DU 6. TRANSFORMATIONS IN MATTER : ENERGY

1. ENERGY CAUSES CHANGE

Energy is one of the most fundamental parts of our universe. Energy is all around us and in everything we do.

It is clear that our world runs on energy. Driving our cars, washing our clothes, heating our houses, and even running our computers, all these things all require energy. But where does this energy come from? Does it even matter?

In our daily lives, we attempt to be **energy conscientious or energy efficient** for two main reasons: to **reduce cost associated with energy consumption,** and to **minimise the environmental impact** (reduce by-products of fuel production, minimise the consumption of raw materials used to produce energy, such as trees and oil).

Understanding what energy is, transformations and learning about energy sources will allow us to understand our world and this is the first step towards becoming environmentally friendly.

Change Is Evidence of Energy

Figure 6.1

When you see changes in the world around you, you are seeing evidence, or proof, of energy. Look at the picture. What changes do you think are happening?

- As the wave crashes onto the shore, the **water moves**. That is one change.
- Imagine you are there on the seashore. You hear the **sound** of the water splashing against sand and rocks. The sound changes because of the water's movement and the wind.
- Another change is the **sand's movement** as it is pushed by the water.
- And there's a change happening that you cannot see—**the sand's temperature is changing** as it is **warmed** by the bright sunlight or **cooled** by the water.

All these changes are caused by some form of energy.

2. DEFINITION OF ENERGY

Whenever there is a **change**, there is some form of **energy** causing the change. Energy is the ability to cause change.
Energy is a quantity that is **transferred** from system to system.

Energy is also defined as the ability of a system to do work or transfer heat.

Work

A system has done **work** if it has exerted a **force** on another system over some **distance**. When this happens, energy is transferred from one system to another.

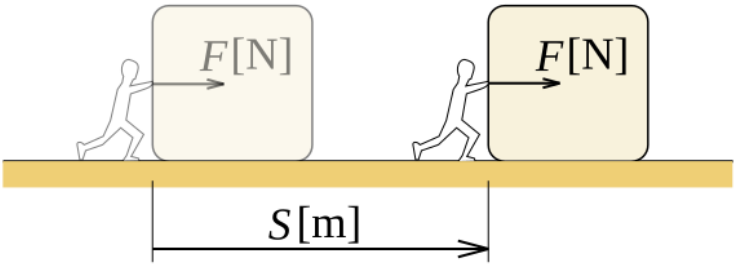

Figure 6.2

At least some of the energy is also **transformed from one type into another during this process.** One can keep track of how much energy transfers into or out of a system.

Thermal energy and heat

The energy of a system or object that results in its temperature change is called **thermal energy.**

When there is a net transfer of energy from one system to another, due to a difference in temperature, the energy transferred is called **heat**.

Heat transfer happens in three ways: **convection**, **conduction**, and **radiation**.

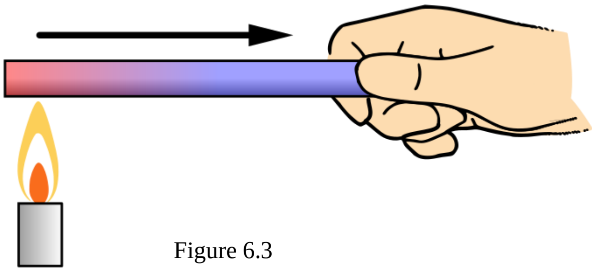

Figure 6.3

Like all energy transfer, **heat transfer** involves forces exerted over a distance at some level as systems interact.

The Law of Conservation of Energy

Energy is neither created nor destroyed. Energy can be transformed from one form to another or **can be transferred** from one body to another, but the overall the energy remains the same.

Units of energy

Many different **units** are used to quantify energy.

As with other physical quantities, many different units are associated with energy. For example, **the SI unit, joule (J)**, calorie and kilowatt-hour are all units of energy.

Given a quantity of energy in one set of units, one can always convert it to another (e.g., 1 calorie = 4.186 joules).

3. <u>FORMS OF ENERGY</u>

In our daily lives, we constantly interact with different forms of energy. Energy is contained in gasoline, cat food and the stars, and energy moves from one form to another via wind, motion, and heat.

Energy comes in different **forms** and can be divided into categories. Forms of energy include light energy, elastic energy, chemical energy, and more. There are two categories that all energy falls into: **kinetic and potential**.

Kinetic describes types of energy associated with **motion**.

Potential describes energy possessed by an object or system due to its **position** relative to another object or system and the forces between the two.

Some forms of energy are part kinetic and part potential energy.

Chemical and **nuclear reactions** involve **transfer and transformation of energy**.

The energy associated with nuclear reactions is much larger than that associated with chemical reactions for a given amount of mass.

Nuclear reactions take place at the centre of stars, in nuclear bombs, and in both fission- and fusion-based nuclear reactors.

Chemical reactions are pervasive in living and non-living Earth systems.

Objects Can Store Energy

When you see the waves crashing on a beach or watch a spinning carousel, you can see changes happening. The changes are evidence of energy. But energy can also be present even when you do not see such evidence.

