2 Engineering and manufacturing past, present and future

Introduction

In the 300 years since mechanisation brought about the first industrial revolution, engineering has underpinned every aspect of human endeavour. Today, industry and wider society are adopting and adapting to technological innovation at unprecedented speed.

In this chapter, you will learn about the activities undertaken in a wide range of engineering sectors. You will also reflect on some of the key developments that brought us to this point and how new and emerging technologies might shape the future.

Learning outcomes

By the end of this chapter, you will understand:

1. the main activities, products and/or services relating to different sectors of the engineering industry
2. how technological advances and their operations have evolved and contributed to engineering and social and economic development, in areas such as transportation, healthcare, housing, employment and sustainability
3. how innovation and emerging trends are evolving and could influence manufacturing, environmental considerations and social and economic development.

2.1 Sectors of the engineering industry

The engineering industry encompasses a diverse range of specialist sectors. The activities, goods and/or services relating to some of these sectors are outlined in Table 2.1.

▲ Figure 2.1 Aircraft maintenance is conducted by the aerospace sector

▼ Table 2.1 Sectors of the engineering industry

Engineering sector	Main activities, products and/or services
Aerospace	Research and development, design, manufacture and maintenance of manned and unmanned aircraft, rockets, missiles, satellites and spacecraft
Rail	Research and development, design, manufacture and maintenance of rolling stock and rail infrastructure
Agriculture	Research and development, design, manufacture and maintenance of specialist equipment and machinery used in forestry, horticulture and farming
Automotive	Research and development, design, manufacture and maintenance of cars, motorbikes, trucks and other road-going vehicles
Chemical	Research and development, design, manufacture and maintenance of industrial chemical processes, processing plants and equipment Applications across multiple sectors, including chemical manufacturing, petrochemicals, electronics, pharmaceuticals, food processing and healthcare
Structural	Research, development and design of load-bearing structures, such as buildings and bridges
Materials	Research, development and manufacture of metals, ceramics, polymers and composite materials used across engineering and a wide range of other sectors
Logistics	Research, development and design of systems to optimise the processes and activities involved in supply-chain management, such as purchasing, storage, warehousing and distribution
Defence	Research, development, design, manufacture and maintenance of a wide range of equipment and technologies involved in maintaining national security and equipping the armed forces Includes everything from communications, munitions and body armour, to tanks, submarines and combat aircraft
Electrical and electronic control	Design, manufacture and maintenance of control systems, instrumentation, monitoring and automation for electro-mechanical engineering systems used in a range of sectors
Medical	Research and development, design and manufacture of instruments, equipment, machines and devices for use in healthcare, including heart monitors, MRI machines, surgical instruments and prosthetics
Manufacturing	Research and development, design, manufacture and maintenance of processes, systems, equipment and machinery involved in manufacturing a wide range of products in a range of sectors
Marine	Research, development, design, manufacture and maintenance of oil rigs, offshore wind installations, ships, submarines and other sea-going vessels
Petrochemical	Design, manufacture and maintenance of machinery and equipment used for oil exploration, extraction, transport, processing and refining

Engineering sector	Main activities, products and/or services
Power generation (renewables)	Research, development, design, manufacture and maintenance of infrastructure, machinery and equipment used in generating electricity from renewable resources, including photovoltaic solar, wind turbine, hydroelectric, tidal and geothermal systems
Power generation (non-renewables)	Research, development, design, manufacture and maintenance of infrastructure, machinery and equipment used in generating electricity from non-renewable fossil fuels, such as coal, gas and oil
Power generation (nuclear)	Research, development, design, manufacture and maintenance of infrastructure, machinery, equipment and waste-management technologies used in generating electricity from nuclear fuel
Telecommunications	Research, development, design, manufacture and maintenance of telecommunications infrastructure and equipment, including fixed and mobile telephone networks, fibre-optic broadband networks, satellite communications, television and radio
Water and waste management	Research, development, design, manufacture and maintenance of water and wastewater treatment infrastructure, machines and equipment, including the water distribution network and the collection, treatment and reuse of wastewater

Industry tip

Many engineering sectors overlap or are interlinked. Whatever sector you work in, you will deal with a wide range of products, services and colleagues from across the engineering industry.

