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UK TEN POINT PLAN FOR A GREEN INDUSTRIAL REVOLUTION

How materials science and innovation will help the UK achieve net-zero

INTRODUCTION

The government has set out a bold plan to put the UK on a path to net-zero carbon emissions by 2050. Materials science and engineering will be critical in providing the solutions needed for each of the ten points. Delivering these will require the development and utilisation of a range of new and advanced materials with a focus on sustainability, considering the full life-cycle from initial raw material extraction, through to manufacture and end-of-life reuse or recycling.

As acknowledged in the government's recent UK Innovation Strategy - leading the future by creating it, the UK has strong historical strengths across materials and engineering. Finding better ways to maintain and renew materials to extend their useful life or recycle them into fresh products is vital. As our understanding improves of how materials such as metal alloys, composites, ceramics, and biomaterials work at the atomic and molecular level, we are better able to design and engineer new materials, often at lower economic or environmental cost. Understanding and predicting how materials react and respond in challenging environments – for example at sea, in a nuclear reactor, or in a rapidly charging battery – is fundamental to the safe operation of many systems and can also help us prolong service life. Linked to this is the need to ensure materials used for infrastructure are resilient to future climate change. Finally, there will be materials-related issues that emerge as we develop the new technologies that we are not yet aware of.

This set of briefing notes highlights the importance and cross-cutting nature of materials science. Table 1 shows how different materials systems are applicable to each of the themes in the Ten Point Plan for a Green Industrial Revolution, as well as the applications and enabling technologies that will allow the plan to be put into action. The table is divided into two sections:

MATERIALS CLASSES

There is a wide range of different materials required to ensure a successful energy transition, many of which are currently emerging and will be commercialised over the next 10-20 years. Examples include new sustainable polymers, smart textiles, caloric materials, and composites. The UK has a wide and successful innovation base in materials – identified as one of the seven technology families of strength and opportunity – which can be harnessed to deliver on the Ten Point Plan.

MATERIALS APPLICATIONS

Materials applications include electrical systems such as batteries, capacitors, and fuel cells, as well as other systems such as membranes and lubricants. The UK is a world leader in developing new materials applications and their associated engineering infrastructure.

Development in both of these areas support developments in the underpinning theory and enabling technologies. The UK is a leader in blue-sky research and understanding the underlying theory to materials systems is crucial to designing successful devices with high reliability and long lifetimes, for instance corrosion is a major topic across transport, nuclear, and renewable energy. We must also ensure that new materials and critical elements can be successfully recycled within a UK circular economy, which will not only provide skilled jobs but will also prevent precious and strategic materials being lost from the UK. Some of these key underpinning areas are:

Advanced Manufacturing – Developments in manufacturing technologies will support the efficient scale up of novel materials production and will generate new jobs within the UK economy.

Recycling and Life Cycle Analysis – By considering the full lifecycle of materials, products can be designed with sustainability in mind making end of life recycling and reuse more efficient.

Modelling, Simulation and Artificial Intelligence – The adoption of digital approaches to the discovery and design of new materials (Materials 4.0) has the potential to dramatically increase the speed of innovation. Modelling, simulation and AI can also underpin the management of complex energy networks and aid efficient product design.

Materials Testing – As new materials and devices are developed, new standards for their testing and use will need to be established to support the industries that surround them.

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● Critical to development	MATERIALS CLASSES								MATERIALS APPLICATIONS						
	Ceramics	Composites	Glasses	Metals	Polymers	Semiconductors	Textiles	Wood	Batteries	Catalysts	Electrolysis	Fuel Cells	Membranes	Lubricants	Structural Materials
1. Offshore Wind	●	●		●	●	●			●	●	●			●	●
2. Low Carbon Hydrogen	●			●	●					●	●	●	●		
3. New and Advanced Nuclear Power	●		●	●										●	●
4. Zero Emission Vehicles	●	●	●	●	●	●	●		●	●		●		●	●
5. Green Public Transport, Cycling and Walking	●	●	●	●	●		●		●			●		●	●
6. 'Jet Zero' and Green Ships	●	●		●	●		●		●			●		●	●
7. Greener Buildings	●	●	●		●	●		●	●				●		●
8. Carbon Capture, Usage and Storage	●	●		●						●			●		●
9. Natural Environment	●	●	●	●	●			●							●
10. Green Finance and Innovation						●									

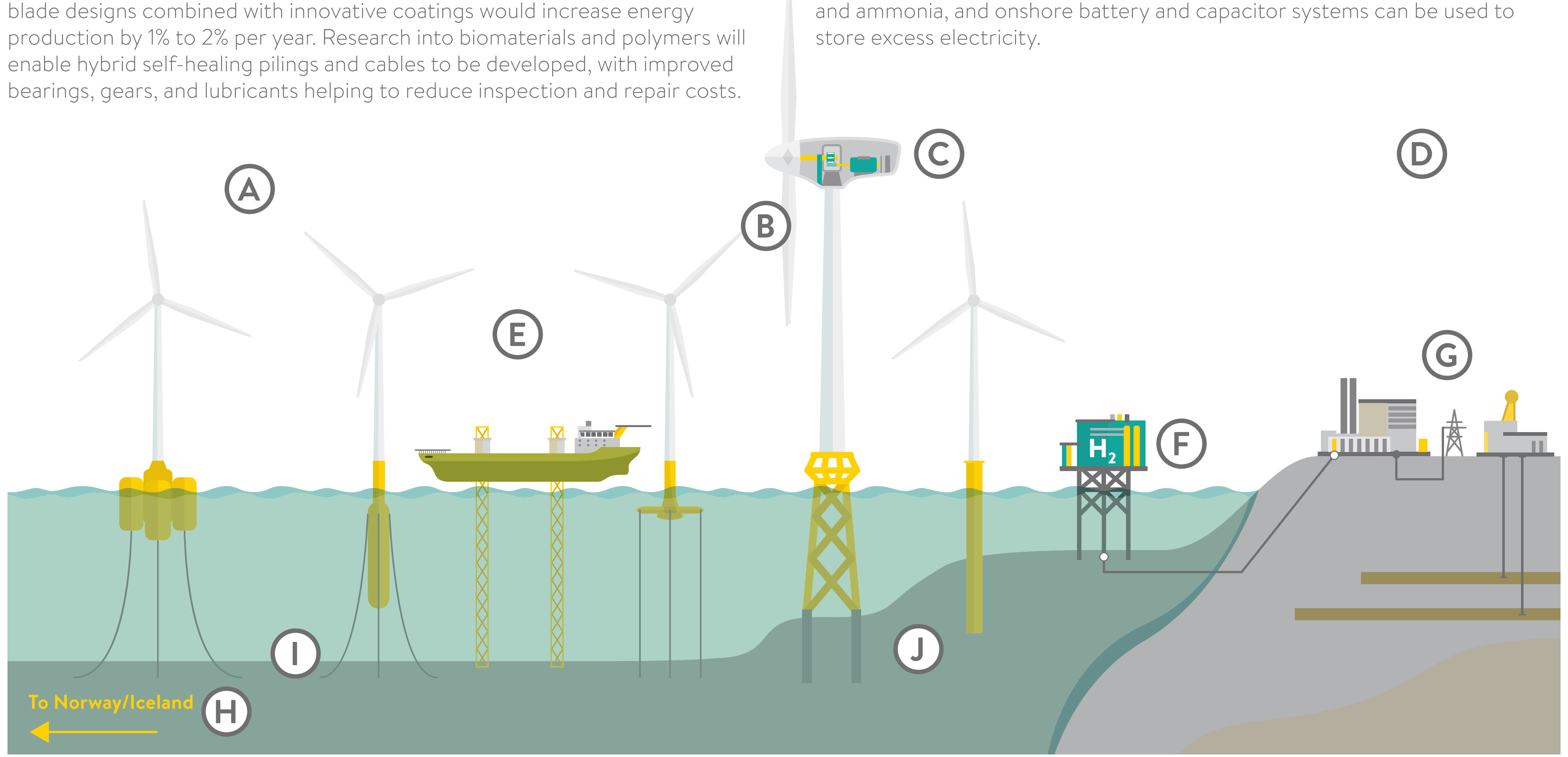
Table of Materials Classes and Applications critical to the delivery of the Ten Point Plan.