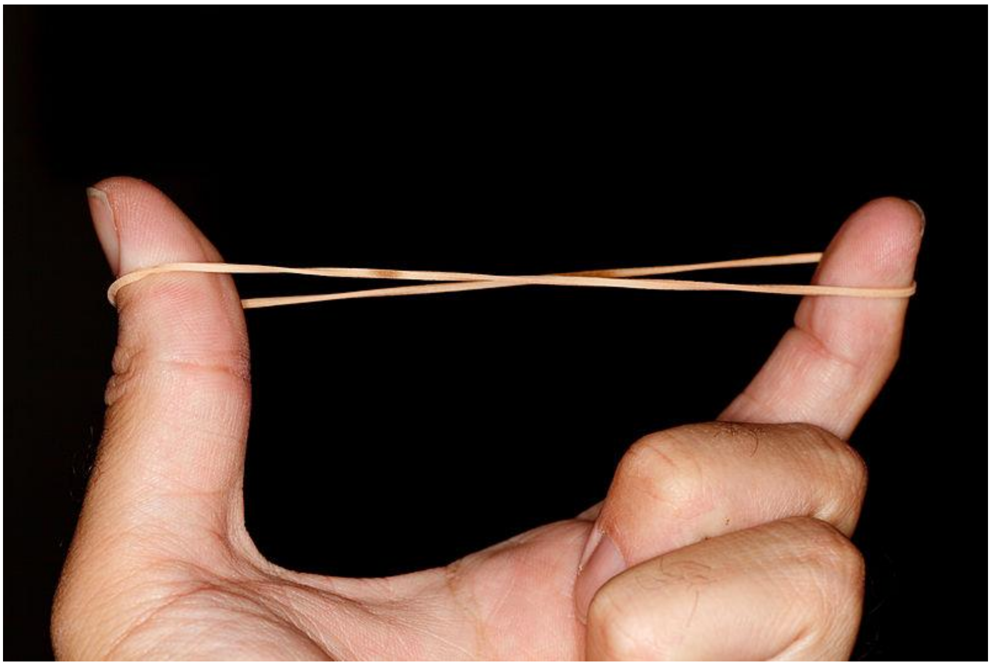

Figure 6.4

When a rubber band is not stretched, it is not causing any change. There is no evidence of energy. But when the rubber band is stretched, it now has the ability to cause changes if it is released or let go. The stretched rubber band has **stored energy**. When the rubber band is released, it moves and makes a sound. Those changes are evidence that energy was stored in the stretched rubber band.

Inside a battery are chemicals that store energy. When you put a battery in a flashlight or a toy, the stored chemical energy will be released and cause change. The energy can make the torch light up or the toy move.

We can identify specific **forms of energy**:

- **Mechanical energy** is the energy of mechanical systems, such as a ball rolling on a ramp, or a swimmer jumping into a pool. Mechanical energy can be in three forms:

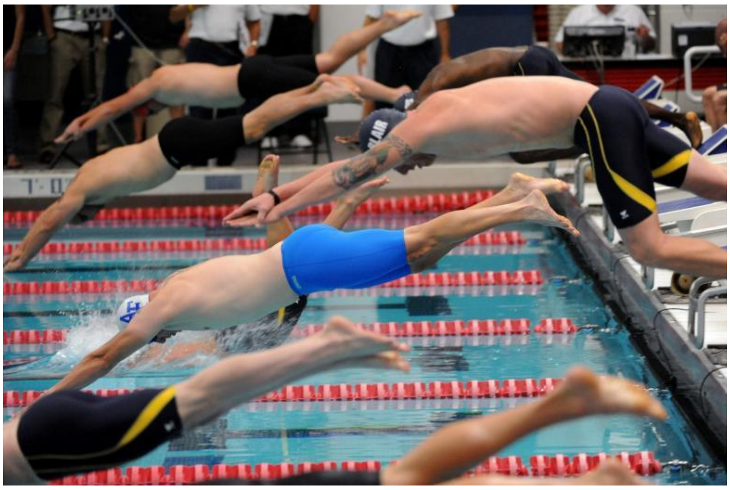

Figure 6.5

  - **Gravitational potential energy** is the energy of an object or system due to gravitational attraction. For example, imagine that you pick up an apple and hold it up above your head. Like a stretched rubber band, the apple has the ability to change position. If you release the apple, it will fall. We can calculate the potential energy of the apple that is going to be released from a high window, or the gravitational potential energy of the water in a reservoir used for hydropower.
  - **Kinetic energy** is energy due to an object's motion. A speeding car, a baseball lofted into the air, and a skier sliding downhill are all examples of objects with kinetic energy.
  - **Elastic potential energy** is the energy stored in a stretched spring, rubber band, or other elastic material.

- **Internal energy** is the energy that includes **all the forms of energy that exist inside a body**. It is closely related to thermal energy, which makes up most of a body´s internal energy. **Internal energy includes energy on a microscopic scale,** and it is the sum of all the microscopic energies such as kinetic energy and (potential energy from intermolecular interaction.

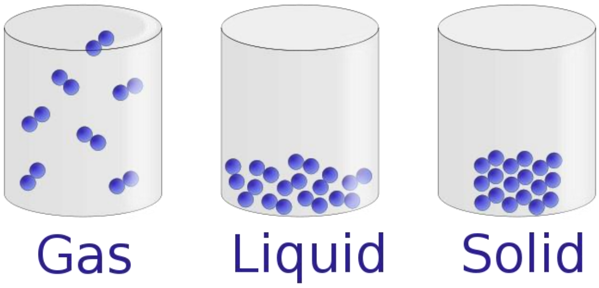

Figure 6.6

- **Thermal energy**, **resulting from kinetic energy of a substance's molecules**. A hot tea kettle has more thermal energy than a cold one. Objects that feel warm are emitting thermal energy, and the transfer of thermal energy causes changes in temperature.

Figure 6.7

- **Radiant energy** is the **energy transported by electro-magnetic radiation**. Electromagnetic radiation (light) is electromagnetic waves that propagate through space. There are many types of these waves depending on the frequency, X-rays, Ultraviolet, Visible light, Infrared etc.