Test yourself

A company designs control systems and instrumentation to be installed in offshore wind turbines. What engineering sector does it belong to?

Research

Choose an engineering sector you are interested in and conduct your own detailed research into the products and services it provides. Find out about potential employment opportunities in that sector and the qualifications you would need in order to gain employment.

2.2 Significant technological advances in engineering from a historical perspective

Development of materials

Throughout history, human progress has been shaped by taking advantage of the materials available to us. Early humans spent hundreds of thousands of years reliant on just the natural materials they found in their local environment. In contrast, we are now in a period where our understanding of material science, processing and manufacturing means that we can call upon thousands of materials with a massive range of properties.

Some materials have had a significant impact on the development of modern society:

- In 1855, the development of the **Bessemer process** allowed the cost-effective mass production of steel. Steel is the most widely used metal in engineering and has perhaps had the biggest impact on industrial development. It has allowed us to build railways, bridges, dams and other structures that form essential infrastructure and dominate the built environment. Steel is essential in the manufacture of machine tools, cars, ships and any product or structure held together with screws, nails or nuts and bolts.
- In 1907, Bakelite became the world's first synthetic polymer. However, it was not until the 1960s that the use of polymers became preferred over traditional materials and they became ubiquitous. Today, polymers can be found in a massive array of applications across all engineering sectors.

Key term

Bessemer process: method of producing steel by burning off carbon and other impurities in pig iron by blasting air through the molten metal.

- Ceramics are among the oldest types of materials used by humans. They include glass and ceramic pottery, both of which have had important applications in cookware and food storage for centuries. Modern ceramic materials, such as tungsten carbide, have important applications in manufacturing, where they are used in cutting tools and abrasives.

Electrical power

The harnessing of electrical power underpins much of the scientific progress and societal and technological changes that have occurred in the last hundred years.

Today, we tend to take the supply of electricity for granted, and it is easy to forget that the widespread use of electrical power is very recent. The world's first large-scale, coal-fired power station was opened in London in 1882, but extensive availability of electrical power did not happen until well into the twentieth century. It was not until 1935 that the world's first integrated national grid was completed, connecting power stations and electricity customers, and enabling widespread distribution of electricity in the UK. By 1940, two thirds of homes in the UK, mostly concentrated in urban areas, had a supply of electricity.

One of the first practical applications for electricity was to provide a safe and clean form of artificial light (this is explored further in the next section). Soon after, a wide range of domestic labour-saving appliances were invented, designed to automate or assist in an array of everyday household chores. These included washing machines, electric irons and vacuum cleaners.

Other domestic appliances, such as refrigerators and freezers, allowed food to be preserved for longer. This led to changes in shopping habits, as it was no longer necessary to shop every day for fresh ingredients. Food from larger weekly shops could be refrigerated until needed.

Refrigerated transport led to more fresh fruit, vegetables and fish being available in large cities, which in turn led to improvements in diet and general health.

Electricity also made consumer electronics possible, for example radios, televisions and, more recently, computers and the internet.

The impact of these technologies is explored later, but their importance is such that all technologically advanced societies have become entirely dependent on a reliable and accessible supply of electrical power. Modern life as we know it could not exist without it.

▲ Figure 2.2 The National Grid distributes electricity throughout the UK

Electrical sources of artificial lighting

Prior to the availability of reliable electric lights in 1878, street lighting in major cities and large towns ran on gas. Gas lighting was also used in commercial buildings and some large homes, but most of the population still relied on candles and oil lamps for lighting, and on open coal fires for warmth.

Domestic electric lighting began to replace gas as more homes were connected to the electricity grid. This revolutionised home life, which was no longer constrained by seasonal daylight hours.

In factories, electric lighting allowed manufacturing to continue throughout the night, enabled the introduction of shift work, and increased both capacity and industrial output.

