WJEC EDUQAS GCSE (9–1)

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SAMPLE CHAPTER

Design and Technology

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DYNAMIC LEARNING

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Each topic starts with a **What will I learn?** summary of the learning objectives that will be covered, based on what students should understand from the specification.

Chapter 1
Design and technology and our world

Learning objectives

By the end of this chapter you should have developed a knowledge and understanding of:

- how new and emerging technologies have had an impact on industry and enterprise
- the impacts that new products can have on the environment, and how products can be designed and manufactured in a sustainable way
- the effects that global production has on culture and people
- legislation that affects products
- consumer rights and protection for consumers when purchasing and using products
- moral and ethical factors related to the manufacturing, sale and use of products
- the advantages and disadvantages of computer-aided design (CAD) and computer-aided manufacture (CAM)
- how computer-aided manufacture (CAM) equipment can be used in a variety of applications
- how the critical evaluation of new and emerging technologies informs design decisions
- how energy is generated and stored in order to choose and use appropriate sources to make products and to power systems.

KEY WORDS

Mass production: when hundreds or thousands of the same product are produced (usually on a production line).

Assembly line: a line of workers and equipment in a factory. A product is gradually assembled as it moves through each stage of the line until it is completely assembled.

Automated production: the use of automatically (computer) controlled equipment or machinery to manufacture products.

1.1 The impact of new and emerging technologies

New technologies that change the way in which we live our lives are constantly being developed. As designers it is important to be aware of new and emerging technologies and both the positive and negative impacts they can have on society and the environment. This helps us to make effective decisions about the materials, components and systems we use when designing and making new products.

The impact of new and emerging technologies on industry and enterprise

Throughout history developments in technology have had an impact on our industry and business activities. Think about the Industrial Revolution in the late 1700s and early 1800s: the use of steam to provide power led to huge innovations in machinery and manufacturing equipment which meant that products could be produced more quickly and economically by machines rather than by hand. The ability to generate electricity allowed factories to house larger machines for the **mass production** of products on **assembly lines**.

Developments in computer technology and electronics mean that modern factories increasingly make use of **automated production**. Thousands of identical products of consistent high quality can be produced quickly and cheaply. Robots are used to carry out some of the repetitive and monotonous tasks that were previously performed by humans.

Figure 1.1 The car industry often uses robot arms to carry out tasks on assembly lines.

Activity

Create a mind map or list examples of ways in which technology has changed the way we work (think about how we communicate in the workplace and how we manufacture products). Compare your examples with two or three other students.

Market pull and technology push

Market pull describes the development of new products in response to demands from users. Through market research a designer identifies a need or discovers a problem that requires a solution. Designers then produce new or revitalised products driven by the needs and wants of the users. The mobile phone is an example of a product developed because of market pull – people wanted a way to be able to contact each other when they were away from the home or office.

Technology push is when developments in materials, components, or manufacturing methods lead to new or improved products being developed. Tablets and smartphones are examples of products created because of technology push – developments in electronics mean that small, powerful components can be put into these devices, which allow them to perform a range of functions.

The development of new materials is also an example of technology push. For example, the development of graphene is likely to lead to a host of new products that make use of the strength, light weight, flexibility, transparency, and the ability of this new material to conduct heat and electricity. Graphene is likely to have applications in a wide range of industries, including transport, medicine, electronics and energy.

KEY WORDS

Market pull: a new product is produced in response to demand from the market.

Technology push: a development in materials, components or manufacturing methods leads to the development of a new product.

Life cycle: the stages a product goes through from initial idea to disposal.

Clear definition boxes highlight the **key words and terminology** that students need to know.

Figure 1.2 Technology push: developments in electronics allowed smartphones and tablets to be produced.

Clear and colourful images and diagrams aid understanding and cater for different learning styles.

Consumer choice

Development of new products is led by consumer choice. Designers and manufacturers aim to ensure that people want or need the product they design. New technologies can influence the products a consumer wants to buy, as people often want to own the latest technologies and products. When a mobile phone company releases a new model, many people will want to replace their existing phone with one that includes the latest technology and design.

Product Life Cycle Analysis (LCA)

The product **life cycle** is an important concept in marketing. It describes the four stages a product goes through from its initial introduction to the market until it is replaced or withdrawn because it is not selling well enough. The four main stages of the cycle are introduction, growth, maturity and decline (see Figure 1.3).

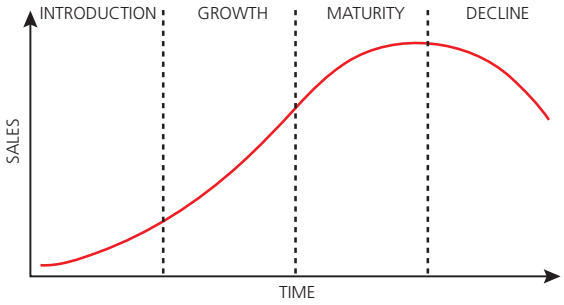


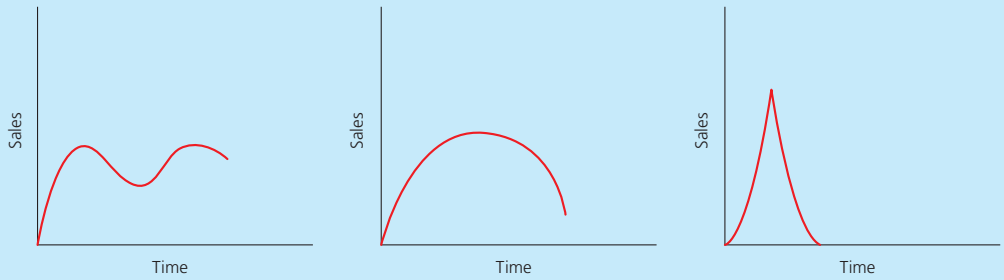
Figure 1.3 The product life cycle

- **Introduction:** this is when new products are launched and are heavily publicised so that consumers know that they are available. This might be a new product or a new version of an existing product, for example a new model of a smartphone with a larger memory or longer battery life.
- **Growth:** once the product is available, sales will grow as more people become aware of the product and buy it to replace previous products or older models.
- **Maturity:** sales of the product reach their peak. Companies will want this stage to last for as long as possible so that they get the maximum number of sales.
- **Decline:** at this stage, most interested consumers have already bought the product or a newer model will be available, at which points sales will begin to fall.

Activities enable students to check and apply the skills, knowledge and understanding they have developed in the topic.

Activity

Look at these different types of product life cycle and identify a product that each of the curves might apply to.



Activity

Carry out some research into a new technology that is likely to reduce the impact that products have on the environment. Write a short summary of what the technology is, its benefits and drawbacks.

