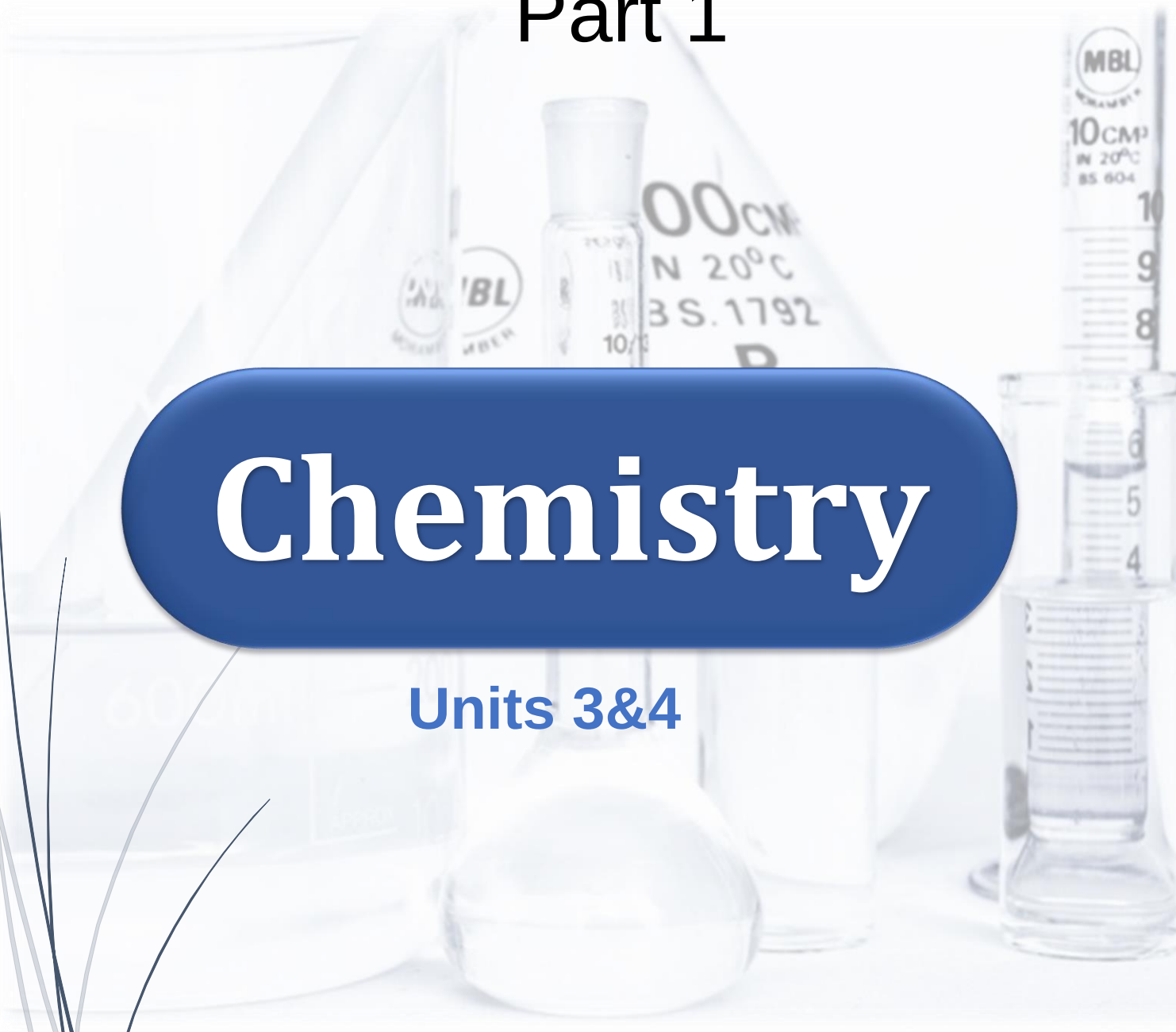
RoshChem

Carbon based fuels

Part 1



Chemistry

Units 3&4

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What are fuels?

Fuels are substances that have chemical energy stored within them, and they can release energy when burnt.
Eg: wood, coal, natural gas, LPG, ethanol, Petrol

Sustainable energy

The efficient provision of energy that can fulfil the needs of the present without compromising the energy needs of future generations. All renewable energy sources such as solar, wind, and hydropower are sustainable as they are available in huge amounts.