The internal combustion engine

From its invention in the 1860s, the **internal combustion engine** began to replace the steam engines used to drive machinery and run electrical generators in factories and light industry. By the 1890s, the technology had matured sufficiently to allow Carl Benz to launch the first commercially successful motor car powered by an internal combustion engine. However, it was not until Henry Ford introduced the affordable, dependable and easy-to-drive Model T in 1908 that motoring became widely accessible to ordinary families.

Key term

Internal combustion engine: engine where fuel is burned inside the engine itself.

In the first half of the twentieth century, the socio-economic impact of the motor car was enormous. It provided ordinary people with unprecedented freedom to travel wherever and whenever they wanted, without reliance on public transport. People were able to travel for work, visit friends and relatives out of town, or take trips to popular tourist destinations, helping to grow the economy in the process.

Roads and transport infrastructure spread across the country, allowing freight to be transported quickly and easily in vans and trucks, thereby improving access to goods and services.

In the fields, tractors and farm machinery using internal combustion engines soon replaced horses and steam-driven traction engines to power agriculture, leading to greater efficiency and increases in food production.

An enormous industry emerged to satisfy the demand for cars, which itself helped to grow the economy and provided well-paid jobs for thousands of factory workers. The need for cheap and plentiful petrol led to the development of the worldwide oil industry, which still dominates many economies. Demand increased for steel, rubber and other raw materials that were essential for car manufacturing, and the size of the industries that supplied these materials increased too.

However, the unfortunate legacy of the widespread use of internal combustion engines is that they are responsible for around 20 per cent of global carbon-dioxide emissions. That makes them a major contributor to climate change and will ultimately lead to their decline as they are replaced with electric vehicles.

Test yourself

What effect did the internal combustion engine have on agriculture?

Electric motors

The first electric motors were developed as early as the 1830s. However, it was not until the 1890s that practical and powerful electric motors found applications in electrically operated trams and lifts.

As the electricity network began to spread in the first half of the twentieth century, electric motors began to replace steam engines in factories. Up until then, machinery was driven by belts running on a complex system of overhead line shafts powered by a single steam engine. These needed constant care and maintenance and suffered large losses due to friction in the shaft bearings and belts.

The transition to electric motors ended the need for line shafts and belts, and meant that each piece of equipment could be operated independently. Electric motors required much less maintenance and were more efficient and reliable, which enabled a significant increase in manufacturing output.

Today, electric motors find applications in an enormous range of products, for example providing haptic feedback in game controllers, powering electric vehicles and running the compressors in refrigeration equipment.

Replaceable parts and mass production

At the start of the industrial revolution, tools, equipment and machinery were manufactured in workshops that produced every component part, right down to individual nuts and bolts.

The development of machine tools, measuring equipment and agreed standards for screw threads enabled the standardisation of mechanical components in the early 1800s.

One of the first examples of mass production using replaceable, interchangeable parts was in the manufacture of muskets. These needed to be inexpensive and easy to manufacture, maintain and repair. Previously, muskets were made individually by skilled gunsmiths, with each part made to fit a specific gun. However, this meant that they could only be maintained and repaired by those gunsmiths, who would have to make and fit any replacement parts needed.

By the 1830s, several manufacturers had succeeded in achieving 100 per cent interchangeability of all the parts used to make their muskets. This resulted in higher production rates, lower costs and much easier maintenance and repair, so that more muskets were available and easy to keep serviceable by conducting field repairs using interchangeable spare parts.

These ideas soon spread to other industries. The mass production of complex products, such as domestic sewing machines and motor cars, was heavily dependent on the interchangeability of parts.

Television

Following on from its pioneering work with radio, the BBC began broadcasting regular black and white television programs in 1936.

After the Second World War (during which television broadcasts were suspended in the UK), television became a popular alternative to radio for affluent and middle-class families. However, the expense of new television sets meant that many families still relied on their radios for news and entertainment.

Television radically changed how people spent their leisure time. For young people especially, time in front of the television soon took the place of reading or playing outdoors as their favoured pastime.

As well as programming aimed at children and to entertain family audiences, television brought educational documentaries, news and current affairs into the home. Indeed, the declared mission of the BBC remains to inform, educate and entertain.