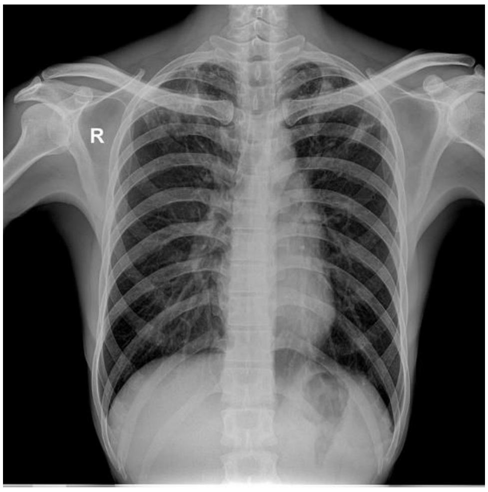

Figure 6.8

Chemical energy is **energy stored in chemical bonds**. Gasoline and food are examples of compounds with chemical potential energy. During **chemical reactions**, chemical energy can be released or absorbed, for example, in **combustions**. Food stores chemical energy.

Figure 6.9

- **Electrical energy** is the energy caused by the movement of electrical charges. The faster the charges move, the more electrical energy they carry. **Lightning**, **batteries,** and even **electric eels** are examples of electrical energy in action.

  As the charges that cause the energy are moving, **electrical energy is a form of kinetic energy**.

Figure 6.10

- **Nuclear energy** is a name given to the energy that results from mass-to-energy conversion during nuclear reactions (**nuclear fission or nuclear fusion**). This is a potent and plentiful source of energy because a small amount of mass can be converted into a large amount of energy as described by Einstein's famous equation $E=mc^2$. Fusion occurs in stars, like the Sun on a huge scale, releasing massive amounts of energy.

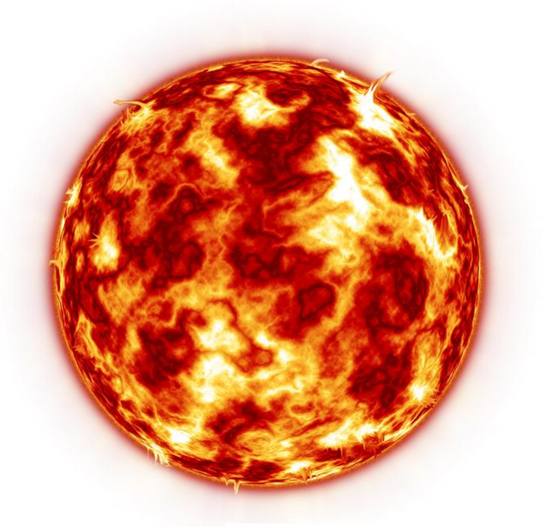

Figure 6.11

Regardless of what form energy takes, energy has a numerical value that we can measure and assign to objects or systems. When the system undergoes some change, energy can be transformed from one type of energy to another.

4. ENERGY TRANSFORMATION

The Law of Conservation of Energy states that energy is neither created nor destroyed.
Energy can be transformed from one form to another or **can be transferred** from one body to another, but the overall energy remains the same.

Energy Transformation

Electrical energy $\longrightarrow$ **Heat and light energy**

Figure 6.12

For example, we put electrical energy into a bulb and the bulb produces light (which is the desired form of output from a bulb), but we also get heat from the bulb (undesired form of energy from an electric bulb).

Therefore, energy that flows into and out of any energy conversion device can be summarized in the diagram below:

Figure 6.13

Energy Flow Diagram for an Energy Conversion Device

When all forms of energy coming out of an energy conversion device are added up, it will be equal to the energy that is put into a device. Energy output must be equal to the input. This means that energy cannot be destroyed or created. It can only change its form.

In the case of an electric bulb, the electrical energy is converted into light and heat.

The amount of electrical energy put into a bulb = the amount of light energy (desirable form) plus the heat energy that comes out of the bulb (undesirable form).

Living Beings

All organisms need free energy to keep themselves alive and well. The source of energy is just one, **solar energy**.

Only plants use that energy directly.

What the organisms use is **chemical energy in the form of food**.