1. Advancing Offshore Wind

There are nearly 11,000 wind turbines across the UK (2021) with an aim to quadruple generating capacity by 2030. New and advanced materials are needed to increase turbine efficiency, lifetime, and recycling potential. The key materials challenges are the upscaling of infrastructure to handle larger turbine blades and arrays, and the decarbonisation of the production processes for the steel and composite materials. Increasing the reliability of turbine components coupled with new corrosion resistant materials could reduce lifetime energy generation costs by 3% to 7%. In addition, improved blade designs combined with innovative coatings would increase energy production by 1% to 2% per year. Research into biomaterials and polymers will enable hybrid self-healing pilings and cables to be developed, with improved bearings, gears, and lubricants helping to reduce inspection and repair costs.

Improvements in materials design are also needed to increase the recyclability of turbines. New designs and composite components are being developed in tandem with recycling initiatives and a growing UK capability in recycling generator materials.

Offshore wind can also be combined with a range of complementary technologies to solve the problems of variable and seasonal output. Electrolysis using catalytic materials can be used to produce green hydrogen and ammonia, and onshore battery and capacitor systems can be used to store excess electricity.



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KEY | ADVANCING OFFSHORE WIND

A	Corrosion and biofouling resistant materials for floating wind turbines
B	Blade coatings to improve efficiency
C	Improved generator materials (e.g magnets)
D	Long lifetimes with end of life recycling designed in
E	More reliable turbines with lower maintenance costs
F	Local H_2 and ammonia production
G	Distributed power networks and battery storage (e.g. battery, geothermal, etc.) interlinks
H	Materials for long range power networks (e.g. links to Norway and Iceland)
I	Biomaterials for self healing cables and foundations
J	Decarbonised steel & cement

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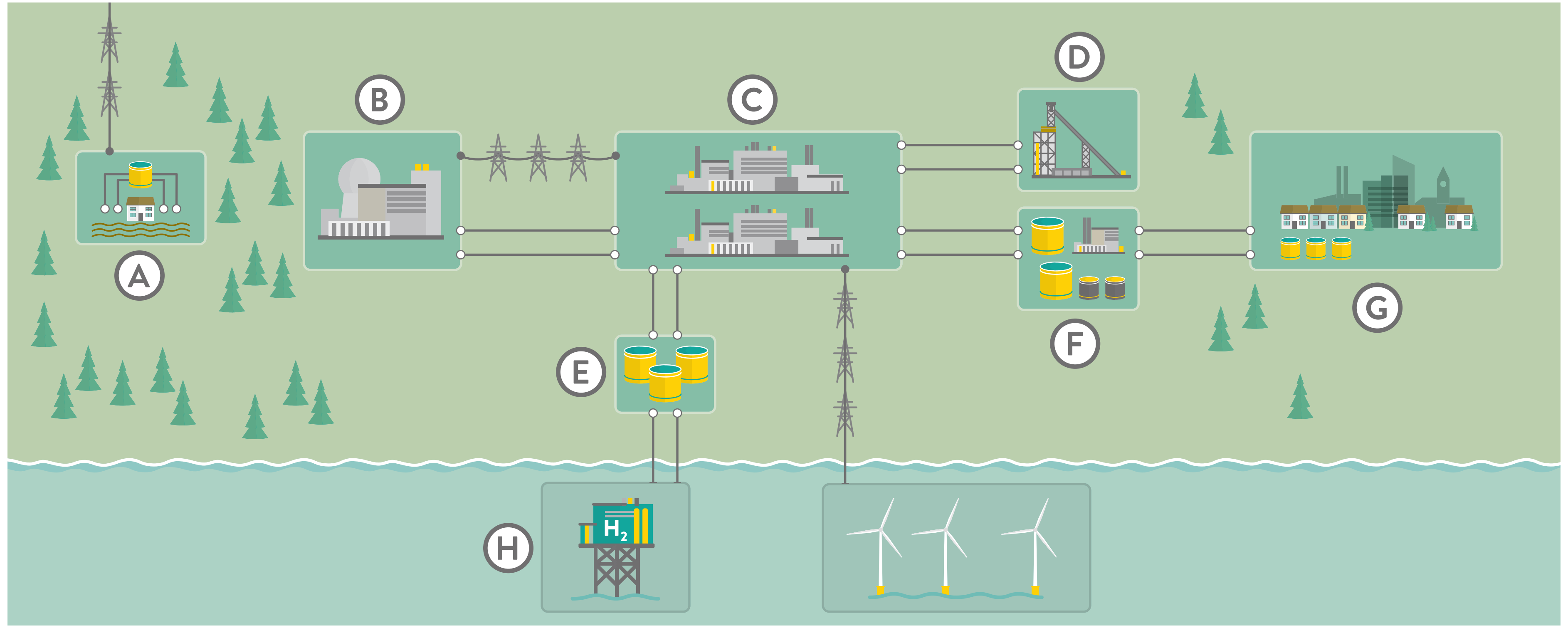
2. Driving the Growth of Low Carbon Hydrogen

The UK has a leading position in hydrogen research but while 'green' hydrogen production is a proven technology there is currently no infrastructure to deliver it at scale, hampering ambitious plans such as steel decarbonisation. Commercial scale up of electrolysers requires the development of novel catalysts and membranes. These can be integrated with wind and solar power-sources or connected to high-heat-output industries such as nuclear to produce sustainable hydrogen supplies for the UK. This will allow the use of hydrogen in a variety of industrial processes including synfuels, syn-petrochemicals, and ammonia production as well as making hydrogen for heating and transportation applications.

