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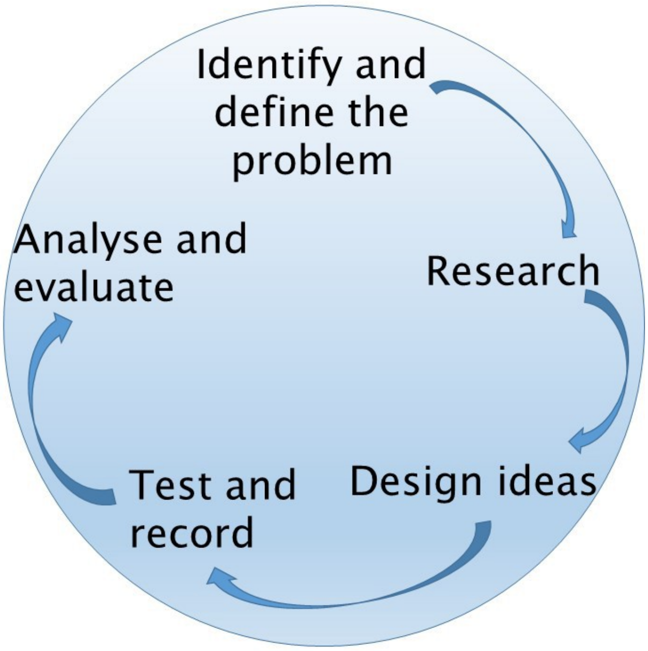
The Challenge

In a world where our understanding of the impacts of carbon dioxide (and other greenhouse gases) on our climate is expanding but our demand for energy is higher than ever, it is vital that energy production becomes more efficient and environmentally friendly. While there are renewable sources of energy, many of these are still expensive and/or inefficient. This means that for the foreseeable future, fossil fuels will play a role in our energy mix.

One of the key ideas to minimise the amount of carbon dioxide, associated with fossil fuels, being released to the atmosphere is through using carbon capture utilisation and storage (CCUS) methods.

Your job is to investigate the advantages and difficulties of CCUS and try to come up with a solution to minimise carbon release into the atmosphere.



Background Information

Carbon dioxide is a greenhouse gas in our atmosphere. There are many ways in which carbon dioxide can enter the atmosphere including; respiration of living things, volcanic eruptions, and in the production and burning of fossil fuels. Since the industrial revolution, the amount of carbon dioxide released into the atmosphere has increased (Figure 1), and climate scientists attribute much of this increase to the burning of fossil fuels to produce energy.

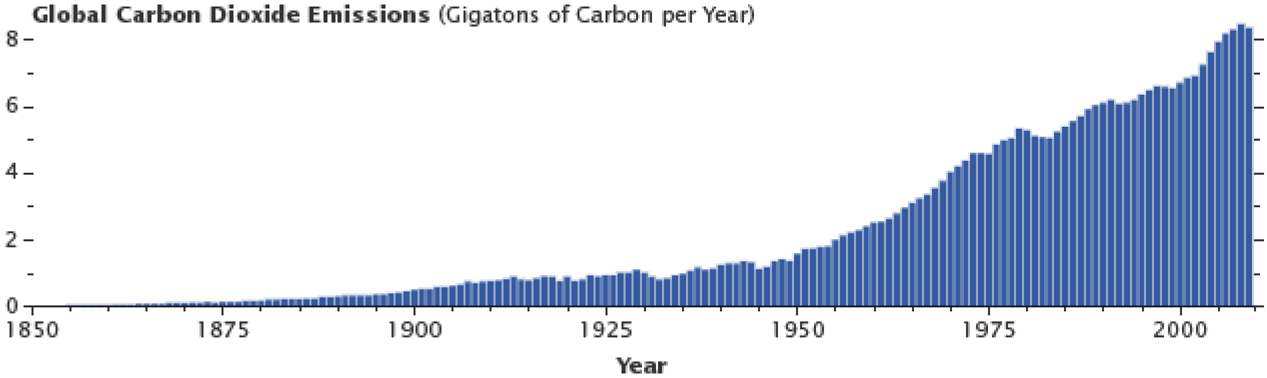


Figure 1. Global carbon dioxide emissions (gigatons of carbon per year) (Earth Observatory, 2011)

Carbon dioxide plays a vital part in the Greenhouse Effect, as illustrated in Figure 2. Without the Greenhouse Effect the Earth would be too cold to support life as we know it (like Mars) but higher levels of greenhouse gases can make a planet too warm (like Venus). Having the right amount of greenhouse gases in the atmosphere is vital to the survival of life on Earth. The increase in the amount of carbon dioxide in the atmosphere has been linked to an increase in global temperatures, which is causing polar ice to melt and sea levels to rise, among other problems.