More examples of energy conversion

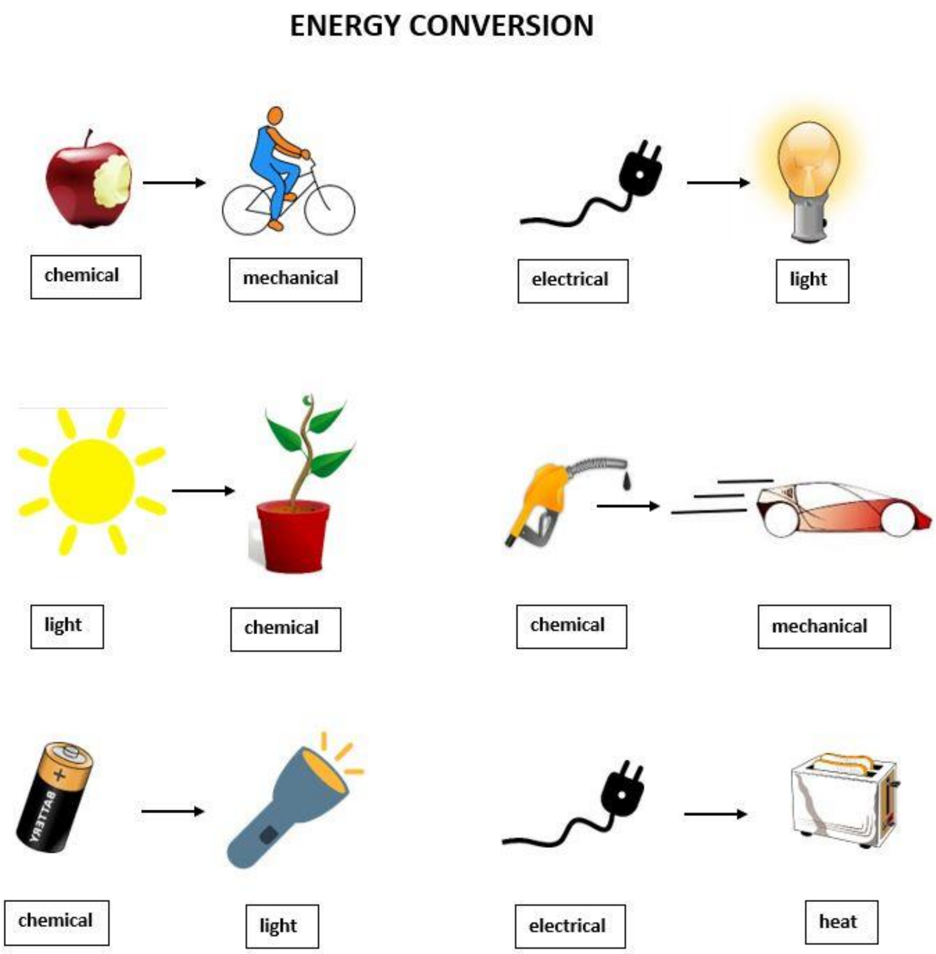

Figure 6.14

5. ENERGY SOURCES

Most of the Earth's energy comes from the Sun. Ultimately, energy from the Sun is the driving force behind **weather and climate, and life on earth.**

The original **energy** from the **Sun** is captured through photosynthesis and stored in chemical bonds as plants grow, which provide oxygen and food for the entire animal kingdom.

Dead organisms and waste products deteriorate into the **fossil fuels** used to power much of the world.

Scientific research asserts that these fossil fuel emissions lead to air pollution and acid rain.

Solar energy is created by **nuclear fusion,** in which nucleus of hydrogen atoms collide in the Sun´s core and fuse to create a helium atom. Each hour, the sun provides more energy to the Earth than we need to meet an entire year's worth of global energy demand.

There are two types of energy sources, depending on their duration: non-renewable and renewable energy sources.

➢ Non-renewable energy sources.

Non-renewable resources are natural resources that are limited in supply and cannot be replaced for millions of years.

Non-renewable energy resources include **fossil fuels** and **radioactive elements such as uranium.**

Fossil Fuels

Fossil fuels are **mixtures of hydrocarbons that formed over millions of years from the remains of dead organisms.**

They include **petroleum** (commonly called oil), **natural gas**, and **coal**.

- **Fossil fuels** provide most of the energy used in the world today. They are burned in power plants to produce electrical energy, and they also fuel cars, heat homes, and supply energy for many other purposes. You can see examples of their use in the figure below.

Figure 6.9

Natural gas burns with a blue flame on this gas stove. Many homes also have natural gas water heaters. Some motor vehicles burn natural gas as well.

Figure 6.15

Petroleum is used to make gasoline, which fuels most motor vehicles. It is also used to make kerosene for camp stoves or airplanes.

Figure 6.16

Electrical power can be generated by burning coal in power plants like this one.

Form of Energy:

Fossil fuels contain **stored chemical energy** that came originally **from the sun**. Ancient plants changed energy in sunlight to stored chemical energy in food, which was eaten by other organisms. After the plants and other organisms died, their remains gradually changed to fossil fuels as they were pressed beneath layers of sediments. Petroleum and natural gas formed from marine organisms and are often found together. Coal formed from giant tree ferns and other swamp plants.

Advantages:

Fossil fuels provide **substantial amounts of energy** when they are burnt

The technology related with this type of energy is highly developed.

Disadvantages:

When fossil fuels burn, they release thermal energy, water vapour, and carbon dioxide.

- **Carbon dioxide** produced by fossil fuel use is a **major cause of global warming.**
- The burning of fossil fuels also releases **many pollutants into the air**.

- Pollutants such as sulfur dioxide become **acid rain**, which kills living things and damages metals, stonework, and other materials.
- Pollutants such as nitrogen oxides cause **smog**, which is harmful to human health.
- Tiny particles, or particulates, released when fossil fuels burn also harm human health.

- Natural gas releases the least pollution; coal releases the most
- Petroleum has the additional risk of **oil spills**, which may seriously damage ecosystems.
- The total supply of fossil fuels in the world is limited and cannot be replaced once it is used up. This makes fossil fuels a non-renewable resource.

Nuclear Energy

Like fossil fuels, the radioactive element uranium can be used to generate electrical energy in power plants.

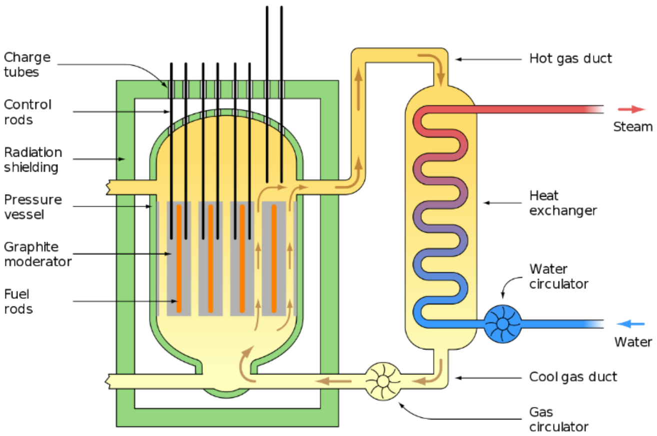

Figure 6.17

Nuclear reactor diagram

Form of energy

In a nuclear power plant, the nuclei of uranium atoms are split in the process of **nuclear fission**.

Advantages:

- This process releases a tremendous amount of energy from just a small amount of uranium.
- Nuclear energy does not release carbon dioxide.