The materials science that prevents corrosion in materials for offshore and nuclear applications is also important to prevent the degradation by hydrogen of components within gas networks. The development of novel materials for hydrogen production will also allow the UK to be less reliant on mined sources of Platinum Group Elements (PGE) and nickel (Ni). Materials developments will also allow for the development of smaller devices to create a distributed network of hydrogen production which would benefit remote areas and the agriculture industry.



KEY | DRIVING THE GROWTH OF LOW CARBON HYDROGEN

- A — Smaller fuel cells for rural areas and distributed energy networks
- B — Developments in nuclear engineering to utilise reactor heat to generate H_2
- C — Materials developments support novel membranes and catalysts for hydrogen and ammonia production
- D — Hydrogen infrastructure supporting steelmaking and chemical industries
- E — Materials for safe and efficient hydrogen storage
- F — Combining CO_2 capture from industry with H_2 to make higher value products, e.g. Sabatier reaction for green synfuel production and other syn-petrochemicals
- G — Opportunities for using H_2 and hydrogen derivatives (synfuel and ammonia) in transport and urban settings
- H — Offshore production of hydrogen and ammonia

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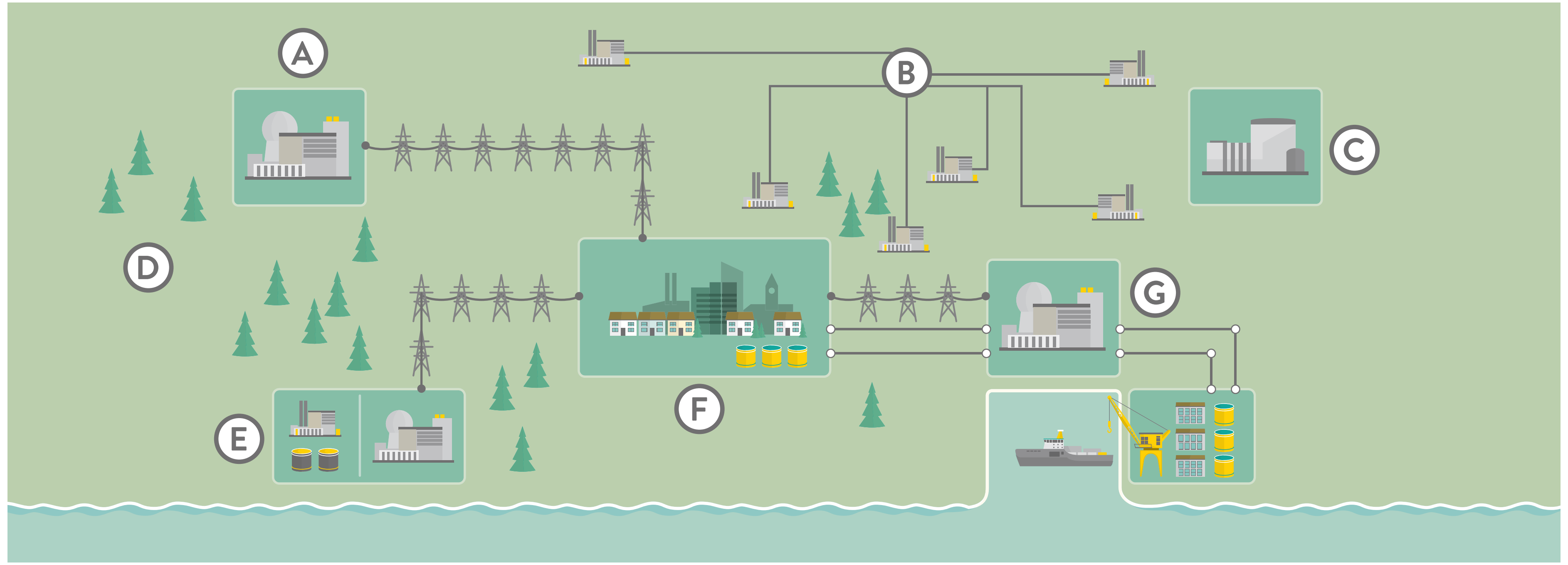
3. Delivering New and Advanced Nuclear Power

The UK currently has 15 operational nuclear reactors, with a shift to new reactors planned over the coming years to replace the Advanced Gas-cooled Reactor (AGR) fleet. Many of the challenges faced by next generation nuclear can only be overcome by further developments in materials and better understanding degradation mechanisms. Research into materials degradation for existing graphite moderated reactors has already enabled savings of £1.6 billion per annum through extending the working life of existing AGRs to 2030. This existing knowledge will also be applied to the next generation of reactors to reduce lifetime costs. Advances in materials science for the fission reactors above will also support the development of materials for prototype fusion reactors.

The development of Modular Reactors, which can be manufactured off-site, will have wide economic benefits for the UK nuclear industry through reduced costs, the creation of advanced engineering jobs, and opportunities for export. For example, Small Modular Reactors (SMRs) could be swiftly constructed on existing nuclear-licensed sites to provide secure baseload electricity supply in conjunction with larger reactors. Developments in materials and the understanding of component degradation are critical to the construction of Advanced Modular Reactors (AMRs) and, in particular, Very High Temperature Reactors (VHTRs) which can also be used to generate heat and hydrogen for local industrial centres. Materials scientists are developing low (<200°C) and high (>200°C) temperature steels, alloys, and coatings to prevent degradation of reactor materials, as well as advanced fuels, materials for novel cooling systems, and materials that are stable under high neutron bombardment.



