Innovate UK

INSIGHTS REPORT

Welcome to the future Innovate UK's 50 Emerging Technologies

TECHNOLOGIES THAT WILL SHAPE THE UK ECONOMY IN 2040 AND BEYOND

Innovate UK's 50 Emerging Technologies report

Future technology trends matter to businesses. As the UK's innovation agency we are frequently asked what the future holds. It's our duty to help businesses explore and answer this.

We work in a great research and innovation environment where, with input from our partners in Research Councils and beyond, we have the unique ability to identify interesting emerging technologies and trends. We have drawn on our ecosystem, securing input from 300 stakeholders to deliver a glimpse of the future that helps the businesses we work with every day to explore emerging opportunities.

Development of this report followed a well-established and robust emerging technology identification process that has been independently reviewed. Input came from a wide range of academics, Government departments, and Research Councils including EPSRC, BBSRC, NERC, MRC and STFC. For more on how we made the report go to page 6.

Read, share and discuss Innovate UK's 50 Emerging Technologies report.

Contribute your thoughts to horizonscanning@iuk.ukri.org

Your input aids the UK in attaining strategic advantage within crucial future technologies.

Start creating the future, today.

Five key questions:

1. **As technology is more embedded in our bodies, will humans turn into something new and different?**
   What makes us human will be increasingly questioned.
2. **Should AI be allowed to make decisions on our behalf?**
   All aspects of business and society will be transformed through AI and computing.
3. **If humans can expect a century of good health, what does this mean for employment, pensions or housing?**
   The quality and length of our lives will be greater than ever before.
4. **Will a shift towards cleaner, affordable energy change the way we live and work?**
   A transformed energy system could help new industries to thrive.
5. **What will a vast expansion of our understanding of the world mean for the UK economy?**
   The UK's ability to draw on its research and business strengths will help us solve big problems and seize opportunities.

Your answers to questions like these will shape our future.

Unleashing opportunities for the UK's leadership

FOREWORD BY
Indro Mukerjee
Chief Executive,
Innovate UK

The UK is an important global player in innovation. Our nation boasts recognised expertise across many technological domains, ranging from artificial intelligence and materials science to robotics and healthcare. At the same time, there are many challenges facing the economy, society and the environment that make it essential that we drive innovation further and faster.

Innovate UK is the UK's innovation agency, and we work to support economic and productivity growth through supporting innovative businesses.

We also work to help catalyse, connect, and stimulate ideas- and that work is at the heart of this Innovate UK 50 Emerging Technologies report.

The Innovate UK team has delved into some key cutting-edge technologies which are still in their infancy, and framed thoughts to stimulate discussion; to stimulate ideas; and to stimulate possible future innovation.

The ideas presented have the potential to, directly or indirectly, stimulate activities which could help UK organisations seize the initiative and explore nascent sectors of the economy with potential for growth.

Consider, for instance, space-based solar power, a concept that offers the tantalising prospect of an uninterrupted, clean energy source. Furthermore, soft robotics holds tremendous potential for the development of artificial muscles and organs that closely resemble their biological counterparts.

The Innovate UK team recognises that the most crucial element lies not in the technology itself, but rather in the people and innovative businesses and organisations behind them, spread across the UK.

It is these visionary entities that possess the ability to recognise potential and transform it into commercially successful products of the future. In this report, we are not seeking to predict the future, but to stimulate curiosity, share knowledge, and consider the art of the possible.

We will share this report across our innovation ecosystem- across businesses, research and technology organisations, governmental bodies, investors, lenders, academic institutions, and others. We are keen to receive feedback and keen to stimulate innovation in action for the benefit of the UK economy and so that we can work on our shared goal to transform tomorrow together.

Contents

Introduction	05
How the report is organised	05
How we made the report	06
AI, Digital and Computing Technologies	07
AI emotion and expression recognition	08
Artificial general intelligence (AGI)	08
Biologically inspired AI	08
Brain machine interface (BMI) technologies	09
Quantum algorithms	10
DNA data storage	10
New computing models	11
Novel immersive interfaces	11
Advanced Materials and Manufacturing	12
4D printing	13
Biomimetic materials	13
Nanoparticle manufacturing	13
Metamaterials	14
Electronics, Photonics and Quantum Technologies	15
Alternative and novel semiconductor systems	16
Emerging microscopy techniques	17
Hyperspectral imaging	17
Millimetre wave and terahertz technologies	17
Photon generators	18
Plasmonics	18
Post-quantum cryptography	19
Room temperature superconductors	19
Energy and Environmental Technologies	20
Cross-linked polymer recycling	21
Gridscale wireless energy transmission and charging	21
Hypersonics	22
Novel propulsion or ion based propulsion	22
Novel hydrogen production and storage technologies	23
Novel negative emissions technologies	24
Nuclear fusion	24
Space-based solar power	24
Biotechnology	25
Artificial cells and artificial life	26
Bacteria and microbe manufacturing	26
Biocatalytic membranes	26
Bioelectronics and electroceuticals	27
Hybrid microbe biotechnology	28
Programmable cells	28
Biofabrication in tissue engineering	28
Health and Medical Technology	29
Adult stem cell generation	30
Fluxomics	30
Anti-ageing drugs	30
Antibiotic replacements	31
Microbiome therapeutics	32
Personalised RNA therapeutics	32
Phased genome assembly tools	32
Sensation detection implants	33
Whole body-on-a-chip device	33
Robotics and Space Technologies	34
Fully autonomous vehicles	35
Nanoscale robotics	35
Robotic off-world manufacture	35
Soft robotics	36
Space nuclear power and novel space propulsion systems	36
Very low earth orbit (VLEO) satellites	37
Conclusions and the way forward	38

Our showcase technologies are highlighted in bold.

The aim of this report is to share some of the most significant emerging technologies likely to be important to the UK's industries of 2040 and beyond.

INTRODUCTION BY
Simone Boekelaar,
Head of Horizon Scanning, Innovate UK

Looking this far into the future means we can start talking with partners across the innovation ecosystem about what support, if any, is required to realise the technology's full potential.

These technologies may not be those getting the most interest in policy or investment right now. They may not be the hottest topics in research and development circles. But our analysis says they have economy and society-shaping potential.

When reading this report, we need to remember that technologies themselves have little intrinsic value. It is only when they are put to use that value manifests.

We know the greatest value is created when multiple technologies are combined. When several mature technologies are brought together – that can really change the world.

For example, remote surgery brings together robotics, AI, advanced materials, sensors, imaging technologies. Or a smartphone combines touchscreen and camera technologies, internet and Bluetooth connectivity, GPS, to name just a few.

The focus here is primarily on the technology rather than their potential applications. On the building blocks, rather than end results.

Our hope is that by discovering these technologies, you can consider original combinations. These may then inspire new applications or solutions to societal challenges. Then innovators are inspired to develop these technologies into new products and services.

And we will all be inspired to embrace the change this future will bring.

How the report is organised

Our 50 emerging technologies are organised within the UK Innovation Strategy's seven technology families. They were, in turn, inspired by Innovate UK's taxonomy for structuring and understanding the 1,000+ technologies we support.