By the 1960s, most households had a television set, and in 1969, colour television was available on all three UK terrestrial channels (BBC1, BBC2 and ITV).

Since then, there have been other key milestones in the history of television:

- Satellite television was first available in 1989 with the launch of Sky.
- Internet-based, on-demand television services were first available in 2006.
- Internet-streaming service Netflix was launched in 2012.

The technology used in televisions has come a long way since the first sets were introduced. Early television was dependent on the **thermionic valve**, an electronic device used to amplify electrical signals and a forerunner to the transistor.

They also used **cathode ray tubes (CRTs)** to create the image on a small screen on the black and white sets of the 1950s. CRTs direct a beam of electrons onto a fluorescent material coating the inside of the screen. This causes the coating to glow and builds up the picture pixel by pixel. Similar CRT technology was still being used in the large colour sets of the late 1990s.

Test yourself

What are thermionic valves?

▲ Figure 2.3 A cathode ray tube of the type used in televisions up until the late 1990s

By the early 2000s, cathode ray tubes had been superseded by liquid crystal displays (LCDs) back lit with **light-emitting diodes (LEDs)**. The liquid crystal was manipulated by an electrical signal to allow it to transmit colour for each pixel and build up the image. By eliminating the large glass cathode ray tube, this technology allowed televisions to be built in the flat-screen format we are now familiar with.

Unlike previous technologies that used fluorescence or light transmission to create an image, individual **organic light-emitting diodes (OLEDs)** can now be used to emit brightly coloured light for each pixel.

OLED technology has allowed the development of curved screens that provide a more immersive viewing experience.

Key terms

Thermionic valve: electronic device that amplifies electrical signals by controlling the flow of electrons in a vacuum tube.

Cathode ray tubes (CRTs): vacuum tubes that direct a beam of electrons onto a fluorescent surface to produce images.

Light-emitting diodes (LEDs): electronic devices that produce light when current flows through them.

Organic light-emitting diodes (OLEDs): special types of LED that contain an organic material layer that produces light when current flows through it.

▲ Figure 2.4 Modern OLED television with a high-definition curved screen

4K or 5K resolution refers to the number of vertical pixels available on a television screen. The higher the number of pixels, the sharper and more realistic the image, and the larger the screen size can be without loss of resolution. High pixel density is made possible by miniaturisation of the OLEDs used in these screens.

Radio

Marconi invented the 'wireless telegraph' in 1895. This enabled simple morse-code messages to be transmitted and received wirelessly using radio waves.

By 1922, the BBC was using radio to transmit news, music and drama across the UK. In 1932, King George V was able to address millions of listeners across the world when the BBC World Service was launched.

Radio revolutionised the mass media, enabling news and political debate to be delivered directly into homes for the first time. During periods of national upheaval, tragedy or celebration, the radio soon became an essential part of everyday life. In wartime, it encouraged a national sense of community and common purpose.

Radio also revolutionised popular culture, bringing a huge variety of music and entertainment into our living rooms. It promoted the success of new music, bands and entertainers and helped cultivate nationally recognised celebrities.

Radio remains popular, with millions of regular listeners in the UK and around the world.

Automated machines

Prior to around 1770, people tended not to travel far from where they were born. They grew food and made anything they needed locally.

During the period between 1770 and 1850, new automated machines driven by steam engines were developed. These were able to manufacture goods quickly, efficiently and in much larger quantities than ever before. This period became known as the industrial revolution and it had a massive effect on the economic development of the UK.

In this period, agricultural machinery began to make food production more efficient but in doing so it reduced the number of jobs available for farm workers. At the same time, workers were needed in the new factories of the towns. These factors prompted the migration of hundreds of thousands of people from rural areas into new industrial towns.

The output from these new factories led to a massive increase in the availability of manufactured goods, and efficient production meant lower prices. The UK become known as the workshop of the world, massively growing its economy by selling factory-made goods across the globe.

Other major economies were swift to realise the advantages of mechanisation to boost industrial output. Notably, the USA embraced industrialisation, mechanisation and automation technologies, and by 1890 became the world's largest economy.

