 3 years)	resource efficiency

Source: (EIO, 2012)

Greennovatel (2012) calculated that applying best available technology across the value chain of a steel-based product would save up to 50% of non-renewable materials and energy over the life-cycle. If applicable across product categories this implies that significant savings can be made by coordinating efforts in a more *systemic* manner than currently done.

In 2011 the UK emitted 186 $MtCO_2e$, of which 1/3 of which was from industry and 80% of that was CO_2 (Committee on Climate Change, 2012). By 2020 there are opportunities across various sectors to reduce emissions by 72 $MtCO_2$ (Table 3). Given national competencies it is likely that some of this, in particular energy efficiency, will be captured through arbitrage. However, others, notably carbon capture and storage, require regulatory support, technological development and significant capital investment.

Table 3: Potential for greenhouse gas emissions reductions across various sectors

Strategy	Emissions reductions
Energy efficiency	6 $MtCO_2$ by 2020
Biomass, heat pumps and CHP	6 $MtCO_2$ by 2020
Carbon Capture and storage	40 $MtCO_2$ by 2050
Substituting wood for construction materials	6 $MtCO_2$ by 2050
Steel recycling, clinker substitutes, flaring reduction	12 $MtCO_2$ by 2030

Industry-wide adoption of best practice efficiency initiatives can deliver upwards of a 4% increase in carbon intensity. Adopting good practice across sectors could result in an average of 32% improvement above the background rate, or an annual saving of £1.9bn over 2010 energy spend (Next Manufacturing Revolution, 2013). Allwood et al. (2011) estimates that CO_2 emissions across current process chains can be reduced by 23% - 40% by adopting best practice across all plants and by adopting state-of-the-art technology. However, commonly used materials such as iron and aluminium are expected to yield far fewer gains as they are already operating near optimally.

In addition to process optimisation, UK manufacturing can potentially capture value from low-carbon technologies worth £39.5 - £126.5bn between 2010-2050, potentially increasing to £189.5bn-£877.5bn if supply chains are considered (EEF, 2012b). Significant energy savings can be leveraged in addition to new value added (Table 4), although there are challenges to full realisation of this value, including: uncertainties in demand, capital constraints, the need for further R&D to develop some technology and cost reduction to stimulate deployment.

Table 4: Energy savings and contribution to UK GDP, selected environmental technologies

Technology	Cumulative energy savings, 2010-2050	Cumulative contribution to UK GDP, 2010 – 2050 (% of global market)
Bioenergy	£42bn	£19bn (5%-10%)
Carbon Capture and Storage	>>£100bn	£3bn-£16bn (4%-6%)
Energy networks and storage, including electric vehicles and low carbon technologies	£9bn	£6bn-£34bn (4%)
Heat pumps, networks and storage	£14-£66bn	£2bn-£12bn (4%-9% in some European markets)
Tidal and wave energy	£3-£8bn	£1.4bn-£4.3bn (15%)
Offshore wind	£18-£89bn	£7bn-£35bn (5% - 10%)

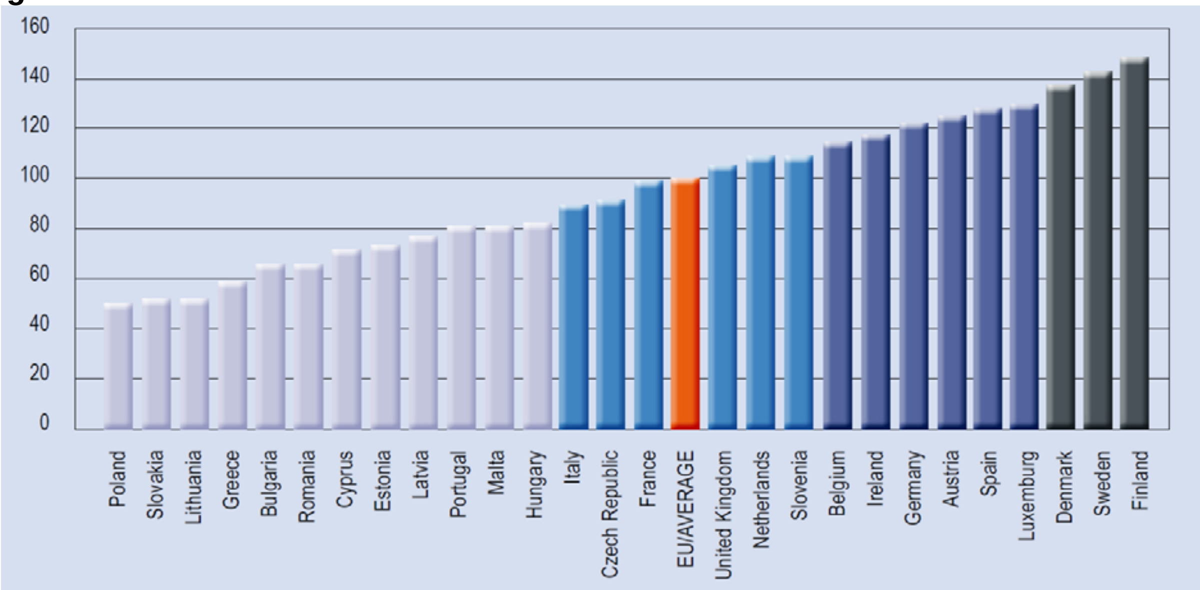
Source: (EEF, 2012b)

To go beyond best practice efficiency towards 80% greenhouse gas emissions reductions by 2050 existing strategies will have to be coupled with almost complete decarbonisation of the power sector and radical technology innovation for some sectors, including forestry, transport, building and CCS sectors (European Climate Foundation, 2010).

3.1 International competitiveness

The UK is overall a mediocre player in both the eco-innovation arena and clean technology investment. The Eco-Innovation Scoreboard (Figure 4) (EIO, 2012) ranks the UK marginally above the EU average. This is attributed primarily to a structural lack of support for R&D activities (EIO, 2012. Table 4.1).