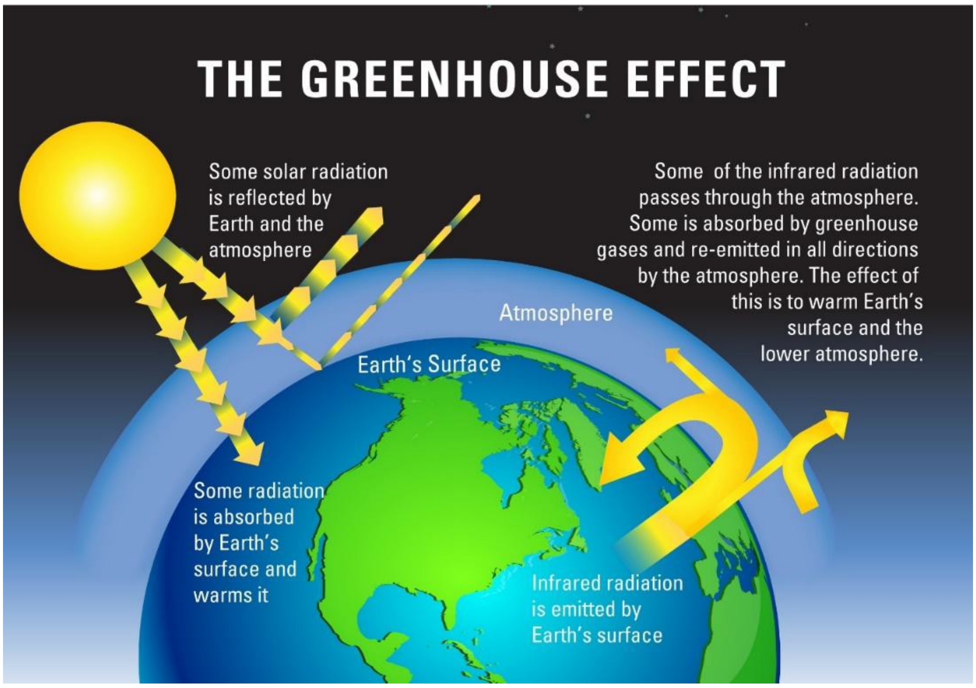


Figure 2. The Greenhouse Effect helps to keep the planet warm, but higher levels of greenhouse gases can lead to too much heat energy being trapped, causing an increase in global temperatures (The Royal Society, 2019).

The carbon cycle is a natural, global cycle which, when in balance, allows life on Earth as we know it to thrive. One of the largest carbon sinks is the ocean, which removes carbon dioxide from the atmosphere. It currently absorbs about one third of the carbon dioxide released by the burning of fossil fuels (NOAA, 2017). When carbon dioxide absorbs into the ocean its pH levels decrease, this is known as acidification. Acidification of the oceans has been linked to coral bleaching and thinning of shells of marine organisms, which in turn has destroyed some marine ecosystems.

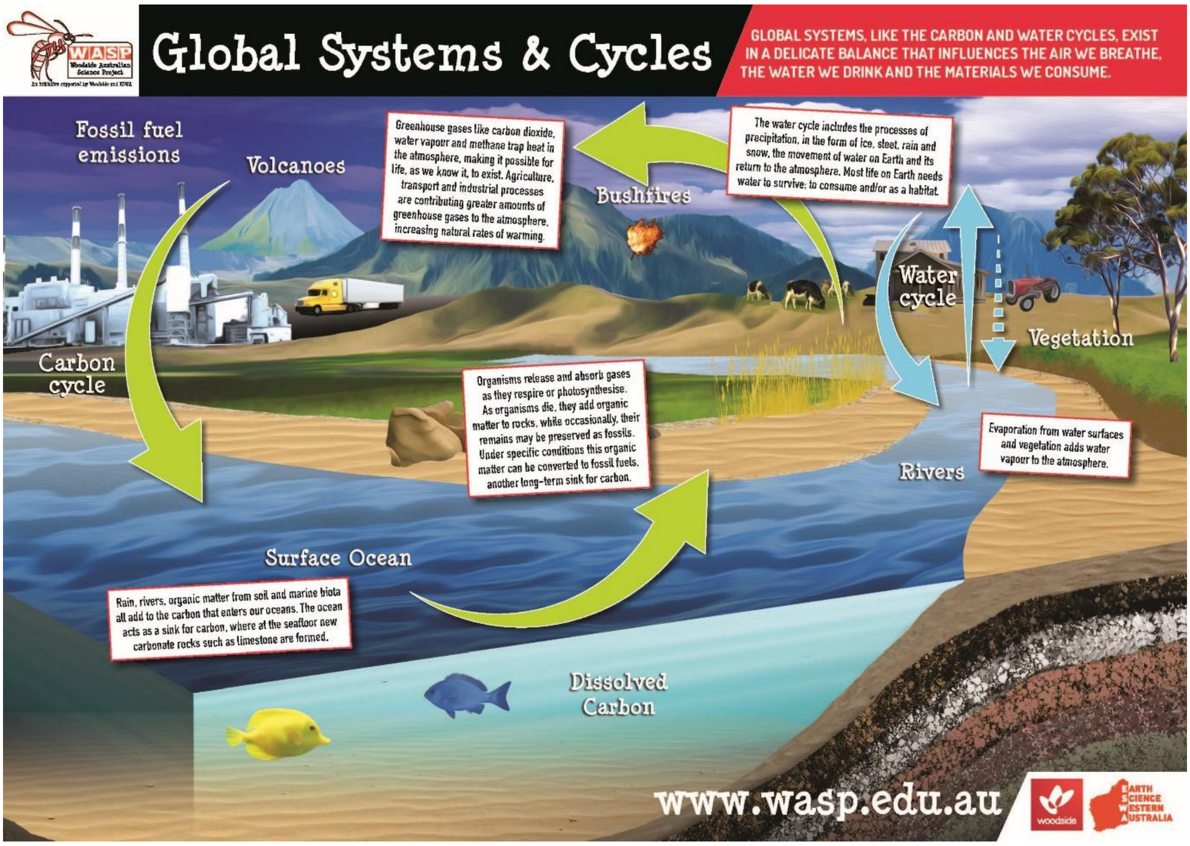


Figure 3. The carbon cycle has natural and manmade inputs. The ocean is a major sink for carbon.