This allows us to explore the relationships between technologies and technology families. It ensures the technologies we track cover all areas of science and technology, and all parts of our economy.

For each technology, we define and explain why it is important, and explore its potential future significance. In each family we highlight one technology we think could have a particularly meaningful economic or societal impact.

Turn the page to see how we selected the 50 technologies.

Read. Share. Discuss. Innovate.

How we made the report

1 — Define

Our question: Which emerging technologies are likely to be important to the UK economy beyond 2040?

2 — Gathering

- Survey of scientists and researchers
- Discussions with experts
- Undertake a review of technology scans undertaken by others.

3 — Filtering

Combine new ideas with existing data. Consider:

(i) Is it truly emerging and

(ii) Is there someone in the UK with expertise, to create a shortlist.

4 — Analysis

Compare each shortlisted idea, using 30+ metrics. Our criteria:

- Timing
- Additionality
- UK Capability
- Opportunity
- Societal Impact.

6 — Output

Use analysis to select interesting technologies for report.

7 — Communication

- Share findings
- Seek feedback
- Use feedback for next report.

8 — Conclusion

See on page 38.

AI, Digital and Computing Technologies

These technologies might not just transform the way we live our lives, but also make us consider what it means to be human.

They could blur the boundaries between the real and virtual world, and create a step-change in what tech can do in the home and workplace. While there are many possibilities which offer great hope, ethical considerations need to be fully considered. If we do that, we can make sure that our future society harnesses the world of AI, digital and commuting technology to the greatest benefit of the most people.

AI, Digital and Computing Technologies

"It moves us towards computing that mimics human brain processes."

AI emotion and expression recognition

What is it? Developing AI that recognises and interprets human emotions.

Why is it interesting? Can you imagine a world where AI and humans work seamlessly together? Where Siri and Alexa assist us in more than simple tasks?

"Sentient" AI can recognise our emotions and offer assistance, companionship or alert medical professionals when we need help. We may need machines to express emotional behaviours of their own, for example in AI used in robots. This would help patients in care homes where emotional interaction is key to improved wellbeing.

How could it change our lives? It has the potential for very positive impacts, improving our daily lives in areas such as care and companionship. Development with strong ethical considerations will open up endless opportunities.

Artificial general intelligence (AGI)

AI is as capable of learning intellectual tasks as humans are. With the flexibility and resourcefulness of human intelligence, capable of producing new ideas.

Why is it interesting? AGI enables machines to behave, learn, create and perform as humans do. It will help us explore the creative abilities of AI and understand the increasingly 'natural' interactions between humans and machines.

How could it change our lives? AGI raises intriguing questions about what it means to be human. Will we always be able to tell if we are interacting with machines or humans? Will that matter to us? The answers will change our lives in ways we don't yet expect and cannot yet forecast.

Biologically inspired AI

What is it? It springs from the idea that intelligence emerges as much from cells, bodies, and societies as it does from evolution and learning. Traditionally, AI has tried to reproduce human abilities. Newer approaches take inspiration from biological structures that can organise themselves. These include evolutionary computation and electronics, artificial neural networks, immune systems, biorobotics and swarm intelligence.

Why is it interesting? It moves us towards computing that mimics human brain processes, potentially allowing creative behaviour by machines. It could provide new algorithms for planning, remembering and visual stimulation.

How could it change our lives? It could accelerate the development of AI and enable things that otherwise wouldn't be possible. It will likely inform us about how our world functions.

SHOWCASE TECHNOLOGY:

Brain machine interface (BMI) technologies

What is it? Technologies that connect the brain with a computer or machine. It translates our thoughts into commands that can control external software or hardware, such as a computer or robotic arm.

Interface technologies are often divided into those that 'read' brain activity and decode its meaning, and those that 'write' to the brain to manipulate activity in specific regions and affect their function.

Why is it interesting? It gets us closer to a full interface with the human brain. The ultimate ability to share data between humans and machines could alter the way we regard mankind itself.

What industries could use this? Medical, ageing society, sports, military/defence, manufacturing, services sector.

How could it change our lives? Advanced BMI technologies are being trialled in prosthetics for people with motor or sensory impairments. They could allow people who are paraplegic or quadriplegic to regain limb control. Those missing limbs could have direct control – from brain to device – of their prosthetics.

What do we need to start discussing? The balance between helping and protecting people who need or want this technology is a big topic. We need to think about who should have access to this technology, and what regulations, if any, are needed. We would also need to work out what happens if a product is no longer supported – this is an inconvenience with a smartphone, but a much bigger issue when a device is linked to your brain.

> "The ultimate ability to share data between humans and machines could alter the way we regard mankind itself."

Quantum algorithms

What is it? Quantum algorithms are a key element of the software and tools that will help quantum computers to potentially outperform standard computers. Quantum algorithms can be applied to areas such as cryptography, search optimisation, and simulation of quantum systems.

Why is it interesting? Quantum computers are coming! It is essential that for new computing paradigms we also develop the software and tools to provide the applications these computers can support.

How could it change our lives? The key to getting value from quantum computing will be finding the specific set of algorithms that quantum computers are better at than classical computers. We know some of these already, but there are lots more to find and develop!

DNA data storage

What is it? It could exponentially increase data storage capabilities and, theoretically, be preserved indefinitely. It's the process of encoding and decoding data to and from synthesized strands of DNA or RNA.

Why is it interesting? Imagine being able to store zettabytes (that's a hard-to-imagine one billion terabytes), in compact, high-density and molecular-level data storage? Harnessing the power of biotechnology could meet our escalating data storage demands, especially important as we look to access sophisticated AI technologies.

How could it change our lives? We are reaching the physical limitations of computing hardware design. DNA synthesis could remove this limitation, opening up new computing applications, capable of storing and retrieving vast volumes of data.

> "Imagine being able to store zettabytes (that's a hard-to-imagine one billion terabytes), in compact, high-density and molecular-level data storage..."

AI, Digital and Computing Technologies

"These advances could help the world become more equitable."

New computing models

What is it? New computing techniques not based on traditional circuit technology.

Why is it interesting? Beyond quantum computing, these are new computing models offering orders of magnitude performance improvements out of reach of conventional computers. These include biological, photonic and neuromorphic computing.

How could it change our lives? These technologies for completely new ways to build computers will allow scientists to answer questions which are impossible today. These include modelling the human brain, complete climate simulations, and understanding data from space exploration.

Novel immersive interfaces

What is it? Offers new ways of interacting, creating and displaying content, applications and experiences. These could involve augmented reality, a blend of real and virtual experiences, or a fully simulated digital experience. It requires new forms of media that deeply involve all our senses to create a truer perception of reality.

Why is it interesting? Will blur the off- and online world by allowing us to use computer technology through multiple senses.

How could it change our lives? Augmenting our senses with technology creates opportunities, ranging from performing surgery remotely to advertising. It will change the way we view the world and access media, and allow us to travel via our senses. These advances could help the world become more equitable.