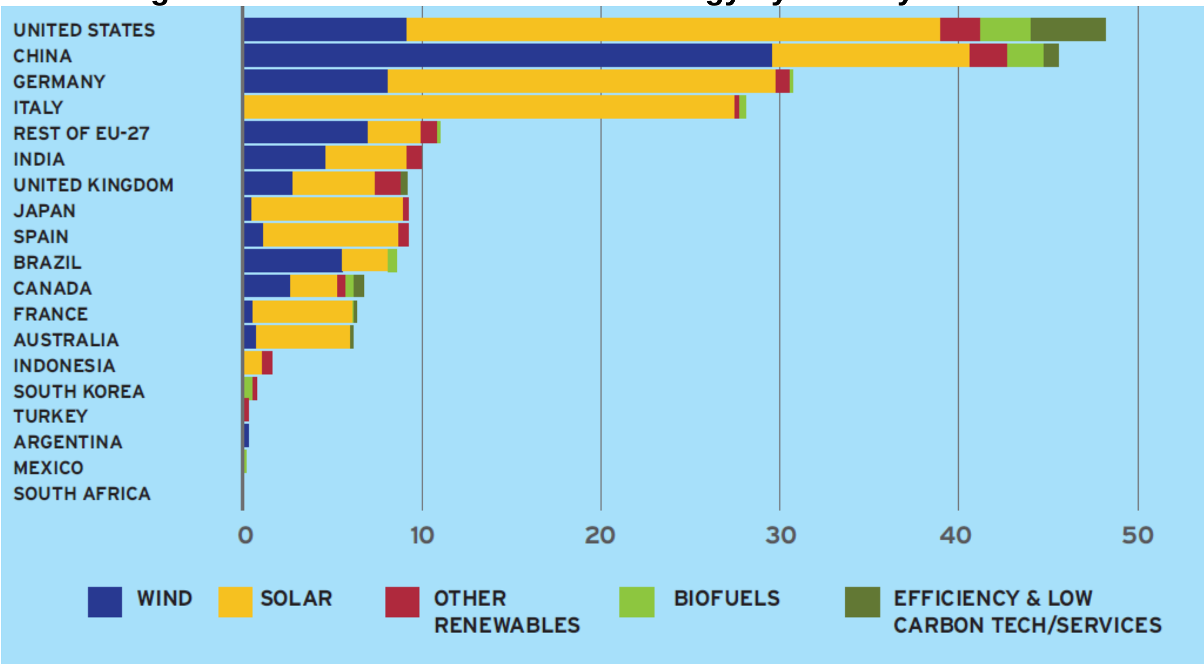
Figure 4: Eco-Innovation Scoreboard 2012



The scoreboard ranks EU member states' efforts in environmental innovation using a composite index consisting of indicators for public and private investment; firms active in eco-innovation; academic input; environmental efficiency and socio-economic outcomes. Source: EIO, 2012

International investment in clean technology in 2011 was dominated by the US ($48bn), China ($45.5bn). Germany ($30.6bn) and Italy ($28bn) (Figure 5) (Pew Charitable Trusts, 2012). The UK invested $9.4bn and was ranked 7th in the G-20 in terms of investment.

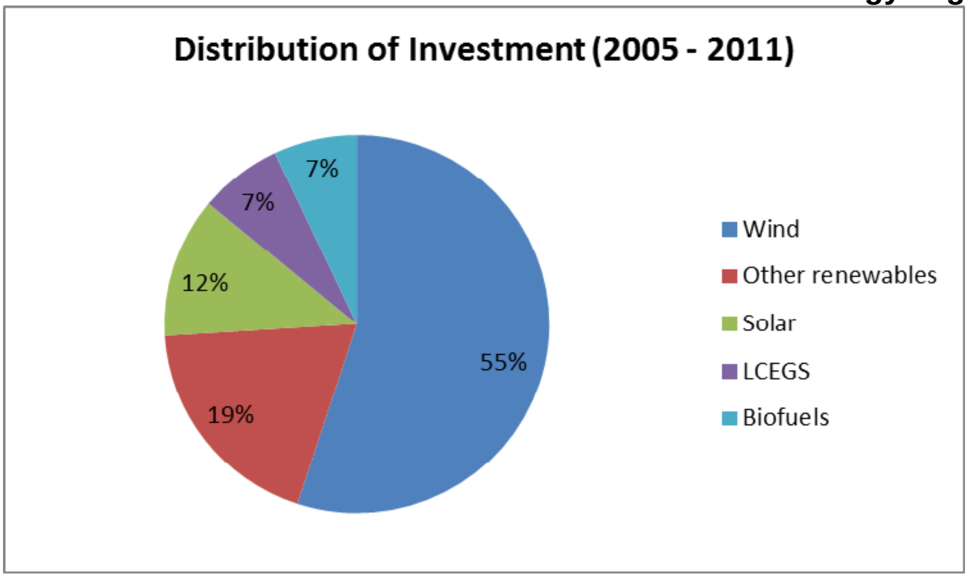
Figure 5: Investment in clean technology by country and sector



Source: Pew Charitable Trusts (2012)

UK investment has been mainly in wind power (55%) and efficiency initiatives and LCEGS accounted for 7% since 2005 (Figure 6). Given UK manufacturing competencies, described below, this investment is not coherent and needs to be realigned in order to support particular strengths.