Computers

Early electro-mechanical computing machines were developed in the 1940s and used with great success in the UK to break military codes used by Nazi Germany during the Second World War. These machines were the forerunners to the modern computer. It wasn't until the development of the silicon chip and the microprocessor in the 1970s, however, that practical and affordable personal computers became a reality.

▲ Figure 2.5 IBM Personal Computer XT circa 1983

Today, computers are essential to many aspects of modern living. They are extremely powerful tools for communication and information management, and they have been universally embraced by businesses and government organisations:

- Computers are important for controlling the basic functions of business, from communication with customers, to managing sales and financial transactions.
- In manufacturing, computers can be used to control stock and create production schedules. They also facilitate computer-aided design (CAD) and computer-aided manufacturing (CAM).
- Financial and banking systems are underpinned by secure computer networks, without which business could not function.
- In healthcare, computers are used to store medical records, help diagnose disease and control complex medical equipment.

Personal computers, laptops, tablets and smart phones enable easy access to the internet and the advantages that connectivity brings.

Computer processors are embedded in products manufactured in a wide range of sectors. For example, in the aerospace sector, they enable the safe control and operation of complex aircraft systems.

Test yourself

Which key technological developments led to the invention of the modern personal computer?

The internet

In 1989, a British scientist called Tim Berners-Lee invented the World Wide Web (WWW) in order to connect scientists and academics so they could share research. The first web page appeared in 1991. Today, there are estimated to be around two billion websites, containing up to fifty billion pages of content.

The internet has become essential to modern living in many ways:

- Email connects businesses worldwide, speeding up internal communications and increasing productivity.
- Social media connects huge online communities. Platforms such as Twitter enable millions of people to access news and opinion as it happens and engage in political debate. Other platforms, such as Instagram, TikTok and YouTube, have enabled social-media personalities to attract vast numbers of followers and become extremely influential.
- The convenience and low cost of online retailing led to the rapid growth of companies such as Amazon and eBay, while having a detrimental effect on high-street shops.
- The availability of online educational resources has revolutionised access to learning.
- Advice and guidance on health helps to relieve pressure on face-to-face medical services and educates the public on heath matters.
- Remote working is now a reality for many people, with all interaction with colleagues taking place online.
- Access to entertainment, music, television and film has been revolutionised. A subscription to an online music service can provide access to millions of songs. On-demand film and television services make huge back catalogues of work available and are now more popular than live television broadcasts.

2.3 Areas of innovation and emerging trends in engineering

Artificial intelligence (AI)

Artificial intelligence (AI) describes the ability of machines to gather information, perform analysis and make autonomous decisions. Current forms of AI rely on complex mathematical algorithms and computing power to allow them to learn behaviours that were previously only possible by animals and humans.

Key term

Artificial intelligence (AI): ability of machines to gather information, perform analysis and make autonomous decisions.

AI has already found applications in healthcare by learning to recognise health conditions such as skin cancers using data from photographic images. This has improved rates of early diagnosis and, in turn, survival rates among patients.

In manufacturing, data from temperature and vibration sensors monitored by AI can be used to accurately identify maintenance issues before they cause breakdowns. This enables machinery and equipment to run more reliably and maintenance schedules to be optimised to minimise downtime.

Co-operative robot systems, combining vision sensors with AI to see and interpret the local environment, can work safely alongside humans. These co-operative robots, or cobots, can be quickly trained to assist their human co-workers in a wide range of manual tasks from workholding to welding.

In future, a wide array of complex tasks could be performed by AI much more quickly, efficiently and effectively than by humans and could improve our quality of life.

Virtual reality (VR)

Virtual reality (VR) is an immersive technology that allows a user to experience a digitally generated scene as if they inhabited the virtual space. By wearing a head-mounted display and motion sensors, the user can move around and interact with the computer-simulated environment.

In the future, VR will become more realistic and absorbing. A full range of simulated training environments will be possible for complex tasks such as learning to drive, flying a plane or performing surgery. Meta (the parent company of Facebook) is already developing an entire virtual world it has called the Metaverse. Here, inhabitants can socialise, work and play together without ever having to leave their homes. The widespread use of VR will impact how we experience the world, build relationships and socialise, with online communities formed across geographical and social boundaries.