Advanced Materials and Manufacturing

When we think of how society will look in the decades to come, advanced materials will play an integral role.

These incredible materials all have properties made through the development of specialised processing and synthesis technology. They open the door to new possibilities in healthcare and transport, and can pave the way to a more energy-efficient future. These materials will be the basis of the business innovation we need to create a desirable future society.

Advanced Materials and Manufacturing

"Offers smart materials which adapt over time, with the potential for 'self-repair'."

4D printing

What is it? 3D printing is achieved by layering 2D structures on top of each other. Now, technology is developing to change 3D shapes over time through the addition of heat, light, electricity or liquid, creating a 4D structure.

Why is it interesting?
Offers smart materials which adapt over time, with the potential for 'self-repair'. This offers possibilities such as manufacturing in space, better soft robotics and new medical solutions.

How could it change our lives?
If materials can repair themselves, it reduces our need to perform dangerous maintenance tasks. 4D materials could create structures in space or other challenging locations. They could allow us to create medical devices that change with the patient over time.

Biomimetic materials

What is it? Synthetic materials developed using inspiration from nature. Designed to replicate material attributes of a living organism.

Why is it interesting?
Biomimetic materials often offer higher structural performance for lower energy input. They are easier to reuse and recycle than comparable materials. This technology inspires us to explore the natural world for more sustainable solutions.

How could it change our lives?
Could open up new ways of creating materials inspired by nature, cheap to make and less harmful to the planet. This could help us discover new ways of making materials, grounded in millennia of evolution.

Nanoparticle manufacturing

What is it? As the name suggests, the manufacturing of nanoparticles. These incredibly tiny particles are made either by breaking down larger pieces of material, or by assembling single atoms and molecules into nanostructures. The top-down approach is useful for making interconnected structures such as in electronics; while the bottom-up process can create identical structures with atomic precision.

Why is it interesting?
Nanotechnology has emerged over the past decade or so as an essential technology for many industries. Finding more effective, efficient and lower cost ways to manufacture nanoparticles will help us to expand the uses and benefits of nanotechnology.

How could it change our lives?
Giving us stronger, cleaner and "smarter" surfaces and systems; removing pollutants from energy production; contributing to smaller and lighter electronics and better batteries; and new ways to treat disease. Nanoparticles will be essential to our future lives.

SHOWCASE TECHNOLOGY:

Metamaterials

What is it? Metamaterials can be formed from traditional materials that are easy to find in any natural environment. They are engineered structures designed to interact with electromagnetic radiation. These structures are very small, usually smaller than the wavelength of the radiation they are interacting with. These so-called meta-atoms can interact with the electric and magnetic components of light in a way that natural atoms do not, giving metamaterials unusual properties.

Why is it interesting? When metamaterials are engineered in an intelligent and innovative design they behave in amazing ways. They operate at the sub-wavelength level offering properties never found in nature, which extend the way light and matter interact. This opens up many new sensing and other possibilities.

What industries could use this? Transport, medical, scientific research, telecommunications, energy, creative industry.

How could it change our lives? Science fiction meets reality with metamaterials. They could make substances with which they interact invisible – giving rise to the possibility of a real-life invisibility cloak!

Harnessing invisibility could remove blind spots in cars, enable us to create more precise medical imaging or telecommunications antennae, and significantly improve the efficiency of solar power generators.

What do we need to start discussing? Funding and support for the science behind metamaterials is a big issue. We then need to think about how they can be translated into commercialised products.

> "They could make substances with which they interact invisible – giving rise to the possibility of a real-life invisibility cloak!"

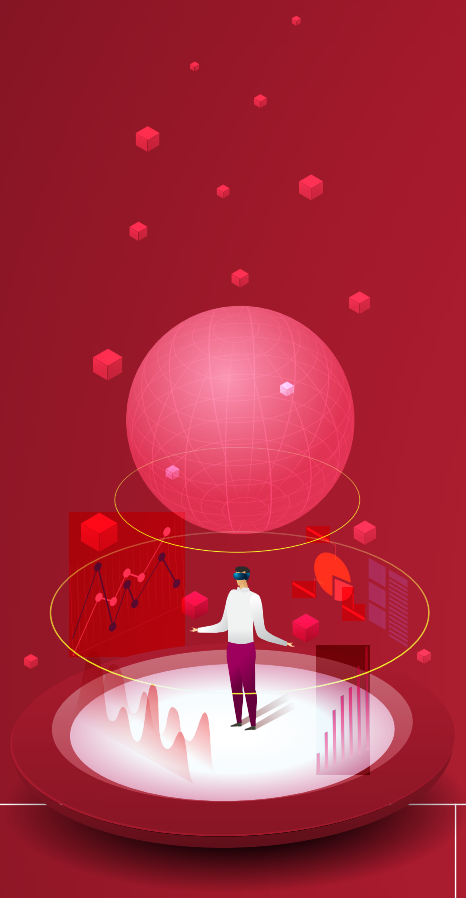
Electronics, Photonics and Quantum Technologies

The world of digital and electronics have transformed how we live over the past few decades.

The emerging developments on these pages suggest a new era is on the horizon of faster, lighter, smarter technology. They will allow us to do more with less. There are real technological challenges to overcome, but if they are, they could change every aspect of our lives, from healthcare and computing through to cutting our energy bills.

SHOWCASE TECHNOLOGY:

Alternative and novel semiconductor systems



What is it? A semiconductor is a substance or device that conducts electricity under certain conditions but not others, used in many electrical appliances. The next generation of semiconductors are those which don't only use silicon. They include various types of compound semiconductors, which are made from two or more elements. Compound semiconductors have physical properties superior to silicon making them better suited to many applications in dependent technologies such as telecoms, net zero and quantum technologies.

Why is it interesting? Current technologies are reaching their performance limits in a growing number of applications. Wide Bandgap (WBG) compound semiconductors can operate at higher voltages, temperatures and frequencies which will provide much improved performance compared with current semiconductors.

What industries could use this? Almost every industry is affected by this technology. Key uses are in 6G, photonics and power electronics.

How could it change our lives? Next generation WBG semiconductors will be smaller, faster, more efficient and more reliable than current types. This will help create lighter, more energy-efficient devices.

What do we need to start discussing? How we will supply the minerals and materials needed to produce novel semiconductors, approaches to international collaboration, and understanding the role of UK industry in novel semiconductor supply chains.

"The balance between helping and protecting people who need or want this technology is a big topic."

"Terahertz waves may be able to play a role in protein analysis and drug discovery."

Emerging microscopy techniques

What is it? Recent advances in microscopy are changing the way proteins and molecules can be imaged. For example, electron microscopy uses a beam of electrons to create an image, allowing much smaller objects to be examined in finer detail.

Why is it interesting? This technology allows us to view biology at work in both space and time, from single molecules to entire organisms, providing access to knowledge and insights never before seen.

How could it change our lives? These technologies enable scientists to more accurately explore the relationships between structures and properties for a wide variety of materials to better understand their behaviour. This helps us develop new materials, better understand materials and organisms, and enable better disease diagnosis.