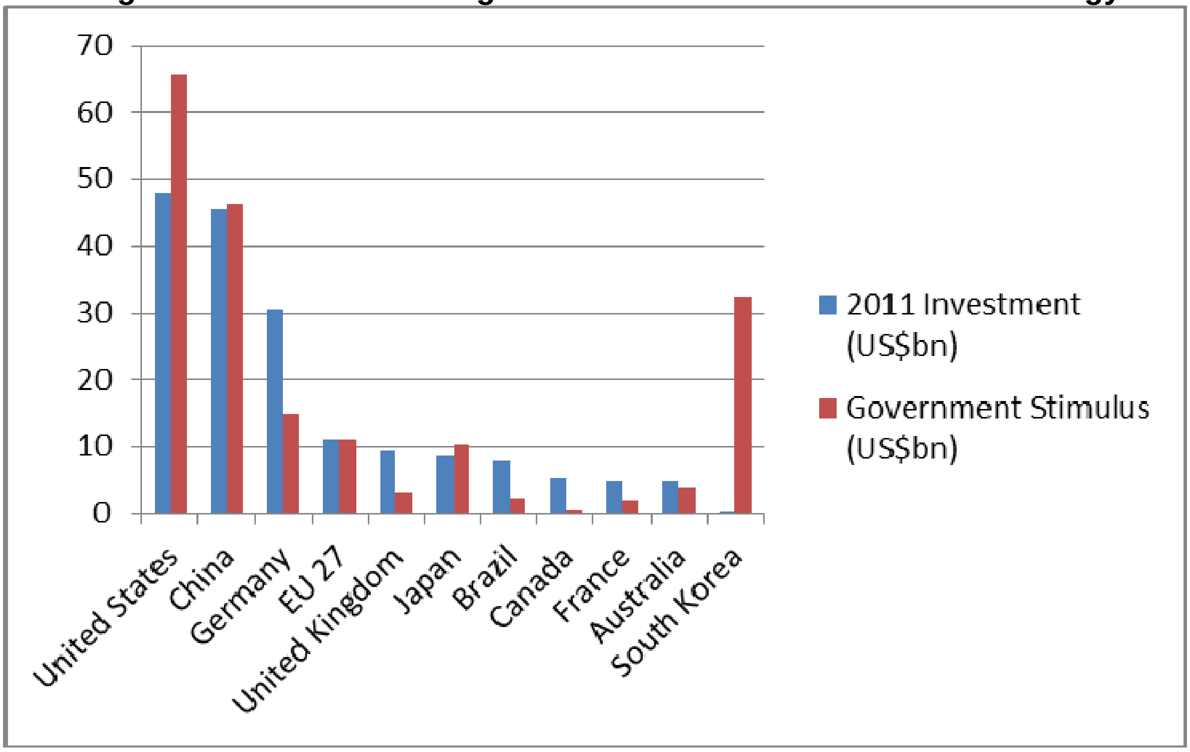
Figure 6: UK distribution of investment across clean technology segments



Source: Pew Charitable Trusts (2012)

Over US$194bn in government stimulus funds worldwide were allocated in 2011 (Figure 7) (Pew Charitable Trusts, 2012). UK industry received US$3.4bn against private investments of $9.4bn. This can be contrasted with South Korea, where industry received US$32.4bn in stimulus funds versus US$0.3bn in private investment. South Korea is an anomalous situation, as seen in Figure 7, and it is instructive to compare levels of investment in the UK with others. While the funding is not normalised to allow direct comparison, the ratio of public to private investment is more balanced in many competitor counties. It strengthens the argument drawn from Figure 5, that investment is not appropriately directed in a way that supports UK manufacturing.

Figure 7: Investment and government stimulus for clean technology



Source: (Pew Charitable Trusts, 2012)

4. Sustainability performance in the manufacturing sector

The manufacturing sector in the UK employs 2.6 million people (Zaczkiewicz, 2013) and contributed £154bn in gross added value (GVA) to the economy in 2011 (ONS, 2012). The largest contributions to this came from metal products, machinery and equipment, beverages and motor vehicles, accounting for an increase of £5.7bn in GVA in 2011 compared to 2010. Given the importance of the sector to the economy it is crucial that it is able to respond appropriately to the challenges that the world in 2050 is projected to present. The sector is good at making things efficiently, but is mediocre at translating basic science into commercial technology, attributed to the lack of a clear vision and coherent innovation policy (Science and Technology Committee, 2013). Failure to address this would see a decline in global competitiveness past 2020 – 2030, when efficiency initiatives are projected to be exhausted and novel technologies are required.

Manufacturing responses to sustainability challenges have primarily been focused on efficiency and it is predicted that this will continue to be the case to 2020/2030 as a strategy to hedge against rising commodity prices and increasingly vulnerable supply chains. However, performance across sectors is variable and neither ambitious targets or comprehensive and relevant data is collected in some.

4.1 Transportation: automotive and aviation

Automotive sector

The overall demand for transport activity is predicted to roughly double between 2005 and 2050, with the global vehicle fleet set to multiply three to four-fold, mainly in developing countries (OECD, 2012). The number of cars owned by a household increases with income and this can be expected to happen as developing economies become richer. As the energy mix is predicted to be dominated by fossil fuels to 2050 (IEA, 2012) without breakthrough technology in powertrains and decarbonisation of the electricity supply the vehicle fleet in 2050 will be continue to emit GHGs.

As the global urban population rises and car ownership doubles by 2050 increasingly warmer and congested cities could result in an extra 3.6 million deaths per annum, attributable to pollution from industry and transportation sources, including photochemical smog and particulate matter (OECD, 2012). A recent study estimated the social costs of motorised transportation at between 7.5% - 15% of GDP for Beijing (Creutzig and He, 2009).

Greenhouse gases

Although the automotive industry has increased carbon intensity by an average of 4% between 2002 and 2010 (Next Manufacturing Revolution, 2013) a business-as-usual scenario, where efficiency increases at historical levels, projects that GHG emissions from cars could double by 2050 (FIA Foundation, 2009). Increasing the efficiency of the global car fleet by 50% by 2050 is thought possible by deploying best practice across the sector and introducing effective demand-side pricing policies and some decarbonisation of the electricity supply (European Commission, 2011). It is predicted to save 6 billion barrels of oil (FIA Foundation, 2009) and thus reduce health risks in congested urban areas, but savings may be offset by the projected increase in the number of vehicles on the road. To reduce GHGs further than 50% will require new technology, including hydrogen fuel-cell vehicles (FIA Foundation, 2009).