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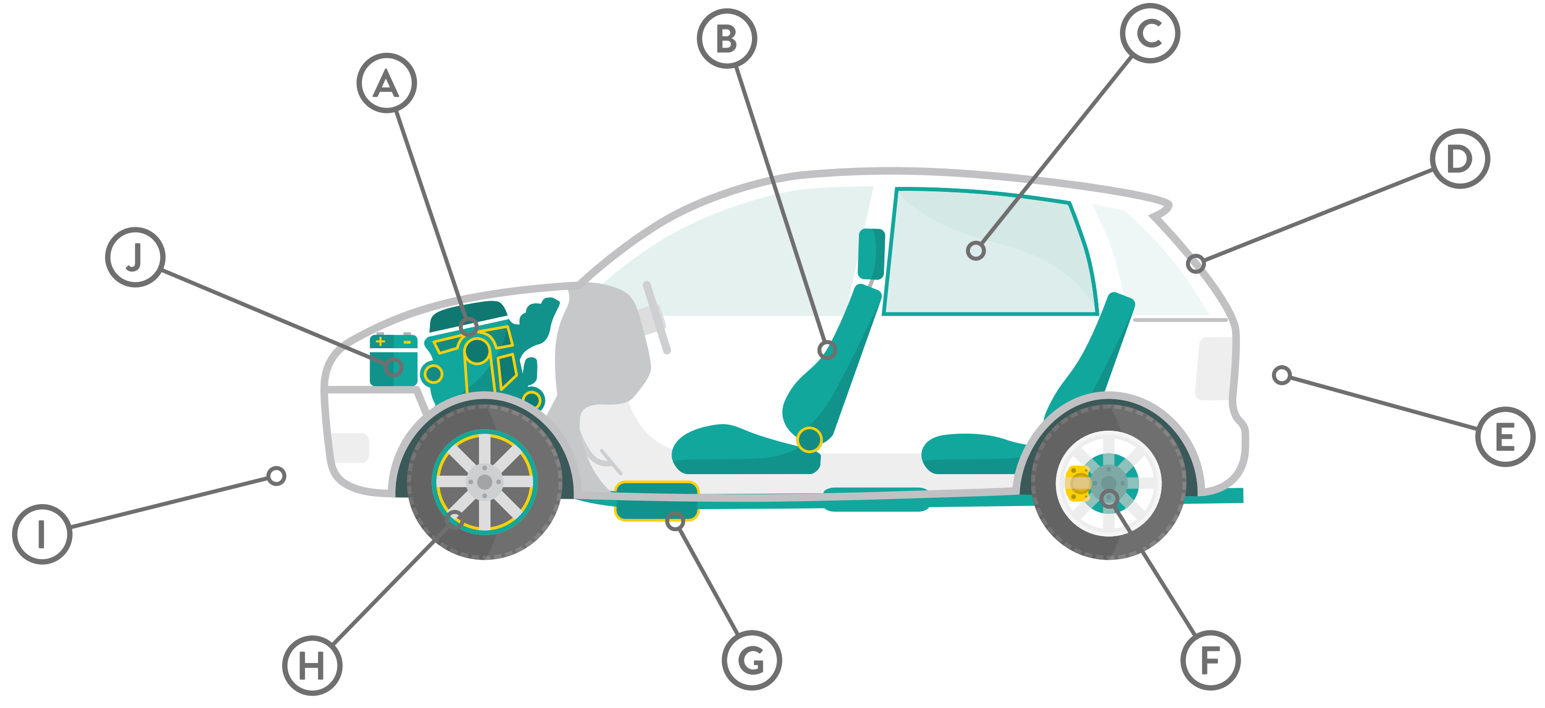
KEY | DELIVERING NEW AND ADVANCED NUCLEAR POWER

A	Developments in modular design allow for lower cost nuclear and more reactors across the UK
B	Modular Reactors benefit the wider materials and components supply chains due to distributed manufacture
C	Key research in materials degradation for next generation fission reactors also benefits materials development for future fusion reactors
D	Materials science was critical to extending the lifetimes of existing AGRs to their decommissioning in 2030
E	SMRs can be assembled on existing nuclear licensed sites
F	SMRs can take up the existing electricity baseload form AGRs
G	VHTR-AMRs can connect to district grids to provide heat and power for industrial production (e.g. H_2, NH_4) and domestic uses

4. Accelerating the Shift to Zero Emission Vehicles

The UK has nearly 40 million cars on the roads (2021) and the full range of vehicles (including cars, buses, and HGVs) must be transitioned to hybrid or electric over the coming 20 years. Materials challenges are associated with the safe delivery, storage, and use of the new fuels used for vehicles (electricity, hydrogen, synfuels) – for example ensuring that hydrogen for fuel cells is delivered at the correct purity and can be stored in tanks that do not add significantly to the cost or size of the vehicle. In all stages of design, the lifetime and circularity of the materials involved must be considered, for example batteries and catalysts will require up to decade-long lives with suitable end-of-life recycling facilities available in the UK to prevent loss of precious materials from the UK economy. The issue of range and geography are important for the distribution of charging/refuelling points and for the solutions available in cities vs rural geographies.

50% of vehicle particulate matter emissions are non-exhaust, such as from tyre and brake pad erosion. Tyres are the single biggest causes of microplastic pollution in UK waterways. The heavier nature of electric vehicles can lead to around 20% higher Tyre Wear Particles (TWP) when braking. New materials will be able to overcome this through new biopolymers for tyres and improved regenerative braking systems. Safety and reliability will be key priorities as new materials are incorporated into zero-emission vehicle designs.



4

KEY | ACCELERATING THE SHIFT TO ZERO EMISSION VEHICLES

A	New materials for greener engines and advanced manufacturing processes
B	Sustainable bio-polymers and novel textile materials for interiors
C	Decarbonisation of UK steel and glass making, greater focus on retaining materials and critical elements in the UK economy
D	New materials structures to enhance light-weighting without compromising safety
E	Circular economy and recycling of components built into vehicle designs
F	Materials for new braking systems for electric vehicles, and more environmentally friendly brake pads
G	Novel catalyst materials to reduce precious metal usage and loss and to improve and increase component lifetimes
H	New materials for wheels to reduce particulate emissions and microplastic release into the environment
I	New sustainable lubricants for the different components in electric vehicles
J	Developments in battery technology to increase range and speed up charging

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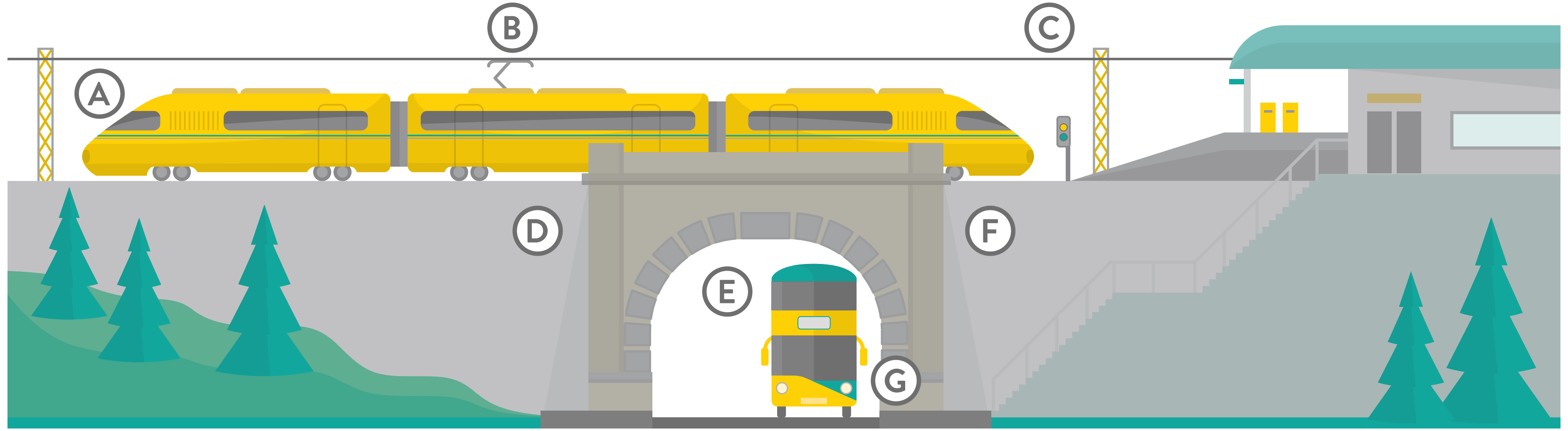
5. Green Public Transport, Cycling and Walking

Rail and bus services are key to enabling thriving national and local economies. Materials science will play a major role in making these services more comfortable, reliable, and sustainable.