Hyperspectral imaging

What is it? A technique that analyses a wide spectrum of light instead of giving primary colours to each pixel. The light striking each pixel is broken down into many different spectral bands to provide much better information about the image.

Why is it interesting? Combining spectroscopy with imaging beyond the visible light wavelengths at multiple frequencies provides for exciting 'fingerprinting' of an object's make-up.

How could it change our lives? Could herald new precision agriculture and biotech, with higher and more reliable crop yields. Could save lives by monitoring extreme climate events and better understanding of weather systems. Has potential benefits for healthcare through better classification of wounds and clearer imaging of microbes.

Millimetre wave and terahertz technologies

What is it? Millimetre and terahertz waves are electromagnetic waves just like micro and audio waves. Millimetre wave frequencies are small, measured from 1-10mm, while terahertz waves are much smaller, measuring 100 microns up to 1mm.

Why is it interesting? Has great potential for non-invasive sensing and imaging, including healthcare diagnostics.

How could it change our lives? Millimetre or terahertz waves have a shorter range than radio waves, but can transmit much more data. They also provide higher spatial resolution in imaging applications, enabling high-definition images to be obtained. Terahertz waves may be able to play a role in protein analysis and drug discovery. They may help detect toxic gas, and examine concrete structures.

Electronics, Photonics and Quantum Technologies

Photon generators

What is it? Photons are tiny particles of light that have unique quantum properties.

Photon generators are light sources that emit light as single particles or photons.

Why is it interesting? We need to develop new, controllable photon-emitting light sources to utilise quantum technology. But because quantum processes are inherently random, producing single photons on demand is extremely challenging.

How could it change our lives? Developing highly efficient and perfectly controlled building blocks for quantum technologies is vital to opening up the world of quantum technology. Quantum light is central to the development of secure communications and more powerful computing, powered by quantum.

Plasmonics

What is it? Plasmonics focuses on the interaction of light and electron charges in metallic nanostructures and nanoparticles. It involves exploiting waves of electrons triggered when light strikes a metal surface. These are much shorter than wavelengths of light, making it possible to use light indirectly in the very small dimensions of today's integrated circuits.

Why is it interesting? Has applications in imaging, nanoparticles and is an important enabler of other emerging technologies.

How could it change our lives? Plasmonics will impact the worlds of science, engineering, and medicine. It's an unsung hero as it will likely have many small impacts across industries and technologies used in our everyday lives.

"Quantum light is central to the development of more powerful computing..."

"Room Temperature Superconductors could make consistently low electricity bills possible..."

Post-quantum cryptography

What is it? Focuses on developing cryptographic systems that are secure against both quantum and classical computers and can operate within existing communications networks.

Why is it interesting? Quantum computing provides a threat to traditional encryption techniques. Therefore, an important goal is to develop new cryptography safe for both traditional and new computing paradigms.

How could it change our lives? We look to quantum technology to provide efficient solutions to today's technical challenges. Quantum computing comes with novel threats which will make most currently used cryptographic solutions insecure. We will therefore need to begin using post-quantum cryptography technologies to combat future threats.

Room temperature superconductors

What is it? Superconductors are currently used in MRI technology and in maglev trains. They need very cold temperatures or very high pressures to work. The challenge is to discover a superconductor effective at normal pressures and higher temperatures, to greatly expand how they could be used.

Why is it interesting? Room temperature superconductors remain a challenging emerging technology. But if established, would allow for electricity to be conducted with no waste of energy. As the UK aims to reach net zero by 2050, this would be hugely desirable.

How could it change our lives? Could make consistently low electricity bills possible and radically change the economics of energy production and distribution.

Energy and Environmental Technologies

Recent geopolitical developments have highlighted the issue of energy supply and security.

We need the right energy mix to protect our standard of living and transition towards a net zero economy. Renewable energy sources, carbon removal technologies and energy vectors such as green hydrogen, will play an increasing role in the energy mix as we move toward a cleaner, greener society. How we store and supply energy to key markets is a challenge as we use more sustainable energy. The technologies we explore here are likely to underpin how we live and work in future decades.

Energy and Environmental Technologies

"Developing advanced recycling methods could reduce plastic pollution and demand for new polymers."

Cross-linked polymer recycling

What is it? Cross-linked polymers are extremely difficult to recycle, adding to landfill and causing harm to the environment. However, progress in materials science and chemistry mean that recycling of these materials is now a real prospect.

Why is it interesting?
Given the continuing issue with single-use plastics, any methods which enable the recycling of cross-linked polymers are of significant interest.

How could it change our lives?
Polymers don't decompose easily and have a limited service life. They have brought many positives to everyday life, but the waste from polymeric material can be found in every environment and even the human food chain. Developing advanced recycling methods could reduce plastic pollution – and demand for oil to produce new polymers.

Gridscale wireless energy transmission and charging

What is it? Wireless charging is commonplace in homes and workplaces, at very small scales. Gridscale wireless energy transmission and charging applies this principle to large energy uses.

Why is it interesting?
Conveying electric power safely over distance without cables is a potential step-change in how we use the electronic devices we rely on.

How could it change our lives?
Progress here would enable storm and weather-proof power transmission. It would completely change the structure and operations of our energy transmission grid, so we can move power to where it is needed more easily.

Hypersonics

What is it? Hypersonic technologies could enable aircraft, missiles and spacecraft to reach speeds faster than Mach 5 – nearly 4,000 miles per hour. The key challenge to be overcome is that the airflow temperature around a hypersonic aircraft is so high that the chemical bonds vibrate and then eventually break.

Why is it interesting?
Hypersonic weapons are already being introduced. Hypersonic transport would shrink the earth as the jet engine did in the 20th century, transforming the movement of people and goods.

How could it change our lives?
London to Sydney in 3 hours! Aberdeen to London in thirty minutes or less! (One of your authors is an Australian expat living in the north of Scotland, so may be biased in the potential benefits ultrafast transport could bring.)

Novel propulsion or ion based propulsion

What is it? Ion is a form of propulsion used for spacecraft. It creates thrust by giving an electron energy to break free of an atom. Ion thrust engines are only practical in space.

Why is it interesting?
Ion thrusters already keep satellites in their correct orbits. Ion propulsion requires significantly less propellant than chemical thrusters. Could help space travel become a reality and increase satellites' lifespans.

How could it change our lives?
Could be a reliable technology to propel us when exploring deeper into space.

"Ion propulsion... could be a reliable technology to propel us when exploring deeper into space."