Biofuels, as a strategy for reducing the carbon intensity of fuel, are predicted to have limited penetration due to population-driven competition for land for fuel. At low to medium penetration (less than 8% to 2020) it is predicted that this fuel will not reduce carbon emissions below business-as-usual scenarios (Committee on Climate Change, 2010). Moving towards greater levels of decarbonisation and developing zero emissions cars requires transformational innovation across the supply chain. Battery electric vehicles (BEVs) and fuel-cell electric vehicles (FCEVs) have the potential to emit zero emissions, but currently rely on fossil-fuel generated power. BEVs currently have similar levels of CO2 emissions to petrol cars (Royal Academy of Engineering, 2010). As the energy mix is projected to be similar in 2050 (IEA, 2010), biofuels will have limited market penetration and wide-spread deployment of CCS is extremely ambitious (Centre for Low Carbon Futures, 2011), it is thought unlikely that BEVs will be able to contribute significantly to radical carbon reductions without improvements cross-sector decarbonisation.

Fuel cell electric vehicles suffer from the same problem today, but have the potential for zero emissions if renewable energy is used to generate hydrogen fuel via electrolysis. A number of initiatives are in development in the UK and globally, but full deployment requires further development of the technology and the supporting infrastructure (Fuel Cell Today, 2012)

In Japan, Germany and Scandinavia major car manufacturers have partnered with energy companies to develop fuel cell technology and expand the necessary refuelling infrastructure. Japan is the most active country, with Toyota, Honda and Nissan working to reduce manufacturing costs. Hyundai are planning full commercial production of their *ic35* model in 2015 at a cost of US$50000. Ford, Nissan-Renault and Daimler are collaborating to bring FCEVs to market by 2017 (Ford, 2013).

Materials

There are sufficient material resources available to produce vehicles similar to those produced today to 2050, possibly with the exception of natural rubber. The demand for ferrous materials in 2050 is projected to be 65Mt/year in 2050, up from 42Mt/year between 2000 – 2030. It is estimated that 40Mt/year will be recovered in 2050, leaving a 25Mt/year unmet demand for virgin material (WBCSD, 2004).

Transformative initiatives in the automotive sectors are most at risk from the supply of rare earth metals, used currently in magnets and batteries in electric vehicles. This is seen as an issue of economics and politics rather than physical scarcity, but as oil is replaced by batteries this places extra demand on the rare earth supply chain. Modern cars contain a significant proportion of electronic components and these are at risk from supply chain disruption due to extreme weather events, as described above.

Lightweighting powertrains could increase sector demand for rare earths from 15% of current global production to 55% by 220. The demand for carbon fibre could reach 20 times that of today (McKinsey Global Institute, 2012) and put the automotive sector in direct competition with aerospace.

Water

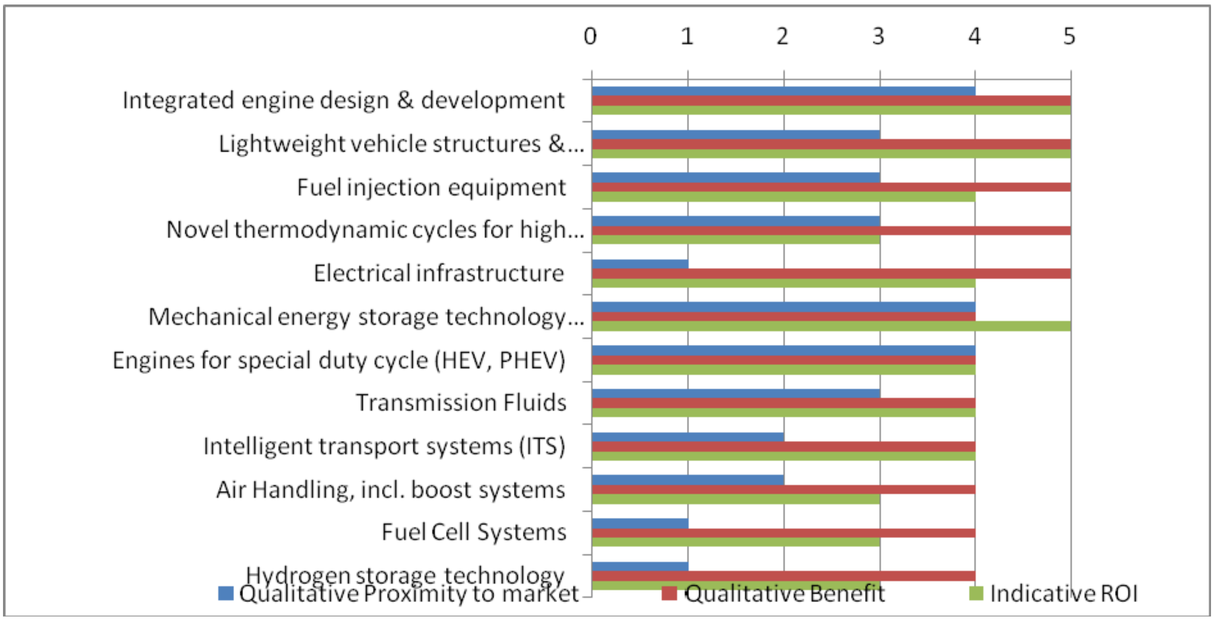
Between 2000 – 2011 water use per vehicle was reduced by 47.9% with a 10.8% drop in absolute usage recorded against a 5.8% rise in output (SMMT, 2012). Toyota have reported reductions in water usage at their UK plants of upwards of 75% over 14 years by applying their existing performance management techniques to key environmental metrics (Evans et al., 2008).

It is estimated that 95% of water is consumed in the automotive production phase, with only 10% associated with the automotive assembly plants (Berger et al. 2012). Steel, iron and polymers production accounted for 70% - 80% of water use. However, most water consumption occurs in Europe where scarcity is currently not an issue.

UK capability

A number of low carbon automotive technology categories based on proximity to market, benefit and indicative return on investment have been identified (Figure 8) (Technology Strategy Board, 2012). Technologies with a low score on "proximity to market" require R&D, but could provide attractive benefits if successful. Success will require capital investment, policy support and depend on adequate demand.

Figure 8: Low carbon automotive technology categories: proximity to market, benefit & indicative return on investment



PROXIMITY TO MARKET: Qualitative indication of the ease with which UK can deliver the technology category to meet the product roadmap requirements in the short, medium and long term. BENEFIT: Qualitative assessment of the potential for the UK to capture value in each technology category over whole of short, medium & long term timescale. INDICATIVE ROI: By comparing the level of effort required to deliver to the product roadmap and the potential for the UK to capture value a qualitative assessment of the potential "return on investment" has been made. 5 (high); 4 (medium-high); 3 (medium); 2 (medium-low); 1 (low). Source: (Technology Strategy Board, 2012).