The product life cycle will depend on the product being sold. A product which is popular for a short time will have a short life cycle with a steep growth period and an equally steep decline. Some products may decline and then start growing again, for example an item of clothing that comes in and out of fashion.

People, culture and society

Technology can also have an impact on our lifestyle, values and beliefs. When designing and manufacturing products we need to consider how they will affect our society and their moral and ethical implications. Designers also need to ensure they abide by legislation and protection that has been put in place to protect consumers.

Global production and its effects on culture and people

We live in an increasingly global society. Developments in transport mean that products are now shipped all over the world. Components and parts for some products may be produced in several different countries and transported between countries during the manufacturing process. Increasing automated production in factories has speeded up production processes, helping to reduce manufacturing costs.

Similarly, developments in communications technology and the internet mean that we can work with, sell to and buy products from people almost anywhere in the world. This means

there is greater competition between companies to market and sell their products, which keeps prices low and helps us to get the best deal. Mobile technology and the internet means we can now communicate with people all over the world at any time and in any place through email and social media. These developments make us better connected and can increase our awareness of other cultures and societies.

However, there are downsides to these new technologies and global production. Importing cheaper products from other countries instead of buying products produced locally can lead to job losses in our own society. It may have been possible to produce those products more cheaply in another country, but this may be because workers in that country are paid low wages and work in poor conditions; this can be detrimental to their lives and health. We need to question the ethical and moral implications of making these choices.

Increasing automated production may have freed up our time, reduced manual labour and stopped us from having to carry out menial tasks, but has caused job losses in some industries as fewer people are needed to perform these roles.

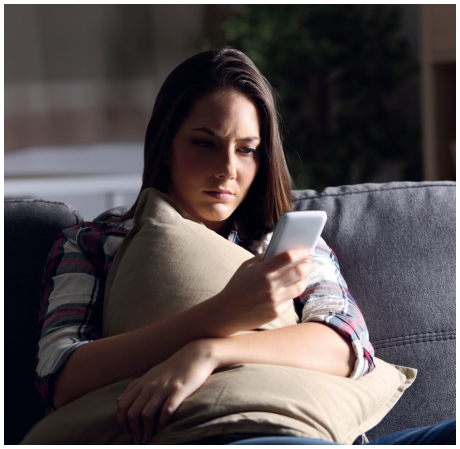


Figure 1.4 Mobile technology and social media means we are better connected than ever before, but it may make us feel isolated.

While mobile technology may have increased the frequency of our interactions with other people, it may lead to us having fewer face-to-face interactions, which causes us to feel isolated. Being constantly connected is not always seen as a positive; many people feel it has blurred the boundaries between their work and leisure time and has a negative impact on their sleep and mental well-being.

As designers, we also need to question the cultural implications of global production. We need to be sensitive to the ideas, values, beliefs and customs of different cultures when we are designing products – what may be acceptable in one culture or society may be misunderstood or seen as offensive in another culture. Colours, patterns and symbols, for example, can have different meanings for different people and we need to bear this in mind when making choices for our products to ensure we do not offend. Global production can threaten the traditional industries, skills and techniques of some cultures; we need to consider carefully the impact new products may have on these traditions.

Activity

In pairs, make a list of five advantages and five disadvantages of the global production of products on culture and people.

KEY POINTS

- New products are usually developed because of a want or need (market pull), or because of developments in technology (technology push).
- Developments in technology have changed our industry and enterprise: automated production and robotics mean we can now produce products quickly and cheaply with a smaller workforce.
- Producing new products uses materials and energy; designers have a responsibility to consider the impact a product will have on the environment at every stage of its life cycle and to produce products with sustainability in mind.
- In our global economy products are sold to people in different societies and with different cultures; we need to consider the positive and negative implications of this and think about how the products we design will affect people, their communities and cultures.

Legislation and consumer rights

The Consumer Rights Act 2015

KEY WORDS

Counterfeit: an imitation of something valuable, sold with the intention to defraud or deceive someone.

Compensation: payment, usually money given to someone as a result of loss.

When you buy products or services, the Consumer Rights Act 2015 protects you when things go wrong, such as buying a defective product or not receiving the expected level of service. The law covers you for faulty goods, **counterfeit** goods, poor services and problems with builders, including rogue traders and contracts. The law states that goods must be of satisfactory quality, as described or seen when purchased, and fit for purpose. The Act also covers digital products and buying online.

You can claim a refund, repair or replacement when something you purchase does not meet the following standards:

- The product should function as intended and you should be able to use it as explained to you by the seller at the time it was purchased. This includes advertising content as well as a verbal exchange, and applies to an actual product and digital downloads. For example, a Bluetooth portable speaker should play music on instruction or a downloaded film should play without interference. The product should always be fit for purpose.
- The product should be of satisfactory quality. It should not be damaged or be defective in any way when you receive it. The law does not protect you if you bought faulty goods knowingly, as sometimes happens with sale items. If you buy goods over the internet it is best to check the quality immediately on receipt.
- The product should be as it was described at the time of purchase. This is particularly important when buying online. Clothing, for example, should be in the colour and size you ordered or if a sports shoe is described as leather it should not be made of cheaper synthetic imitation leather.

The law also protects consumers when a service that has been agreed fails to meet expectations. The provider is still legally bound to offer some form of **compensation** even if it is not practical to bring it in line with what the customer originally purchased (for example if the service and catering at a restaurant for a party was not as agreed). The seller should at least offer a partial refund.

If a product develops a fault or is defective in some way, you have up to 30 days from the day you received the product to get a full refund. You can ask for a repair or replacement if that is your choice. Outside 30 days, the seller should offer a repair service if it is feasible and reasonable to do so. If the repair is unsuccessful then you can ask for your money back or a reduction in price. The same rules apply for digital content; in addition, you might be entitled to additional compensation if a device has been damaged as a result of the faulty downloaded digital content.

The Consumer Rights Act also covers contracts like those for mobile phones. Terms and conditions should be clearly displayed with no additional charges or unfair terms hidden in the small print.

Activity

Discuss the following scenarios.

1. Thomas has downloaded a game for his computer. Initially all was fine – the game was great until his computer seemed to get a virus. Thomas cannot access any of his computer files and the game no longer plays either. What are his rights?
2. Jasmine organised a pool party for her 5-year-old niece's birthday. On arrival at the leisure centre along with 20 invited guests, they were told the pool was closed for repairs so the leisure centre would organise a few games in the hall instead. What are her rights?
3. Alex's new designer sunglasses that were purchased online are great. They even came with a certificate of authenticity. They seem a bit more like plastic than they appeared on the website but they still look really cool. Ten days after receiving them one lens falls out and one of the arms is loose. What are the issues here?

