Year 10

Science

Agriculture in Education:
an educational resource for Year 10 Science

Biofuels

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AGRIFOOD SKILLS AUSTRALIA

Biofuels

Year 10 Science

Content Description	
Different types of chemical reactions are used to produce a range of products and can occur at different rates.	ACSSU187

Source: Australian Curriculum v8.1
http://www.australiancurriculum.edu.au/science/curriculum/f-10?layout=1#level9

learn

Learning Outcomes

At the end of the unit, students have a greater understanding of:

- The role and importance of biofuels;
- Types of biofuels;
- How bioethanol is produced;
- Environmental benefits of biofuels; and
- The importance of agriculture in producing feedstock for biofuel production.

It is suggested that teachers read the Background Notes and Teacher Preparation notes before commencing the unit.

Description

This unit is designed to demonstrate to students the importance and environmental benefits of biofuels. The unit focuses on biodiesel and ethanol production – the two main biofuels produced and used in vehicles in Australia. A case study of the processes used to produce ethanol in Australia's first grain to ethanol plant is provided both in the teacher background information and in the accompanying video.

It is expected that students will have prior knowledge of:

- renewable and non-renewable resources (ACSSU116 - Yr 7);
- chemical change (ACSSU225 - Yr 8);
- energy transfer and transformation (ACSSU155 - Yr 8);
- chemical reactions including combustion reactions and the effects of their products on the environment, respiration and photosynthesis (ACSSU179 - Yr 9); and
- matter and energy flow through ecosystems (ACSSU176 - Yr 9).

Depending on the teaching sequence students may have already encountered the carbon cycle and how this is affected by human activity (ACSSU189 - Yr 10).

Pre-preparation is required for the major activities:

- Student Activity 2: Investigating the effect of temperature on fermentation; and
- Student Activity 3: Investigating the heat of combustion of ethanol.

Teachers are advised to introduce the unit by discussing fossil fuels and biofuels.

Activity 1: below is provided to allow teachers to determine student prior knowledge of processes already learnt in Yr 9 (photosynthesis, respiration and combustion). It will also enable teachers to determine students' understanding of the impact of fuels on the environment.

Activity 1:	Analysing the carbon cycle and fuels
Activity 2:	Investigating the effect of temperature on fermentation
Activity 3:	Investigating the heat of combustion of ethanol
Activity 4:	Producing ethanol from sorghum – The Dalby Bio-Refinery
Activity 5:	Comparing fuels

Student assessment could be incorporated into:

- Activity 2: Investigating the effect of temperature on fermentation. Students could prepare an experimental report that examines the experimental design and results and determines the effect of temperature on reaction rate;
- Activity 3: Investigating the heat of combustion on ethanol. Students could prepare an experimental report that examines the experimental design and results suggesting ways to improve the experiment methodology; and
- Activity 4: Producing ethanol from sorghum. Students identify the chemical and physical processes involved in the production and compare the rates of the different processes. They could also consider how the co-products are also useful and the net environmental impact of the production process.

Background Notes for Teachers

The following information covers:

- the role and importance of biofuels;
- types of biofuels;
- production of biofuels with particular emphasis on bioethanol;
- environmental impact of biofuels compared to fossil fuels; and
- role of agriculture in providing feedstock for biofuel production.

It is suggested that teachers determine student understanding and assumed prior knowledge through discussion and questioning. Teachers may provide the background information to students, or discuss relevant aspects, before or as each activity is conducted.

At present, fossil fuels such as crude oil, coal and natural gas, power cars and generate heat and electricity. Fossil fuels are a non-renewable, therefore finite resource, because they take millions of years to form from decayed plant and animal remains. When burnt, fossil fuels release carbon dioxide, which has been stored for a very long time, back into the atmosphere adding to greenhouse gases and contributing to Global warming and climate change.

Biofuels differ from fossil fuels in that they come from recently formed renewable biological material such as crops and algae. The carbon dioxide released when burning a biofuel is that used for photosynthesis during a plant's life cycle, so there is no net increase in atmospheric carbon dioxide.

Using biofuels to power motor vehicles is not a new idea. A century ago the first car produced by Henry Ford ran on ethanol while Rudolf Diesel powered his diesel engine with peanut oil. However, both inventors soon discovered that refined crude oil produced more power and was cheaper than biofuels.

So what has changed to generate the resurgence of biofuels as a major source of fuel for cars? A number of factors are combining to reduce reliance on fossil fuels.

These include:

- the continually increasing costs of crude oil and therefore petrol and diesel
- the looming scarcity of crude oil (a non-renewable resource)
- increasing reliance on imported oil
- increasing concerns about the environmental impact of fossil fuel use

Many governments have invested significant amounts of money to support the development alternative energy sources. For example, in Brazil in the mid-20th century, the dictator Gen. Ernesto Geisel, heavily subsidised and financed new ethanol plants. He directed the state owned oil company to install ethanol tanks and pumps around the country and also offered Brazilian car makers tax incentives to produce cars designed to burn straight ethanol. The result was that by the mid-1980s nearly all the cars sold in Brazil ran exclusively on ethanol.

Currently, the Australian Government is investing in research and development of biofuels, particularly bioethanol and biodiesel, from a range of feedstocks. The Australian Renewable Energy Agency (ARENA) states 'Australia has natural advantages in producing bioenergy including expertise in agricultural science, an established agricultural economy and an abundance of natural resources.' (Australian Renewable Energy Agency; Australian Government; *http://arena.gov.au/funding/investment-focus-areas/biofuels/*; accessed 16/01/2016).

There are currently three main areas of focus in terms of biofuels for motor vehicles: bioethanol, biodiesel and biogasoline (green gasoline).

Background Notes for Teachers (cont)

Biogasoline is gasoline (petrol) produced from plant material including woody biomass and algae. It has a similar chemical composition to unleaded petrol, containing between 6 (hexane) and 12 (dodecane) carbon atoms per molecule. While current production processes vary, the intention is to produce a biogasoline to match the chemical, kinetic and combustion characteristics of unleaded petrol but with higher octane levels, to enable it to be used with existing petrol engines. Currently, biogasoline is not being produced in Australia, however significant research in America is looking at using waste material from agriculture eg. the stalks remaining after harvesting corn and forestry eg. sawdust.