Aviation sector

Greenhouse gases

In 2010 the airline industry emitted 2% of global CO2 emissions. It has committed to reducing these by 50% from a 2005 baseline by 2050, but growth in demand is exceeding historical efficiency gains (KPMG International, 2012) and emissions are predicted to increase by 250% by 2050, projecting historical improvements in efficiency (Sustainable Aviation, 2012). A 50% reduction implies that other sectors will have to reduce their emissions by more than 80% in order to compensate.

Demand for aviation is projected to rise by over 200% between 2005 and 2050 (Committee on Climate Change, 2009), especially linking the major urban centres that will exist. It is likely that the aircraft fleet in 2040 will comprise of similar aircraft to that seen today, although with improved performance (Air and Space Academy, 2011). Annual improvements in efficiency of 0.8% and a 10% penetration of biofuels by 2050 would result in reduction of carbon intensity by 35% compared to 2005. Under this scenario keeping 2050 CO2 emissions to the same level of those of 2005 would require growth in air traffic movements to be limited to 60% of 2005 demand.

Airlines are currently reliant on fossil fuels and assumed to be so to 2050 (Air and Space Academy, 2011). They are likely to incur significant costs as fuel prices increase and they are brought under emissions trading schemes.

The necessity to balance performance, survivability, environmental impact and cost produces additional constraints at the design and manufacture stages (Materials & Structures National Technical Committee). ACARE (European Commission, 2010) has suggested that the simultaneous reduction of CO2 emissions by 50% per passenger kilometre, NOx emissions by 80% and perceived aircraft noise by 50%, by 2020 is currently not possible with existing technology. Radical technological and behavioural solutions are necessary to address all three criteria simultaneously (European Commission, 2010, EEF, 2012b), and could include new wing designs and propulsion systems, optimised air traffic management, decarbonisation of the energy supply and behaviour change initiatives.

Materials

Carbon composites are seen as an attractive material that can be used to lightweight aircraft, with GKN Aerospace and Airbus working on new wing designs. There is the potential for supply chain disruption as other sectors, notably the automotive, increases demand for carbon fibre. There is no acceptable substitute for vanadium in titanium alloys used in the aerospace sector, however the supply risk is considered low (Erdmann and Graedel, 2011).

Water

There is very little data available on water usage in the aviation sector other than firm-level reduction targets. For example, Airbus have reported targets of 50% reduction in water consumption and an 80% reduction in water discharge by 2020 (Airbus, 2013).

Construction

Greenhouse gases

Building construction globally accounts for 40% of the stone, sand and gravel, 25% of the virgin wood, 40% of the energy and 16% of the water used annually and produces a comparable amount of waste (Arena and de Rosa, 2003). Building emissions accounted for 35% of UK GHGs emitted in 2011 (Committee on Climate Change, 2010), with 10% coming from construction and 89% from direct energy used. The construction industry has the potential to influence 45MtCo2 at the manufacture stage (HM Government, 2010b).

The UK Low Carbon Transition Plan commits to reducing emissions in residential homes by 29% and in non-domestic buildings by 13% by 2020 compared to 2008 levels. All new homes should be zero carbon by 2016 and new public sector buildings zero carbon by 2018 (HM Government, 2009).

It is believed to be technologically feasible to reduce GHG emissions by 80% by 2050, but this would require complete deployment of existing solutions, including those that currently have a weak business case. Almost 95% of “easy to treat” and 70% of “hard to treat” houses would have to be retrofitted with insulation and effective glazing solutions. However, in order to reach 80% reduction in GHG emissions biofuels will have to be used for transportation and carbon capture and storage in the energy intensive cement and steel sectors (Green Construction Board, 2013).

Growth opportunities identified are in heating, including improved insulation, heat recovery and new technologies such as fuel cells and heat pumps; in lighting in order to reduce energy demand; the development of cooling innovations as a response to global warming (HM Government, 2010b). It is estimated that by 2030 the annual spend on retrofitting could be £4-£4.5bn, creating 129,000 jobs per year(Green Construction Board, 2013).

Materials

The UK is self- reliant on most construction materials, but dependent on importing some metals, clays and coal (British Geological Survey, 2006). As economically-viable resources are depleted it may be increasingly reliant on imported aggregate and building materials in order to meet demand for new houses (HM Government, 2010b). There is a role for construction in recovering cement, iron and steel from infrastructure at the end of life of existing stocks and in using materials efficiently to help meet climate change targets and reduce the impact of higher commodity prices.

Water

Water usage data across the construction supply chain is not widely reported. Water management is inconsistently applied across the sector, including setting targets for reduction and monitoring consumption. WRAP (2012) estimates that savings typically range from 13% - 24%, with a cross-sector average of 20% possible between 2008 – 2012.

Agri-Tech

The demand for food is set to rise with world food production and predicted to increase 70% over 2005 levels by 2050 (UNEP, 2012). Demand for agricultural land is predicted to peak by 2030 and then decline as crop productivity increases. This will be driven by an increasing population and a change in diet from grain- to meat-based. It is estimated that annual meat production will need to rise by 200 million tonnes by 2050, with associated animal cereal rising by a third to 3 billion tonnes (FAO, 2009). There will be competition between agricultural land, biofuel production and timber for industry. As a consequence deforestation and pressures on biodiversity are likely to continue (OECD, 2012). As room for expansion will be limited there is a need to increase crop yield in order to meet demand for food and this will impact food prices, with prices for important commodities such as maize, rice and wheat predicted to rise by between 30% - 127% to 2050 (Foresight, 2011), which would compromise food security for the poor.

