Oxford Cambridge and RSA

Friday 15 October 2021 – Morning

A Level in Design and Technology: Design Engineering

H404/02 Problem Solving in Design Engineering

Resource Booklet

Time allowed: 1 hour 45 minutes

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INSTRUCTIONS
- Use the Resource Booklet to answer **all** the questions.
- You should spend **35 minutes** reading this Resource Booklet.
- Do **not** send this Resource Booklet for marking. Keep it in the centre or recycle it.

INFORMATION
- This document has **8** pages.

ADVICE
- Read this Resource Booklet carefully before you start your answers.

The stimulus in this booklet relates to issues and opportunities surrounding the extensive progress of technology and the need for renewable energy sources.

The environmental impact of technological progression

Over the last 250 years, the development of technology has brought about huge changes in the way we live. The First Industrial Revolution, which began in the 1760s, saw the growth of industries such as coal, iron, railways and textiles and the use of steam engines to power the factory machinery which replaced more traditional hand manufacturing methods. During the Second Industrial Revolution, which started in the 1870s, there was rapid growth in the petroleum and steel industries. The discovery of electricity also led to a transformation in the way factories were powered. Electric power was distributed to people's homes to be used for lighting, heating, cooking and refrigeration.

Throughout the 20th century, advances in electronics created a demand for a large range of consumer products such as radios, TVs and other household appliances and gadgets. In the second half of the 20th century, there began to be a shift away from mechanical and analogue technologies towards digital electronics. This Digital Revolution has brought about a monumental shift in the way we live our daily lives and it has triggered a manufacturing industry to feed people's appetite for new physical products such as phones, smart home hubs and virtual reality headsets.

In recent years, the rate of technological progress has been vast. Thirty years ago, people barely knew what a computer was. A decade ago, you could not buy a plane ticket, book an Uber or rent an Airbnb on your phone. Technology is constantly moving forward, but will this have an adverse impact on our planet?

The Industrial Revolutions led to new manufacturing processes in Europe and the United States of America (USA) but, more recently, there has been a shift towards global manufacturing with a significant growth in developing countries who benefit from lower labour and overhead costs. These countries have enjoyed the wealth to be gained from investing in industrialisation, but there is evidence that this has been achieved with limited concern over the impact on the environment and the misuse and damage of our Earth. Manufacturing of technological products has become efficient and cheap and has supported a throw-away society, driven by trends and fashion.

Whilst the technological revolutions have brought prosperity and a better lifestyle to huge numbers of people, they have damaged our world in several ways:

1. Air and water pollution

Air pollution occurs when harmful or excessive quantities of gases are introduced into the Earth's atmosphere as shown in **Fig. 1**. The consequences of air pollution include negative health impacts for humans and animals and global warming where the increased amount of greenhouse gases cause a gradual heating at the Earth's surface.

Fig. 1

Water pollution is the contamination of water bodies such as lakes, rivers, oceans, and groundwater from mainly human activities. Some of the most common water pollutants are domestic waste, industrial sewage and insecticides/pesticides. A throw-away society that fails to recycle and recapture materials adds significantly to the problems of pollution.

2. Depletion of natural resources

Resource depletion refers to the consumption of a resource faster than it can be replenished. The worldwide ecological footprint is such that it takes the Earth about 18 months to regenerate what humanity uses in 12 months, which is clearly not sustainable. There are several types of resource depletion with the most severe being water depletion, deforestation, mining, contamination of resources, soil erosion and overconsumption of resources. These mainly occur because of agriculture, excessive water usage and consumption of fossil fuels and minerals, all of which have been made worse by advancements in technology.

3. Increase in energy demands

With the increase in technology there is an inevitable need for more energy to power this technology and to power the infrastructure behind each product. With this increase in demand across numerous energy sources as shown in **Fig. 2**, there is a need to build energy generation and distribution systems that can handle the demand.