The 16,000 km UK railway network has a long history of innovation. Line electrification and battery or hydrogen powered trains will bring new materials challenges. More wear-resistant and fatigue-resistant wheel and rail materials, along with improved suspension and braking systems, will improve reliability and reduce maintenance times. Anticipating more extreme weather events associated with climate change will require new and improved materials for building and maintaining the railway infrastructure.

There are currently 32,000 buses in the UK which will need to be replaced in order to meet the demands of a zero-emissions future. Many of the materials for zero-emission vehicles are applicable to buses with materials science enabling new electric and fuel-cell engine designs with increased comfort through the elimination of engine vibrations. Additional materials developments will provide improved components to withstand heavy public use and the stop-start wear on brakes and engines. New textile materials and alloys with anti-bacterial and anti-viral properties will make public transport safer to use. The urban and rural infrastructure networks to support charging and refuelling are also reliant on the successful scale-up of existing materials and technologies.

Innovations in textiles will also improve the experience of cycling and walking; smart materials and fabrics will recharge devices and track health as well as provide enhanced comfort in ever changing weather conditions.



KEY | GREEN PUBLIC TRANSPORT, CYCLING AND WALKING

A	Lightweight materials for chasis and carriages
B	Battery/hydrogen powered high-speed trains
C	Materials for line electrification and signalling
D	Materials for long life geotechnical assets
E	Smart textiles and antibacterial surfaces
F	Fast charging materials and onboard charging points
G	Battery/hydrogen powered buses for short journeys (cities) and long distance routes (rural areas)

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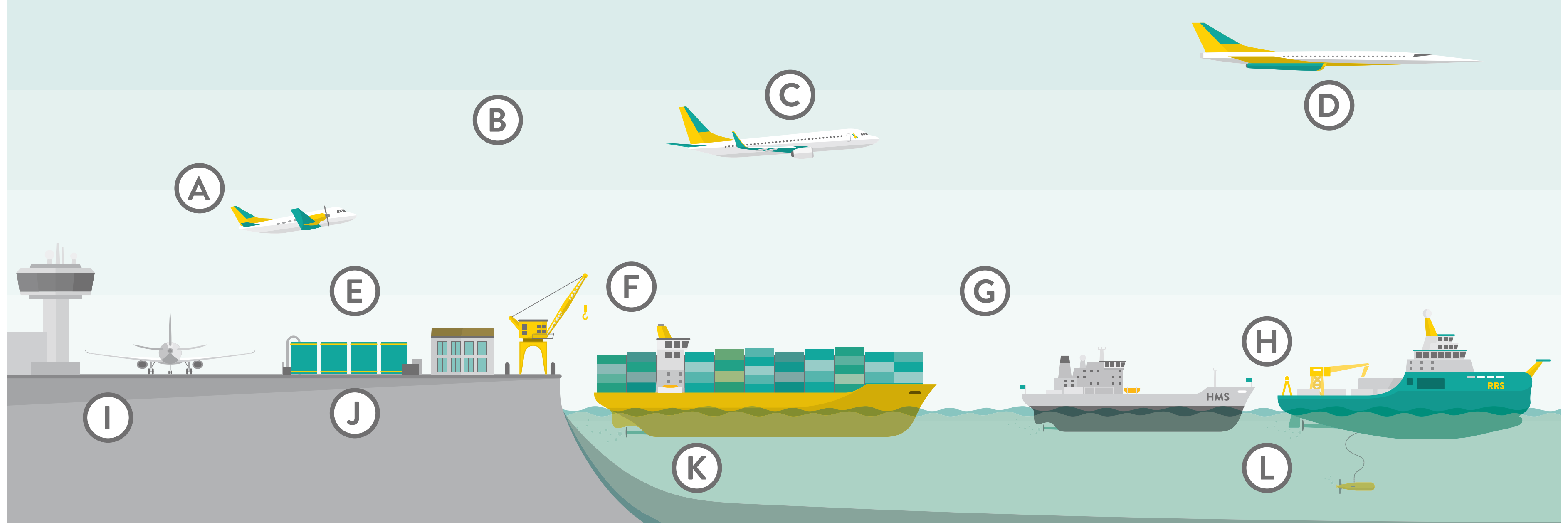
6. 'Jet Zero' and Green Ships

The UK's maritime and aerospace sectors underpin global Britain and allow us to be an international trading hub. These are areas where materials innovation can increase sustainability and enable new export markets.

The UK already has extensive airport infrastructure and is a major aerospace hub for flights utilising a total of 12.4 million tonnes of aviation fuel in 2019. The demand for international travel will remain strong, even in a net-zero and post-covid age, and materials science will be required to develop sustainable and safe propellor and jet planes for short- and long-haul flights. The design of lightweight high-performance battery and hydrogen powered engines and auxiliary-systems into composite aircraft superstructures is dependent on advances in materials science to produce the seals, lubricants, and composites to enable them to run smoothly and safely. Commercial supersonic flight could be enabled through research into high temperature materials and coatings to reduce drag at high speeds.

Aircraft lifetimes are typically several decades and so the phase out of a fleet powered by fossil fuels must be managed in a sustainable manner including the recycling of metals and materials. Sustainable synthetic fuels could act as a bridging technology, however, more development work is required before they can be scaled-up and produced in the UK. Future terminal designs will need to deal with a range of aircraft and fuel types due to the international nature of flight (fossil, synfuel, battery, hydrogen).

Short-haul hybrid (diesel-electric) shipping is already in service on the Isle of Wright ferry and a hydrogen powered ferry to Orkney is proposed. Materials research is enabling the synthesis, storage, and use of a range of possible fuels (methanol, ammonia, hydrogen, and LNG) and will be crucial to developing the necessary storage and refuelling infrastructure. Materials science will also underpin the development of fuel cells and batteries for hybrid shipping, and materials and coatings for hulls and rudders to reduce drag and increase efficiency.