Climate change will affect crop yields. While CO2 can increase yields of some crops increasing temperature can stop growth and encourage weeds and pests. Changing weather patterns, including floods and prolonged droughts, may drastically impact crop productivity and where we can grow crops (EPA, 2012). Agriculture is responsible for over 2/3 of all water used by humans and it is estimated that there could be an between 16.5% - 17.7% reduction worldwide of water available for agricultural use by 2050 as a result of climate change, increased municipal and industrial demand and more extensive environmental management (Strzepek and Boehlert, 2010). Agriculture will thus be in direct competition with industry.

The growth in crop yields has slowed for major crops, in particular cereal growth rates were 1.5% in 2000, down from 3.2% in 1960. New technologies that promote growth, conversation and resilience simultaneously are needed and this will require large amount of global investment. It has been reported that investment in agricultural R&D can generated large returns, but this was not quantified (FAO, 2009).

It is estimated that one-third to one-half of food produced that is suitable for human consumption is wasted (UNEP, 2012, Foresight, 2011). Wastage in rural countries is primarily associated with spoilage post-harvest due to poor quality preparation, storage and transportation infrastructure. Waste in industrialised countries is associated with over consumption. WRAP (2011) estimates that an avoidable 12% of UK food and drink was thrown away in 2010, representing £12bn in retail value, 17M tonnes of CO2e, 4.3% of the country’s water footprint.

To meet these challenges a number of levers must be used (Foresight, 2011): new science and technology needs to be developed, including genetically modified crops; there must be wide-spread implementation of existing best practice; demand for resource-intensive food must be reduced; governance of the food system must be improved; and waste must be minimised.

The UK agri-tech sector has expertise in areas that would position it to capture value to 2050, but this is being eroded. In response to the UK Government’s call for a national agri-tech strategy (HM Government, 2012c), the National Institute for Agricultural Botany argue that while the UK’s science base is strong, translational and applied research is weak and basic science is not being translated into practice. This has resulted in a yield gap between commonly-planted crops versus best possible yielding crops.

Commercialisation of science thus needs to be strengthened in order to meet future demand for food (NIAB, 2012).

Energy intensive industries

Energy intensive industries include those that use large amounts of energy or generate greenhouse gases as an inherent part of their manufacture. This includes iron and steel, chemicals, cement, nitrogen fertilisers, paper and ceramics. They account for 45% of CO2 emissions from UK businesses and the public sector, directly employ 125,000 people and generated over £5bn in GVA (Centre for Low Carbon Futures, 2011).

Energy efficiency programmes have been extensively implemented primarily in order to offset rising fuel prices, resulting in reductions of GHG emissions and cost savings. As a result a number of industries are now working at near maximum efficiency given the technology available. Under a "business-as-usual" scenario, projecting historical efficiency trends, the industries will decline as the cost of fuel rises further (Bassi et al., 2012). Introducing a unilateral carbon price for such industries is thus unlikely to increase carbon intensity and may reduce the global competitiveness of the sector (POSTNote, 2012).

In order to meet 2050 targets new strategies for further substantial reduction will have to include the deployment of best practice across the industry; the capture and use of under-utilised resources, such as recycling waste heat; developing cross-sector synergies; innovation in new materials and processes; development of carbon capture and storage systems; and the use of decarbonised electricity, all of which will require an increase in R&D activities (EEF, 2012b, POSTNote, 2012). A number of new technologies, including Ultra Low CO2 Steel, cement kiln processes and clinker replacement, are predicted to reach market maturity between 2010 and 2030, but will still require deployment in conjunction with carbon capture and storage (Climate Action Network Europe, 2010).

5. Decoupling environmental impact from industrial growth

The UK Government's 2050 Pathway Analysis describes possible sectoral trajectories that are projected to reduce GHG emissions by 80% by 2050 (HM Government, 2010a). What is clear from the various trajectories is that "heroic" efforts are needed in some sectors, dependent on trajectory chosen, in order to achieve these cuts. These will all have to be supported by an annual capital investment of up to 1% of GDP in order to drive deployment of existing technology options at scale and development of new and risky options; inter-sector and international dynamics, including collaboration and resilience planning; regulatory and market instruments; and behaviour change initiatives.

This task is difficult technologically and conceptually: in order to manage growth and associated consumption in a sustainable environmental impact needs to be *decoupled* from economic growth.

Relative decoupling occurs where resource usage rises, but at a slower rate than growth, is synonymous with efficiency. Jackson (2009) reports that carbon intensity has fallen globally from 1kg of CO2 per dollar in 1980 to 770 gram of CO2/$ in 2006. However, global fossil fuel consumption, CO2 emissions and extraction of various metals increased between 1980 - 2006 and efficiency initiatives are considered insufficient to adapt to the world in 2050 and beyond (Jackson, 2009). *Absolute decoupling*, where environmental impact decreases while economic growth and well-being increases, is a sustainable aspiration. This means making more things for a growing global population while using far fewer virgin resources and emitting far less emissions. Absolute decoupling of all impacts is not considered feasible given the current notions of economic growth and this reflects the positions taken across expert reports cited in this paper: breakthrough innovations that have no short-term business case are necessary to meet the demands of 2050. However, there are examples of absolute decoupling for specific environmental impacts.

The notion of decoupling has been implemented in Japan and China through the use of the 3Rs, reduce-reuse-recycle, across industrial sectors (UNEP, 2011).

In Japan the "Sound Material Society" is supported by regulation and specifies targets for resource productivity (60% improvement by 2015 compared to 2000), cyclical use rate (40% - 50%) and final disposal amount (60%). Trends towards these targets are positive and the cyclical use rate and final disposal amount targets were met in 2009. In addition the "Top Runner" energy efficiency programme, where best in class products becomes the new legal standard across the sector, has resulted in significant energy efficiency improvements (Table 5). However, although relative decoupling of material and CO2 emissions from economic growth is evident this is considered insufficient to qualify for "absolute" decoupling.

Table 5: Energy efficiency improvements a result of Japan's "Top Runner" initiative

Product Category	Actual energy efficiency improvement, %
Gasoline passenger vehicles	22.8
Electric freezers	29.6
Electric refrigerators	55.2
Computers	99.1

Source: (UNEP, 2011)

In China the 3Rs are articulated through the "circular economy" concept and this is supported by a number of incentives, including integration into the national 5-year plans, regulation, environmental management, taxation, government procurement and a dedicated investment fund. As a result primary energy consumption, industrial wastewater discharge and SO_2 emissions have been relatively decoupled from economic growth since the 1990s, while industrial solid waste discharges and freshwater consumption have been absolutely decoupled.