SHOWCASE TECHNOLOGY:

Novel hydrogen production and storage technologies

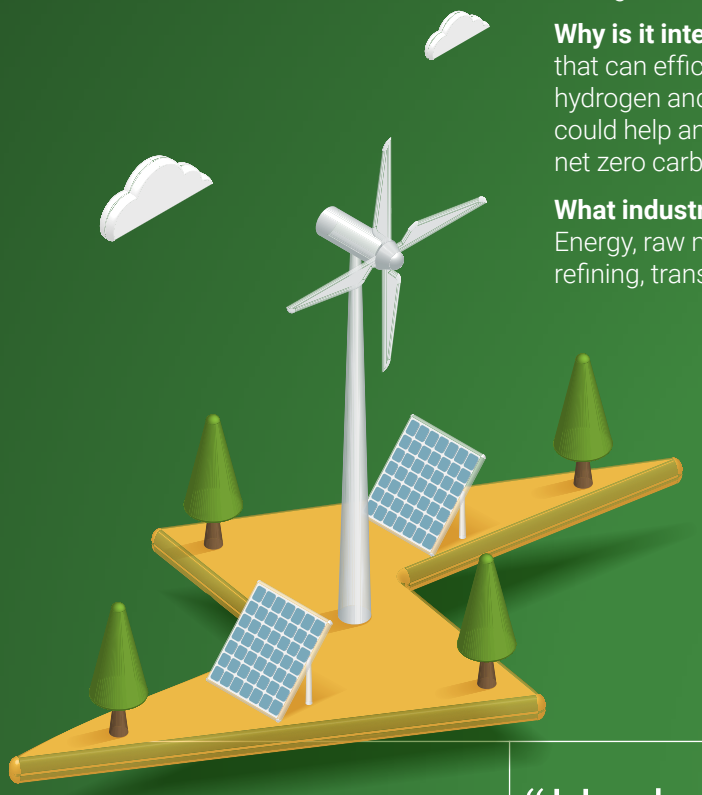
What is it? Novel hydrogen technologies are essential to create cheaper, more efficient hydrogen production. We need scalable, affordable hydrogen storage so it can be widely used.

Why is it interesting? Technologies that can efficiently produce green hydrogen and store it effectively could help answer our drive towards net zero carbon emissions.

What industries could use this? Energy, raw material extraction and refining, transport, manufacturing.

How could it change our lives? Hydrogen is a clean energy source that, when consumed in a fuel cell, produces only water as a by-product. This makes it an attractive low-to-zero emission fuel source for our homes, transport, power generation and portable devices. Hydrogen can also be used to store, move and deliver energy from wind and solar power, which currently have to be consumed immediately or stored in batteries

What do we need to start discussing? Topics such as retrofitting infrastructure, safety regulations and the environmental impact of hydrogen production, use and storage should continue to be discussed.



> "Hydrogen is a clean energy source that, when consumed in a fuel cell, produces only water as a by-product."

Energy and Environmental Technologies

"Nuclear fusion...has the potential to single-handedly achieve our clean energy quest."

Novel negative emissions technologies

What is it? Includes all novel emerging technologies to extract carbon dioxide from the environment. Moves beyond burying carbon dioxide underground, or reusing it in industrial processes.

Why is it interesting?
Reaching net zero requires more than just reducing emissions. To account for processes that will be very difficult to decarbonise completely, such as steel or cement making, we will need to remove greenhouse gases from the atmosphere.

How could it change our lives?
It could help fight climate change by removing new and existing greenhouse gases from the earth's atmosphere.

Nuclear fusion

What is it? A way of producing potentially limitless amounts of energy – and a recent, major breakthrough means nuclear fusion is a step closer. It's the process by which two light atomic nuclei combine to form a single heavier one while releasing massive amounts of energy.

Our sun is powered by nuclear fusion, which must take place at immensely high temperatures, for the natural repulsion between atoms to be overcome. To achieve fusion in a lab, scientists have devised a solution in which a super-heated gas, or plasma, is held inside a magnetic field.

Why is it interesting?
Even with recent advances, nuclear fusion will still be very hard to achieve. But it has the potential to single-handedly achieve our clean energy quest.

How could it change our lives?
If it can be replicated on earth at an industrial scale, nuclear fusion could provide virtually limitless clean, safe, affordable energy.

Space-based solar power

What is it? The concept of collecting solar power in high-earth orbit and transmitting the energy securely to a fixed point on the earth. It could deliver clean energy, year-round, in all weathers.

Why is it interesting?
It could give an uninterrupted clean source of energy, therefore making it an exciting part of the drive towards decarbonisation.

How could it change our lives?
Solar power is currently hampered by an imbalance between where power can be generated and where demand is greatest. Removing the effects of weather, by placing solar arrays outside the earth's atmosphere, would mean increased power generation available continuously anywhere on Earth.

Biotechnology

Biotechnology, including synthetic and engineering biology, is the set of methods for designing, building and testing engineered biological systems.

They can be used to construct materials, process chemicals, produce energy, provide food, and help maintain or enhance human health and environment. This family includes technologies such as biofuels, lab-grown meats and synthetic tissues.

"We could develop artificial blood cells ... reducing the need for blood donations."

Artificial cells and artificial life

What is it? An artificial cell is an engineered structure that mimics one or many functions of a biological cell. Artificial life can be considered an extension of artificial cells. It's where synthetic living organisms could theoretically be created, particularly from artificial cells that can divide and reproduce.

Why is it interesting?
They could play an increasingly large role in areas of medicine. Interesting when we consider what life means in the future.

How could it change our lives?
Already used to treat kidney failure. With development we could develop artificial blood cells, reducing the need for blood donations, and increasing the safety of blood products. Artificial cells could be used in biomanufacturing processes to produce long-lasting, high yield, and high-purity proteins and enzymes.

Bacteria and microbe manufacturing

What is it? Using natural biomaterial synthesised by bacteria and microbes as a manufacturing process.

Why is it interesting?
Bacteria can be used to manufacture drugs including antibiotics, useful molecules, bioconcrete and other interesting materials. The list is constantly growing and changing.

How could it change our lives?
Substances synthesised by bacteria can create new materials with useful qualities. Substances produced through bacterial manufacturing are expected to have uses in food, personal care, household chemicals, biomedicine, and textiles. Could touch almost every aspect of our daily lives.

Biocatalytic membranes

What is it? An emerging type of membrane inspired by the structure and functions of cell membrane. They have useful properties like enhancing reaction efficiency, improving the removal of pollutants, and enabling the re-use of enzymes in some processes.

Why is it interesting?
The applications of biocatalytic membrane technology are beginning to be exploited in the pharmaceutical and biotechnology industries. They could contribute towards more sustainable, efficient, and less polluting pharmaceutical production methods.

How could it change our lives?
Could improve production systems in sustainable ways – key to supporting our living standards alongside human population growth. Could produce new or improved foodstuffs where nutrients aren't lost during heating, novel pharmaceuticals, and waste water treatment.

SHOWCASE TECHNOLOGY:

Bioelectronics and electroceuticals

What is it? Bioelectronics is an emerging area of medicine. It uses tiny, implantable devices to deliver electrical stimulation to nerves to control a wide range of bodily functions. Electroceuticals are a type of bioelectronics aimed at replacing drug treatments.

Why is it interesting? They widen the range of treatments possible without drugs or surgery. These technologies will drive a need for technology developments such as wireless power supply.

What industries could use this? Health and wellness.

How could it change our lives? They have huge healthcare benefits. Applications could range from pacemakers to deep-brain stimulation for Parkinson's disease. New applications are emerging, for example to stimulate the vagus nerve to combat arthritis. These devices will allow us to monitor and treat disease in real time, improving the quality of life for potentially millions.