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KEY | 'JET ZERO' AND GREEN SHIPS

- A — Materials for short haul/propeller driven flights, with high-speed, lightweight motors using materials with high magnetic flux density and able to carry high voltages and currents
- B — Integration of new battery materials/hydrogen fuel cells into aircraft superstructure in line with existing/enhanced safety regulations
- C — Materials for long haul/jet driven flights, and electric systems with high power densities and hydrogen engine designs
- D — Materials for new generation supersonic passenger jets, including materials for heat dissipation at supersonic speeds and temperature extremes, i.e. polar-to-equatorial flights
- E — Decarbonised steel and aluminium and end of life recycling
- F — Exhaust cleaning materials for low NOX shipping zones
- G — Wind based propulsion systems and solar power on deck, off-shore fuel electrolysis for fuel cells and batteries enabling hybrid shipping
- H — Materials for long-range and extreme conditions and specialised research ships, and ships for the Royal Navy
- I — Airport infrastructure supporting numerous modes of refuelling
- J — Methanol/Ammonia/Hydrogen/LNG fuels storage and distribution, on-shore synthesis and electrolysis
- K — New fuel/electric engine designs
- L — New materials and coatings for rudders and hulls. New anti-corrosion materials

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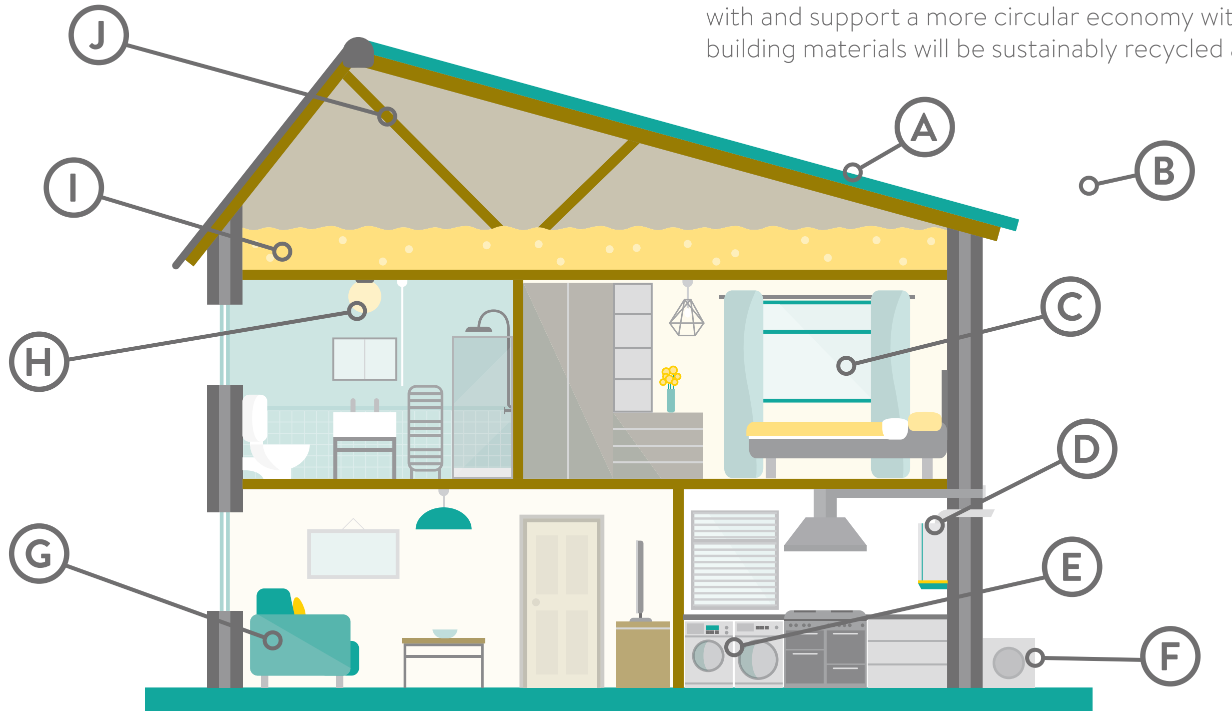
7. Greener Buildings

Domestic heating and hot water accounts for 25% of total UK energy use. Materials science is enabling energy savings and emissions reductions across different areas of the home. In particular, caloric materials can replace refrigerants in fridges, freezers, and heat pumps, replacing less efficient and difficult to recycle halocarbon gases. Advances in lighting materials have been cutting energy use as we move away from tungsten filament bulbs to LEDs.

Developments in traditional materials, such as wood and bio-based composites, play a role in creating sustainable buildings which can self-regulate their temperatures and 'breathe'.

Existing homes can be retrofitted to generate and store energy through local solar and energy harvesting grids. Materials scientists will ensure these new developments comply with building regulations and are sympathetic to heritage designs. Buildings can also utilise water more efficiently and can aid local water collection and filtration. New materials and regulations will be needed to ensure safety is never compromised when using hydrogen fuelled boilers and battery devices within buildings.

A further challenge is the broader issue of decarbonising construction materials such as steel, glass, cement and concrete which currently result in significant CO_2 emissions due to their manufacturing processes. Given that 50% of resource extraction in Europe is linked to construction, new materials and manufacturing technologies need to be developed that are compatible with and support a more circular economy with an explicit focus on how the building materials will be sustainably recycled at end of life.