5.1 New business models for 2050

Although "decoupling" of environmental damage from economic growth is an often-stated goal of business it is unclear how this can be achieved given the rapid rate of population growth and demographic shift to a middle-class consumptive lifestyle in industrialising countries. Business models need to be developed that support the simultaneous reduction in impacts across inter-related sustainability dimensions and scale social barriers to the adoption of new ways of consuming.

Business models are market-based mechanisms that act to coordinate activities using price signals and result in value being captured from transactions involving existing products or service over a certain timeframe. Contemporary business models should be effective in driving efficiency gains, including reductions in GHG emissions or resource usage, if this also results in a financial return on investment over a short time window, typically 3-5 years. The development of radical technology, though necessary to meet 2050 sustainability targets, is unlikely to generate a return over such a short window and thus there is not a business case that can currently be made. Arguably revenues from incremental product development could be used to fund radical innovation, but the perceived and actual risks of doing so in a short-term market would need to be overcome. Business models that "de-risk" and create incentives for long-term investment are necessary to catalyse this.

In effect the future is not priced appropriately. Similarly many current resource streams are inappropriately priced including under-utilised by-products of industrial processes, such as product parts and components that would normally end up in landfill; low-grade heat in power generation and steel making; "externalities", such as transport-based pollutants; and many ecosystem services. If these resource streams are priced appropriately they can be incorporated into business models and drive efficiency gains using contemporary business models.

5.2 Closed-loop business models

Contemporary business models are based predominantly on a linear conception of a value chain, where, at one end, resources are extracted, converted into something of perceived value and then disposed of at the other end. By associating a cost with the end and the waste products a linear value chain can be joined up either with other value chains, as in the networks of industrial symbiosis, or with itself, as conceived in "closed-loop", "cradle-to-cradle" or "circular economy" (CE) strategies. In effect these are all articulations of the "3R", reduce-reuse-recycle waste hierarchy, applied at different scales, from product to industrial.

In a circular value chain various 3R strategies can be implemented that act to reduce reliance on virgin raw materials and energy usage, insulated manufacturers from price volatility to an extent. These include reuse, remanufacturing and recycling and can act to reduce exposure to supply chain volatility risks, particularly of note in the automotive and electronic sectors (HM Government, 2012b). At the industrial scale effective markets for secondary materials need to be developed so that what would otherwise be "waste" is perceived as "resource".

The closed-loop model at a product level requires that products are designed for durability, standardisation of components, modularity and easy of disassembly (Allwood and Cullen, 2012) so as to facilitate upgrading and remanufacture and have low toxicity to allow for biodegradation where appropriate. If this approach were to be adopted by the EU it is estimated that savings of between $340bn - $630bn, depending on degree of penetration, could be realised by 2035 (Ellen MacArthur Foundation, 2012). Annually the benefits could be worth between $170-200bn for the automotive sector, $110-130bn in the machinery and equipment sector and $75-90bn for electrical machinery. The value that the UK could capture from this approach has not yet been calculated.

Going beyond products "industrial ecology" uses waste from one industrial process as resource into another and again has the potential to reduce reliance on virgin raw materials and mitigate against energy price volatility. Two examples are:

> **Adnams**, a UK brewer, has developed a number of initiatives based on industrial ecology principles. A solar-powered anaerobic digester (Adnams Bioenergy) converts brewery and local food waste to fertiliser and biogas, replacing liquid fossil fuel in their transport fleet. This is predicted to reduce CO2 emissions by 200%.
>
> **AB Sugar** produces over 420kt of sugar annually. It has built a bio-refinery to capture value from "waste" products, including low-grade heat, and manufacture a number of co-products, including animal feed, bio-ethanol and tomatoes (SustainValue, 2012). Innovations are currently developing innovations to enable them to exploit the bio-plastics market.

Manufacturing processes that are based on the direct exploitation of agricultural feedstock may find fewer barriers to developing industrial ecology solutions than those that use technical feedstock, such as electronics, due to the relatively complexity of the latter. Revenues can be realised from the practice, but with an upfront research and engineering cost that may be higher than that for a traditional linear business model.

Numerous barriers exist to adopting a fully circular economy. Fundamentally it will change the way manufacturing is conducted, as products will have to be redesigned in order to be considerably more durable; new behaviours, relationships and transactions need to be developed with suppliers and customers; and new regulations will have to be enacted. An example of new transactions comes from the National Industrial Symbiosis Programme (NISP), which coordinates secondary markets in waste products between industrial organisations.

Whether a circular economy would lead to real emissions and resource reductions is questionable: reductions from UK production only affect a small proportion of emissions associated with UK consumption (WRAP, 2009, HM Government, 2011b) and increasing the efficiency of production systems does not take address fundamental patterns of consumption (Preston, 2012). These business models have not been extensively tested and there are significant barriers to adoption. It is not clear how these models will work for B2C in a hyper-consumptive economy or rapidly growing markets where ownership can be a sign of affluence.

A portfolio of business models archetypes that explore the valuation of under-utilised and mispriced resource streams have been collated (Short, 2012). While giving a wide range of options to explore it is unclear how any current business model can enable breakthrough innovation to be developed and diffused at the scale needed to respond to 2050 sustainability targets while also allowing the UK, or any country, to remain globally competitive. Such innovation is likely to require "systems change", similar to industrial ecology, but on a much wider scale. As exemplified by the cases of Japan and China above the driving force for any systems change has to be framed as a coherent future vision that will act to align society in a desired direction. As any change will necessarily include a wide-range of associated actors and sectors it likely have to be backed by regulatory drivers and price-based incentives as well as behaviour change initiatives.