Biodiesel has a slightly different chemical composition from diesel, so these two fuels have slightly different chemical properties. Biodiesel has lower carbon dioxide and carbon monoxide emissions than diesel. The heat of combustion of diesel is 42.6 kJ/g. Biodiesel's heat of combustion, around 37 kJ/g, will vary depending on the feedstock crop as canola oil, soybean oil and peanut oil all have different heats of combustion.

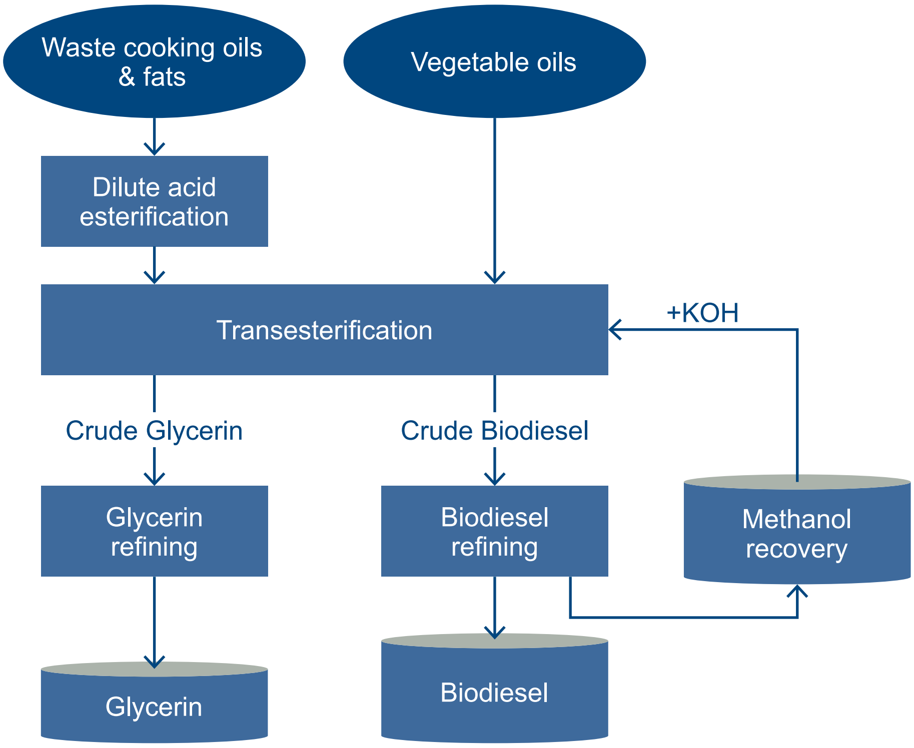
In Australia biodiesel is produced from oilseeds such as canola oil, used cooking oils and animal fats (tallow). Other new feedstocks under development include Indian mustard seeds (Western Australia), Pongamia pinnata trees (Queensland, Western Australia), Moring oleifera (Western Australia) and algae (Queensland, South Australia, Victoria). There is a lot of research into the use of algae as a source of vegetable oil for biodiesel. Algae would not require prime agricultural land for its production and it has the potential to produce a very high yield – 10 000L of oil per hectare compare to the next best, which is palm oil, with a yield of 5 000 L per hectare.

The word equation for the production of biodiesel can be summarised to:

$$\text{vegetable oil} + \text{methanol} \rightarrow \text{biodiesel} + \text{glycerol}$$

Biodiesel is made through a chemical process called transesterification. This process produces two products biodiesel (methyl esters) and glycerine (usually sold to be used in the manufacture of soaps and other products).

The following diagram shows an outline of a process for producing biodiesel.



Biofuels Association of Australia 2015, *http://biofuelsassociation.com.au/biofuels/biodiesel/how-is-biodiesel-made/)*

Background Notes for Teachers (cont)

The following video shows the processes involved in the production of biodiesel.
How it's made – biodiesel production https://www.youtube.com/watch?v=xLa83KIaEyw

According to Australia's National Greenhouse Accounts (NGA) 2.7 kg of CO_2 is produced for every litre of diesel combusted in an engine. In 2104, 68.8 million tonnes of CO_2 were produced by motor vehicles using diesel. Using biodiesel reduces greenhouse gas emissions. The reason being, that the carbon dioxide released from biodiesel combustions, is offset by the carbon dioxide used for photosynthesis during the growth of the feedstock.

Blend, B100 (100 % biodiesel) reduces CO_2 emissions by more than 75% compared to diesel from fossil fuel sources. Blend, B20 (20% biodiesel) reduces carbon dioxide emissions by 15%. (US Department of Energy). Replacing diesel with B20 blend diesel would reduce carbon dioxide emissions by 10.32 million tonnes. (B100 blends are not currently available in Australia.)

At present, biodiesel is generally blended with diesel from fossil fuels so that it is a competitive price. In Australia, service stations currently supply bends between 5% (B5) - 20% (B20) biodiesel. These can be used in normal diesel engines without the need for any modification.

Biodiesel is also safer to handle, store and transport. One reason is because biodiesel has a flash point (the lowest temperature at which a flammable liquid could ignite) greater than 130°C, compared with about 52°C for petroleum diesel.

Bioethanol, usually referred to as just 'ethanol', is the most well-known biofuel. Ethanol is not used as a stand-alone fuel. In Australia, ethanol is currently only used as a fuel additive. E10 is the most commonly available blend and is a mixture of unleaded fuel with 10% ethanol. Australian Government legislation defines an ethanol blended fuel as containing more than 1% ethanol, but limits the amount of ethanol in petrol to 10%. E10 is commonly used in cars and light vehicles and is compatible with most vehicles produced since 1986.

Ethanol is the fuel of choice in high performance V8 supercars and Formula 1 vehicles. E85, which contains 85% ethanol, has been the fuel of choice for V8 supercars since 2009. It has a much higher octane rating than petrol, so it can produce a significant increase in power to the vehicle.