Renewable energy resources

Fuels are considered to be renewable if they can be replaced at a sustainable rate.
A renewable resource is one that can be used repeatedly and does not run out because it is naturally replaced.
Eg: solar power, biochemical fuels

Non-renewable energy resources

Resources that are used at a faster rate than they can be replaced
Eg: fossil fuels

Fossil Fuels

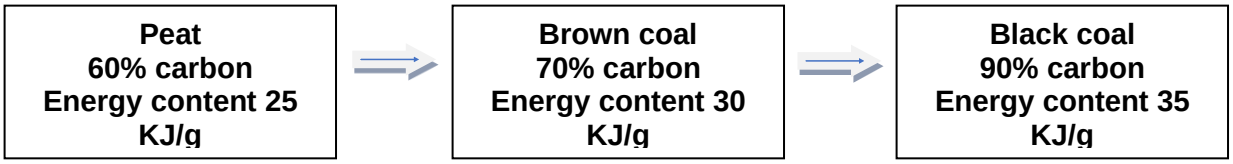
They are made from primitive plants and animals. Formation of fossil fuels take millions of years and plant and animal material undergo many changes during this period. The energy that we get by combustion of fossil fuels comes from the energy that plants absorbed from the sun millions of years ago.
Eg: Coal, crude oil (petroleum), petroleum gas, coal seam gas

1. Coal

Coal is composed mainly of carbon together with other elements such as hydrogen, nitrogen, sulfur.

As wood is converted into peat, brown coal and then to black coal, the carbon content increases and the proportion of hydrogen and oxygen decreases. The amount of water also decreases.

When coal is burnt, some amount of energy is used to vaporise water. This decreases the energy content of coal with high percentage of water. Therefore, black coal with less amount of water can release more energy than peat or brown coal.



2. Crude oil

Crude oil is a naturally occurring flammable liquid consisting of a complex mixture of hydrocarbons (mostly alkanes) of various molecular weights and other liquid organic compounds. Crude oil itself is of no use as a fuel, but many of the compounds in it are. Crude oil is separated into fractions with a process called **fractional distillation**. Fractions such as **Petrol**, diesel, kerosene, liquefied petroleum gas (LPG) are used as fuels while some fractions can be use as raw materials for plastics and pharmaceuticals.

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3. Natural gas
Natural gas is mainly methane (CH_4) with small amounts of other hydrocarbons such as ethane and propane.

Natural gas can be found trapped between layers of rocks and also as a component of petroleum deposits.

Natural gas is accessed by drilling a hole to the required depths of the rocks. This causes the natural gas to flow to the surface.

a. Coal seam gas or CSG.
Natural gas can be found in coal deposits where it is bonded to the surface of the coal. Coal seams usually contain water, and it is the pressure of the water that keeps the gas adsorbed to the coal surface. Natural gas found this way is known as coal seam gas.

b. Shale gas
Natural gas can be found trapped in shale rock, where it is referred to as **shale gas**.

Fracking
This is a process used to extract natural gas from coal or shale rocks. First a well is created by drilling a hole into the deposit. Water, sand and other chemicals are then pumped into the well under high pressure. This high pressure fractures the rock and creates fissures where the gas can flow.

4.

Disadvantages of using fossil fuels

- Pollution
- Global warming can increase sea levels and change the weather patterns
- Crude oil reserves are limited

Biochemical fuels:
(biofuels) are fuels derived from plant material. These fuels release carbon dioxide during combustion. However, they are made by plants, and plants absorb carbon dioxide during photosynthesis. So, the net carbon dioxide emission is less.
Eg: bioethanol, biodiesel and biogas

1. **Bioethanol**
This is produced by **fermentation** of glucose in the presence of yeast.

$$C_6H_{12}O_6(aq) \xrightarrow{\text{enzymes}} 2C_2H_5OH(aq) + 2CO_2(g)$$

Photosynthesis to produce glucose

Green plants carry out photosynthesis, one of the key chemical reactions that support life. Plants use photosynthesis to make their own food in the form of glucose. Photosynthesis is an endothermic chemical reaction carried out in chloroplasts in the cells of green leaves. Energy from sunlight is used to produce glucose from carbon dioxide and water.

$$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(s) + 6O_2(g) \quad \Delta H = +2803 \text{ KJ/mol}$$

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The manufacturing process of bioethanol

Glucose is present in plants as glucose itself and also in the larger carbohydrates (sucrose-a- a disaccharide and starch and cellulose – polysaccharides).

Future bioethanol feedstocks in Australia

- Sugar cane (high in sucrose)
- Wheat (high in starch)
- Forest waste (high in cellulose)

Carbohydrates undergo a series of steps to convert them into ethanol. Initially, the biomass is blended with water to create a pulp, breaking down the plant structures. Next, a variety of enzymes are introduced into the mixture to degrade the carbohydrate molecules into glucose.