In manufacturing, VR is an important design tool that allows complex products and systems to be assembled and tested virtually before any physical parts are built. This is a key technology in aircraft design, pioneered by aerospace companies like Boeing and Airbus.

▲ Figure 2.6 An engineer exploring a product using virtual reality

Augmented reality (AR)

While VR describes a self-contained virtual world, **augmented reality (AR)** allows users to enhance their real-world experience with real-time, computer-generated augmentations or overlays.

Key terms

Virtual reality (VR): immersive technology that allows a user to experience a digitally generated scene as if they inhabited the virtual space.

Augmented reality (AR): technology that allows users to enhance their real-world experience with real-time, computer-generated augmentations or overlays.

AR already has applications in medicine, allowing virtual anatomical models to be studied in the classroom. Its ability to provide real-time annotation of what the user can see could find applications in education, navigation and policing. It could also be used to guide field repairs on complex equipment or even assist in surgical procedures.

In manufacturing, Boeing uses AR to provide wiring diagram overlays for workers tasked with installing the thousands of electrical connections required in their aircraft.

Test yourself

What is the key difference between VR and AR?

Digitalisation

Digitalisation is the process of converting physical objects such as documents, paper-based systems or other artefacts into digital data that can be read, displayed, processed and distributed by computer. This will have an impact wherever instant access to current or real-time data is required.

For example:

- Digitalisation of medical records could mean better integration and communication between healthcare providers, leading to patients being treated in a more timely and effective way.
- Access to real-time domestic electricity consumption data will allow more efficient management of electricity generation and distribution.
- In manufacturing, assembly instructions and engineering drawings displayed on screens at individual workstations eliminate the need to manage paper documents.

Robotics

Robotics involves the design, development and manufacture of robots that are able to perform physical tasks that would previously have been carried out by humans.

Robots already have widespread applications in manufacturing. These include the assembling, welding and painting of car bodies, assembling electronic circuits, and the picking, packing and palletising of finished goods.

In the future, robots could be combined with AI to make entirely autonomous machines to perform complex or dangerous tasks, such as medical procedures, space exploration or mine clearance. When combined with suitable sensor technology, they could be used in exoskeletons to give independence to patients with paralysis or provide fully functioning prosthetic limbs.

Drones

Drones are unpiloted aerial vehicles. They vary in size and complexity, from small toys to full-sized aircraft.

Key terms

Digitalisation: process of converting physical objects such as documents, paper-based systems or other artefacts into digital data that can be read, displayed, processed and distributed by computer.

Robotics: design, development and manufacture of robots that are able to perform physical tasks that would previously have been carried out by humans.

Drones: unpiloted aerial vehicles.

Drones have already had a significant impact in military applications, where they are widely used for reconnaissance or in direct support of ground troops.

Drone cargo aircraft have also been developed. Royal Mail plans to use a fleet of these to deliver mail to dozens of remote islands around the UK.

In the future, drone technology is likely to find wider applications in law enforcement to conduct searches from the air. Autonomous drones could be used to monitor the condition of structures such as offshore wind-turbine installations, explore and map underground cave systems, or monitor the health and wellbeing of livestock.

In manufacturing, the use of drones is not yet commonplace. However, drones could be used to carry out stocktaking in large warehouses, deliver components or even help to monitor the condition of large machines and equipment.

Case study

In 2022, Royal Mail conducted trials to explore the use of autonomous drones to deliver letters and parcels to remote island communities. The goal is to establish permanent, regular delivery services by drone as soon as the technology is fully tested and UK regulations allow it. Drones are fast and reliable and have much lower emissions and running costs than larger, conventional aircraft.

Questions

1. What are the potential dangers of using large autonomous drones in UK airspace?
2. What other businesses or organisations could benefit from using similar drone technology?

▲ Figure 2.7 Royal Mail plans to use drones to deliver mail to remote island communities

Autonomous systems

Autonomous systems integrate AI, vision systems, sensor technology and robotics to achieve independent and self-directed operation. This has applications in self-driving cars and autonomous robots and drones.