Almost any plant-based material can be used as a feedstock to make ethanol. The production method depends on the type of feedstock used. The process is shorter for starch-based feedstocks (eg. barley, sorghum, maize, corn) and sugar-based ones (eg. sugar cane, sugar beet) than for cellulose (wood, crop residue) feedstocks.

In simple terms, the main way in which ethanol is produced is by fermentation. The feedstock contains sugar, either as individual sugar molecules (e.g. sugar cane) or in the biological polymers starch (e.g. sorghum) or cellulose (plant stalks, wood). The following stages are generally used:

- Stage 1: starch/cellulose is firstly broken down to sugar (sucrose) then further broken down to glucose using enzymes
- Stage 2: glucose → ethanol + carbon dioxide, through fermentation using yeast
- Stage 3: ethanol is separated from the fermentation mixture by distillation (ethanol has a boiling point of 78°C)

In Australia there are three major ethanol production facilities. These facilities produce ethanol primarily from wheat starch, grain sorghum and molasses.

Background Notes for Teachers (cont)

The facilities are:

- Manildra ethanol Plant, NSW which uses waste starch
- Dalby Bio-refinery, QLD which uses grain sorghum
- Sarina Distilleries, QLD which uses molasses

There is also a pilot plant (QUT Mackay Renewable Bio-commodities Pilot Plant) in Mackay which is researching a range of biomass sources to produce ethanol.

These biomass sources include:

- sugarcane bagasse
- sweet sorghum (which is different to grain sorghum)
- eucalypt wood chips
- corn stover (post-harvest residues of stalk, leaf, husk and cob)
- sunn hemp
- Bana grass (cow cane)
- elephant grass
- banana fibre

(Refer to *http://biomassproducer.com.au/case_study/testing-plant-materials-for-biofuel-potential-mackay-pilot-plant/#pilot* for more information on this pilot plant.)

Producing ethanol from sugar cane is well known and has been occurring at the Sarina distillery in Queensland since 1901. Molasses, a by-product in the production of crystallised sugar, is fermented to produce ethanol. The production of ethanol from sugar cane molasses is a renewable and sustainable process.

Wilmar BioEthanol (Australia) Pty Ltd 2015, http://www.ethanolfacts.com.au/cleaner-greener

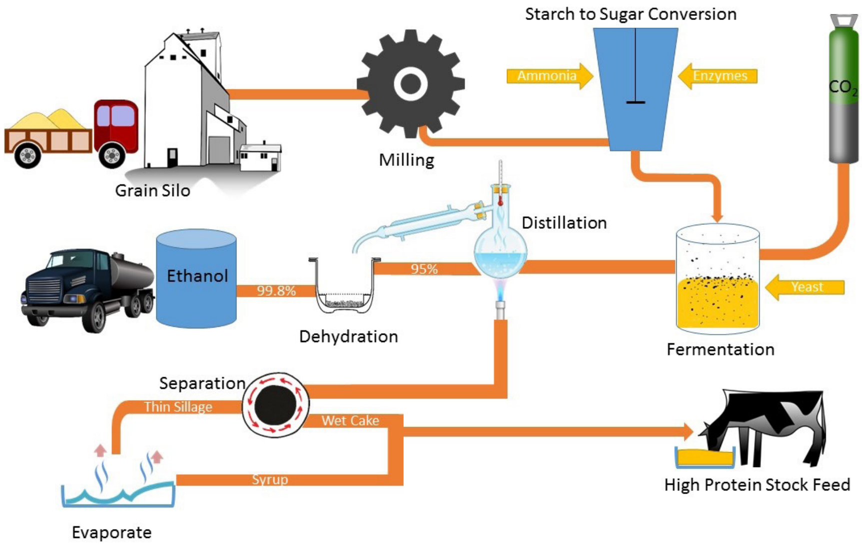
Background Notes for Teachers (cont)

Producing ethanol from sorghum – The Dalby Bio-refinery

The Dalby Bio-refinery is Australia's first grain to ethanol plant. Ethanol is produced by breaking down the starch in the sorghum grain to sugars then fermenting the sugar. Grain sorghum was identified as an excellent crop for sustainable ethanol production because it uses one-third less water to grow than other comparable feed grains and produces the same amount of ethanol.

One tonne of sorghum grain can produce between 375 - 395 L of ethanol. The amount produced depends on the starch content of the sorghum. Higher starch content means more sugars thus more ethanol. The process from delivery of the sorghum to final ethanol production takes 60 hours.

The process for producing ethanol from sorghum is not as simple as that for molasses because the original energy is starch not sugar. Therefore, additional steps are needed in the process which is shown in the diagram below.



Adapted from Dalby Bio-refinery Ltd, http://www.dbrl.com.au

All steps in the process are subject to stringent quality control to ensure high grade ethanol is produced.

The steps in the process are:

1. Delivery of sorghum – a sample of sorghum is taken from the load and undergoes a quality check using near infra-red spectroscopy. The sorghum must be first quality according to Sorghum Grain Trading Standards (GTS). This will ensure it has the required minimum starch content for conversion to ethanol.
2. Grain dump – the grain is dumped into an underground bin and moved by conveyor belt to the silos, each of which holds 1200 tonne. When the plant is running at 50% capacity it will process between 7000 – 10000 tonnes of sorghum per month. 1 tonne of sorghum produces between 375 – 395 L of ethanol.
3. Milling – the sorghum moved by conveyor belt from the silo to the hammer mill where the grains are pulverised into a fine powder called flour. This increases the surface area so water will be more readily absorbed.

Sorghum Flour

Background Notes for Teachers (cont)

4. Liquefaction – the flour is mixed with water at 85°C to begin to dissolve the starch and kill any bacteria which comes with the sorghum. The enzyme, alpha-amylase, is added. Conditions in the tank are monitored online to ensure temperatures no greater than 88°C and pH between 4.5 – 5.5. pH is balanced by adding either ammonia (if pH is too low) or sulfuric acid (if pH is too high). Samples taken for analysis every 3 hrs. During this process the starch becomes part of a liquid solution.