5.3 Efficiency and effectiveness

It is useful to speculate how far efficiency can be pushed in existing systems before radical change has to occur in order to continuously capture economic and sustainable value. Examples given above show that some manufacturers are performing significantly better than sector peers and also that there are substantial gains that have been made across product ranges. However, it is not clear how far these improvements will take us towards meeting inter-dependent 2050 goals. Focusing on energy efficiency in buildings Goldstein (2008) suggests that this research has not been done, but that 80% - 90% improvements could be achieved by using available technologies and whole systems design. Similarly, Brown et al. (2012) suggest that 50% - 90% energy savings can be achieved across a wider range of products by considering available or near-market ultra-efficient components and designs. However, they state that the market for these needs to be developed.

So while appropriate levels of efficiency can be achieved in some sectors and for some products, they cannot be in others using current technology, including energy intensive industries. Understanding which sectors will benefit from R&D support and which from efficiency optimisation will allow resources to be channelled appropriately.

It is also important to consider the challenges presented in this paper as multi-dimensional and systemic. While achieving energy efficiency is an admirable goal it has to be addressed in the context of megaforces: resource scarcity, population growth and others not considered here. Optimising design and manufacturing against different criteria is technically difficult and emphasising different modes of consumption, for example as exemplified by the “degrowth” movement, are politically, economically and socially challenging.

6. Conclusions

In this paper, well-supported secondary literature has been used to describe the world out to 2050 and to project the major biophysical and social changes that are believed to be probable. For manufacturing to successfully address the sustainability issue a set of inter-related risks have to be tackled. These are different challenges from those industry is familiar with today.

Interpreting data from industry reports and examples from company case studies has indicated it is likely that out to 2020/2030 manufacturing will predominantly emphasise process and material efficiency in lieu of complete sustainability solutions, as there will be financial and resilience drivers to do so. The effects of climate change and population growth will only start to become evident during this time and thus will not drive substantial change beyond “eco-efficiency” until post-2030.

Further out to 2050 and beyond the manufacturing industry will need to develop novel innovations and methods of production in order to meet demanding sustainability targets and create new economic growth. The world of 2050 and beyond will be constrained in radically different ways than it is today. The physical and geopolitical effects of climate change and the growth in global population will reframe the opportunities that UK and global manufacturing can, and will have to, capitalise upon in order to contribute sufficiently to economic growth.

These opportunities will result from the consequences of the effects of climate change and population growth, including inter-dependent risks from rising global temperatures, material resource scarcity, regional water scarcity, demographic shifts and mass urbanisation. In order to meet these challenges manufacturers must conceive of new ways to do old things and make old things in entirely new ways, moving away from a focus primarily on process optimisation. It is unlikely that the manufacturing sector can do this alone and will require support from all societal actors.

6.1 Drivers to 2020/2030

It is likely that energy and resource efficiency programmes will dominate manufacturing strategy in the near term. Rising and volatile commodity prices and the potential of geopolitical resource protectionism of critical metals will reinforce the need to reduce the effective costs of raw materials and energy use. Sunk capital costs in factory design and infrastructure will constrain the types of physical changes that can be expected to occur.

These constraints offer significant opportunities to capture value. The global market for energy efficiency has been estimated at US$1.2 trillion by 2020, with the UK placed to capture value in the efficient production, transport and building efficiency sectors, as well as alternative fuels and water treatment technology.

Creating value from currently under-utilised resources, including low-grade heat, will contribute to reducing waste and provide additional revenue options for companies. The strategic development of intellectual property to support this, in the form of business model and technological innovation, will create economic value.

Industrial efficiency programmes have the potential to significantly reduce the use of energy and resources. However, a major barrier to a significant improvement is that economic growth is currently predicated on increasing consumption. Early wins will be in the B2B and M2M sectors as organisations hedge against the increasing costs of energy and resource usage.

6.2 Drivers to 2050

Meeting the sustainability challenge means simultaneously addressing greenhouse gas emissions, water usage, resource usage and the way that these will be influenced by a growing population. By 2050 it is projected that resources will be scarce and labour abundant.

Sustainability targets to 2050 reported by most sectors are insufficient to meet the challenges of sustainability. Historical levels of progress towards single-issue targets such as decarbonisation are inadequate for this task. Successfully developing appropriate technology for meeting these challenges requires radical innovation that will take years or decades to develop and research and development needs to be scaled from now. Policy that supports this effort is currently lacking and needs to be rapidly developed.

Resources will be scarce and manufacturers are likely to be put in a position where they have to compete against each other and against the use resources that could be used for the basic needs of society. Manufacturing and its supply chains will thus be under pressure to be more innovative in what it makes and how those products are made and the contemporary idea of consumption and economic growth will need to be negotiated.

This may necessitate the reconfiguration of the manufacturing sector, including optimising for the size and geographical location of factories and supply chains as well as reimagining the role of manufacturing in the context of society so that social opportunities can be captured alongside economic value.

6.3 Summary

There is strong evidence that the UK manufacturing sector possesses the capabilities to address the challenges of eco-efficiency, but it is currently let down by lack of structural support, in particular effective policy and appropriately directed investment, resulting in the UK being a mediocre player in eco-innovation compared to peers in the EU-27. Incremental eco-efficiency is a necessary precursor to more radical innovation and, other than niche companies, there is little evidence to suggest that the UK is engaging with the radical agenda at the scale necessary to either reactively or proactively capture future value from the more profound sustainability challenges that are projected to arise. Support in promoting research and translating that commercial value would lead to significant value creation opportunities for the UK: this support is currently lacking.

The drive towards sustainability in the UK is lacking clear direction from the highest levels and this has translated into an isolated and weak R&D environment. Sustainability challenges are global and all countries face similar constraints and opportunities. The implementation of ambitious policy, supported by targets for progress and funding for research and commercialisation will allow the UK manufacturing sector to compete globally and competitively into the future. There is little evidence to suggest that any country has a scalable advantage currently, but many have policy and capital support that could propel them into the lead.

Past successes, from the industrial revolution onwards, have been predicated on the willingness to take risks and having the support to do so. Countries that fail to capitalise on these opportunities will not only miss out on significant economic growth, but will be unable to compete in a substantial global market for new sustainability-oriented technology.

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