Disadvantages:

- The world's total supply of uranium is quite limited and cannot be replaced once it is used up. This makes nuclear energy a non-renewable resource.
- Accidents at nuclear power plants also have the potential to release large amounts of radioactive material into the environment.
- Nuclear power plants create **radioactive waste** that can remain radioactive and dangerous to human health for thousands of years.
- When a **power plant** has stopped generating electricity, it has to be **dismantled,** and all the components must be removed. However, the radioactive waste will continue to be dangerous for hundreds or thousands of years.

Renewable energy sources.

Renewable resources are natural resources that can be replaced in a relatively short period of time or are virtually limitless in supply.

Renewable energy resources include sunlight, moving water, wind, biomass, and geothermal energy

Sunlight____

Figure 6.18

Solar panels on the roof of this house generate enough electricity to supply a family's needs.

Form of Energy

The energy in sunlight, solar energy, is radiant energy that can be transformed into electrical and thermal energy

Advantages

- The Sun is an inexhaustible and free energy source.
- Available everywhere.
- Does not release carbon dioxide.

Disadvantages

- Its efficiency depends on climate, it may not be practical in often cloudy areas.
- Solar panels are expensive and must be large enough to absorb energy.

Moving Water. Hydroelectric Energy

Figure 6.19

Water flowing through this river dam generates electricity.

Form of Energy

When water cascades downhill, its **potential energy is converted into kinetic energy** that can turn a turbine and **generate electricity**. The water may fall naturally over a waterfall or flow through a dam.

Advantages

- Dams do not produce any waste.
- Dams can regulate river flow, and give us the use of water for irrigation, and supplies towns for public use.

Disadvantages

- A drawback to dams is that they flood land upstream and reduce water flow downstream.
- Either effect may harm ecosystems.

Wind Energy

Figure 6.20

This old-fashioned windmill captures wind energy that is used for **grinding grain**. In certain areas its uses in land drainage and water pumping were equally important. Windmills like this one have been used for centuries.

Form of Energy

Wind is moving air, so it has kinetic energy that can do work. Wind turbines change the **kinetic energy of the wind into electrical energy.**

Advantages

- It is a clean energy source with relatively insignificant impact on the environment compared to conventional power
- The technology needed for installing wind turbines is relatively simple.
- It does not require a major initial investment.

Disadvantages

- Only certain areas of the world get enough steady wind to produce much electricity.
- **Wind Turbines** could lead to noise and visual pollution
- It is a threat to wildlife.
- **Wind turbines** generate a lot less power than the average fossil fuelled power station, requiring multiple **wind turbines** to be built in order to make an impact.

Biomass

Figure 6.21

Biomass—especially wood—is an important energy source in countries where most people cannot afford fossil fuels.

Form of Energy

The **chemical energy stored in trees and other plants** is called **biomass energy**.

When plant materials are burned, they produce **thermal energy** that can be used for **heating**, **cooking**, or **generating electricity**.

Some plants can also be used to make **ethanol**, a fuel that is added to gasoline.

Ethanol produces less pollution than gasoline, but large areas of land are needed to grow the plants needed to make it.

Advantages

- Carbon neutrality. The amount of carbon that is released into the atmosphere is a major contributor to climate change. Biomass reduces this because, although burning biomass releases carbon dioxide into the atmosphere, all plants absorb carbon dioxide from the atmosphere when growing.
- Low cost in comparison to fossil fuels.
- Biomass fuels are abundant. Much like with the sun and water, they can be found practically anywhere on the planet.

Disadvantages

- Burning wood and other plant life does create other emissions in addition to carbon.
- Possible deforestation. Though biomass fuels are renewable, they also need to be maintained. Failure to do this can lead to widespread deforestation.
- It requires water. An often-unseen disadvantage of biomass energy is the amount of water needed in production. All plants need water to live, which means sources must be available at all times.

Geothermal Energy

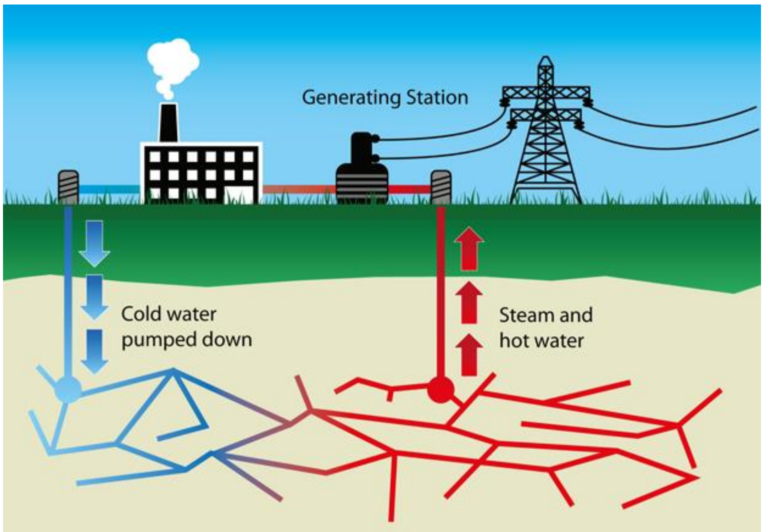

Figure 6.22

Heat below the Earth's surface—called geothermal energy— can be used to produce electricity.

Form of Energy

A power plant pumps water underground where it is heated. Then it pumps the water back to the plant and uses its **thermal energy to generate electricity**.

Advantages

- On a small scale, geothermal energy can be used to heat homes, thus reducing our dependency on energy from other countries.
- It has a much smaller environmental impact than non-renewable energy sources because it produces truly little waste.

Disadvantages

- Installing a geothermal system can be very costly due to the need to drill through underground rocks.

6. THE ENERGY PROBLEM AND ENERGY DECISIONS

Humankind has always needed energy, and while the source and usage of energy have changed over time some patterns have remained constant. In earlier times food was the key source of energy for people and their livestock.