Moral and ethical factors related to manufacturing products and the sale and use of products

A global free market allows unrestricted trade. People who want to make a profit by growing their business leads to healthy competition, which in turn should help workers improve their lives by having an income through regular employment. There is, however, no obligation for companies to support workers in their employ in this way. Businesses are constantly making decisions but not all are considered ethical or morally acceptable. In many areas of global trade not everyone is treated equally and fairly.

Businesses have a moral duty to supply goods and services that are fit for purpose, safe to use and as advertised. Sadly, some businesses put profit above everything else. This could mean poor working conditions and pay for workers and inferior products for unsuspecting consumers.

Some manufacturing companies follow a more ethical approach to trade. These companies focus on how their goods and services directly benefit consumers but also support socially responsible and environmental causes. They also aim to provide advertising that is honest and trustworthy. Ethical traders share a breakdown of costs for products – this transparency is important to them. For other manufacturing companies, costs are not revealed for a number of reasons – for instance, if profit margins and cost breakdowns were disclosed for a specific product, it could reveal poor wages and working conditions for some workers. This is particularly true of the garment manufacturing industry. Organisations like Fairtrade, discussed later in the chapter, seek to redress the balance in trade.

Sustainability

Designers, manufacturers and consumers have become increasingly aware of the negative impact that new technologies and the development and disposal of products can have on the environment, and many now look for ways in which they can reduce their environmental impact.

Sustainability is about meeting today's needs without compromising the needs of future generations. When developing new products, designers and manufacturers have a responsibility to do so with sustainability in mind. See Section 1.2 for examples of how sustainability can affect design.

KEY WORD

Sustainability: producing goods and services without impacting on the needs of future populations.

Figure 1.5 Hybrid technology is helping to reduce CO_2 emissions associated with traditional petrol and diesel car engines.

There are many examples of ways in which new and emerging technologies can be utilised to help us to use, manufacture and dispose of products in a more sustainable way. For example:

- **Hybrid technology and electric cars** – the development of hybrid cars, which use both petrol or diesel and an electric motor, reduces fuel consumption and means the car emits less carbon dioxide. Fully electric cars have similar advantages, and as technology develops they are likely to become more popular.
- **Developments in renewable energy** – technology that will help us to make better use of alternative sources of energy and reduce our reliance on **fossil fuels**. Wind, solar, tidal and hydroelectric power technologies are becoming increasingly efficient and helping us to maximise the use of these renewable sources of energy. See page 18 for more on renewable and non-renewable energy sources.
- **Recycling technology** – we recycle only small amounts of the plastic we consume, and products such as Styrofoam cups and plastic bags are difficult to recycle. Recycling companies are focusing on developing technologies that can break down these plastics more effectively and safely.

KEY WORD

Fossil fuels: finite resources that cannot be replaced.

KEY POINTS

- Know that the Consumer Rights Act 2015 protects consumers when they purchase products, including digital downloads and online purchases. All goods should be as advertised or described, be fit for purpose and of satisfactory quality.
- Know that if we continue to live as we currently do we will cause irreparable damage to the environment. Simple adjustments like buying sustainable products is a good start.
- Think before throwing something away – has it got another use? Reduce land mass currently being used for landfill.

Figure 1.6 CAD designer

Production techniques and systems

Computer-aided design (CAD)

Computer-aided design (CAD) has become one of the most valuable tools available to designers and manufacturers. Once a highly specialised and expensive tool, CAD packages are becoming easier to use, more powerful and their cost is dropping dramatically. It has improved the quality of design work at all stages in the design process, from generating and communicating initial ideas, through to producing 3D models and subsequently extracting working drawings.

Making drawings by hand was extremely time consuming, required a huge level of skill, and errors or adjustments often resulted in the drawing being restarted. Now CAD is accessible to all, from people planning the basic layout of their new kitchen, to engineers developing CAD drawings that can be used to manufacture working prototypes.

CAD models can also be used by manufacturers to simulate how potential products will perform in a particular environment. Simulations of the aerodynamic performance of a car or how a given product may perform under a particular force can all be undertaken using a 3D CAD model. This saves money, time and resources.

Cloud-based technology is an emerging technology which has made collaborative work easier. Designers can share projects in the cloud, allowing for different components to be developed simultaneously by designers who could be working on the other side of the planet. This improvement in communication has improved efficiency and reduced the amount of travelling between designers and manufacturers.

CAD software is accessible to all, but if a complex design or component is needed, the level of skill and knowledge of the CAD designer must be comprehensive. Generative design is a new development that makes use of mathematical algorithms to design components based on a set of parameters or design requirements. This often generates unique and highly efficient designs that would have not been possible to create using traditional skills.

The advantages of CAD:

- The quality of presentation is generally higher than hand-drawn ideas.
- 2D and 3D CAD models can be created, amended and edited easily.
- Textures and colours can be applied to make models photorealistic.
- The design can be securely stored, shared and worked on collaboratively.
- The 3D model can be exported to CAM machines which can produce a working prototype.
- Ideas, concepts and models can be exposed to the clients/users and opinions sought to further develop products.
- CAD can speed up the designing process and reduce lead-in time to get the product to market quicker.

The disadvantages of CAD:

- Powerful computers are necessary for 3D modelling and rendering.
- Designers and other users will need training to use the software to its full potential.
- It requires a high level of expertise to use efficiently.
- It can be slower to generate initial ideas than with pen and paper.
- Software is continually being updated and can be expensive to keep up to date.
- Hardware such as 3D printers can be expensive and quite slow to manufacture large objects.

Computer-aided manufacture (CAM)

CAM machinery is used to produce products and components directly from CAD drawings. A CAD drawing is converted into a code that can be interpreted by a CAM machine. Most CAM machines operate on the principle of a head that moves along an X, Y and Z axis. The code is a series of numerical commands that tell the machine where to move and at what speed, in order to cut out, print or machine the CAD design. As a result of this code they are also often referred to as Computer Numerically Controlled (CNC) machines.

CAM machines are frequently found in industry, where the need to manufacture large volumes of identical and consistent quality products occurs. The initial costs of these machines can be expensive and workers need extensive training to programme and operate them effectively. They have the benefit of being able to run for long periods without breaks, and as such they are much more efficient than the human workforce that they replace. They do however need ongoing servicing and maintenance which can be expensive and impact on the output of a production line.

Figure 1.7 CNC router machining a prototype from polyurethane modelling foam

KEY WORDS

CAD: Computer-Aided Design.

CAM: Computer-Aided Manufacture.

CNC: Computer Numerically Controlled.

CAM machines are also found in some schools: vinyl cutters, laser cutters and more recently 3D printers. They are usually smaller than their commercial equivalents but are perfect for cutting and shaping thin materials such as self-adhesive vinyl, card, plywood and acrylic.