World energy consumption by source

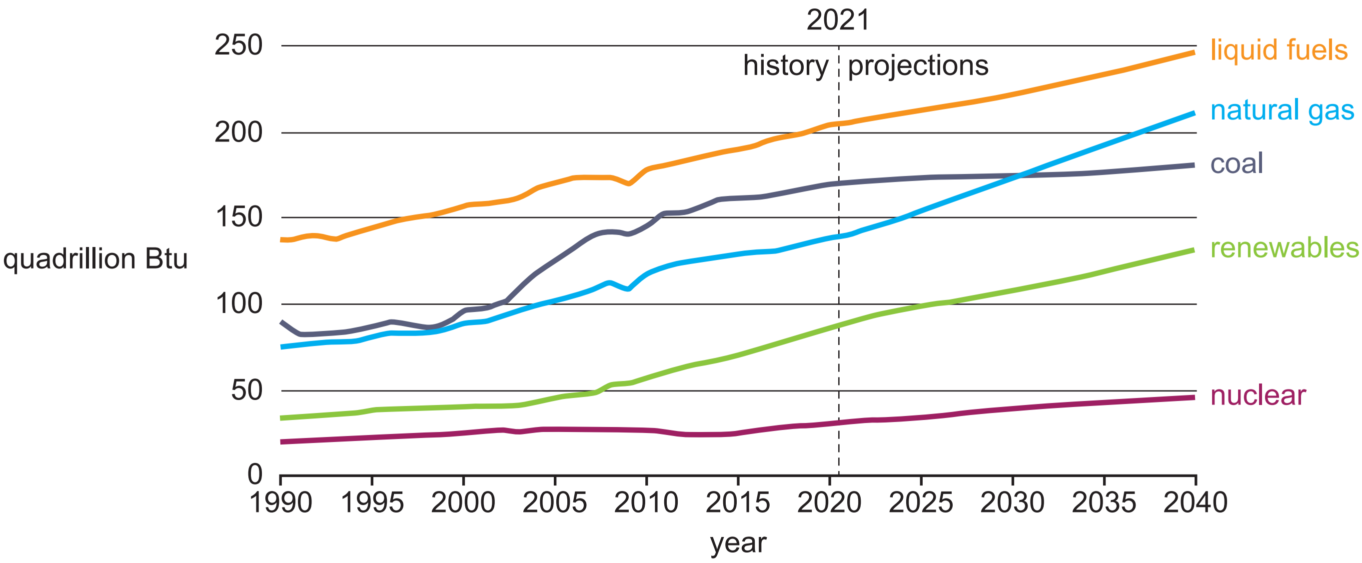


Fig. 2

How can design engineers help?

As creators of new 'stuff', from advertising posters through to smartphones and manufacturing systems, design engineers have a role to play in the responsible sourcing of materials and production of goods. Equally, digital designers creating new websites, apps and artificial intelligence technology are at the forefront of a movement that is helping to cut physical waste by bringing music, books, radio and more into the digital space.

However, it is easy to forget that digital products such as websites and apps also have a carbon footprint. The internet, powered mostly by servers in data centres, consumes a massive amount of electricity as does the network of mobile phone transmitter masts and its associated systems.

Being able to recognise mistakes made in the past and being able to learn from them has enabled many areas of engineering to develop and will enable design engineers to develop more efficient systems and methods of production and disposal in the future.

Understanding a product's lifecycle assessment (LCA), particularly the areas where the highest levels of pollution are produced, can be key in identifying how improvements can be made. More designers are using sustainable, recycled and upcycled resources in their designs. They are also thinking about the impact a product will have at its end of life (EOL). Material optimisation and conservation should be a priority in a product's design criteria, along with exploring the impact and use of eco-materials.

Having an awareness of a product's engineered lifespan, making it repairable and 'future-proof' will also help to address the likelihood of it being disposed of too early.

The Snake Wave Energy Converter (WEC)

An engineering company is developing a prototype WEC to generate renewable electricity from the kinetic energy of waves on the sea. The name given to the prototype WEC is 'The Snake'.

The Snake is shown in **Fig. 3**.