From the burning of wood and coal to nuclear **power**, the development of **energy** sources has been crucial to the advancement of society.

The figure below shows the mix of energy resources used worldwide from 2000 to 2020.

Fossil fuels still provide most of the world's energy, with oil being the single most commonly used energy resource. Emissions from fossil fuels are the dominant cause of global warming. In 2018, 89% of global CO_2 emissions came from fossil fuels and industry.

Natural gas is used less than the other two fossil fuels, but even natural gas is used more than all renewable energy resources combined.

Wind, solar, and geothermal energy contribute the least to global energy use, despite the fact that they are virtually limitless in supply and non-polluting.

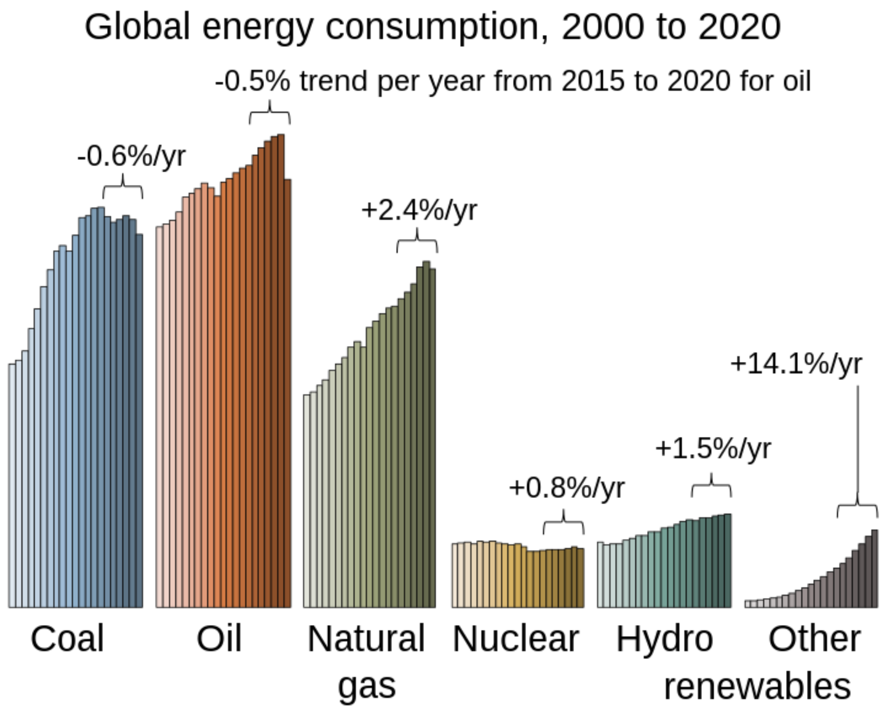

Figure 6.23

Global sources for energy from 2000 to 2020. The trend since 2015 is also highlighted in this chart.

The Paris climate conference may set nations against each other, and spark huge arguments over economic policies, green regulations, and even personal lifestyle choices. But one thing is not up for debate: **the evidence of climate change is unequivocal**.

Causes of Climate Crisis

The Earth's atmosphere works like a giant glass greenhouse. As the Sun's rays enter our atmosphere, most continue right down to the planet's surface. As they hit the soil and surface waters, those rays release much of their energy as heat. Some of the heat then radiates back out into space.