5. Saccharification – the liquefied starch mixture (called mash) is cooled and another enzyme, gluco-amylase, is added to convert the liquefied starch into glucose. This process takes approximately 90 mins.

6. Fermentation – yeast (which is cultured onsite in a yeast propagation tank) is added to the mash to ferment the glucose into ethanol and carbon dioxide. The fermenters are maintained at 30°C (too low or high temperatures kill the yeast) for the 40 – 45 hr fermentation process. Samples are tested every 6 hrs to check: glucose content, alcohol content, pH, yeast viability, lactic acid and acetic acid levels. The fermentation process is deemed to be completed when the glucose concentration is zero. The carbon dioxide produced is released into the atmosphere.

7. Distillation – the fermented mash, containing 11-14% ethanol, is distilled to separate the ethanol (93% strength) from the remainder of the mixture (residue mash co-product)

8. Dehydration – the ethanol passes through a molecular sieve to remove remaining water and producing fuel grade ethanol of approximately 99.3% purity.

   The ethanol produced is Fuel Grade Ethanol (FGE) and is not fit for human consumption because it still contains methanol which is highly toxic to humans. The plant can, if required, produce Analytical Grade Ethanol which is 100% pure. This is what is used in hospitals, laboratories and the production of other products including pharmaceutical medications.

Ethanol

9. Denaturation – ethanol that is to be used for fuel has a 2-5% petrol added to make it obviously unfit for human consumption and is placed in storage tanks.

While the ethanol production process uses the starch component to produce ethanol other nutritional components of the sorghum (protein, fat, fibre, vitamins and minerals) are concentrated in the residue mash co-product. This co-product provides a valuable feed for livestock.

The residue remaining after distillation is run through decanters then is centrifuged (at 3000 rpm) to separate the grain solids (wet cake) from the liquid solubles (sillage). The liquid solubles are then further concentrated to produce 'syrup'. The concentrated syrup can be sold as a liquid feed or remixed with the wet cake to provide an excellent source of protein and energy. The wet cake has a short shelf life (max 7 days) so it is dried to remove 90% of the water to produce dry cake (WDGS – wet distillers grain solid).

Syrup (top left), wet cake (lower left) and dry cake (middle right)

Background Notes for Teachers (cont)

Benefits of ethanol

- Ethanol is a sustainable, renewable fuel which is produced from biomass. The production of ethanol in Australia does not use food crops but utilises waste starch, molasses and grain sorghum.
- The use of E10 reduces greenhouse gas emissions by 12-19%.
- Burning ethanol results in cleaner air. Ethanol burns more cleanly due to its higher oxygen content than petrol producing less particulate emissions (up to 50%) and reducing carbon monoxide emissions by up to 30%.
- Ethanol's higher octane results in improved fuel consumption.
- Ethanol reduces dependence on crude oil.
- The global warming impact of the modern ethanol plant is 40% lower than that of a petroleum plant.

discuss

Setting the Scene

Teachers could introduce the unit by discussing the differences and similarities between fossil fuels (non-renewable resource) and biofuels (renewable resource). In Year 9, students will have learnt about combustion reactions, respiration and photosynthesis (ACSSU179). This activity may be used to determine prior knowledge of these processes and then to allow students to predict the impact of fossil fuels and biofuels on the carbon cycle.

- Photosynthesis (sunlight + water + carbon dioxide → glucose + oxygen)
- Respiration (glucose + oxygen → carbon dioxide + water + energy)
- Combustion (hydrocarbon + oxygen → carbon dioxide + water + energy)

Activity 1 - Analysing the carbon cycle and fuels, provides teachers with a means of determining students' prior knowledge and discussing the impact of both fossil fuels and biofuels on the normal carbon cycle.

Questions 7-10 are provided to probe student understanding of the relationship between carbon dioxide, global warming and climate change. They may be used here to determine current student understanding or removed if thought too difficult at this stage.

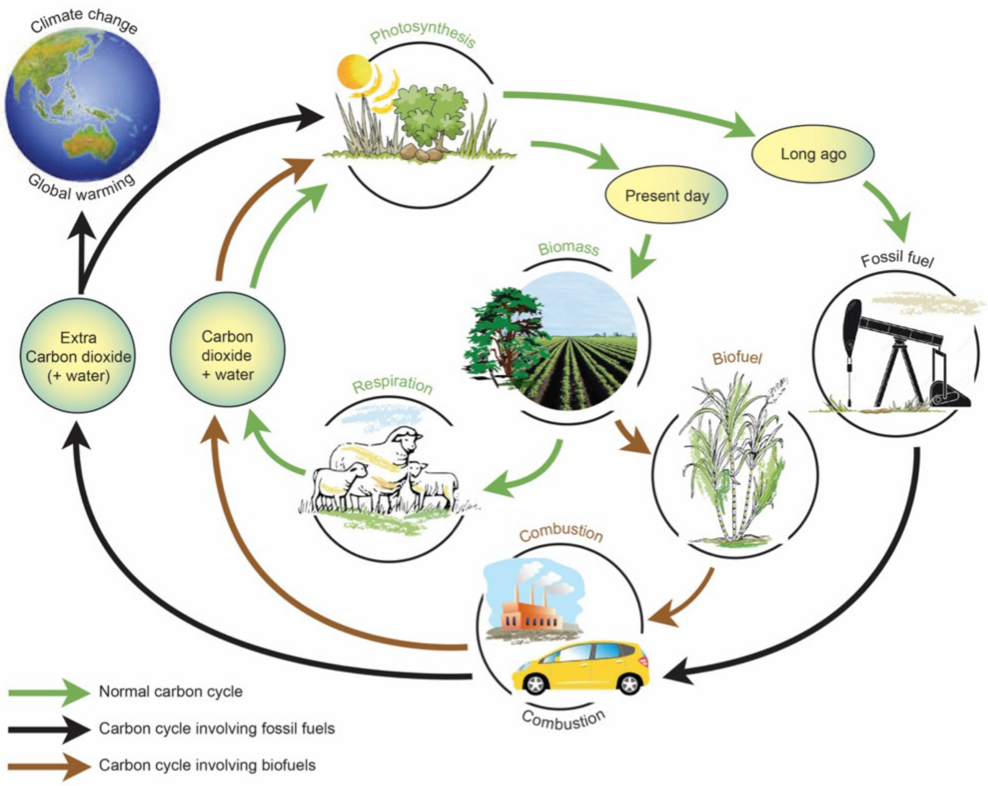
The completed diagram is shown below.