What do we need to start discussing? Discussions are underway in the usual medical and health regulation bodies regarding how these treatments should be used. We may want to discuss who accesses these technologies, particularly while costs are relatively high. These devices will create data of some sort. We need to expand discussions about ownership of personal medical data, and ethical uses for the health, medical and insurance sectors.

"Applications could range from pacemakers to deep-brain stimulation for Parkinson's disease."

"Biofabrication... could create fully functional tissues and, potentially, organs."

Hybrid microbe biotechnology

What is it? It has two key forms under development. The first is creating new artificial microbes by combining two different organisms into one functioning entity. The second combines artificial and biological components to obtain microbes with new functions.

Why is it interesting? Microbes are essential to our lives in a myriad of unexpected ways – from helping us digest and helping our immune systems, through to their critical roles in manufacturing and industrial processes. Bio-engineering at the microbe level offers potential for improving our health and food, and making manufacturing more efficient.

How could it change our lives? Could reduce pollution and help with green energy. An emerging example of hybrid microbe biotechnology looks to create a system that converts solar energy into chemical energy. This has potential in treating and removing environmental contaminations. It would reduce pollution and produce clean energy from a single technology.

Programmable cells

What is it? Creating cells which can be programmed for many uses, such as in healthcare and the environment. They are programmed by putting chemical switches into synthetic gene circuits to open up a range of logical functions to use in cells.

Why is it interesting? Would open up new ways of treating and preventing disease. Programming cell behaviour to represent data processing expands possibilities of biological computing (see Next Generation Computing in AI, Data and Advanced Computing for more).

How could it change our lives? Enables programmable cells, or living technology, that can sense their environment, make a decision and act on it. Standing to benefit are medicine, energy, the military and agriculture. Could create living diagnostics and therapeutics, to treat disease and reduce the likelihood and impact of pandemics.

Biofabrication in tissue engineering

What is it? Biofabrication could produce living 3D tissue constructs to repair or replace damaged or diseased tissues and organs. There are a variety of manufacturing approaches for tissue engineering include 3D printing, electrospinning, sheet rolling and mould shaping.

Why is it interesting? Could create fully functional tissues and, potentially, organs. A key advantage is flexibility. Can create tissue which meets the customised needs of human and animal patients.

How could it change our lives? Replacing organs and tissues to help save lives. This could help with surgical treatments but also improve the accuracy of laboratory research, such as identifying effective new medications.

Health and Medical Technology

One of our biggest societal challenges remains healthcare.

We benefit from technological advances whenever we visit a doctor's surgery or, increasingly, in our homes or on our phones. But as we look towards the middle of the 21st century, a new set of technologies is vitally needed. They are essential to help us combat disease, to better support those who are physically impaired, and so we can all live healthier lives for longer.

Health and Medical Technology

"These technologies ...could enable us to live healthier for longer."

Adult stem cell generation

What is it? Adult stem cells maintain tissue health and can replace cells that die due to injury or disease. Research suggests some adult stem cells could create various types of cells through a phenomenon known as transdifferentiation. If proved, it will open up new frontiers in stem cell technologies.

Why is it interesting?
This is the beginning of new aspects of stem cell medicine and regenerative therapies.

How could it change our lives?
Can help create cells to repair tissues from injuries, such as to the skin or brain. Adults can give consent for use of their stem cells, so this is much less controversial than using embryonic stem cells for research and treatment.

Fluxomics

What is it? Fluxomics helps us to understand how nutrient flows are carried out in diverse cellular systems. It gives a complete picture of molecular interactions in the central metabolism of biological systems.

Why is it interesting?
The significance of fluxomics is that it gathers data from multiple different-omics fields, portraying the whole picture of molecular interactions. This connection of areas including genomics, transcriptomics, proteomics and metabolomics makes it particularly interesting.

How could it change our lives?
Could help to find and develop new pharmaceutical treatments or new screening techniques. It is also a key enabler for personalised medicine.

Anti-ageing drugs

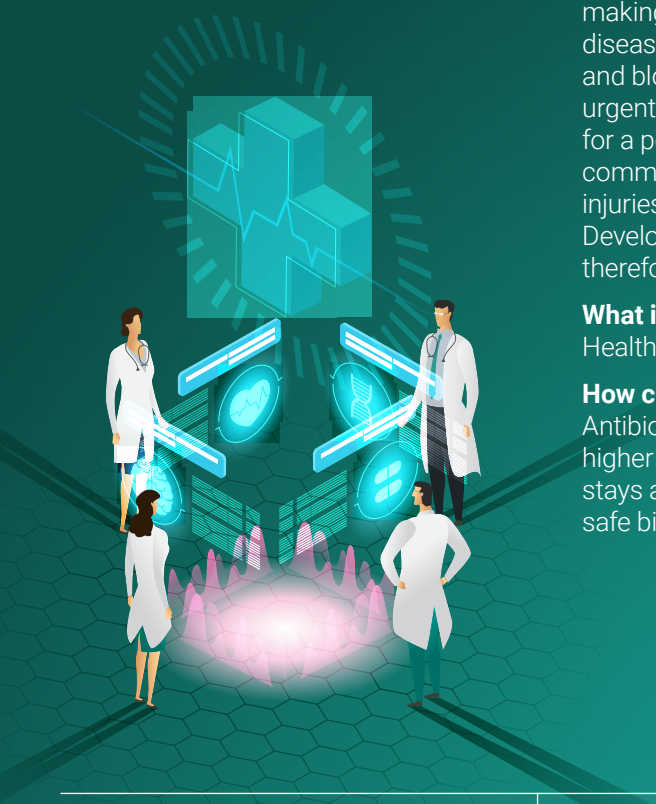
What is it? 'Geroprotective' drugs aim to affect the root cause of ageing and age-related diseases, lengthening the lifespan of animals. Approaches are being explored to selectively kill ageing, or 'senescent', cells or to suppress inflammation associated with ageing.

Why is it interesting?
'Senotherapeutic' approaches can revolutionise how age-related diseases and ultimately ageing itself can be treated, with potentially far-reaching ramifications.

How could it change our lives?
These technologies and related treatments could enable us to live healthier for longer, decreasing the burden of age-related disease on society and potentially extending life expectancy.

SHOWCASE TECHNOLOGY:

Antibiotic replacements



What is it? Alternatives to antibiotics.

Why is it interesting? Antibiotics are used to prevent and treat bacterial infections but bacteria from common diseases are becoming antibiotic-resistant. New resistance mechanisms are emerging and spreading globally, making it harder to treat infectious diseases, such as pneumonia and blood poisoning. Without urgent action, we are heading for a post-antibiotic era in which common infections and minor injuries can once again kill. Developing alternatives is therefore a global health priority.

What industries could use this? Health, agriculture, animal health.

How could it change our lives? Antibiotic resistance could lead to higher medical costs, longer hospital stays and increased mortality. New, safe biological antimicrobial solutions are needed so we can continue to treat infections and remove bacterial contaminants from food sources. Technologies under development in this area offer real hope of a solution.