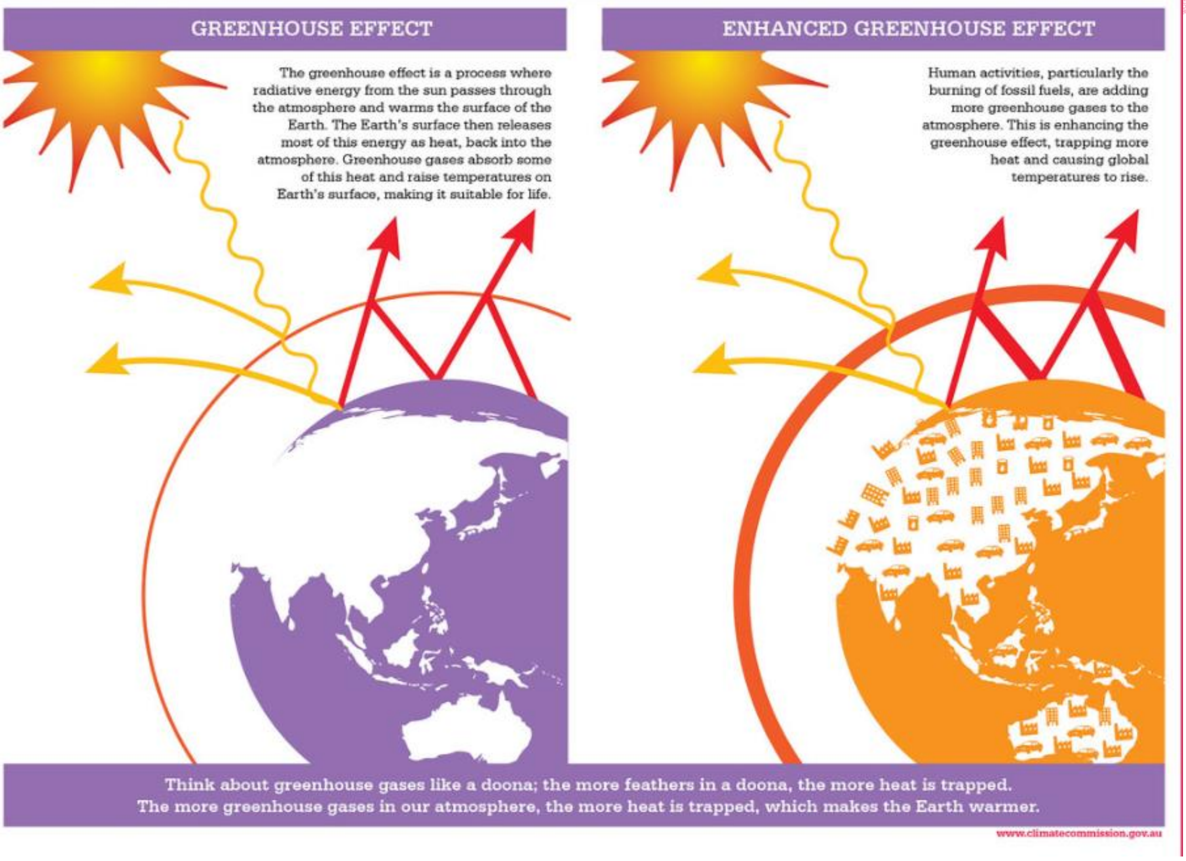

Figure 6.24

Greenhouse gases absorb and re-emit some of the heat radiation given off by the Earth's surface and warm the lower atmosphere.

The most important **greenhouse gas** is **water vapour**, followed by **carbon dioxide** and methane, and without their warming presence in the atmosphere the Earth's average surface temperature would approximately be -20°C.

While many of these gases occur naturally in the atmosphere, **humans are responsible for increasing their concentration through burning fossil fuels, deforestation, and other land use changes**.

Records of air bubbles in the ancient Antarctic ice show us that carbon dioxide and other greenhouse gases are now at their highest concentrations for more than 800,000 years.

What does the future hold?

Figure 6.25

Extreme weather is more common than ever

The continued burning of fossil fuels will inevitably lead to **further climate warming**.

The complexity of the climate system is such that the extent of this warming is difficult to predict, particularly as the largest unknown is how much greenhouse gas we will keep emitting.

The climate model projections suggest the mean global surface temperature could rise by between 2.8°C and 5.4°C by the end of the 21st century.

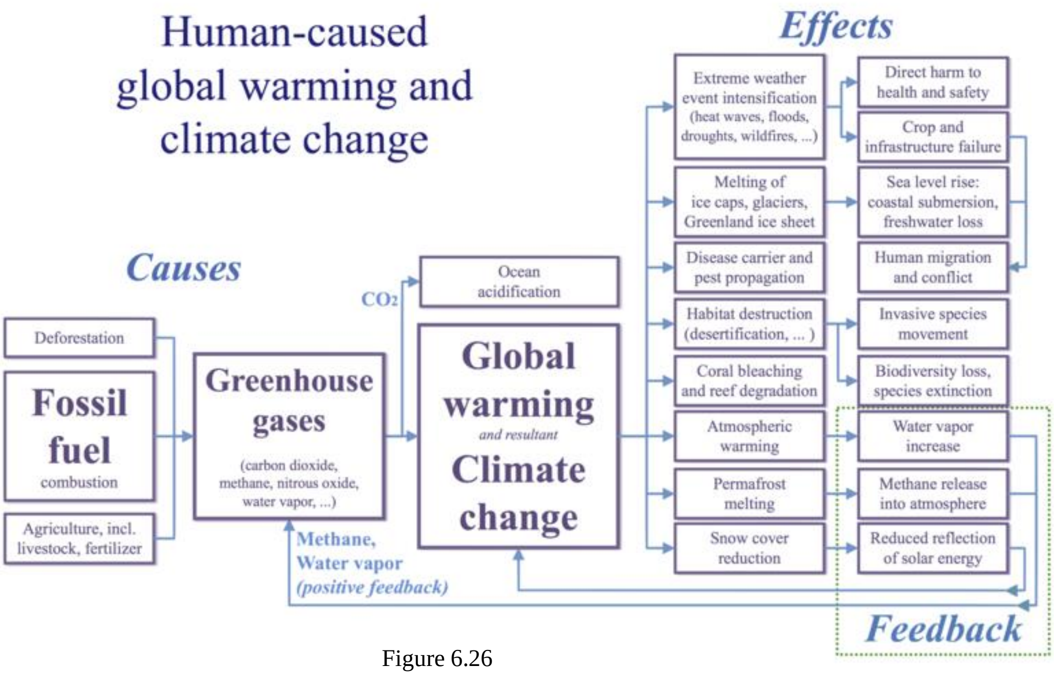

Figure 6.26

Effects of global warming

Effects:

- The sea level is projected to rise by between 52cm and 98cm by 2100, threatening coastal cities, low-lying deltas, and small island nations.
- Snow cover and sea ice are projected to continue to reduce, and some models suggest that by the latter part of the 21st century the Arctic could be ice-free in late summer.
- Heat waves, droughts, extreme rain, and flash flood risks are projected to increase, threatening ecosystems and human settlements, health, and security.
- One major concern is that increased heat and humidity could make physical outdoor work impossible.
- Changes in precipitation are also expected to vary from place to place. In some areas the year-round average precipitation is projected to increase, while in most sub-tropical land regions it is projected to decrease by as much as 20%, increasing the risk of drought.
- In many other parts of the world, species and ecosystems may experience climatic conditions that are on the limits of their optimal or tolerable ranges or even beyond.
- The human's conversion of land use for food, fuel, fibre, and fodder, combined with targeted hunting and harvesting, has resulted in the extinction of some species, 100 to 1000 times higher than past rates. Climate change will only speed up these consequences.

In 2015, the world's governments signed up to the Paris Agreement committing to reduce carbon emissions. However, a recent report shows that globally, although we are to limit global warming by 1.5˚C, we are on track to produce more than double the amount of coal, oil, and gas than we can burn by 2030

So, more needs to be done.

Energy conservation vs. energy efficiency

Energy conservation is the practice of trying to use less energy **in order to lower costs and reduce environmental impact**.