Teachers could use the carbon cycle diagram (Activity 1) to identify that fossil fuels are a non-renewable resource (Yr 7 – ACSSU116) formed through natural processes over a long period of time. Biofuels, however, are produced from a renewable resource by chemical processes designed by scientists.

At this stage, teachers are advised to discuss the advantages and disadvantages of producing fuels from a renewable resource.

Next, teachers could introduce the idea of using specific chemical reactions to produce a required product, noting that various factors affect the rate at which these reactions occur.

The experiment in Activity 2 allows students to engage in a hands-on process that is an example of these concepts. Point out that the fermentation of glucose to produce ethanol, using yeast, is a chemical process that is widely used in many industries, including the production of wine and biofuels. These industries require the reaction to occur at optimum conditions produce maximum yield.

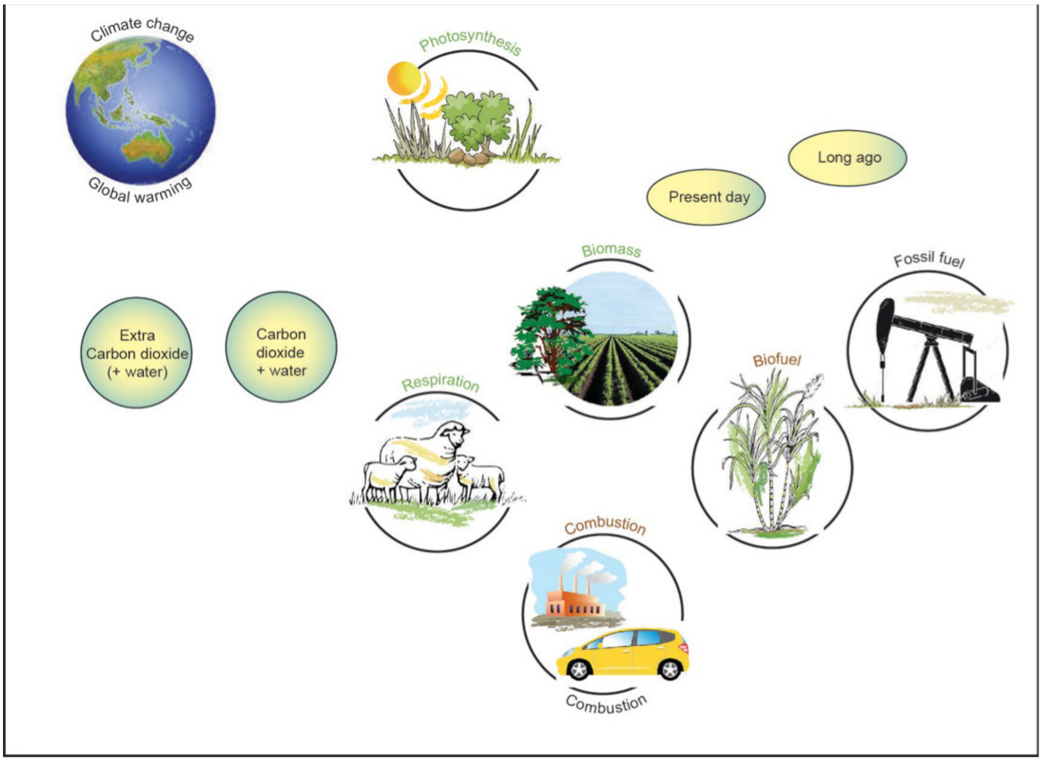


task

Student Activity 1: Analysing the carbon cycle and fuels

The diagram below shows the main processes in the carbon cycle including fuels but lines and arrows connecting the different processes have been omitted.

The Carbon cycle and fuels



1. You have learnt about photosynthesis, respiration in an earlier year level. Show the relationship between these processes (including the growth of plants, biomass). Use a coloured pencil or pen to draw the lines with arrows between them (without fuels).
2. Write the equations for photosynthesis and respiration and explain the relationship between these two processes.
3. Suggest why is a relatively constant concentration of carbon dioxide maintained within the natural carbon cycle.
4. Using a different coloured pencil or pen draw additional lines with arrows showing what you think might be the effect of fossil fuels within the cycle.
5. Using a third coloured pencil or pen draw additional lines with arrows showing what you think might be the effect of biofuels within the cycle.
6. Suggest what is the main process through which use of fuels adds carbon dioxide to the atmosphere?
7. Explain why the use of fossil fuels and biofuels might be considered to have a different impact on the environment.
8. What is the relationship between carbon dioxide and global warming?
9. If all fossil fuels were to be replaced with biofuels predict an effect on the carbon cycle.
10. Suggest possible reasons why biofuels are not widely used.