As a global priority, industry and government are investigating how to minimise the amount of carbon dioxide which is released into the atmosphere through human activities. There are some companies using carbon capture and storage methods, however, at present this is very costly. Companies who aim to be both more environmentally friendly and economically competitive are investing in research to look at means of using the carbon dioxide, these processes are known as Carbon Capture, Utilisation and Storage (CCUS).

Background Research

1. What are some of the industrial uses for carbon dioxide?

Suggested site: https://sciencing.com/uses-carbon-dioxide-gas-6364016.html

2. Explain the following different ways of capturing carbon and describe the pros and cons of each process.

Name	Method	Pros	Cons
Pre-combustion capture			
Post-combustion capture			
Oxy-fuel combustion			

Suggested site: https://www.brighthubengineering.com/power-plants/35764-capturing-carbon-dioxide-an-overview/

3. Fill in the table below for three locations where carbon capture is being conducted.

Location	Carbon capture capacity (millions of tonnes/annum)	Year opened or expected to open

Suggested site: https://www.carbonbrief.org/around-the-world-in-22-carbon-capture-projects

4. Draw and label an ideal location to store carbon dioxide, include the key words: porous, and permeable and name any geological structures, such as fault or folds. Attach this as a separate document.

Suggested sites: https://hub.globalccsinstitute.com/publications/brazilian-atlas-co2-capture-and-geological-storage/co2-geological-storage and https://hub.globalccsinstitute.com/publications/building-capacity-co2-capture-and-storage-apec-region-training-manual-policy-makers-and-practitioners/module-

5- co2-storage-options-and-trapping-mechanisms

5. What is enhanced oil recovery? Draw and label diagrams to aid your explanation. Attach these as separate files or insert below.

Suggested site: https://en.wikipedia.org/wiki/Enhanced_oil_recovery

6. What are some of the effects of climate change, and possible outcomes in the future?

Suggested site: https://climate.nasa.gov/effects/

7. Why is carbon capture and storage not carried out at every power station instead of releasing carbon dioxide into the atmosphere?

Suggested site:
https://en.wikipedia.org/wiki/Carbon_capture_and_storage#Limitations_of_CCS_for_power_stations

Investigating the Effect of Carbon Dioxide on the pH of Water

Objective

To determine the relationship between the amount of dissolved carbon dioxide in water and the pH of the water. Then use this information to highlight any challenges in designing carbon capture utilisation and storage (CCUS) systems.

Hypothesis

As the amount of dissolved carbon dioxide increases, the pH of the water will_____________

this is because

Equipment

- Glass or cup
- Cabbage leaf indicator (how to make explained here: https://www.thoughtco.com/making-red-cabbage-ph-indicator-603650)
- Aspro clear or other effervescent tablets/powder.
- Teaspoon

Method

1. Half fill the glass with water then add enough indicator so that you can determine the pH
2. Put in half an effervescent tablet or half a teaspoon of powder.
3. Note the colour change and determine the pH
4. Repeat the investigation adding an extra half tablet/ teaspoon each trial.

Results and Analysis

1. What was the pH of the water before the carbon dioxide was added?

An initiative supported by Woodside and ESWA

2. Complete the table below with your results.

Amount of tablet/ powder added	Colour of water after reaction	pH of water
0.5		
1		
1.5		
2		
2.5		

3. Describe the relationship between the amount of dissolved carbon dioxide and the pH of the water.

____

4. Does an increasing amount of dissolved carbon dioxide make water more acidic or alkaline?

5. What effects might adding carbon dioxide to liquids have on the equipment and the rocks used for carbon capture and storage, and why does this cause design challenges for CCUS systems?

Evaluation

1. Were there any potential sources of error in your investigation?

2. How could you improve this investigation?

3. Outline any ideas you have to investigate the relationship between concentration of dissolved carbon dioxide and pH of water further.

Investigating the Effects of Acid on Materials

Objective

To investigate how different metals and rocks react to acid. Then relate your findings to the design of suitable methods for transporting and storing carbon dioxide.

Background Information

Adding carbon dioxide to water increases its acidity (see ocean acidification). To assist with appropriate design, it is vital that engineers designing carbon capture utilisation and storage (CCUS) models are aware of how different materials will react to acidic water. Using pipeline materials which are easily corroded will result in ongoing need for replacement, making them costly. Storing carbon dioxide underground, within and around the wrong type of rock, could lead to it migrating upwards, entering freshwater aquifers or even the atmosphere. This defeats the point of burial. Therefore, it is vital that the scientists and engineers designing the CCUS processes understand the properties of materials involved.

Equipment

- Small samples of different types of metals
- Vinegar
- A glass jar for each sample
- Sticky labels and markers
- Small tongs
- Camera
- Weighing scales

Method

1. Label each jar ready for the samples .
2. Measure out the same volume of vinegar into each jar. Ensure that there is enough to cover the samples you will be using.
3. Take photos of the samples and weigh the samples on the scales, recording your results in the table.
4. Place each sample in its own jar of acid (carefully) and note any reactions that occur in the observations table.
5. Leave the samples in the jar for a week. Ensuring you have stored them in a safe place.
6. Safely remove the samples using the tongs and dispose of the vinegar down the sink. Rinse and dry the samples then take photos of them and weigh them again on the scales – recording observations in the table.