The Snake WEC

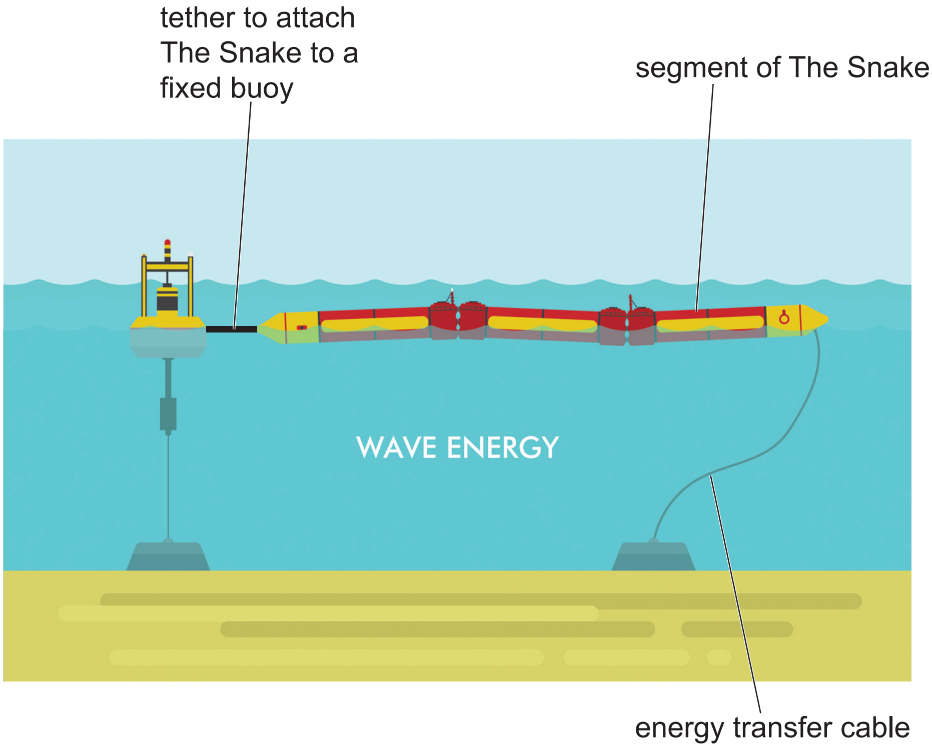


Fig. 3

The Snake consists of several identical segments which are joined together. Further segments can be added to increase the length of The Snake to increase the power output.

The Snake is aimed at entrepreneurs who are looking to venture into the renewable energy industry, using a modular and expandable system. The electricity produced will be sold to make a profit.

When in use, The Snake will float on the surface of the sea. The segments can pivot where they are joined and the action of the waves will cause the segments to move in an oscillating motion. A mechanism inside each segment converts the oscillating motion into rotary motion to power a small generator.

Fig. 4 shows the movement between two joined segments in The Snake.