The extent of pretreatment necessary to make the enzymes effective depends on the strength of the bonds within the carbohydrate feedstock. Cellulose, for instance, is found in abundance in forest waste but presents challenges due to its strong hydrogen bonds that hold cellulose molecules together. Conversely, sugar cane contains smaller, highly soluble sucrose molecules that do not require any pretreatment.

The next step is fermentation. The enzymes serve as catalysts for the fermentation process, which transforms glucose into ethanol. To ensure the preservation of microorganisms and enzymes, fermentation is conducted at a temperature of 35°C, as higher temperatures could lead to their destruction.

Distillation

Fermentation yields a solution with approximately 10% ethanol (v/v). To make ethanol suitable for use as a fuel, it must be separated from water. This separation is achieved through distillation, a process that uses the different boiling points of the two liquids. The solution is heated until it reaches a boiling point then introduced into tall distillation columns. Precise temperature control ensures that water (boiling point at 100ºC) settles at the bottom of the column while the ethanol vapour (boiling point at 79ºC) is collected from the top.

At this stage, the ethanol still contains residual water, which is subsequently eliminated using micro-filtration and dehydrating agents. In Australia, a small amount of methanol is often added to ethanol, making it unsuitable for human consumption, leading to its common name, 'methylated spirits.'

While the distillation process itself is relatively simple, it demands a substantial amount of energy to boil the ethanol solution. This energy consumption makes bioethanol production **not a carbon-neutral** process.

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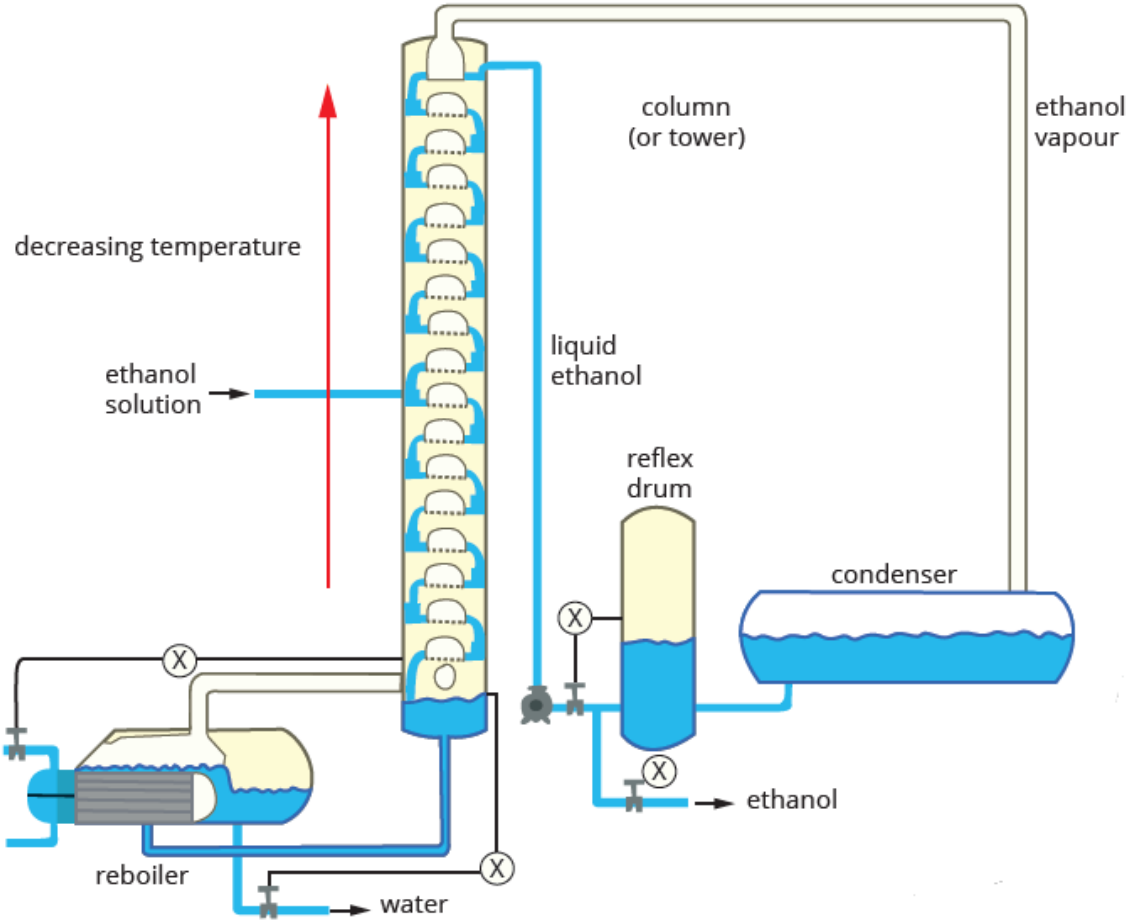

Comarision of E10 and pertrol

Bioethanol is a widely used fuel in Australia, often blended with Petrol. The Australian government has imposed regulations limiting the ethanol content in Petrol to 10%, which is sold under the label E10 at most service stations.