In manufacturing, autonomous robots can be used to automatically locate, collect and transport components to a manufacturing cell at exactly the right time.

Distributed energy systems

Distributed energy systems represent a move away from conventional centralised electricity generation. Instead of a small number of large power stations, a larger number of smaller and more localised generating schemes are used. This has been made possible by the emergence of reliable and efficient renewable energy technologies such as photovoltaic (PV) cells, wind turbines and battery storage.

These systems will reduce our reliance on fossil fuels and increase the resilience of our electricity network – factors that are key to reducing the impact and extent of any future climate change.

In manufacturing, the energy costs of running a factory are high. Consequently, the use of PV cells or wind turbines on industrial sites is becoming more common. Using its own renewable generating capacity reduces emissions, saves money and helps to isolate a business from any volatility in energy pricing.

Hybrid technology systems

Hybrid technology systems combine two or more different technologies in a single product or system to optimise utility and/or efficiency. For example, it is common for small-scale renewable electricity generation systems to use a combination of PV cells and wind turbines. The use of two distinct technologies helps ensure continuation of supply as generation continues whenever there is sufficient wind or daylight.

In manufacturing, it is becoming increasingly common for factories to generate a proportion of their electricity needs using PV and wind turbine hybrid systems.

Cyber-physical systems

Cyber-physical systems integrate computerisation, networking, and physical processes, equipment or machinery. Examples include:

- remote monitoring and control of wind-turbine installations
- precision farming, which directs resources such as water, fertiliser and herbicide exactly as needed to reduce costs and increase yield
- the integration of 3D modelling and manufacturing simulation software with physical machines and equipment.

Key terms

Autonomous systems: systems that integrate AI, vision systems, sensor technology and robotics to achieve independent and self-directed operation.

Distributed energy systems: small-scale, localised electricity generation systems that usually use renewable energy sources.

Hybrid technology systems: systems that combine two or more different technologies in a single product or system to optimise utility and/or efficiency.

Cyber-physical systems: systems that integrate computerisation, networking, and physical processes, equipment or machinery.

Internet of things (IOT)

The **internet of things (IOT)** describes a network of physical machines, equipment and devices that are embedded with computerised sensors and networking technology to make them capable of interconnection through the internet.

For example:

- Wearable technology that monitors health conditions can be accessed remotely by medical teams to improve patient outcomes.
- Monitoring and control of domestic heating equipment can reduce energy consumption by only heating rooms that are in use.
- Real time condition monitoring of machines and equipment using IOT enabled sensors can be used to optimise maintenance schedules.

Cloud computing

Cloud computing allows users to remotely access a wide range of computer services such as data storage, software and networking through the internet. It is often more cost-effective to pay a subscription to access these services instead of buying, operating and maintaining the physical equipment and software that would otherwise be required.

In manufacturing, real-time collaboration across multiple locations, access to software and shared resources, IOT and cyber-physical systems are all dependent on cloud-based data sharing.

Key terms

Internet of things (IOT): a network of physical machines, equipment and devices that are embedded with computerised sensors and networking technology to make them capable of interconnection through the internet.

Cloud computing: where users remotely access computer services such as data storage, software and networking through the internet.

Sustainability

Sustainability requires us to fulfil our current needs without compromising the needs of future generations. Much of our industrial and economic development has been dependent on the unsustainable exploitation of non-renewable natural resources. As a consequence, we are now dealing with the effects of deforestation, pollution and, of course, climate change. As a society, it is important that we learn to live much more sustainably to minimise our impact on the environment.

Key term

Sustainability: ability to fulfil our current needs without compromising the needs of future generations.

Product life cycle

From design to eventual disposal, each step in the life cycle of a product should be sustainable:

- Design: decisions made during the design of a product have the greatest impact on its sustainability, as they determine how it functions and the materials used in its construction.
- Raw material extraction and processing: the use of new materials that require extraction and processing should be avoided if possible. Renewable or recycled materials are the most sustainable.
- Manufacturing: energy-efficient, low-waste and non-polluting processes are the most sustainable.
- Distribution: packaging materials should be lightweight and reusable or recyclable, and both shipping weight and volume should be minimised.
- Product use: low energy consumption and long service life maximise sustainability during the lifetime of a product.
- Disposal: materials should be easy to separate at the end of the product's life so that they can be reused or recycled.