Results and Analysis

Sample	Mass before experiment (g)	Observations before experiment	Mass after experiment (g)	Observations when placed immediately in acid	Observations after being left for a week

1. Were any of the materials unaffected by the acid, if so which ones? Use data to support your answer.

2. Which materials were the most affected? Use data to support your answer.

3. Did any of the samples lose mass, if so, which ones and what does that suggest?

4. Did any of the samples gain mass, if so, which ones and what could that suggest?

5. Would there be any issues with using the least reactive materials in the process of transporting and storing carbon dioxide (cost, weight etc.)?

Evaluation

1. Were there any potential sources of error in your investigation?

2. How could you improve this investigation?

3. Outline any ideas you have to investigate the reactivity of materials that might be involved in CCUS further.

Investigating the Effect of Temperature on Solubility of Carbon Dioxide

Objective

To investigate the relationship between the temperature of a liquid and solubility of carbon dioxide gas. Then relate this to storing carbon dioxide at depth in saline aquifers.

Background Information

A method currently under investigation for trapping carbon dioxide is by injecting carbon dioxide gas into saline aquifers deep below ground. It will then dissolve into the brine (salty water) and eventually react to form precipitates, such as calcium carbonate. Injection needs to occur at a depth of 800-2,000 metres to ensure that the carbon dioxide does not contaminate any freshwater aquifers. As you move deeper underground temperature increases, this is known as the geothermal gradient. The average geothermal gradient is 25^{0}C per kilometre, which means for every kilometre you go below ground the temperature increases by 25^{0}C. It is important to know how temperature affects the solubility of carbon dioxide, as the deeper the aquifer the higher the temperature will be.

Equipment

- Ice cream tub or something similar
- Measuring jug or baby bottle
- Aspro clear tablets or other effervescent tablet
- Kettle
- Piece of cardboard

Method

1. Half fill the ice cream tub with water
2. Fill the measuring jug/baby bottle with hot (not boiling) water
3. Place the piece of card over the top of the jug and quickly turn it upside down and place it in the ice cream tub
4. Carefully insert the Aspro clear tablet into the jug
5. When the reaction has stopped measure how much water has been displaced from the jug.
6. Repeat the investigation using warm, then cold water.

Results and Analysis

Temperature	Volume of water displaced (mL)
Hot	
Warm	
Cold	

1. What is the relationship between the temperature of the water and the volume of water displaced?

2. What is the relationship between the temperature of the water and the amount of gas dissolved? (Remember if more gas has dissolved then less water will have been displaced).

3. Considering the geothermal gradient, could more or less gas be dissolved in a deeper aquifer? Use your data to justify your answer.

For consideration:

4. If global temperatures continue to increase, will that make it easier or harder for oceans to trap the carbon dioxide from the atmosphere and what does that mean in terms of the rate of global warming?

Evaluation

1. Were there any potential sources of error in your investigation?

2. How could you improve this investigation?

3. Outline any ideas you have to investigate how the geothermal gradient may impact CCUS methods further.

Investigating the Effect of Salinity on the Solubility of Carbon Dioxide

Objective

To determine the relationship between the salinity of a solution and the amount of carbon dioxide it can dissolve. Then relate this to proposed carbon capture utilisation and storage (CCUS) methods.

Background Information

A method currently under investigation for trapping carbon dioxide is by injecting carbon dioxide gas into saline aquifers deep below ground. It will then dissolve into the brine (salty water) and eventually react to form precipitates, such as calcium carbonate.

Equipment

- An ice cream tub
- Measuring jug/baby bottle
- Water
- Salt
- Tablespoon
- Wooden spoon
- Piece of cardboard

Method

1. Fill the ice cream tub half way with water.
2. Fill the measuring jug with water and keep adding salt to the water, one spoonful at a time stirring each in. Count how many teaspoons you had to add until it became saturated (no more salt will dissolve), creating a saline solution. Record the number in the table below.
3. Put the piece of cardboard over the top of the measuring jug and turn it upside down. Quickly and carefully place the jug into the ice cream tub and take the piece of card away.
4. Carefully, as not to allow much water to escape, add an aspro clear tablet to the jug.
5. When the reaction is complete (no more bubbles are being released) measure how much of the saline solution in the measuring jug has been displaced and record this in your table.
6. Repeat the experiment, reducing the amount of salt added to the ice cream tub by one spoonful each time, ensuring you record how much water was displaced.

Results and Analysis

Amount of salt added (tablespoons)	Original volume of saline solution in measuring jug (mL)	Final volume of saline solution in measuring jug (mL)	Volume of saline solution displaced (mL)

1. Plot your results in a scatter graph, with amount of salt added on the x-axis and the volume of solution displaced on the y-axis. Attach as a separate document.

2. Was there a relationship between the volume of salt added and the amount of saline solution displaced?

3. Which solution was able to dissolve the most carbon dioxide?

4. Do your results indicate that it is a good idea to store carbon dioxide in saline aquifers? Explain your answer using your data to justify your conclusions.

Evaluation

1. Were there any potential sources of error in your investigation?

2. How could you improve this investigation?

3. Outline any ideas you have to investigate the impact of salinity on the solubility of carbon dioxide.

Mineral Trapping

Part 1 - Research

Objective

Research how minerals might play a role in the storage of carbon and discuss the difficulties of the processes involved.