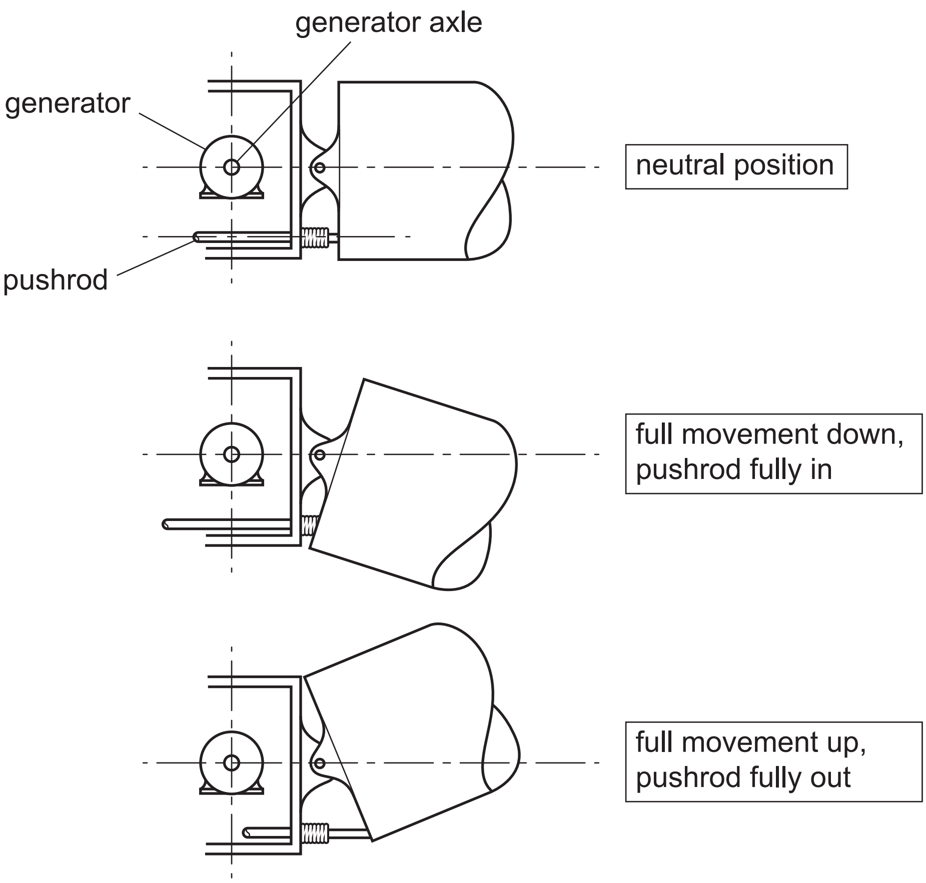


Fig. 4

As the segments oscillate up and down, they cause a pushrod to move in and out in a reciprocating motion.

A mechanical linkage is required between the pushrod and the generator.

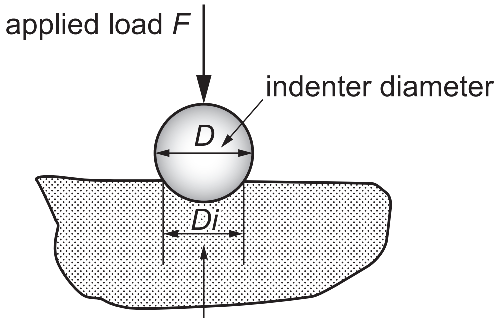
The Brinell Hardness Test

The Brinell Hardness Test is a method which uses a machine (see **Fig. 5**) to test the hardness of a material. The result is a Brinell Hardness Number (BHN), measured in megapascals. Hard materials have a high BHN.

The Brinell Hardness Test is now a widely used method of measuring the hardness of materials which cannot be tested using a scratch method. The test is carried out as follows:

1) The material to be tested is placed in the machine and subjected to an indenter, usually a hardened steel ball bearing of known diameter *D*.

2) A known force *F* is applied to the indenter for a period of time and then released.



Brinell hardness testing machine

Fig. 5

3) The indentation diameter *Di* is then measured using a microscope and the BHN can be calculated using the following formula:

$$BHN = 102 \times \frac{2F}{\pi D(D - \sqrt{(D^2 - Di^2)})}$$

Where:
BHN = Brinell Hardness Number (MPa)
F = Force applied (kN)
D = Diameter of the indenter (mm)
Di = Diameter of the indentation made (mm)

Tether for the WEC

Fig. 3 on **page 4** shows how, when in use at sea, The Snake will be tethered to a fixed buoy by a rope.

The design engineers are investigating the use of a polymer rope made from recycled plastic for the tether.

Data for the rope is given in **Fig. 6**.

Data for the polymer rope under investigation

Length of rope (m)	Cross-sectional area of rope (m^2)	Young's modulus of rope material (N/m^2)
20	2.84×10^{-4}	1.3×10^{9}

Fig. 6

Commercial viability of The Snake WEC

Commercial success of a product such as The Snake is measured by more than simply counting the number of initial sales of the product. The Snake will need to function without any issues for long periods in harsh conditions. It must generate enough power to bring a return to the entrepreneurs who will spend their money purchasing several Snake segment units, hoping to make a profit by selling the renewable electricity produced.

A well-functioning product with a long operating life is likely to lead to positive product reviews and constructive word-of-mouth recommendation to other potential purchasers. This would then create a progressive growth in sales, leading to a sustained period during which The Snake holds a strong position in the renewable energy generator market.

Taking The Snake from the prototype stage into batch manufacturing involves a great deal of financial investment and risk. Before this can happen, the stakeholders will need to be assured that the risk is worthwhile by carrying out feasibility studies focussing on several factors, including those in the list below:

- how well the product performs
- technical difficulty of manufacture and materials selection
- costs and profit
- timescales involved
- balancing supply and demand.

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