The advantages of CAM:

- CAM processes are generally faster than traditional manufacture.
- A high degree of manufacturing accuracy is achievable.
- Consistent and repeatable processes are achievable.
- Less waste is produced than in traditional manufacturing processes.
- It allows for flexible manufacturing systems to be implemented in industry.

The disadvantages of CAM:

- CAM machinery can be expensive.
- CAM machinery can need regular maintenance and servicing.
- Traditional skills and workforces can be displaced.
- Costs generally inhibit CAM use in small-scale manufacture.

Using CAM equipment

CNC embroidery

CAD designs can be sewn or embroidered into a range of textiles and fabrics. CNC embroidery lends itself well to flexible manufacture by being able to personalise garments with dates or names. Designs can be saved or shared to allow for short or long production runs. Uses include the manufacture of school uniforms or applications where branding or logos need to be applied.

Figure 1.8 A CNC embroidery machine producing a multi-coloured logo

Vinyl cutting

Using a roll of self-adhesive vinyl, a simple pattern is cut out from a CAD drawing using a sharp cutting blade. The colour of the design in determined by the vinyl loaded. This process is used to produce lettering or shapes for sign writing or for applying branding to vehicles. Vinyl cutters are probably the most affordable CAM machines, which makes them commonplace in schools.

CNC routing

A rotating router cutter is used to cut around a path or shape determined by the CAD drawing. The profile of the cut can be changed by fitting alternative cutting tools and the depths of the cut are usually determined by different colours being used on the CAD drawing.

More comprehensive 3D shapes can be produced on CNC routers that have attachments that rotate the workpiece while being machined.

Laser cutting

Laser cutters use a directed laser beam to cut through or vaporise material, leaving a high-quality accurate cut. They can be used to cut or engrave a wide range of materials, with some of the more powerful machines cutting through metal. One of the advantages of a laser cutter

is that the workpiece can be easily held as there is no force from a rotating cutter or blade. This means that intricate patterns can be cut out, for example jigsaws and decorative designs in greetings cards.

3D printing

3D printing is becoming ever more popular as the price of the printers is decreasing, and the popularity and flexibility that the process offers designers increases. 3D printing, also known as **additive manufacture**, uses a thermoforming polymer roll or spool of filament that is heated and extruded through a head that moves on an x and y axis, much like a laser cutter and CNC router. Following the printing of the first layer, the bed of the printer moves down and the next layer of polymer is extruded. The strength of the product printed can be determined by the type of material used and also the inner design of the print.

Using 3D printing, a working prototype can be quickly produced. Designers can test products and bring them to market without the need for the expensive tooling previously needed to manufacture plastic products. It also means that small-scale manufacture is possible.

Case study: Underarmour ArchiTech footwear

One company that has been looking at how CAD and CAM can allow them to further develop their products is Underarmour. They used generative design to develop a sole for their 'ArchiTech' shoe, which has a lattice structure that has excellent cushioning properties. The complexity of the design is such that it can only be produced by 3D printing. Although the time taken to produce each sole has limited the scale of production, it gives an indicator of how CAD and CAM are going to be integral to many more products that we take for granted.

KEY WORD

Additive manufacture: the process of building up a physical shape layer by layer.

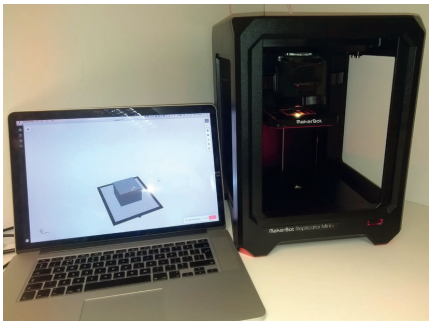


Figure 1.9 3D printer

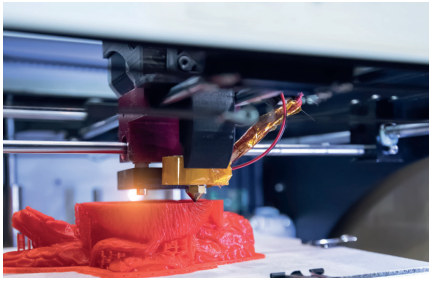


Figure 1.10 3D printing layer by layer

Activity

Find out more about how generative CAD design and advancements in 3D printing are shaping skateboard design and manufacture by researching 'Project T.O.S.T'.

KEY POINTS

- Additive manufacture is the process of building up a physical shape layer by layer.
- Rendering is the process of applying a colour or textures to a drawing.
- CAD is an effective method of drawing, editing and presenting design work digitally.
- CAM is the process of using machinery to produce products. CAM machines run from instructions produced from CAD drawings.

1.2 How the critical evaluation of new and emerging technologies informs design decisions

New technologies are always emerging. Some of these are disruptive and can cause significant changes to our lifestyle. Others create a brief fashion which soon disappears.

The internet has massively changed the way we shop, communicate and entertain ourselves. In some ways, the internet has reduced the amount that we need to travel, but in other ways it has increased our 'road miles' because we expect online goods to be delivered to our door. In this section, we look at how important it is for future designers to make decisions based on consideration for the environment.

The importance of sustainability issues and environmental issues when designing and making

Designers, manufacturers and consumers all have a role to play in promoting a sustainable design strategy. Sustainable design involves:

- Materials – choosing materials for manufacturing that have a low impact on the environment (materials which are recycled, such as paper and card, non-toxic and do not need as much energy to process).
- Manufacturing methods – designing products which are manufactured using efficient, low-energy methods.
- Build quality – products with a higher build quality are likely to work more effectively, for longer and break down less.
- Packaging – reducing unnecessary product packaging and making all packaging recyclable, e.g. cardboard.
- Transportation – reducing the energy needs for transporting the raw materials and the finished product, for example by local manufacturers using locally sourced materials where possible.
- Energy needs – designing energy-efficient products, for example using LED lights instead of filament lamps.
- Product life expectancy – designing products to last, avoiding early obsolescence and designing products to be serviced and repaired.
- End of product life – consideration of what happens to the product when it is no longer needed. Ease of product recyclability.
- Fair trade – designing products which provide a fair income for workers at all stages in the supply and production chain.

KEY WORD

Environmental directive: a type of law to provide protection for the environment.

There is a great deal of international pressure on governments in all countries to reduce energy consumption, reduce pollution and eliminate the disposal of hazardous substances into the environment, and to increase recycling. There are many **environmental directives** (types of laws) which stem from the European Union and from bodies such as the World Energy Council which specify targets to achieve these aims. There are also international agreements on climate change, air pollution and the protection of wildlife.

Manufacturers can apply to have their product awarded the European Ecolabel. To qualify, products have to meet a tough set of environmental criteria which take into account the whole product life cycle. The EU Ecolabel is intended to simplify consumer choice in seeking out products which are good for the environment.