Activity 2: Investigating the effect of temperature on fermentation

Teacher Preparation

Equipment needed

Per group:

- Photocopies of Activity 2: Investigating the effect of temperature on fermentation
- 15 mL Yeast suspension
- 15 mL 5% glucose solution
- Test tube rack
- 4 identical test tubes
- 4 x 250 mL conical flasks
- 4 balloons – to fit over the top of test tube
- 4 thermometers
- Stop watch
- Stirring rod
- 5 mL graduated measuring cylinder
- Water (room temperature and hot water)
- Ice

What to do

1. Prepare the yeast suspension by dissolving 7 g (1 packet) of dried yeast (Brewer's yeast is preferable) per 100 mL of water. Activate the yeast following the packet directions. Prepare at least 10 minutes prior to use.
2. Prepare the 5% glucose solution by adding 5 g of glucose per 100 mL of solution. Sucrose may be substituted for glucose if necessary.
3. Emphasise the importance of maintaining a constant temperature in the water baths. Try to maintain a constant volume in the water bath by removing additional water using a pipette.
4. The yeast need to be incubated so that the oxygen in the test tube will be completely consumed. If the yeast respire aerobically, no pressure change occurs, because a considerable amount of oxygen is consumed as CO_2 is produced. It also takes a few minutes for the yeast to transport the sugar into the cell, to respire at a constant rate, and to reach the proper temperature.
5. If the school has gas pressure sensors these can be used to monitor the production of carbon dioxide in place of the balloon. This will provide additional data.
6. Different groups could be allocated different ranges of temperatures (between 10 - 60°C) which could then be collated into a set of class data. This would provide additional information.
7. Complete Activity 2: Investigating the effect of temperature on temperature. Ask students to draw a graph and complete the questions on the activity sheet.
8. Students may find that initially at low and high temperatures the yeast growth increases then slows as the test tubes reach the desired temperature.
9. Dispose of the yeast mixture on school compost if possible. Yeast that has been poured down the sink may cause ongoing smells.

discuss

After completing Activity 2 and discussing optimal temperature for carbon dioxide and thus ethanol production, the logical next step is to consider factors related to the desired product – ethanol.

Teachers could point out that a lot of time, effort and cost goes into producing ethanol for fuel. They could ask 'Why are biofuels being produced?' leading to a discussion on renewable resources and environmental considerations. They could then ask 'Is ethanol a better fuel than petrol?"

assess

Assessment

Students prepare an experimental report on the investigation. This could provide information on how well students understand the relationship between reaction rate and temperature.

task

Student Activity 2: Investigating the effect of temperature on fermentation

Background

Yeast is a single celled fungus that is used in the fermentation process. Brewer's yeast and wine yeast contain zymase, an enzyme that can convert glucose to ethanol under anaerobic conditions. In the process, carbon dioxide is also produced. The rate of reaction can be determined by the metabolic activity of the yeast. This can be measured by increase in yeast population or the rate of production of carbon dioxide.

$$\text{glucose} \xrightarrow{\text{zymase}} \text{ethanol} + \text{carbon dioxide gas}$$

Like all chemical reactions the rate of fermentation is affected by temperature. Because yeast is a living organism its metabolic activity will be maximised at an optimum temperature. If the temperature is too high the yeast cells will die and fermentation will cease. This is why it is important to monitor and maintain an optimum constant temperature in any fermentation process.

Aim

To examine the effect of temperature on fermentation.

Materials

- 15 mL yeast suspension
- 15 mL 5% glucose solution
- Test tube rack
- 4 identical test tubes
- 4 x 250 mL conical flasks
- 4 balloons – to fit over the top of test tube
- 4 thermometers
- Stop watch
- Stirring rod
- 5 mL graduated measuring cylinder
- Water (room temperature and hot water)
- Ice
- Protective clothing and safety glasses

Method

1. Label each test tube 1 – 4 and place in a test tube rack.
2. Prepare 4 water baths at temperatures given by your teacher in the conical flasks using a combination of tap water, hot water and ice to a volume of 150 mL. Place a thermometer in each flask to monitor the temperature and maintain it at a constant value throughout the investigation.
3. Add 2.5 mL of 5% glucose to each test tube. Add 2.5 mL of yeast suspension to each test tube, gently shaking the test tube to combine.
4. Carefully place a balloon over the top of each test tube to capture any gasses that are released and place each test tube in a separate conical flask.
5. Incubate the test tube for 10 mins in the water bath. Be sure to keep the temperature of the water bath constant. If you need to add more hot or cold water, first remove as much water as you will be adding.
6. After 10 mins start the timer and measure the distance from the base of the test tube to the top of the mixture of each test tube. This represents the starting population of yeast.
7. Measure the distance from the base of the test tube to the top of the mixture for each test tube every minute. This represents the progress of the fermentation through growth in yeast population over time. Record your observations of the test tube and balloon below. Record your distance measurements in Table 1. Monitor the water bath temperature, keeping it constant.
8. Clean up by pouring the yeast mixtures into a large beaker with detergent. (Your teacher will dispose of this for you.) Carefully wash all the equipment.
9. Draw a line graph of the results

task

Student Activity 2: Investigating the effect of temperature on fermentation (cont)

Results

Observations

Table 1: The effect of temperature on fermentation

Test tube	Temp °C	Time (mins)										
		0	1	2	3	4	5	6	7	8	9	10
1												
2												
3												
4												

Graph 1: The effect of temperature on fermentation

discuss

Student Activity 2: Investigating the effect of temperature on fermentation (cont)

Discussion

1. Describe the effect of temperature on the growth of yeast. Include your observations of the balloon that contained the gas produced by the yeast.
2. What is the optimal temperature for fermentation?
3. Were there any changes in the rate of yeast growth at particular temperatures during the investigation? Suggest reasons if this occurred.
4. Why should the fermentation process be kept at a constant temperature?
5. It is sometimes said the rate of growth doubles with every 10°C increase in temperature. Explain whether or not your data supports this.
6. Compare your data with other groups providing reasons for similarities and differences.

Activity 3: Investigating the heat of combustion of ethanol

Teacher Preparation

Activity 3 provides a hands on activity that allows students to measure the heat of combustion of ethanol then compare this with the theoretical value. Much energy is lost from the system in this investigation, but this also occurs in the internal combustion engine. Students could then compare the theoretical values for ethanol petrol as well as considering the clean burning nature of ethanol compared to 'dirty' burning of petrol.

Safety considerations do not allow petrol to be used in a school laboratory.