Energy efficiency means **using specific products designed to use less energy**.

These two concepts are inherently similar but involve **different methods**. Examples of energy conservation include using smart appliances and energy-saving bulbs at home.

Energy decisions

- Will we have enough energy to fuel our society and our economy?
- Can we continue to use energy without causing irreparable harm to the Earth's climate system?
- How much effort and resources are we willing to invest into alternative energy sources?
- Can sufficient energy be distributed fairly, safely, and economically to all parts of the globe?

The answers to these questions are dependent on the decisions we take about energy.

- **Decisions concerning the use of energy resources are made at many levels**. Humans make individual, community, national, and international energy decisions. Each of these levels of decision-making has some common and some unique aspects.
- **Energy infrastructure has inertia**. The decisions that governments, corporations, and individuals made in the past have created today's energy infrastructure. The large amount of money, time, and technology invested in these systems makes changing the infrastructure difficult, but not impossible. The decisions of one generation both provide and limit the range of possibilities open to the future generations.
- **Energy decisions are influenced by environmental factors**. Environmental costs of energy decisions affect energy decision-making at all levels. All energy decisions have environmental consequences.
- **Energy decisions are influenced by social factors**. Questions of ethics, morality, and social norms affect energy decision-making at all levels. Social factors often involve economic, political, and environmental factors.

Energy Saving Tips at home

How can we contribute to combating climate change by becoming more aware of our energy use and our carbon footprint?

Eating, travelling, heating our home… What is the carbon footprint of these activities and how can we make more climate-friendly choices?

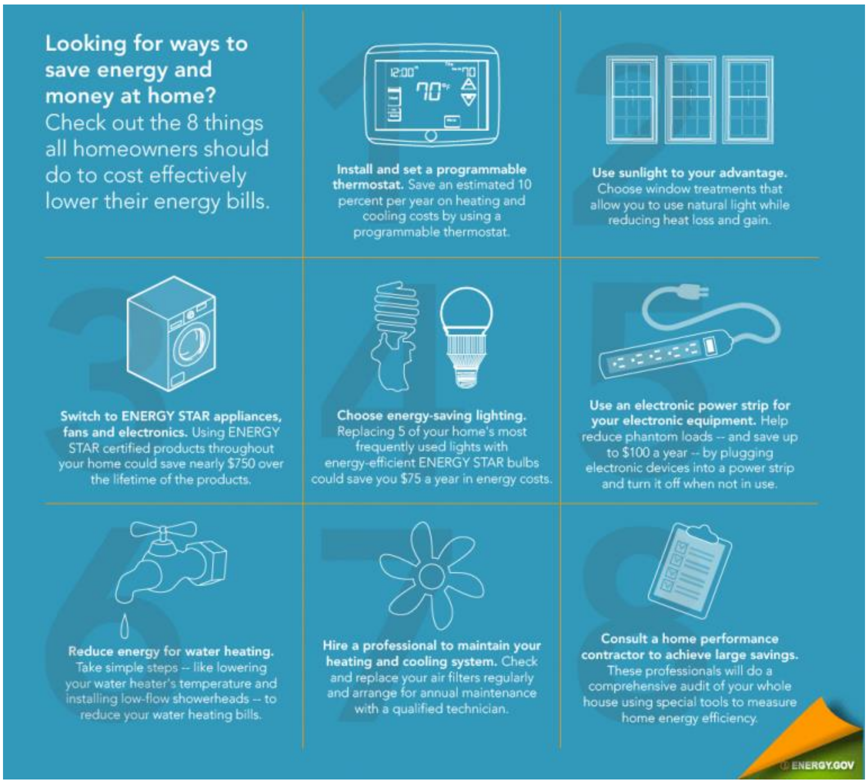

Figure 6.27

When driving a car, buying a pair of trainers, or grilling a steak, we contribute to the emission of carbon dioxide and other greenhouse gases in the atmosphere. It is our carbon footprint. Many countries, institutions and companies have committed to reducing their emissions while the EU has even set the objective of being "climate neutral" by 2050. As an individual, you can also estimate your carbon footprint and reduce it. Discover how.

What is a Carbon Footprint?

Figure 6.28

Greenhouse gases are emitted through the production and consumption of goods and services. **The carbon footprint is a concept used to quantify the impact of an activity, a person, or a country on climate change.**

How much carbon is emitted to produce your t-shirt, meal, or phone? The amount will depend on production and consumption choices. If we take the example of transport, taking the plane emits 285g of carbon per kilometre, compared to 104g for a car and 14g for a train. The same goes for the type of meat or fish you eat or the type of jeans you buy.

How to limit your carbon footprint?

Understanding your carbon footprint can help limit the impact of your consumption on the environment. There are different online solutions to help you estimate your carbon footprint.

Minor changes can make a significant difference in the long run, for example, when it comes to transportation, food, clothing, waste, etc. Here are some tips:

Food

- Consume locally and buy seasonal produce (forget strawberries in winter)
- Limit meat consumption, especially beef
- Select fish from sustainable fishing
- Carry reusable shopping bags and avoid produce with excessive plastic packaging
- Make sure to buy only what you need, to avoid waste

Clothing

- Take good care of your clothes
- Try swapping, borrowing, renting, or buying second-hand
- Buy responsibly made clothes, e.g., made from recycled material or with an eco-label

Transport

- Cycle or use public transport
- Be smart about when and how you drive
- Try the train for your next holiday

Energy and Waste

- Turn down the heating by 1°, it will immediately make a difference
- Take quick showers
- Turn off the water while you brush your teeth or wash up.
- Unplug your electronic equipment and do not leave your phone on charge when the battery is already full
- Do not store unnecessary data in the cloud
- Select energy efficient products with an “A” label
- Limit and recycle your waste