Figure 1.11 The EU Ecolabel

Products displaying the EU Ecolabel tell the consumer that they have achieved environmental excellence, which manufacturers hope will promote sales of the product.

Social, cultural, economic and environmental responsibilities

In addition to environmental directives, designers and manufacturers face pressure from consumers who are becoming more conscious about buying products which are better for the environment.

Many new domestic appliances carry an energy rating label which helps consumers choose energy-efficient products. The label rates the product on a scale from A+++ (most efficient) to G (least efficient). The EU claims that the introduction of the energy rating label, together with consumer education, will reduce energy consumption by an amount equivalent to the annual energy consumption of Italy, saving consumers hundreds of pounds on their annual energy bills.

Linear and circular economy

In a **linear economy**, products are made as cheaply as possible. Resources are extracted and taken from the earth, made into products and then sold. Once the product is broken or no longer wanted it is simply disposed of.

The use of certain materials and processes when manufacturing products can have an extremely detrimental effect on wildlife, the environment and our climate. As a result, there has been a shift in people's perceptions and attitudes. Many people choose not to purchase products that are not environmentally friendly.

A sustainable strategy ensures that, when a product reaches the end of its life, the useful materials in the product are recovered for reuse. Manufacturers have had to change the way they source, process and package products or they risk losing sales. The Government has also forced manufacturers to meet more stringent laws relating to the amount of pollution they produce and how they dispose of waste products.

This 'make–use–recycle' strategy is called the **circular economy**. The circular economy uses as few resources as possible and extracts the maximum from them, using them for as long as possible. Products are manufactured in such a way that they can be repaired or so that as many parts as possible can be reused or recycled once they are broken or no longer required.

Circular economy links with **cradle-to-cradle** production (compared with cradle-to-grave) where a manufacturer considers the stages of a product's life, from its birth, through its use and death, then recycling and ultimate rebirth into a new product.

The six Rs of sustainability

Table 1.1 shows the six Rs of sustainability, which are intended to help consumers ask questions about their lifestyle, how they choose and use products, and how it impacts on the environment.

KEY WORDS

Circular economy: considering how to recover the assets from a product at the end of its life and invest them in a new product.

Cradle-to-cradle: considering a product's complete life cycle, including its rebirth into a new product.

Figure 1.12 Energy rating label on a washing machine

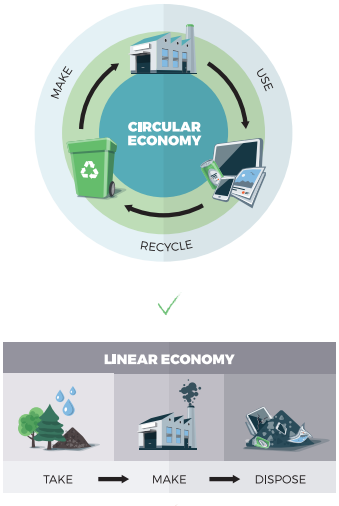


Figure 1.13 Circular versus linear economy

A designer can apply the six Rs during product development, so that excellent environmental qualities are designed into the very heart of the product.

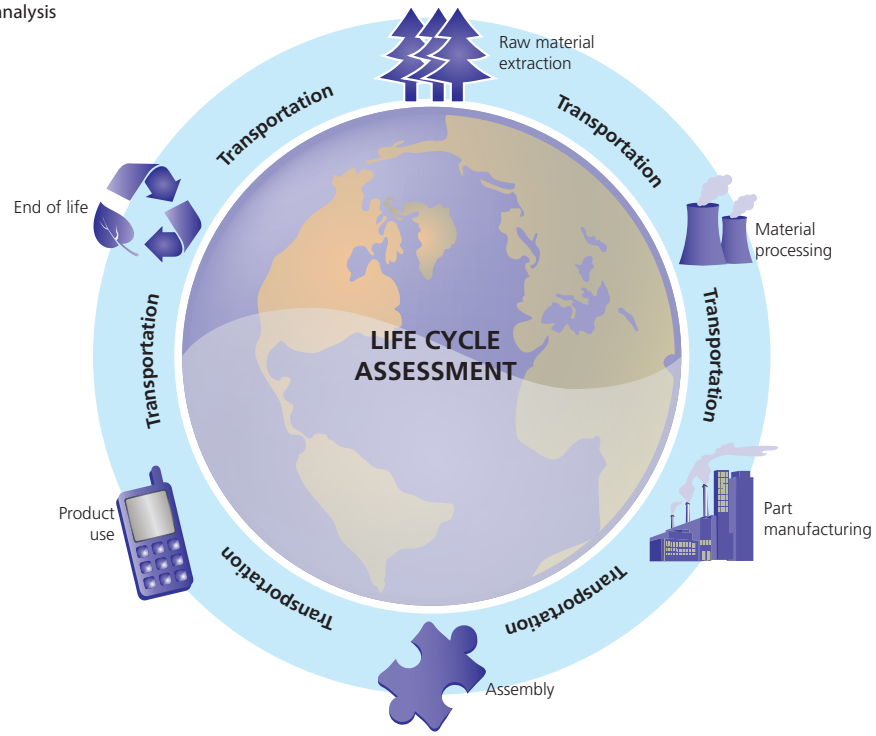
	Questions a designer might ask
Rethink	Does the product do its job well? Is there a better way to solve the problem which is less damaging to the environment?
Reduce	Can we reduce the amount of materials used in the product or its packaging? Are there parts which are not needed? Many products are over-packaged – can this be reduced?
Recycle	At the end of the product's life, can the materials be easily separated and then recycled in order to make new components for new products?
Reuse	Can the product (or parts of it) be used for some other purpose once it has reached the end of its primary life? Can packaging be reused rather than being discarded?
Refuse	Is it necessary to use the product at all? Is it an unethical product? Where is it made, and what are the conditions for the workers who make it? Do they get a fair wage? Is the product Fairtrade? By refusing to buy unethical products, consumers can put a great deal of pressure on manufacturers.
Repair	Can the product be repaired if it breaks down? Can it be better designed so that regular servicing extends its life?

Table 1.1 The six Rs of sustainability

Life-cycle analysis

A life-cycle analysis is carried out to assess the environmental impact of a product during its entire life cycle, from cradle-to-cradle. It looks at the use of materials, the use of energy, and the impact of transporting the materials, parts and the product itself at various points in its life. Table 1.2 lists a series of questions that can be useful when carrying out a life-cycle analysis.