Background Information

One of the main advantages of carbon capture utilisation and storage (CCUS) is that the carbon dioxide gas dissolves into brine or reacts with the surrounding rock, forming carbonate minerals. Therefore, it is trapped as a solid which reduces the risk of carbon dioxide leaking and entering the atmosphere.

Research Questions

1. Provide three examples of carbonate rocks

Suggested site: https://en.wikipedia.org/wiki/Carbonate_rock

2. Write a word and a chemical equation for the formation of calcium carbonate.

Suggested site: https://en.wikipedia.org/wiki/Calcium_carbonate

3. Recent studies in Iceland on the CarbFix project, have shown that the carbonation process can be accelerated when carbon dioxide is injected into basalts. Why are interactions with basalts to form carbonates more effective than with sedimentary rocks?

Suggested site: https://www.carbfix.com/faqs

4. What are some of the weaknesses of the CarbFix method and why might it be difficult to do in Australia?

Suggested site: https://www.carbfix.com/faqs

3D Models for Structural Trapping

Objective

To interpret seismic data to determine the best geological location to store carbon dioxide and to create a 3D model of that site.

Background Information

Choosing an area to store carbon dioxide can be complicated. Firstly, there must be two very different rock types on top of each other with the lower being porous and permeable (enabling it to hold the carbon dioxide gas) and the upper rock type impermeable (to prevent the carbon dioxide from migrating upwards). The deeper the site the less likely it is that carbon dioxide will leak and reach fresh groundwater aquifers or the atmosphere.

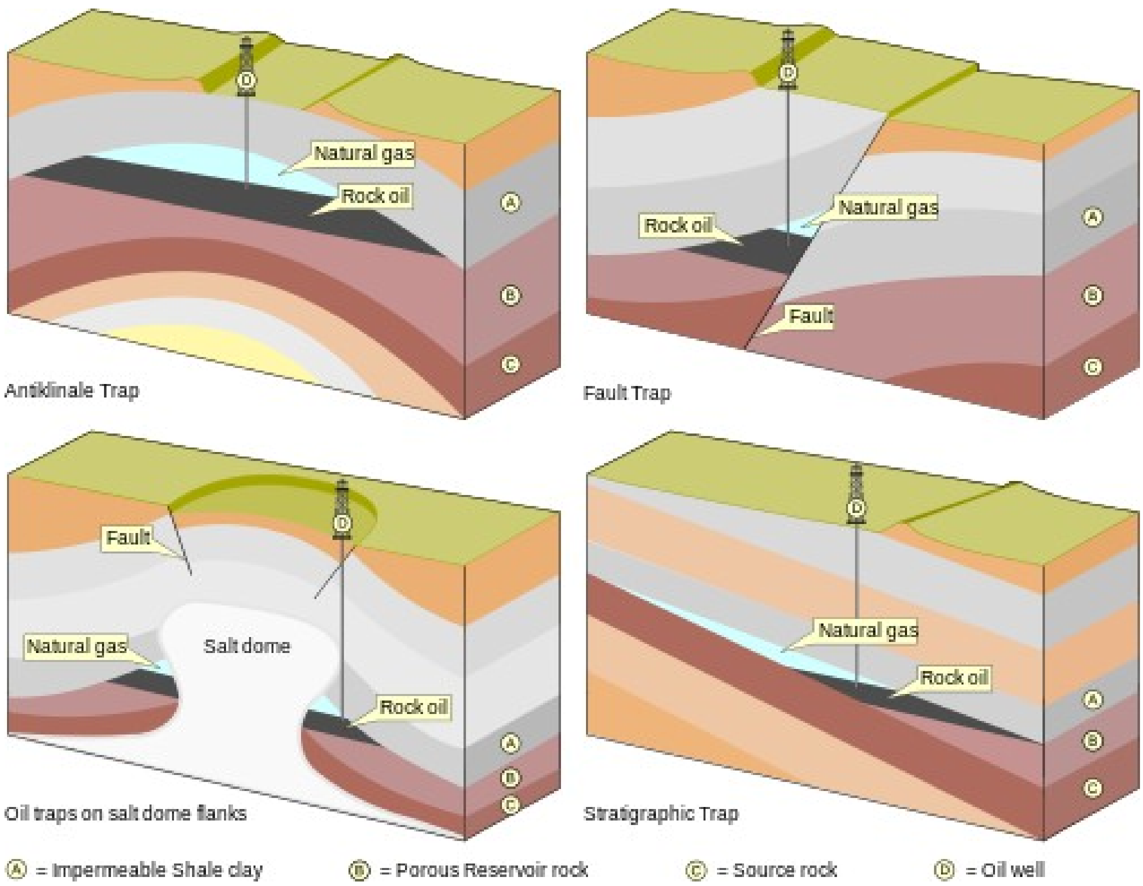


Figure 10. Often oil and gas reservoirs are considered good sites to store carbon dioxide - as they have already trapped oil and gas for millions of years prior to drilling. In these images, rocks types A and C and the salt dome are impermeable and B is permeable and porous, making them ideal geological structures for trapping gas (Wikimedia Commons, 2015).

To determine what is going on below the surface seismic studies are carried out. These result in images which geophysicists interpret to work out the rock types and structures that exist below the surface and ultimately determine the suitability of the area. Folds and faults in rocks occur when there have been compression or tensional forces acting on the rocks squashing them or pulling them apart. An anticline is a fold which bends upwards, these can make excellent traps if they contain the right rock types. Sometimes faults will move rock layers relative to each other (see Figure 10).