What do we need to start discussing? Discussions mostly surround new antibiotics, or avoiding using them unnecessarily. With a rise in bacterial infections, we need to discuss developing alternatives. Acting now should mean we have developed new technologies before functioning antibiotics run out. As individuals, if we are aware of new treatments this should reduce uncertainty and build trust.

> "With a rise in bacterial infections, we need to discuss developing alternatives..."

Health and Medical Technology

"The next technological leap forward will be through using RNA to provide personalised therapies to patients..."

Microbiome therapeutics

What is it? New therapies with the potential for treating disease through manipulation of the gut microbiome.

Why is it interesting? This technology has great potential to reduce the incidence and severity of many human conditions and diseases. If validated, microbiome therapeutics could open up a new branch of medical treatments.

How could it change our lives? Could produce treatments and interventions that are inherently suited for human use, because they are directly shaped through co-evolution. Therefore, these medicines could be safer and more successful than the average clinical programme.

Personalised RNA therapeutics

What is it? RNA therapeutics have become well known through their use in some Covid vaccines. They're also being developed for targeted cancer treatments. The next technological leap forward will be through using RNA to provide personalised therapies to patients with hard-to-treat diseases.

Why is it interesting? Small molecules and antibody drugs currently target only 0.05% of the human genome. RNA technology could open up a vast array of proteins, transcripts and genes as new treatment targets.

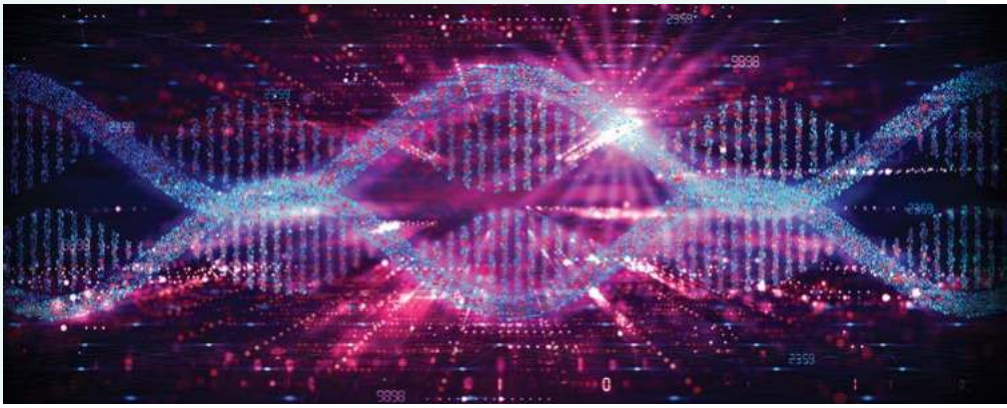
How could it change our lives? They are a rapidly expanding category of drugs that could change the standard of care for many diseases and make personalised medicine a reality.

Phased genome assembly tools

What is it? Tools which help people working in genomics make sense of huge volumes of data. It should allow new ways of genome-based sequencing to speed up what we can do in bioinformatics, while reducing error rates.

Why is it interesting? Next-generation sequencing enables whole-genome phasing which can inform studies of complex traits. Phasing can also provide valuable information for genetic disease research. Given UK expertise in genomics, an interest in developing the next phase of tools to help exploit and advance that expertise makes perfect sense.

How could it change our lives? These technologies will help continued advances in genomics. These can help improve our lives, particularly through positive implications for health and agriculture.



Health and Medical Technology

"It's a potentially life-changing technology for many people."

Sensation detection implants

What is it? Implants that enhance or enable detection of feelings of sensation.

Why is it interesting?
Could help people lacking normal sensation. It could also link to a more immersive computing future. Ethical considerations should be discussed while this technology is developed.

How could it change our lives?
It's a potentially life-changing technology for many people. It could allow people with prosthetic limbs to 'feel' through those devices, to restore or enhance hearing or the sense of smell. It could also give us new ways to interact with digital technologies and machines.

Whole body-on-a-chip device

What is it? Multi-organ systems which can emulate human physiological responses to drugs. Have the potential to identify a drug's efficacy and its toxicity in other organs.

Why is it interesting?
Offers a more accurate and cost-effective way of testing treatments before clinical trial. Body-on-a-chip devices could increase the success rates of clinical trials.

How could it change our lives?
If successful, they could be used to develop or select therapeutics for individual patients. This could revolutionise clinical trial design and deliver a new wave of treatments and interventions, improving global health outcomes.

Robotics and Space Technologies

When many think about future technologies, they immediately think of robotics and space tech.

Here we can see a future of truly driverless cars, 'soft' robots that act a bit like worms, and satellite technology which offer much better monitoring of land and sea. This family of technologies could be applied in almost every sector of the economy and will likely include smart machines that interface with or are embedded in humans.

Robotics and Space Technologies

"Microrobots and nanorobots are finding uses in several fields, including biomedicine."

Fully autonomous vehicles

What is it? Driverless vehicles (ADAS Level 5) that may not even have steering wheels, acceleration or braking pedals. They will be able to do anything a human driver can.

Why is it interesting? Progress has been made in autonomous vehicle development but this ultimate level is the end goal. This technology provokes fascinating ethical, legal and insurance-related discussions. For example, if a truly autonomous car was in a calamitous situation where it had to choose between hitting a pedestrian – one a child and one elderly – what would it do?

How could it change our lives? It could fundamentally change personal transport, turning a driving-based commute into time for leisure or work. May vastly increase mobility opportunities for those physically unable to drive.

Nanoscale robotics

What is it? Nanoscale robotics is an emerging technology field creating extremely small machines or robots whose components are near the scale of a nanometre. Microrobots and nanorobots are finding uses in several fields, including biomedicine.

Why is it interesting? Nanorobots are hugely interesting, due to their possible uses inside and outside the human body. They have potential uses in medicine like 'fixing' genetic code defects, or highly targeted drug delivery. They may be another way of connecting our physical body with the digital world. It's likely we will see self-contained nanorobots devices that can manufacture at the nanoscale.

How could it change our lives? Nanorobots could transform healthcare as they allow for much less invasive procedures instead of surgery and non-targeted chemical and radiation therapies.

Robotic off-world manufacture

What is it? Technologies which enable the production of goods in a location beyond Earth. This includes space or zero-gravity manufacturing as well as lunar and Martian manufacture.

Why is it interesting? Given the desire to return to the moon and explore Mars in more detail and for longer periods, there will be a need to make things on those planets or in space. These technologies are essential for humankind to live beyond our current planet.

How could it change our lives? Manufacturing in space, benefiting from effects such as microgravity and vacuum, will mean we can develop products that are impossible on Earth. In addition, the technologies required to manufacture goods off-world are an important step towards establishing any sort of settlement on the moon or Mars.

Robotics and Space Technologies

"Robots could help with disaster response... 'worming' their way into a collapsed structure..."