Figure 1.14 Life-cycle analysis



Stage	Questions to ask
Acquiring raw materials	• What is the environmental impact of extracting or harvesting the raw materials (e.g. drilling for crude oil)? • How much energy is used in the extraction? • Could recycled materials be used instead?
Material processing	• How much processing is required to convert the raw material into a usable material (e.g. converting crude oil into polymer)? • How much energy is required? • Does the processing use renewable energy sources? • Does the processing use harmful chemicals, or produce pollution or waste products?
Manufacturing	• What manufacturing method(s) is used? Is there an alternative? • How much energy is required (e.g. for machines, factory lighting/heating, etc.)? • Does the manufacturer use renewable energy sources? • Does the manufacturing use harmful chemicals, or produce pollution or waste products (e.g. bleach used during textile dyeing)?
Use	• How much energy does the product use, if any? • Does the product consume energy when not being used (e.g. when on standby)? • Where does the energy come from? Is it a renewable source? • Does the product create pollution or waste products (e.g. a car exhaust)? • Can it be made more energy efficient?
End of life	• Can the product easily be dismantled into component parts? • Are the parts recyclable? • Do the parts contain hazardous chemicals (e.g. mobile phone batteries)? • How much energy is needed to process the product for recycling or disposal?
Transportation	• How far are parts, product and waste transported? • What fuels are used for transportation? • What is the carbon footprint? • Could local materials be sourced? • Could the product be manufactured close to where it is used?

Table 1.2 The stages of a product life-cycle analysis

Activity

Carry out a life-cycle assessment on an electric kettle. Construct a grid with the six stages shown in Table 1.2. In your grid, answer some of the questions asked in the table.

Fairtrade

A key ethical issue for a designer is the working conditions for the people who make the products. Many raw materials are mined or harvested from all over the world, and designers have a responsibility to ensure that materials are ethically sourced. Not all farmers, workers and miners who are involved in the production of products are treated equally and fairly. Many do not share in any of the benefits and profits associated with trade.

Fairtrade sets up partnership schemes between producers, businesses and consumers that offer a different approach. Social, economic and environmental standards are set for all companies, producers and workers involved in the supply

FAIRTRADE

Figure 1.15 FAIRTRADE Mark

KEY WORDS

Exploit: unfairly take advantage of.

Global warming: a rise in temperature of the Earth's atmosphere caused by pollution and gases.

Fairtrade products and ingredients	
Bananas	Herbs
Cereals	Ice cream
Chocolate	Nuts
Cocoa	Olive oil
Coffee	Rice
Cosmetics	Soft drinks
Cotton	Spices
Flowers	Sugar
Footballs	Tea
Gold	Wine

Table 1.3 Some Fairtrade products

chain. One of the aims of Fairtrade is to connect disadvantaged producers and consumers by setting up fairer trading conditions. If disadvantaged producers get a better share of profits and fairer wages for the work they do, it will help improve their lives and combat poverty. Producers who work under the Fairtrade agreement have an equal say in more aspects of the trade chain. Working conditions have to be of a satisfactory standard, to tackle **exploitation** and protect workers' rights.

Products made under the Fairtrade agreement that meet all the standards can carry the Fairtrade mark. This helps shoppers to make decisions about whether a product they are thinking of buying is ethical, or manufactured from materials or ingredients that have been ethically sourced.

Carbon footprint

A carbon footprint is a measure of the amount of greenhouse gases released as a result of our activities. The figure is expressed as kilograms or tonnes of carbon dioxide (CO_2). Carbon dioxide is a greenhouse gas, which means that it traps the Sun's heat at the surface of the Earth. Greenhouse gases cause **global warming**. The more CO_2 an individual generates the bigger the impact on the environment.

Using energy from fossil fuels adds to our carbon footprint. Heating our homes with gas, oil or coal emits CO_2 and makes our carbon footprint bigger. Even if using electricity does not directly give off CO_2 the power station that generated it does! The waste we generate also produces CO_2 and another gas called methane when it goes to landfill. Table 1.4 lists some activities which each have a carbon footprint of 1 kg of CO_2.

Activities which each release 1kg of CO_2
• Driving 4 miles in a car.
• Travelling 7 miles on a bus or train.
• Flying 1.4 miles in a plane.
• Leaving your computer switched on for a day.
• Manufacturing two plastic bottles.
• Producing 100 g of beef (cows produce large amounts of methane gas in their guts).

Table 1.4 Carbon footprint examples

Activity

Use an online carbon footprint calculator to work out your own carbon footprint for your lifestyle. There are many online calculators, such as the one at http://footprint.wwf.org.uk which compares your carbon footprint to the UK annual average.

Across the world, the average annual carbon footprint per person is 4 tonnes. In the UK, the average annual carbon footprint is 10 tonnes per person.

Some carbon-based fuels are carbon neutral. This means that they do not contribute to the amount of CO_2 in the atmosphere. Wood is an example of a carbon neutral fuel. When the wood grew, the tree absorbed CO_2 from the atmosphere and locked the carbon into the wood. When the wood is burned, the same amount of CO_2 is released, resulting in no overall CO_2 change in the atmosphere. All biofuels (Section 1.3) are close to being carbon neutral, although fossil fuels may still be used in their production (for example, to power farm machinery). Energy sourced from renewable sources (Section 1.3) creates no carbon at all.

Activity

Think of one product or gadget you own. Consider its carbon footprint and how that indirectly affects your carbon footprint. Think about:

- Where was it made?
- Were the materials and components made there too?
- Where did you get it from?
- Has it travelled far from its early concept stage to be in your possession?
- Does it need power to use it? Think about that carefully!
- What do you intend to do with it when you no longer want it?
- Has it added much to your carbon footprint? Could you change any actions as a result of this analysis? If so, how or in what way?

(HINT: Denim jeans/clothing are good for this exercise.)

Ecological footprint

A person's **ecological footprint** is the area of the Earth that they need to produce the resources, and absorb the waste, to sustain their lifestyle. It gives us a measure of the impact human activity has on the environment. Our ecological footprint weighs up how quickly we consume resources and generate waste against how quickly nature can absorb our waste and generate new resources.

Resources include food (plants, livestock, fish and drinking water), building materials (timber, mined materials), fuels (fossil fuels, renewable energy farms), other consumables (clothes, paper, etc.). Waste is mainly carbon emissions.

Table 1.5 illustrates what the land is mainly used for that makes up our ecological footprint.

Use	What land is used for
Infrastructure	land needed for buildings – houses and industrial; transportation – roads and railways; reservoirs for hydropower and energy plants
Forestry	land needed to supply timber for products, furniture and construction, wood fuel, pulp, paper; also needed to absorb CO_2 from fossil fuels
Water	fishing grounds for the food commodities from oceans and rivers; water is vital to sustain all life; needed in industry and agriculture
Cropland	land required to grow the food we eat – fruit, grain and vegetables; fibre for textiles such as cotton and linen; animal feed, bio fuel
Grazing land	needed to raise livestock for meat and dairy, wool and leather products
Disposal	land needed to dispose of all the waste we generate
Fossil fuels	production, transportation, heating and cooling

Table 1.5 Ecological footprint

In the UK, the average ecological footprint of each person is 5.6 hectares. One hectare is about the size of a rugby pitch, so each person requiring 5.6 hectares is simply not sustainable. The global sustainable level is 1.8 hectares per person.