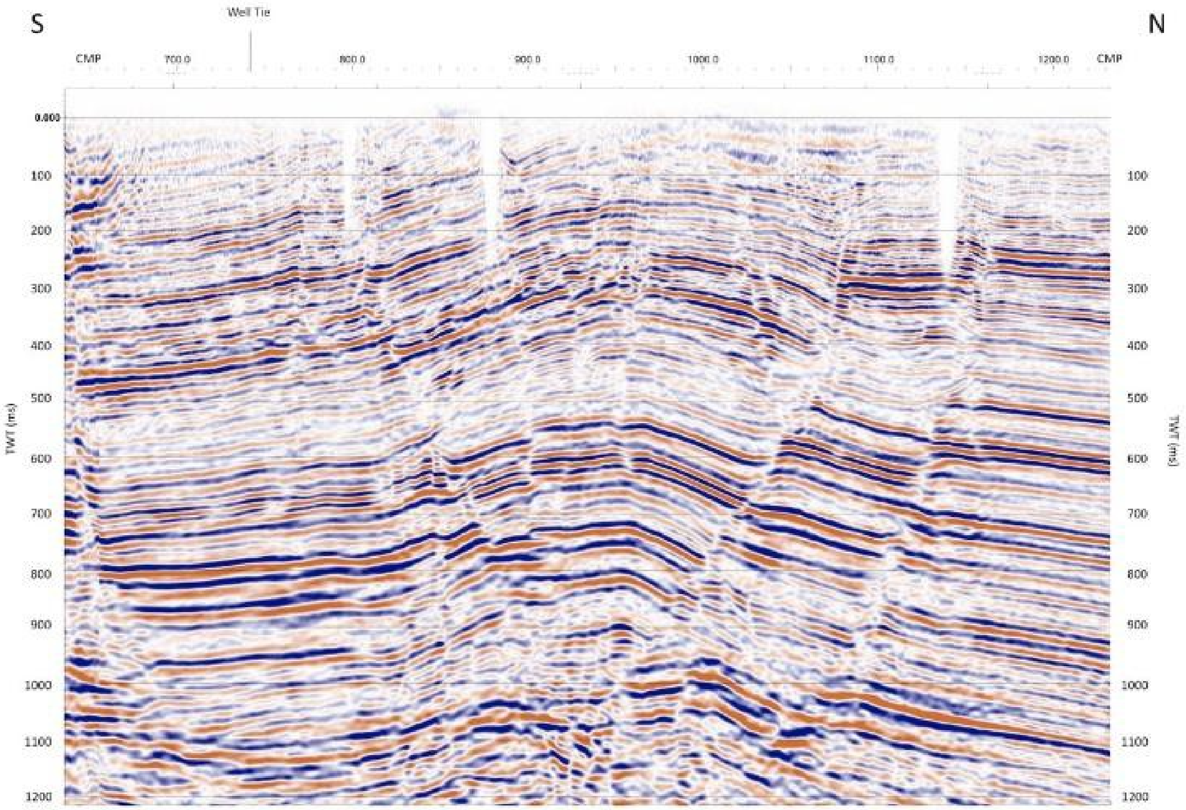


Figure 11. Seismic image - this area contains an anticline (fold) and some faults - can you pick them out? (Sub-Surf Rocks!, 2018)

Method

1. Draw and label the following geological structures: Attach these as a separate document or insert below.
    - Anticline
    - Syncline
    - Normal Fault
    - Reverse Fault

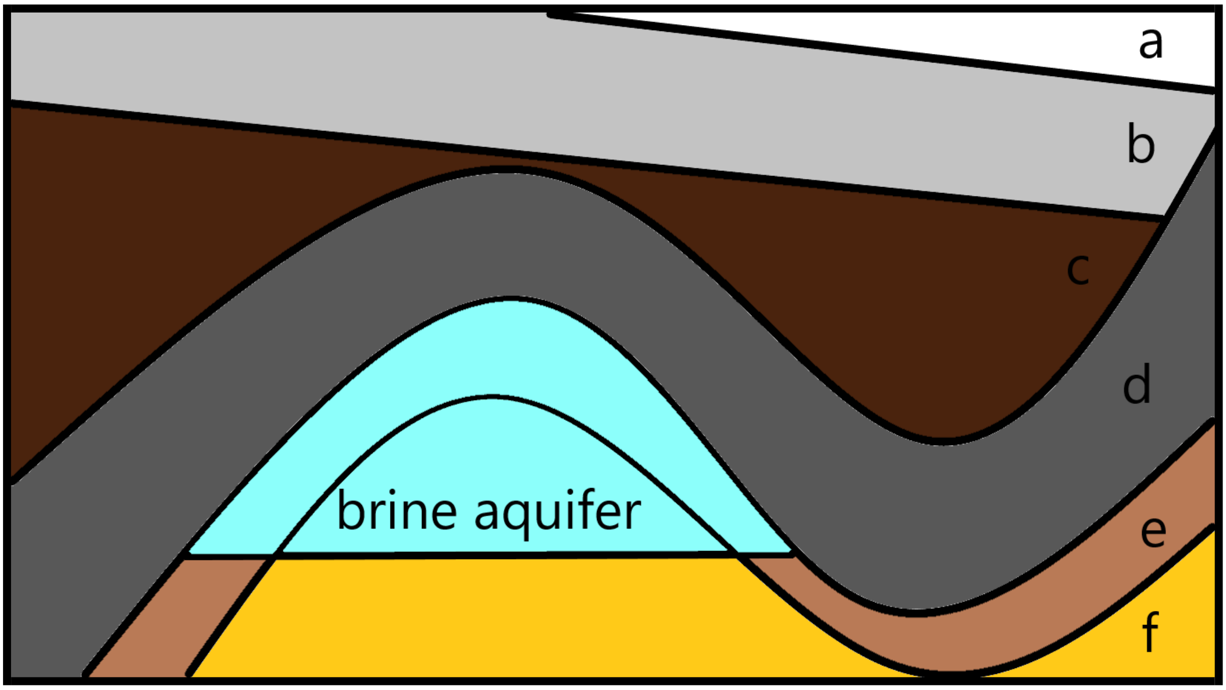
Suggested site: https://english.fossiel.net/information/article.php?id=342&/Geological%20structures