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7

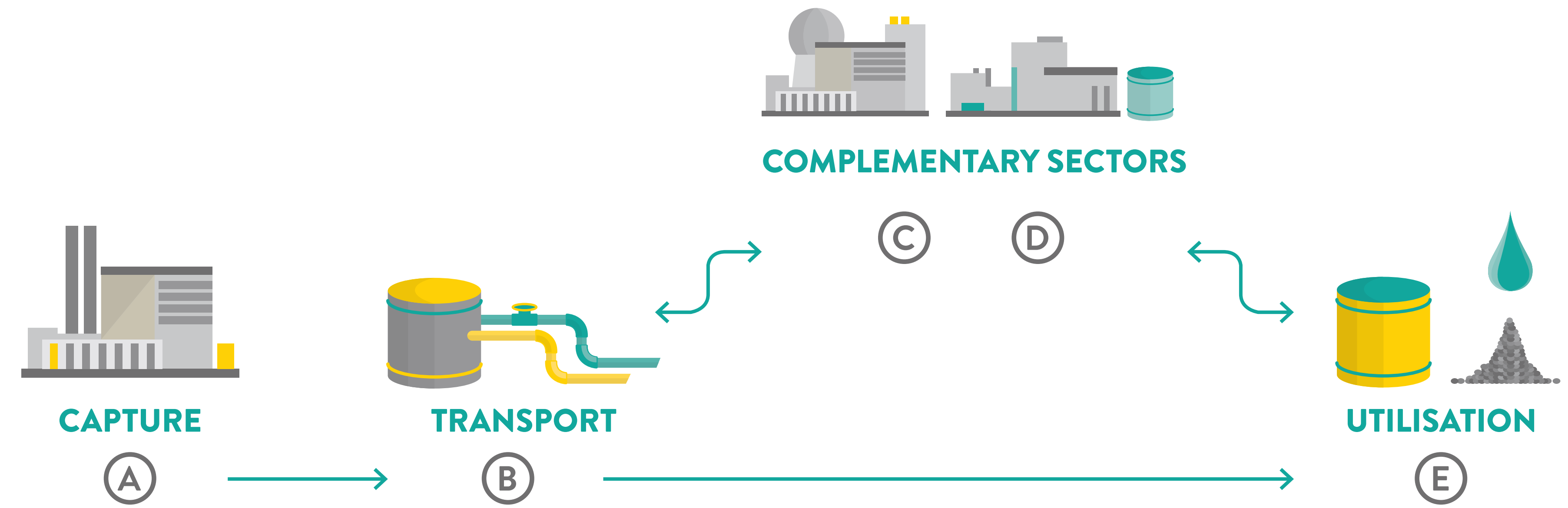
KEY | GREENER BUILDINGS

A	Use of biomaterials within the home
B	Materials and technologies that support a more circular economy
C	Low carbon glass manufacture with coatings to regulate heat and provide energy
D	More efficient boilers and sustainable off-grid heating solutions
E	Advanced components to increase the efficiency of appliances
F	Caloric materials for heat pumps and other heat exchange uses
G	Focus on the recycling of appliances, fixtures and furniture
H	Low energy lighting solutions
I	New materials for breathable insulation to cope with seasonal cycles
J	Developments in wood technology and composites to increase the resilience and use of timber within structures

8. Investing in Carbon Capture, Usage and Storage (CCUS)

Carbon Capture Usage and Storage (CCUS) methodologies are promising techniques to capture CO_2 either from industrial point sources or from the air to then use in the production of higher value products. The UK has a long history of successful chemical innovation and industry, and when combined with other sustainable schemes - such as hydrogen or nuclear - CCUS has the potential to provide the feedstocks necessary for synfuels and other syn-petrochemical products.

For example, Tata Chemicals at Northwich is capable of utilising 40,000 tons of CCUS CO_2 per year by producing sodium bicarbonate for use in foodstuffs, pharmaceuticals, and hygiene products. Other possible processes include polymers, synfuels and other organic chemical products including ethanol. Materials science is critical in supporting the scale-up and roll-out of this technology through developments in catalytic materials and membranes for efficient CO_2 capture, in preventing the corrosion of transport and storage infrastructure, and for developing energy-efficient ways of creating the new range of chemical precursors at elevated pressures – as well as supporting the innovation required in other sectors to support this budding industry.



KEY | INVESTING IN CARBON CAPTURE, USAGE AND STORAGE (CCUS)

A	Novel membranes and catalysts for CO_2 capture from industry and the air
B	Anti-corrosion materials for transporting the captured CO_2
C	Interlinkage with green hydrogen as a feedstock for more complex organic chemicals
D	Energy efficient chemical conversion processes at elevated pressure with heat supplied from nuclear or renewable energy sources
E	Replacements for petrochemicals and chemical precursors

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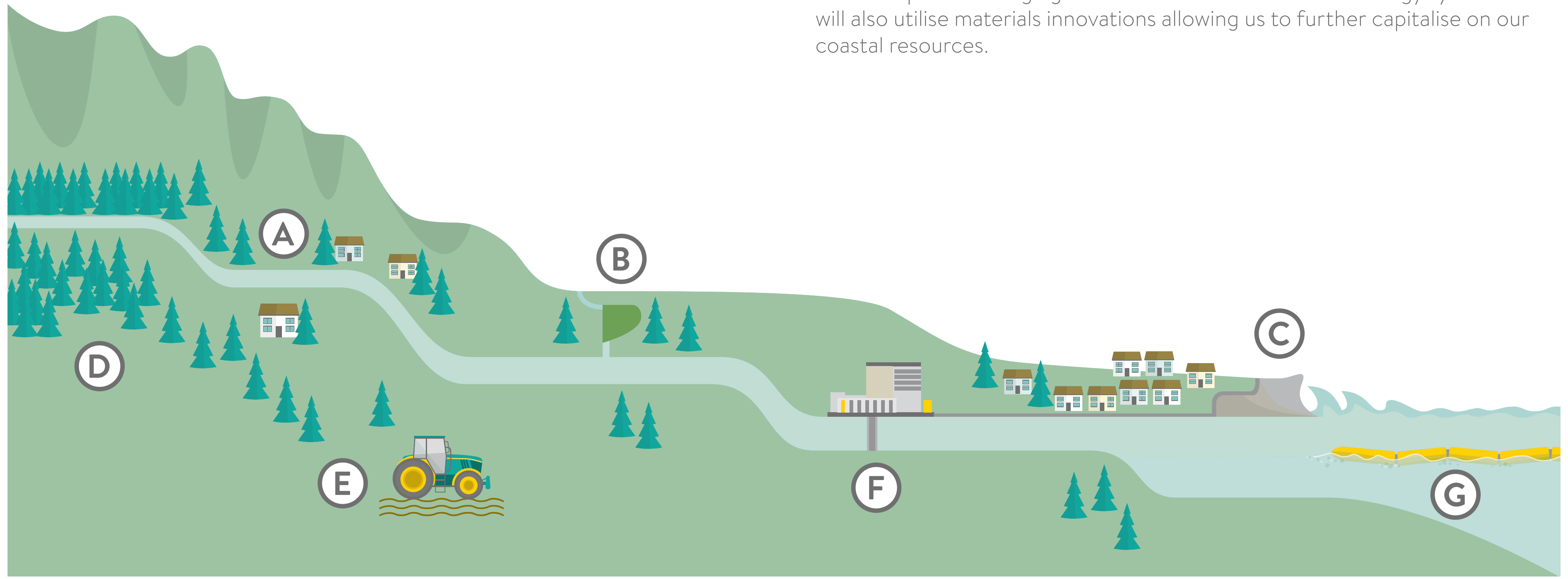
9. Protecting our Natural Environment

The UK uses around 5 million tonnes of plastic, much of which ends up as litter in the environment. Materials science will play a fundamental role in developing new ways to cut down on plastic waste and pollution. It will also help find better uses for the over 10 million tonnes of scrap metal produced in the UK per year and ensure that the increasingly complex devices we use, e.g. computing devices and car batteries, are straightforward to deconstruct, reuse and recycle. Cities can become hubs for 'urban mining' and the reuse of materials, including metals and textile products, will prevent loss of precious resources from the UK's economy.