Worldwide, humanity's ecological footprint is currently the equivalent of 1.7 Earths. Put another way, it takes Earth 18 months to regenerate what we use in 12 months. If we continue to use up the world's natural resources quicker than nature can replace them, we will create an **ecological deficit**.

KEY WORDS

Ecological footprint: a measure of the impact that human activity has on the environment.

Ecological deficit: a measure to indicate that more natural resources are being used than nature can replace.

Activity

Use an online footprint calculator to work out your (and your family's) ecological footprint.

- Investigate how you could lower your ecological footprint by making small changes to the way you currently live your life.
- Discuss how your school could lower its ecological footprint.
- Describe what product designers could do to help consumers lessen their ecological impact.

KEY POINTS

- Sustainable design involves choosing the correct materials, manufacturing methods, packaging, transportation, energy needs and end-of-product-life considerations.
- Environmental directives are laws which aim to protect the environment by controlling use of hazardous materials, energy use and pollution.
- Know the six Rs of sustainability, and how they can be applied to reduce a product's environmental impact.
- A life-cycle analysis is carried out to assess the environmental impact of a product during its entire life cycle, from cradle-to-cradle.
- Products that carry the Fairtrade logo have been certified to meet Fairtrade standards. This helps shoppers to make decisions about whether a product they are thinking of buying is ethical, or manufactured from materials or ingredients that have been ethically sourced.
- Fairtrade lobbies governments for fairer trade deals for disadvantaged producers, and campaigns to make the public aware of the unfair issues associated with trade. The Fairtrade Foundation works closely with and supports farmers in developing countries.
- Carbon footprint is a way of measuring the contribution an activity makes towards global warming.
- Your carbon footprint is the total CO_2 you generate; the more you generate the bigger impact you have on the environment.
- Ecological footprint is a measure of the area of land required to support an activity.

1.3 How energy is generated and stored in order to choose and use appropriate sources to make products and to power systems

As a Design and Technology student, you will need to consider ways that energy is used to:

- manufacture products
- power products and systems.

Energy is always needed to cause something to move, to heat something up, to create light or sound, or even to perform calculations in a computer chip. Energy is also needed to process a material (for example to extract, refine, mould, bend, cut or drill it). Basically, the manufacture and use of products and systems requires energy, and an assessment of this was discussed under life-cycle analysis in Section 1.2.

Types of renewable and non-renewable energy sources

You will have learned in science that energy cannot be created or destroyed, it can only change from one type of energy into another type. When we 'generate' energy, such as electricity, we are transforming another source of energy into electricity. We constantly need sources of energy to supply the demands of industry and consumers.

The energy sources available to us on earth can be classified into **non-renewable** and **renewable** sources. Non-renewable sources are fuels that are extracted from the earth. Once used, they cannot be replenished; they are **finite** sources and they will eventually run out. Renewable energy sources will not run out.

KEY WORDS

Non-renewable: energy sources which are not replenished.

Renewable: energy sources which will not run out.

Source	Explanation
Coal (fossil fuel)	Mined from the ground. Burning coal releases heat energy which is used in power stations to generate electricity, which is then distributed around the country through a national grid.
Oil (fossil fuel)	Crude oil is extracted from the earth by drilling deep into the ground. It is then refined to produce a variety of liquid fuels, such as petrol, diesel and aviation fuel. These hydrocarbon fuels can be used in motor vehicle engines, or aircraft jet engines to produce movement. They can also be burned in central heating systems for buildings, or for generating electricity in power stations.
Gas (fossil fuel)	Natural gas is largely methane, a combustible hydrocarbon. It is used as a fuel in some vehicles. Gas is extracted by drilling, and then it is piped through a national grid pipeline into houses and factories where it is used as a fuel for heating and cooking. Some power stations use gas-powered turbines (similar to a jet engine) to generate electricity.
Nuclear	Uranium ore is mined from the earth. It undergoes a purification and enrichment process to be transformed into nuclear fuel which is then used in a nuclear reactor to generate heat which is converted to electricity in a nuclear power station. Nuclear fuel is not burned. The heat energy is released when the large, unstable uranium atomic nuclei split into two smaller nuclei. This is called nuclear fission.

Table 1.6 Non-renewable energy sources

Figure 1.16 Coal is a fossil fuel.

Source	Explanation
Wind	A wind turbine is designed to extract energy from the wind. The rotating blades are connected to a generator which produces electricity. The hub of the turbine can turn so that the blades always face into the wind.
Solar	Photovoltaic (PV) panels produce electricity when exposed to sunlight. In the northern hemisphere, they normally face south and are angled so that they receive the maximum possible sunlight throughout the day. They produce a low voltage, direct current (DC). This can be used to charge batteries, or it can be converted to high voltage AC and fed into the mains electricity grid. Solar water heating panels can be used to directly heat water for domestic and industrial use.
Geothermal	Cold water is pumped underground where it is heated by the Earth's natural heat. The hot water (or steam) that returns can heat homes, or it can be used in a power station to generate electricity.
Hydroelectric	A dam is built to trap a natural river, forming a lake. The water is released, under control, and the pressure of the escaping water turns turbines which generates electricity. Some small hydroelectric generators do not need a dam, relying instead on the energy of a fast-flowing river.
Wood/biomass	When a tree is harvested, the wood which is not of interest to the timber industry is chipped (or pelleted) and used as fuel in place of burning coal. This can provide heating for houses, or it can be used to generate electricity. In other biomass schemes, plants are grown to produce materials which can be processed into biofuels. Sugar cane is fermented to produce bioethanol, and soy beans can be processed into biodiesel; both these liquid fuels are useful in transportation. A digester unit will process waste food into a burnable biomass fuel, such as converting used cooking oil from restaurants to biodiesel.
Wave	A mechanism is used to convert energy from waves on the sea into electricity. Wave power is not widely used. Tidal power is a more promising aspect for future energy needs. This is a type of hydroelectric scheme which extracts energy from the rising and falling tides.

Table 1.7 Renewable energy sources.

Figure 1.17 Solar PV panels and wind turbines

Issues surrounding the use of fossil fuels

Fossil fuels (coal, oil and gas) currently provide around 80 per cent of the world's energy needs. They are a store of chemical energy, which they release as heat energy when burned. Using fossil fuels has a significant environmental cost. They produce waste products which are emitted into the atmosphere, mainly carbon dioxide gas, but also pollutants such as sulphur dioxide (which raises the acidity of rain) and fine particulates which can cause breathing problems for people. Carbon dioxide is a **greenhouse gas** which means that it traps the Sun's heat at the surface of the Earth. Most scientists agree that carbon dioxide emissions from burning fossil fuels is actively contributing to global warming.