1. This experiment involves burning ethanol to measure the heat of combustion. Emphasise the flammable nature of ethanol to students and reinforce safety instructions.
2. Ensure ethanol is only provided in spirit burners and demonstrate how to extinguish the spirit burner by placing the cap over the wick.
3. The use of a metal can provides better conduction of the heat to the water. A metal food can such those used for soup or baked beans is suggested. Remove any labels and punch holes in each side for the support rod. Ensure the can is clean and dry. The metal can could be replaced with a beaker or conical flask if necessary however less energy would be transferred.
4. Typically only 24% - 50% of the energy is transferred to the water. Energy is 'lost' because it is transferred to the can and surrounding air. Results could be improved using an insulating shield to reduce the loss to surrounding air.
5. The energy absorbed by the steel can be calculated and added to that of water to find a more accurate value for ethanol. The specific heat capacity of a steel can is 0.46 J/g/°C.

   Heat absorbed by the can = mass of can (g) x 0.46 x temperature change.

   (It is assumed that the temperature of the can is the same as that of the water because they should be in thermal equilibrium).

assess

Assessment

Students prepare an experimental report on the investigation explaining why there are differences between experimental and theoretical results. They should also justify how suggest change can improve experimental results. An analysis of the advantages and disadvantages of adding ethanol to petrol could demonstrate an understanding of the purpose of a fuel and the impact of fuels on the environment.

task

Student Activity 3: Investigating the heat of combustion of ethanol

Background

All fossil fuels and biofuels produce carbon dioxide, water and heat energy during the combustion process. Depending on the composition of the fuel and available oxygen supply carbon monoxide, nitrogen oxides and particulates may also be produced. Different fuels produce different amounts of heat energy during the combustion process and this is called their heat of combustion. It is often expressed in kJ/g.

In this investigation you will determine the heat of combustion of ethanol.

ethanol + oxygen → water + carbon dioxide + heat energy

Aim

To determine experimentally the heat of combustion of ethanol.

Materials

- 100 mL distilled water
- 1 metal can
- Spirit burner containing ethanol
- thermometer
- retort stand and boss-head (x2)
- clamp
- retort ring
- steel rod
- stirring rod
- electronic scales
- 100 mL graduated measuring cylinder
- Matches
- Protective clothing and safety glasses

Safety

Risk	Action to minimise risk
Use of chemicals and heat	• Wear safety glasses and wash hands at the end. • Extinguish spirit burner using cap. • Wait for equipment to cool before handling it.
Ethanol – highly flammable	• Only use in spirit burner. • Report any spills to teacher. • Dispose of spills as directed.

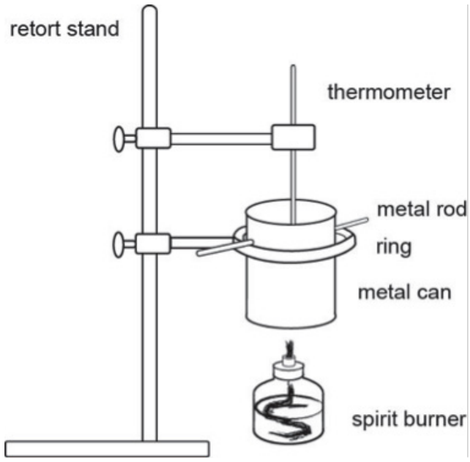
Method

1. Weigh the metal can and record the mass in Table 1.
2. Measure 100 mL of distilled water and add to the metal can. Weigh and record its mass.
3. Weigh the spirit burner and record its mass.

task

Student Activity 3: Investigating the heat of combustion of ethanol (cont)

4. Set up the equipment as shown in the diagram below. Adjust the height of the metal can so it is just above the wick of the spirit burner.



5. Record the initial temperature of the water.
6. Light the spirit burner. Gently stir the water with the stirring rod during the heating.
7. When the temperature of the water has increased approximately 10°C above the initial temperature, extinguish the spirit burner and record the final temperature.
8. Reweigh the spirit burner and record its mass.
9. Allow the water and metal can to cool before dismantling and packing up equipment.

Results

Observations

Table 1

Mass of metal can	
Mass of metal can + water	
Mass of water	

Initial mass of spirit burner	
Final mass of spirit burner	
Mass of ethanol burnt	

Initial temperature of water	
Final temperature of water	
Temperature change	

task

Student Activity 3: Investigating the heat of combustion of ethanol (cont)

Analysis of results and discussion

1. Calculate the mass of water used, mass of ethanol burnt and temperature change – complete Table 1.
2. Calculate the amount of energy released by the ethanol using the formula:

   Heat released (J) = mass of water (g) x 4.2 x temperature change (°C)
3. Calculate the heat released by 1 g of ethanol by dividing the amount of heat released by the mass of ethanol burnt.
4. Determine the experimental heat of combustion of ethanol in kJ/g.
5. Compare your experimental results with other groups and suggest reasons for any differences.
6. The theoretical value for the heat of combustion of ethanol is 29.6 kJ/ g. Compare this with your experimental results and suggest reasons for any difference.
7. Suggest changes which could be made to the investigation and how these could to improve results.
8. Ethanol is said to be a clean burning fuel. Use your observations to comment on this statement.
9. Petrol releases 43.2 kJ/g of energy. Suggest advantages and disadvantages for adding ethanol to petrol.

Activity 4: Producing ethanol from sorghum Dalby Bio-Refinery

Teacher Preparation

This activity provides an opportunity for students to learn about the processes involved in the commercial production of ethanol fuel, using the case study example of Dalby Bio-refinery. While many of the terms may be unfamiliar to the students, it is important that the correct scientific terminology is used.

It is suggested that the students watch the video below -
Biofuels – From Sorghum to Ethanol (https://youtu.be/QJSZ4Ox_I30)

After their initial viewing, ask students to fill in as much of the Steps of Production summary table as possible.

In order for students to complete the table, print and distribute copies of the nine steps outlined in the teacher background material, **Producing ethanol from sorghum – The Dalby Bio-refinery**. In particular, they will need the reaction control column. This identifies the control needed for the various reactions to proceed at optimum levels and links back to Activity 2.

assess

Assessment

Student Activity 4 provides an opportunity to determine student's understanding of chemical and physical and processes and the different ways these processes are used in ethanol production. It also allows for judgements to be made about different aspects involved in the production of a specific chemical and the importance of controlling different aspects of the production process.