Materials scientists are developing advanced materials for agriculture including fertilisers that are less prone to eutrophication and not obtained from natural ore-deposits, and batteries and fuel cells for agricultural equipment to help increase productivity while protecting the environment. The use of wood in construction and for composites in a range of settings will increase the commercial uses for coppiced wood products allowing economically sustainable forestry to preserve the UK's working landscapes while supporting local economies. This increase in forestry will also contribute to passive CO_2 capture and support the UK's unique areas of biodiversity.

The UK has a wide range of inland and coastal habitats that similarly require protection from pollution and can also be utilised sustainably to solve other materials problems such as sustainable food sources and marine materials for biopolymers. Materials will also be required for flood and coastal defences as we adapt to a changing climate. Wave and tidal-based energy systems will also utilise materials innovations allowing us to further capitalise on our coastal resources.



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9

KEY | PROTECTING OUR NATURAL ENVIRONMENT

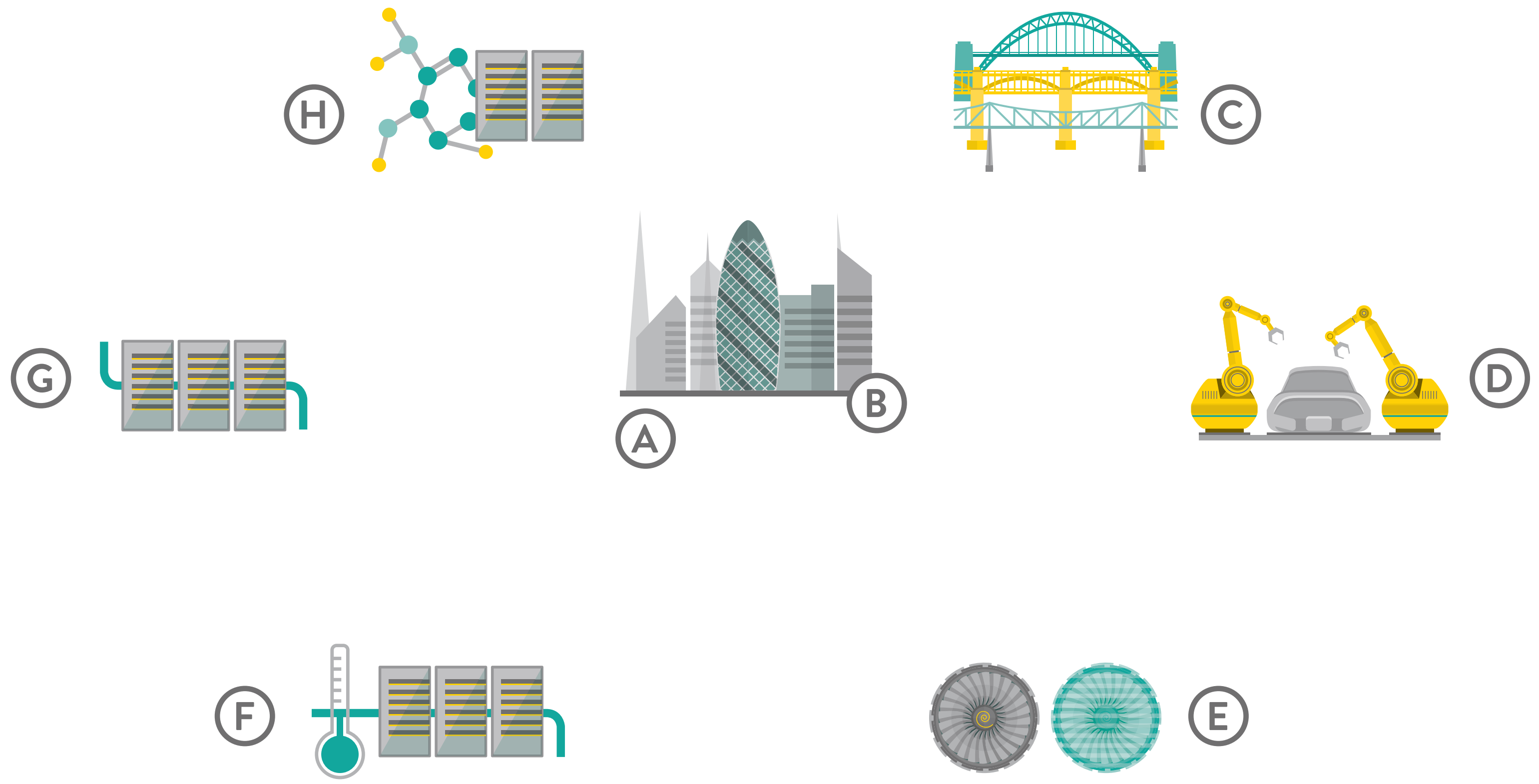
A	Better use and management of rivers
B	Advanced fertilisers for better nutrient delivery and eliminating eutrophication
C	Preventing corrosion of flood defences
D	Developing sustainable forestry and uses for wood and wood-derived materials
E	Batteries and fuel cells for agricultural equipment
F	Materials to improve water quality
G	Wave energy systems

10. Green Finance and Innovation

Whilst the finance sector will predominantly be used to fund the projects to develop and commercialise the new materials systems, it does also benefit from developments in materials science.

New and advanced semiconductor and photonic materials enable the faster and more powerful computation required to power banking, trading, and communication platforms. In the future, new materials will enable quantum computing to further enhance transaction handling and improve security. Advances in computing power also support the use of digital twins which can reduce product development timescales and improve infrastructure and systems maintenance, hence increasing reliability.

Improvements in computing and the use of digital technologies for innovation will support UK science and industry. Artificial intelligence and supercomputers can accelerate new material design and discovery. Improved lab and factory automation will improve productivity and enhance manufacturing capabilities. New device designs will use less electricity and reduce the need for cooling systems thereby supporting wider sustainability targets.



KEY | GREEN FINANCE AND INNOVATION

A	Finance sector can fund development and commercialisation of materials as well as larger scale infrastructure projects involving new materials
B	Materials science can provide faster computers and other semiconductor devices for banking and finance
C	Enhanced management of complex infrastructure systems
D	Capacity for greater automation in manufacturing
E	Greater computing power and storage enables digital twins to be fully exploited
F	New computing materials will be energy efficient using less energy and require less cooling
G	Better supercomputers for public and private modelling purposes
H	Increased computing power allows for more accurate and ambitious scientific modelling

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The Henry Royce Institute is the UK's national institute for advanced materials research and innovation. Royce was established to ensure the UK can exploit its world-leading expertise in advanced materials and accelerate innovation from discovery to application. With an investment of over £330 million, Royce is ensuring that academics and industry in the UK's materials community have access to world-class research capabilities, infrastructure, expertise, and skills development.

From future cities and their energy supplies, to computing, manufacturing and medicine, the research and innovation facilitated by Royce has the potential to significantly impact peoples' lives. With its hub in Manchester and with capability distributed across nine founding Partners and two Associates, Royce works collaboratively to create real solutions and to have a positive economic and societal impact for the UK.

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