KEY WORD

Greenhouse gas: atmospheric pollution which traps heat at the Earth's surface.

Fossil fuels cannot be replaced. Estimates vary about when they will run out, but we are currently using oil at a much faster rate than coal or gas.

Fossil fuels have a very high energy density, which means they hold a lot of chemical energy per kilogram of fuel. This makes them ideal for use in transportation (cars, ships, aircraft, etc.) because they contain a lot of energy for not much weight. They are also quick to refuel – it only takes a couple of minutes to fill a car with petrol. The alternative fuel sources, such as batteries in electric cars, are heavy, offer limited range and take hours to recharge. Battery technology will improve, but fossil fuels are, currently, more convenient.

There is a great deal of international pressure on governments to reduce the pollution from fossil fuels. This pressure is passed on to vehicle manufacturers to make cleaner cars, and it is passed on to consumers in the form of fuel tax and vehicle tax. Eventually, fossil fuel-powered vehicles will be made too expensive to run and drivers will be forced to switch to vehicles powered by cleaner, renewable sources of energy.

The advantages and disadvantages of renewable energy sources

Except for biomass fuels, renewable sources of energy produce no atmospheric emissions and are, therefore, non-polluting.

When biomass (such as wood) is burned it releases carbon dioxide, but new trees are planted which absorb carbon dioxide as they grow, so the process is classed as **carbon neutral**. Biomass fuel availability can be seasonal, and there is a need for the fuel to be transported to where it is needed.

The equipment needed to extract renewable energy can be expensive, so there is often a high initial outlay. However, once installed, it produces free energy.

Wind and solar energy are not always available, so they cannot be relied on as our only energy source. The energy output is also quite small, so several wind turbines are often clustered together in a wind farm. Some people say that wind farms and fields full of black solar panels are unsightly and spoil the natural environment.

There are also environmental considerations for hydroelectric power, as it often involves building large dam structures in rural areas, which flood the countryside and might upset the habitat for wildlife.

Geothermal energy units are very expensive to install and are only profitable in some areas where the underground rocks are particularly hot near the surface.

Increasing numbers of manufacturers are investing in renewable energy schemes to power their manufacturing systems. Solar panels and wind turbines can both generate energy which the manufacturer uses to power their factory. Many factories will also install equipment to recover 'waste' energy, such as the heat energy wasted from moulding thermoforming polymers, and use the recovered energy to heat their offices. This will reduce their energy bills and demonstrates a responsible and ethical attitude towards the environment, which can improve the company image.

Figure 1.18 This solar-powered garden lamp recharges during the day.

Renewable energy sources for products

There are opportunities to use compact, renewable energy sources with some products. Small solar PV panels will produce a small current during daylight hours which will recharge a battery. Small wind generators can recharge a battery providing there is enough wind. The power output from either method is quite small, so only relatively low-power products are suitable. A renewable energy source is sometimes the only option for products when mains power is not accessible. Some electronic roadside signs are powered by a solar PV panel mounted on top of the signpost.

Figure 1.19 A wind-up torch that needs no batteries

A clockwork wind-up mechanism can also provide a temporary source of power for electronic and mechanical products. The user winds up a spring which stores potential energy. This is released slowly to generate electricity when the product is used. Some wind-up products do not use a spring; instead, the user generates electricity as they wind and this is stored in a capacitor and released when the product is used. Wind-up radios, torches and phone chargers all operate on free energy, without the need for batteries.

Energy generation and storage in a range of contexts

Motor vehicles

Most cars use chemical energy stored in petrol or diesel (fossil fuels) as their energy source. As mentioned above, their convenience and high energy density makes them challenging to replace. Electric cars use batteries as their energy source which are recharged by plugging them in to a mains electricity source. The car produces no emissions, although the source of mains electricity may still come from a fossil fuel power station. Electric vehicles are efficient because they can recover some of their kinetic energy when the driver brakes and store this energy in the battery. The battery can take hours to fully recharge, and the car's range is limited. Nonetheless, sales of electric cars are increasing as they are cheap to run and they avoid the ban (or tax) that some cities are now imposing on fossil fuel-powered vehicles.

Activity

Find and photograph five products which are powered by their own renewable energy source. Try to find products around your home and school, or use images from the internet if you have to.

At the end of each section, students can complete a series of **practice questions**, written in the style of the written exam, to test understanding.

A rechargeable hybrid car uses a combination of electric motors for city driving, and a petrol engine for long distances. The petrol engine can also recharge the battery. They can be quickly refuelled with petrol or plugged in for an overnight charge. Therefore, rechargeable hybrid cars combine lower emissions with a good driving range.

Mains-powered products

Products which do not need to be portable can be plugged in to the mains electricity supply, which provides an 'unlimited' supply of energy and avoids the need for recharging. However, the number of mains products which are left 'on standby' is causing concern as these products are continuously using energy when they are not being used.

Activity

Go through every room in your house and itemise the products which are plugged in (or permanently wired in) and 'on standby'. Examples include TVs, microwave ovens, intruder alarms, phone chargers, etc.

Battery-powered products

Mobile phones, cordless vacuum cleaners, smart watches, etc. are powered from the energy stored in their rechargeable battery. Many torches, TV remotes, toys, etc. use non-rechargeable batteries, which are used once then replaced. Used batteries should be disposed of responsibly through proper recycling facilities. These batteries store chemical energy which is released as electrical energy when the product is used.

Some outdoor products use a solar PV panel to recharge a battery within the product. The energy is stored within the battery and released as electricity when the product is used. Solar garden lights and some burglar alarms and security cameras use solar panels as a renewable energy source.

Key point summaries appears at the end of each topic to provide a quick recap so that students can track their learning through the course.

KEY POINTS

- Energy sources are either non-renewable or renewable.
- Using fossil fuels has a significant environmental impact.
- Renewable energy sources are 'clean' but not always available, and they can be expensive.

Check your knowledge and understanding questions at the end of each topic support revision and help students prepare for the exam.

Know it

1. Give one example of a product created because of market pull and one product created due to technology push.
2. Discuss the advantages and disadvantages that automated production has had on industry, people and society.
3. If a company is producing 1000 units of an item, why would they choose to use CNC manufacture where possible?
4. List the six Rs of sustainability and give examples to explain how each one could be put into practice.
5. Explain what is meant by a circular economy.
6. Explain the terms 'carbon footprint' and 'ecological footprint'.
7. Describe how renewable energy sources can be useful in products.
8. Explain how Fairtrade supports disadvantaged producers and workers.
9. Explain how the Consumer Rights Act protects consumers when purchasing digital products.

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