2. Explain how each trap in Figure 10 prevents gases from leaking and migrating upwards. (Hint: think about the rock types and use the terms impermeable, permeable and porous).

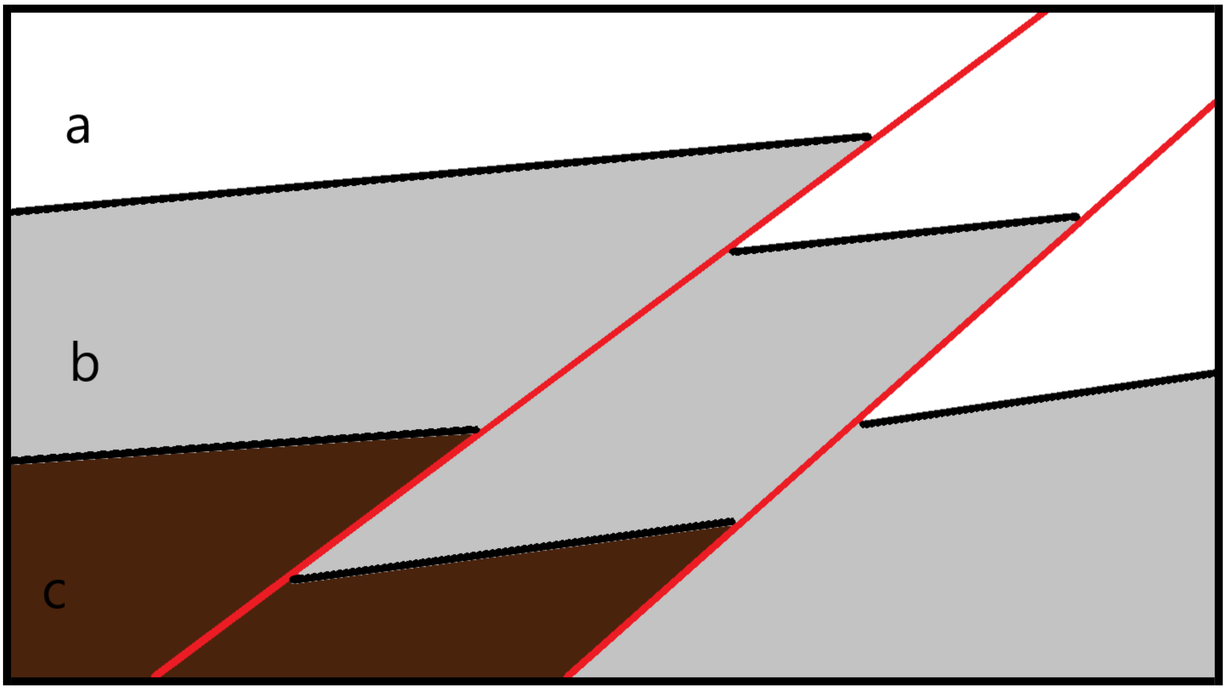
Anticlinal trap	
Fault trap	
Salt dome	
Stratigraphic trap	

3. Below are some geological structures which have been interpreted from seismic data. The red lines show faults. Some drilling has enabled the rock types to be determined:

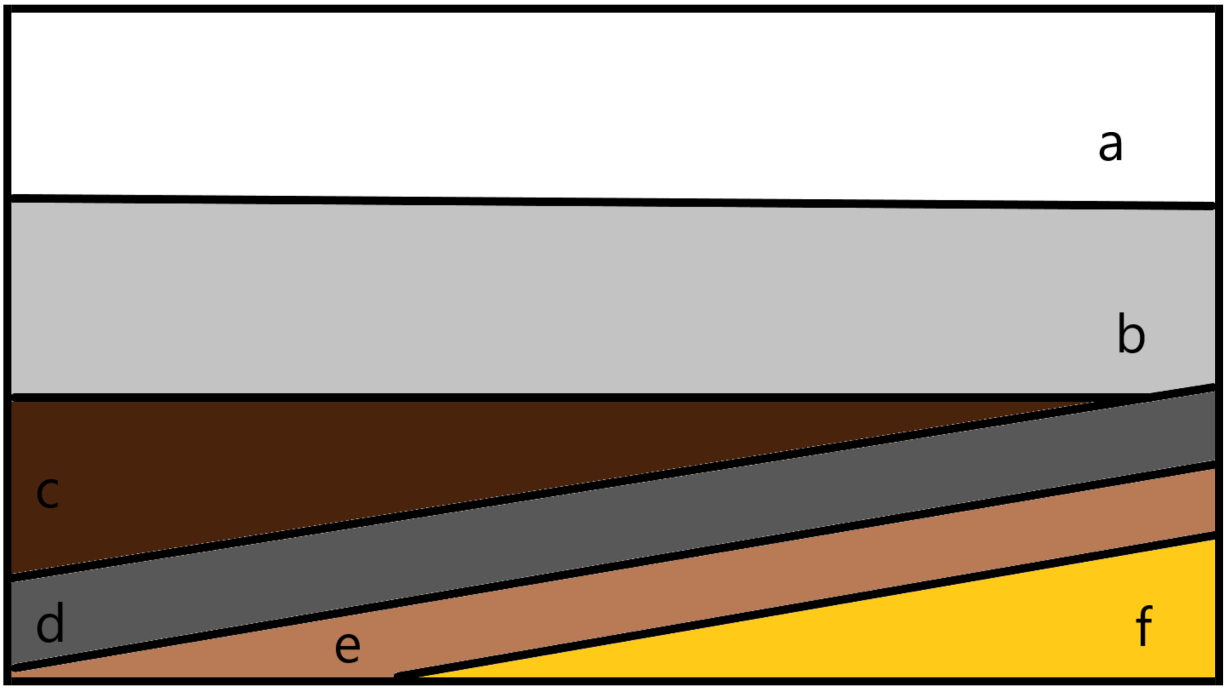
A	Impermeable quartzite	B	Impermeable porous basalt
C	Permeable sandstone	D	Impermeable shale
E	Porous and permeable mudstone	F	Porous and permeable limestone



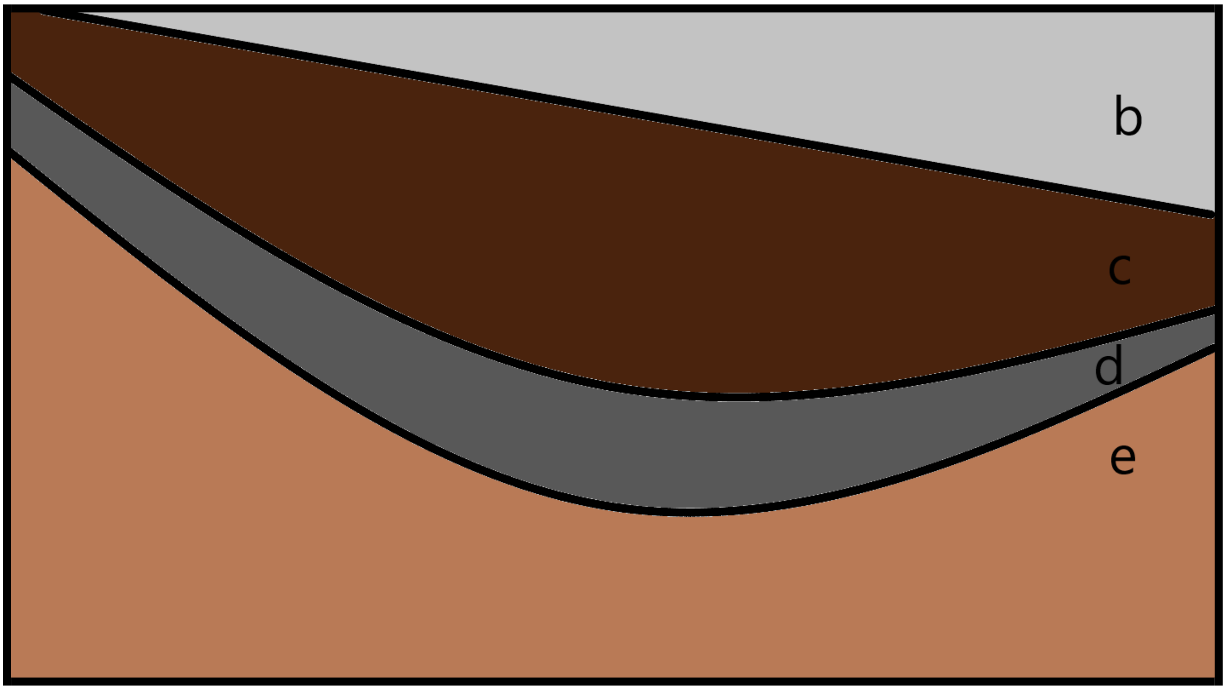
Site 1



Site 2



Site 3



Site 4

Using your knowledge and understanding of carbon storage methods discuss the pros and cons of each site and suggest if and where carbon could be injected.

	Site 1	**Site 2**	**Site 3**	**Site 4**
Pros				
Cons				
Where would you inject the carbon dioxide?				

4. Decide which site (from the four shown above) you would use to inject carbon dioxide in to be stored and create a model of the site to show how it could be safely stored.

Suggested Equipment

- Clear plastic food container
- Sand
- Salt
- Cleaning sponge
- Coloured water
- Plasticine
- Plaster of Paris
- Plastic

Explain how you will test your model.

Evaluation of Model

1. Was your model successful in preventing leakage? How do you know?

2. How well do you think your model compared to actual geological structures?

3. After making your model, do you still feel that the site you selected was suitable for storing carbon dioxide?

4. While making your model was there any other information that might have been useful?