Circular economy

The **circular economy** is a model for sustainable production that involves rethinking both the ownership and use of products. It involves sharing, leasing, reusing, repairing, refurbishing and recycling products to maximise their utilisation and useful service life. The principal aim of the circular economy is to make products last as long as possible, consume only renewable energy and create zero waste at the end of product life.

Key term

Circular economy: model for sustainable production that aims to make products last as long as possible, consume only renewable energy and create zero waste at the end of product life.

Exploring alternatives

Designers and engineers have a responsibility to explore alternative ways of achieving their goals that minimise their impact on the environment and maximise sustainability. This philosophy will impact future design as we migrate from traditional polluting or non-renewable technologies to more sustainable alternatives.

For example, in the search for a more sustainable replacement for petrol and diesel to power our cars, a wide range of alternatives is being explored:

- liquid petroleum gas (LPG), which is a by-product of the petrochemical industry
- biofuel derived from plant materials and not fossil fuels
- hydrogen derived from fossil fuels or by using electricity to split water into hydrogen and oxygen
- electricity stored in on-board batteries
- electricity generated by on-board hydrogen fuel cells.

In manufacturing, sustainable alternatives should be explored at every stage of the product life cycle, from design to disposal. This was explored earlier in the section on product life cycle.

Renewables

Use of renewables is essential in sustainable design. Unlike finite resources, renewables come from natural sources or processes that are constantly replenished and include:

- materials such as cotton, wool, straw and wood
- energy sources such wind, solar and tidal.

Waste and disposal

Sustainable practice will maximise reuse and recycling to keep the generation of waste materials to an absolute minimum. Where waste product cannot be avoided, it must be managed safely and in a way that avoids environmental contamination.

Some manufacturing processes, like machining, rely on material removal to create components. This generates waste metal as small chips or swarf that can be recycled into new raw materials.

Health and safety

Some waste products in the workplace are hazardous and pose a significant threat to health and/or the environment. These can include chemicals used in manufacturing, such as waste lubricants, solvents and paints. These must be handled and stored safely and be disposed of responsibly by approved specialist contractors, in accordance with the Control of Substances Hazardous to Health (COSHH) Regulations 2002 (amended 2004) (see page 190).

The least environmentally responsible approach to the disposal of general waste is landfill. This causes localised pollution and releases methane, which is a powerful greenhouse gas that contributes to climate change. Less harmful alternatives include incineration. There are numerous schemes that heat homes or generate electricity using the heat produced by incinerating waste.

Assessment practice

1. Processing equipment used to manufacture pharmaceuticals is designed and developed by businesses in which engineering sector?
2. Outline the activities performed by the logistics engineering sector.
3. Give an example of how the development of materials has impacted modern society.
4. Explain two economic impacts of the introduction of the internal combustion engine.
5. In the early part of the twentieth century, steam engines used to drive machinery in factories began to be replaced by electric motors. Give two advantages of using electric motors instead of steam engines.
6. Explain the importance of interchangeable parts when considering the maintenance and repair of complex machines.
7. Outline the three main technologies that have been used to display the picture on television screens from the 1950s to the present day.
8. Outline three ways in which widespread access to the internet has affected society.
9. Outline a manufacturing application that could make effective use of augmented reality technology.
10. Describe how cyber-physical systems could be used to increase crop yields in farming.

Project practice

You work as a graduate engineer for a manufacturer of high-technology farm equipment in the agricultural sector. One of your duties is to attend careers events to help promote your industry to students about to leave secondary school.

Design a flyer to promote the agricultural engineering sector that can be handed out at a careers fair.

Your flyer should include:

- an explanation of the main activities, products and services provided by the sector
- an explanation of why this sector is important
- examples of the latest technologies employed in the sector and how these might develop in the future.