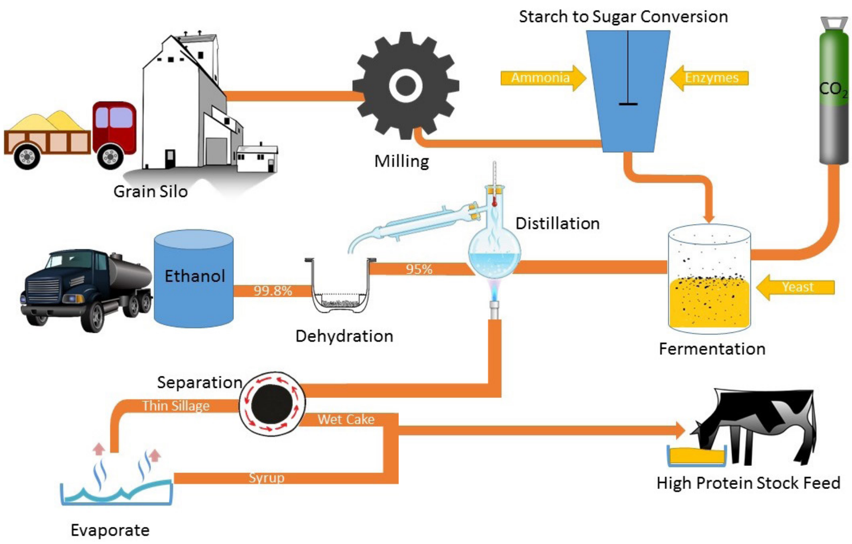
task

Student Activity 4: Producing ethanol from sorghum Dalby Bio-Refinery

The Dalby Bio-Refinery Ltd is Australia's first and only grain-to-ethanol facility. It is one of the largest consumers of sorghum in the Darling Downs Region converting nearly 200 000 metric tonnes of sorghum into 76 million litres of ethanol each year. There is very little waste at this facility. The co-products of the production process, stillage, is converted into wet cake, dry cake and syrup which are high energy animal feed.

Watch the video *Biofuels – From Sorghum to Ethanol* (https://youtu.be/QJSZ4Ox_I30) and answer the questions below.

1. a. Why is grain sorghum used?
   b. What part of the sorghum plant is used to produce the ethanol?
   c. Why does the amount of ethanol produced per tonne of sorghum vary?
2. The diagram below shows the main steps in the ethanol production process.



Adapted from Dalby Bio-Refinery Ltd, http://www.dbrl.com.au

Complete the following table which summarises the main steps in the production process.

Step	Physical or chemical process	Summarise what happens in this step	Reaction Controls	Co-product	Additional information
Milling/grinding					
Liquefaction (hydrolysis process)					
Saccharification (enzymatic process)					
Fermentation					
Distillation					
Dehydration					
Denaturation					

task

Student Activity 4: Producing ethanol from sorghum Dalby Bio-Refinery (cont)

1. Why does the water used need to be cleaned before use?
2. What happens to the carbon dioxide that is produced during the fermentation step?
3. What happens to the substances left after distillation?
4. What is the advantage of drying the wet cake?
5. Suggest why the ethanol is mixed with 5% petrol at the very end of the process?
6. Why is ethanol important as a fuel additive?
7. Suggest what is meant by the presenter when he says “ethanol is better for people”.

task

Student Activity 5: Comparing fuels

Background

Fossil fuels have been the main energy source for transport since cars were first invented. This is due to their low cost and ability to produce large amounts of energy. However, the need for alternative energy supplies has intensified owing to:

- increased concerns about future supplies;
- dependence on imported supplies of crude oil; and
- the impact of fossil fuel use on the environment.

More attention is now being placed on supporting the development of energy supplies for transport from renewable sources such as biomass (plant and vegetation materials). There are currently three facilities in Australia producing ethanol from plant material.

The ethanol produced is blended with petrol to produce E10. Biodiesel is also being produced from vegetable oils and tallow (animal fats).

Task

You are to research the required information about the following fuels and collate it into a table therefore providing a comparison of these fuels.

Fuels:

- Petrol
- Diesel
- Ethanol
- Biodiesel
- E10

Information required:

- Classification of the fuel – fossil fuel, biofuel, blend
- Source of or feedstock for the fuel
- Production process (summary only)
- Amount of energy produced during fuel combustion
- Amount of carbon dioxide produced (can be comparison)
- Impact on the environment

web

Online Teacher Support Resources

1. Biofuels - From Sorghum to Ethanol. Agrifood Skills Australia
   (https://youtu.be/QJSZ4Ox_I30)

2. Dalby Bio-refinery Limited
   http://www.dbrl.com.au/

3. What are biofuels?; Biofuels Association of Australia
   http://biofuelsassociation.com.au/biofuels/

4. Biomass Producer; Rural Industries Research and Development Corporation.
   http://biomassproducer.com.au/projects/

5. About Sucrogen; Wilmar BioEthanol Australia
   http://wilmarbioethanol.com/about-csr-ethanol

6. The biofuel future; Royal Society of Chemistry
   http://www.rsc.org/chemistryworld/Issues/2009/April/Thebiofuelfuture.asp

7. Biofuels factsheet; Australian Institute of Petroleum
   http://www.aip.com.au/pdf/BioFuelFactSheet.pdf

8. What is biofuel (4:00 min); The Energy Crew
   https://www.youtube.com/watch?v=S88ZtNMD-7o

9. Alternative Fuels Data Centre; US Department of Energy
   http://www.afdc.energy.gov/fuels/

10. Earth in 2050 and the biofuels of future HD Documentary 2014 (43:42 min); Documentaries online
    https://www.youtube.com/watch?v=2tEtgBRoUbg

11. Alternative fuels; Parliament of Australia
    http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Browse_by_Topic/ClimateChange/responses/mitigation/Emissions/Alternative

12. Biofuels; Australia Renewable Energy Agency
    http://arena.gov.au/funding/investment-focus-areas/biofuels/

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