Soft robotics

What is it? Soft robots are systems built from 'soft' or compliant materials, rather than the hard-bodied designs of traditional robots. Many soft robots have mechanical properties similar to living tissues, often inspired by invertebrate animals like squid or worms.

Why is it interesting?
It could broaden the range of applications for robotics in society and industry. The simplicity of the systems, such as non-linear movement, organic appearance and soft surface, could help create environments that feel more natural than at present.

How could it change our lives?
Allows us to begin developing artificial muscles and artificial organs more similar to biological systems. This would make those devices more practical and improve quality of life for users. They could help with disaster response, with robots squeezing into small gaps and 'worming' their way into a collapsed structure, then expanding to create an air pocket when they find a casualty.

Space nuclear power and novel space propulsion systems

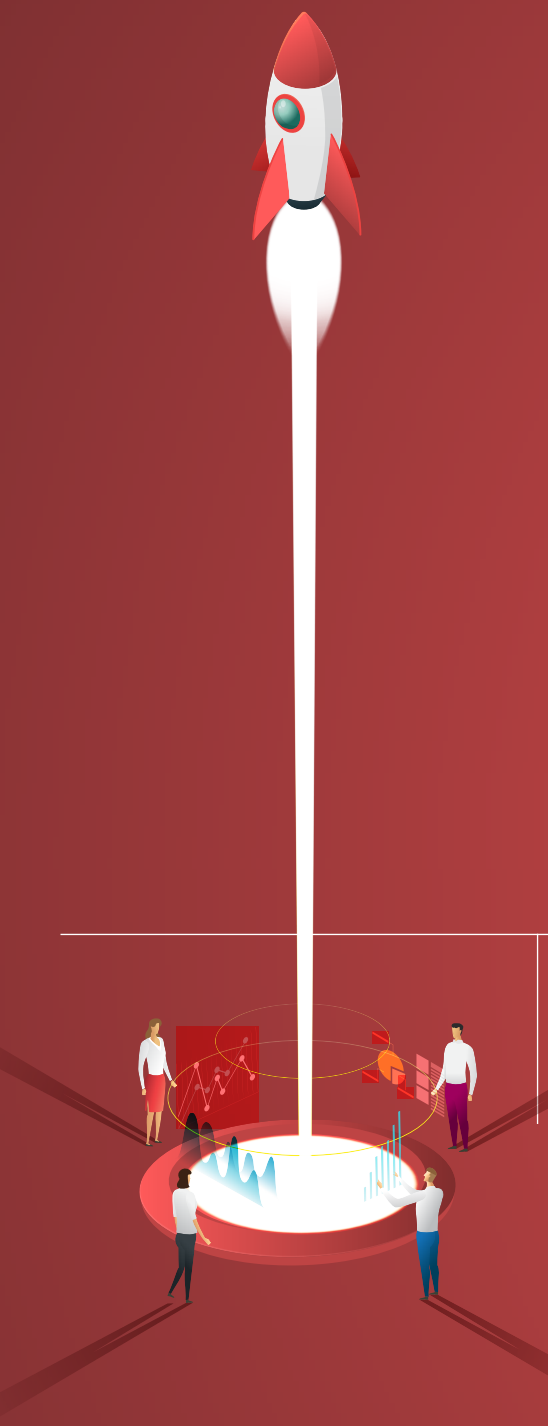
What is it? New non-combustion-based propulsion systems for use in spacecraft, particularly nuclear propulsion. Includes electric propulsion, a spacecraft propulsion technique that uses electrostatic or electromagnetic fields to accelerate mass to high speed, and nuclear-based propulsion systems to overcome the problem of running out of fuel.

Why is it interesting?
Current propulsion methods require heavy and cumbersome fuels. Nuclear power has long played a vital role in space missions but future missions could rely on it, or other novel propulsion technologies, for a broader range of applications over increasing distances.

How could it change our lives?
Development of these technologies is essential to future manned space exploration.

SHOWCASE TECHNOLOGY:

Very low earth orbit (VLEO) satellites



What is it? Low earth orbit satellites have an altitude below 2000km, whereas very low earth orbits are below 500km. These have two major benefits: a massive increase in resolution for satellite images; and less threat of damage as space debris does not accumulate at this altitude.

Why is it interesting? Satellites at lower orbits should offer more applications of the technology. Developing these technologies will lead new propulsion technologies being created as satellites at these heights require ongoing propulsion to overcome the impact of atmospheric drag.

What industries could use this? Telecommunications, agriculture, environmental monitoring, ocean monitoring.

How could it change our lives? Improved satellite imagery will offer greater maritime surveillance, improved environmental monitoring, and potentially new telecommunications technologies.

What do we need to start discussing? Discussions around critical topics like access, debris, end of life, satellite maintenance, ethics of satellite access and data use are already underway for other types of satellites. The need here is to extend them to include the specific nuances of this type of satellite, and the particular implications arising from very low earth orbit.

> "Low earth orbit satellites offer a massive increase in resolution of images."

This report represents a selection of areas of emerging technology we believe will be important for the UK's economy and future innovation.

Conclusions and the way forward

Innovate UK has been consistently tracking and analysing emerging technologies for over a decade. We've often shared our findings with the UK government, and to support our own strategy development. But this marks the first time we've shared our thoughts publicly.

This report represents a selection of emerging technologies we believe will be important for the UK's future economy.

It is our hope that individuals, businesses and industries find the technologies here exciting. That this document helps prompt discussion, interest and ideas in their future development and use.

For this report, we have had responses to our Technologies of the Future survey from a very broad range of experts. We would like to sincerely thank all contributors for their time and effort.

We would particularly like to acknowledge Jonathan Mitchener and the wider Horizon Scanning team at Innovate UK for their contribution, and would like to express our appreciation to our UKRI colleagues and their scientific communities, for responding to our Technologies of the Future survey and sharing their expertise.

We aim to launch our next survey later this year. We hope to engage with an even broader range of contributors from academia, research, industry and beyond to feed into our next report.

In our 2024 report we will give progress updates to see how our technologies are faring. We are open to ideas to make this document more useful, so get in touch if you have suggestions.

We hope you have found this report thought-provoking. We look forward to transforming tomorrow, together.

Note

It is impossible to accurately predict the future. It is only possible to extrapolate trends and combine them with expert analysis to envisage various possible futures. This document represents our views of a selection of interesting technologies. It should not be interpreted as a list of technologies in which we necessarily intend to invest.

About Innovate UK

Innovate UK drives productivity and economic growth by supporting businesses to develop and realise the potential of new ideas. We connect businesses to the partners, customers and investors that can help them turn ideas into commercially successful products and services and business growth. We fund business and research collaborations to accelerate innovation and drive business investment into R&D. Our support is available to businesses across all economic sectors, value chains and UK regions. Innovate UK is part of UK Research and Innovation.

For more information visit the **Innovate UK** website.

Follow us:

Accessibility

To request copies of this report in large print or in a different format, please contact the Equality, Diversity and Inclusion team at UKRI:
01793 444000
equality@ukri.org

To share your thoughts on this report, get in touch with our Horizon Scanning team:

horizonscanning@iuk.ukri.org

Innovate UK