The presence of ethanol in fuel has environmental benefits, as it reduces emissions of particulates and gases like nitrogen oxides. However, it's important to note that high ethanol levels can potentially harm engines, especially in older vehicles. Increasing the proportion of bioethanol in Petrol could lead to reduced overall emissions and lessen the demand for finite fossil fuel resources.

The combustion equation for ethanol is as follows:

$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)\ \Delta H = -1360\ kJ$

When 1 mole of ethanol is combusted, it releases 1360 kJ of energy, equivalent to 29.6 kJ per gram. Ethanol's energy content is approximately 62% that of Petrol, meaning that a larger mass (and volume) of ethanol is needed to provide the same amount of energy. This lower energy content in ethanol can be attributed to partial oxidation (partial burning) of the carbon atoms in the ethanol molecule, with some oxygen already present in the ethanol molecules.

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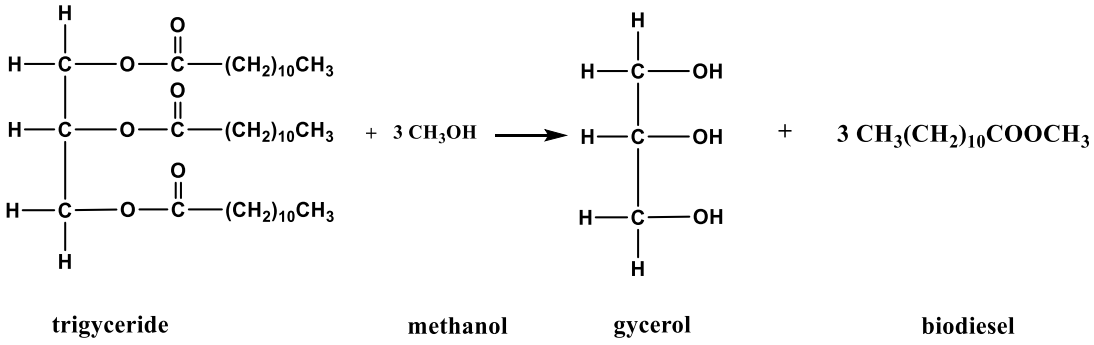
E10	Petrol
• Lower energy density, 46 KJ/g • Cleaner combustion • Can be a renewable fuel • Absorbs CO_2 during formation to cancel the impact of CO_2 emissions during combustion—lower net CO_2	• Higher energy density, 48 kJ/g • More widely distributed • Less CO_2 produced per km when driving

2. Biodiesel

Biodiesel is a mix of esters produced by a chemical reaction between vegetable oil and an alcohol such as methanol.

The triglyceride (fat/oil) is **hydrolysed** by warming it with methanol and potassium hydroxide/sodium hydroxide solution (catalyst). The triglyceride breaks down into three '**fatty acid**' molecules and a molecule of glycerol. Then, the fatty acid reacts with methanol to produce methyl ester of the fatty acid which is known as biodiesel.

Formation of biodiesel



3. **Biogas**

Consists mainly of **carbon dioxide and methane** and is generated when organic materials decay **anaerobically** (in the absence of oxygen). This also contains other gases such as nitrogen, hydrogen sulphide and hydrogen in small amounts. It can be used for heating to power homes and farms.

Comparison of fossil fuels and biofuels

a. Energy content of different fuels

The chemical energy present in a substance is called its energy content. By burning fuels, chemical energy in them can transform into another form of energy such as heat energy, electrical energy, mechanical energy, ect...

Energy content is measured in KJ/g, the amount of energy released when 1g of fuel is burnt.

The **energy efficiency** of a fuel is the percentage of chemical energy in a fuel transformed into the required form of energy. For example, solar cells are about 18% efficient. This means only

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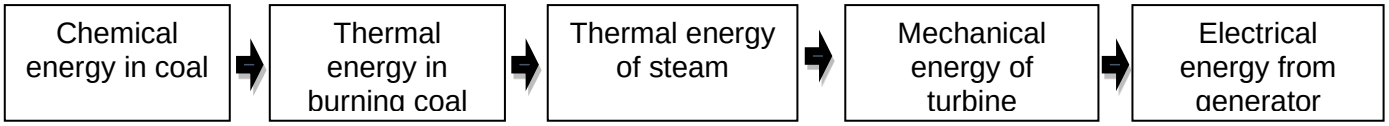
18% of the energy coming from the sun on to the solar panel is converted to electrical energy. The rest is converted to other forms of energy, such as heat energy.

i. Coal

Coal is used to produce electricity in coal-fired power stations. Following energy transformations occur when coal is generating electricity.



Energy is lost in each energy transformation, and the overall efficiency of coal-fired power stations is 30-40%.

Burning coal $C(s) +)O_2(g) \rightarrow CO_2(g)$

The above reaction released about 32 KJ of energy when 1g of coal burned. So, the energy content of coal is 32 KJ/g.

ii. Natural gas

Natural gas is used to generate electricity in gas-fired power stations. The energy efficiency in gas-fired power stations is about 40%.

Burning natural gas $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

The energy content of methane is about 56 KJ/g.

iii. petrol

Petrol is a fraction obtained from crude oil and contains a mixture of hydrocarbons, including octane. This is used as a vehicle fuel. The efficiency of petrol engine is about 25%.

Burning of petrol $2C_8H_{18}(l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(l)$

The energy content of Petrol is about 48 KJ/g.

iv. Biogas

Electricity generation from biogas is carried out in a small scale in sites where the biogas is produced.

Burning biogas $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

The energy content of biogas is less than that of natural gas because the methane content in biogas is lower.

v. Bioethanol

Bioethanol is used in vehicles blended with Petrol. E10 Petrol is the Petrol containing 10% bioethanol.

Burning bioethanol $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

The energy content of bioethanol is about 30 KJ/g. The lower energy content of bioethanol is due to the presence of oxygen atoms in ethanol. Because of this, the carbon atom in ethanol molecule is in a partly oxidised state.

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b. Environmental impact from combustion of fuels

All fuels release carbon dioxide during combustion. Carbon dioxide is a greenhouse gas and increased levels of carbon dioxide can cause global warming and climate change. The mass of carbon dioxide released per MJ of energy produced by different fuels is given below.

Fuel	Mass of carbon dioxide (g) released per MJ of energy produced
Coal	93
Natural gas	56
LPG	65
Petrol	73
Bioethanol	72

Even though bioethanol releases CO_2 during combustion, CO_2 is also absorbed by plants during photosynthesis. Therefore, the use of this fuel should lead to net CO_2 reduction. However, we cannot consider bioethanol as **carbon neutral**. Because during the period of growing plants, transporting and refining of the fuel uses energy and CO_2 is released.

Other emissions from burning fuels are SO_2, NO_2, O_3, particulates (eg: ash), CO. Petrol can produce more CO and particulates than other fuels. This is because its combustion is less complete due to the larger size of the molecule.

SO_2 and NO_2 are pollutants which contributes to the acid rain.

c. Environmental impact of sourcing the fuels

Fuel	**Source**	**Impact on environment**
Biogas	Sewage farms and rubbish tips	Methane is 21 times more effective as a greenhouse gas than carbon dioxide. So, it is better to burn methane present in biogas to release carbon dioxide than releasing methane to atmosphere. Therefore, collection of biogas can minimise the emissions.
Crude oil/petrol	Oil rigs	They have a low impact on the environment. However, if a spill or explosion occurs, significant issues can arise.
Coal	Coal mines	Open-cut coal mines are damaging the local environment. Accidents such as fire can cause adverse health effects in people living in areas close to the mine.
Bioethanol	Crops such as sugar cane and wheat	Growing crops need energy, water and fertilisers. Farming can cause land degradation and erosion. The cost of some food such as corn can increase because they are also used to make biofuels.

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Advantages and disadvantages of different types of fuels

Fuel	Advantage	Disadvantage
Coal	Large Australian reserve Relatively high energy content	Non-renewable High amounts of emissions
Natural gas	High energy efficiency than coal Relatively high energy content Easily transported through pipes.	Non-renewable Limited Australian reserves Causes pollution (less than coal and crude oil/Petrol)
Petrol	Easily transported High energy content	Non-renewable Causes pollution (less than coal) Limited reserves
Biogas	Renewable Reduces waste disposal Low cost as it is made from waste CO_2 absorbed during photosynthesis Reduces methane emission	Low energy content Supply of waste is limited.
Bioethanol	Renewable CO_2 absorbed by plants Fewer particulate emissions than Petrol Burns smoothly Can be made from waste	Lower energy content than Petrol Limited supply of raw materials Growing crops can cause land degradation and erosion. The cost of some food, such as corn, can increase.

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