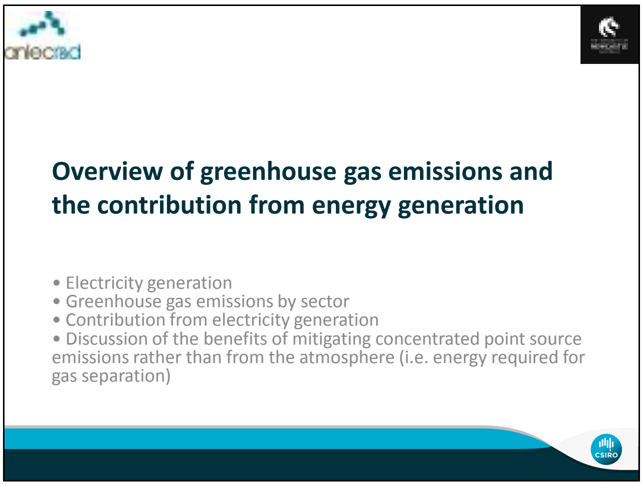
Overview of GHG emissions from energy generation



Greenhouse gas (GHG) emissions are ubiquitous with energy generation. Since the industrial revolution combustion of fossil fuels to produce heat has been the main energy source in use throughout the world. In the past this heat was converted to mechanical energy in the form of steam engines and the like. Today it is the conversion of heat to mechanical energy and then electrical energy that dominates.

Whether you use coal, oil or gas the combustion equation is essentially the same:

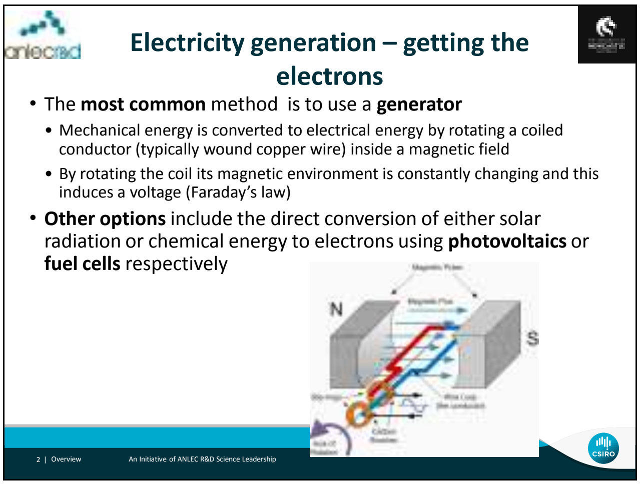
$$\mathrm{C}_x\mathrm{H}_y + \left(x + \frac{y}{4}\right)\mathrm{O}_2 \rightarrow x\mathrm{CO}_2 + \left(\frac{y}{2}\right)\mathrm{H}_2\mathrm{O} + \mathrm{heat}$$

and results in production of the GHG CO_2.

While CO_2 is not the worst GHG in terms of having the greatest ability to retain heat in the atmosphere per molecule (that award goes to sulfur hexafluoride), its presence at relatively large concentration makes it the most important.

The biggest source of CO_2 globally is from large scale electricity generation. Perversely, this large scale generation will have benefits in terms of capturing CO_2 emissions. It requires far less energy to capture from a large scale source with concentrated CO_2 emissions than from small or dilute sources or the atmosphere.

Electricity generation – getting the electrons

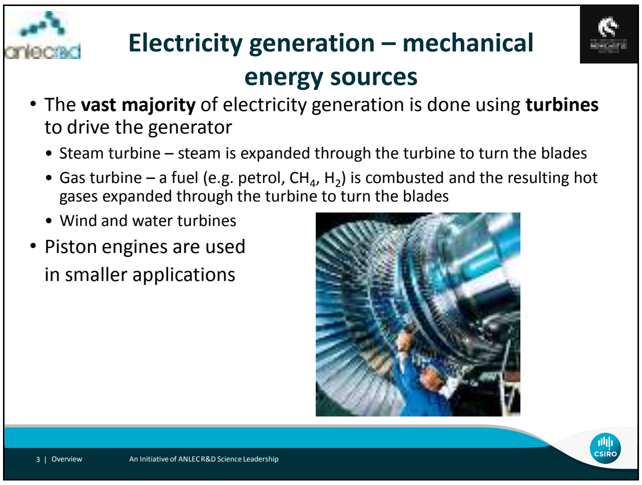


Generators

We are probably all familiar with an electric motor – a copper coil on an axle surrounded by magnets. When you apply a voltage to the coil a magnetic field is induced, and repulsion and attraction between the magnetic field of the coil and the outer magnets leads to rotation of the coil and axle. If you mechanically rotate the coil in a magnetic field the reverse occurs, and a current is produced in the coil (Faraday's law). This is the principle electrical generators use including small ones you can wind manually to charge batteries, wind turbines, to the largest power stations.

Today new classes of electrical generators exist that convert either solar radiation or chemical energy directly into electricity. Photovoltaics or solar cells rely on using solar radiation to give electrons an energy boost and set them free from a molecule such as silicon, resulting in an electric current (the photovoltaic effect). Fuel cells carry out the conversion of chemical energy into electricity via redox (reduction-oxidation) reactions. You have probably heard of hydrogen fuel cells, but there are fuel cells based on other materials as well, even coal!

Electricity generation – mechanical energy sources



Turbines

The most common source of mechanical energy to turn the axle and coil of an electricity generator is a turbine. Turbines consist of a blades attached to an axle, much like a fan. A gas or liquid passing over the blades applies a force to them and causes the blades and axle to rotate.

Steam turbines

Steam turbines are typically used in large-scale base load power stations. Water is heated by burning coal, oil or gas to produce high pressure steam and the steam is expanded through the turbines to turn the blades.

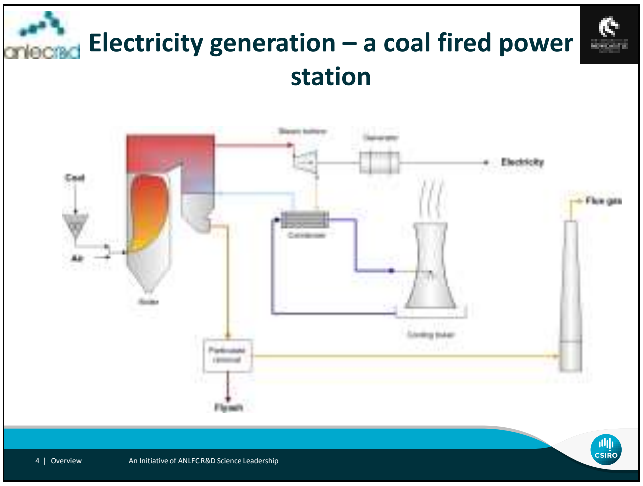
Gas turbines

Gas turbines are usually found in smaller power stations. They are often used as peaking plants (to provide additional electricity during peak demand periods) because they can be more easily turned on/off/up/down. They work by burning a gas such as methane or hydrogen in a combustion chamber. This produces hot gases under pressure that are expanded through the turbine blades.

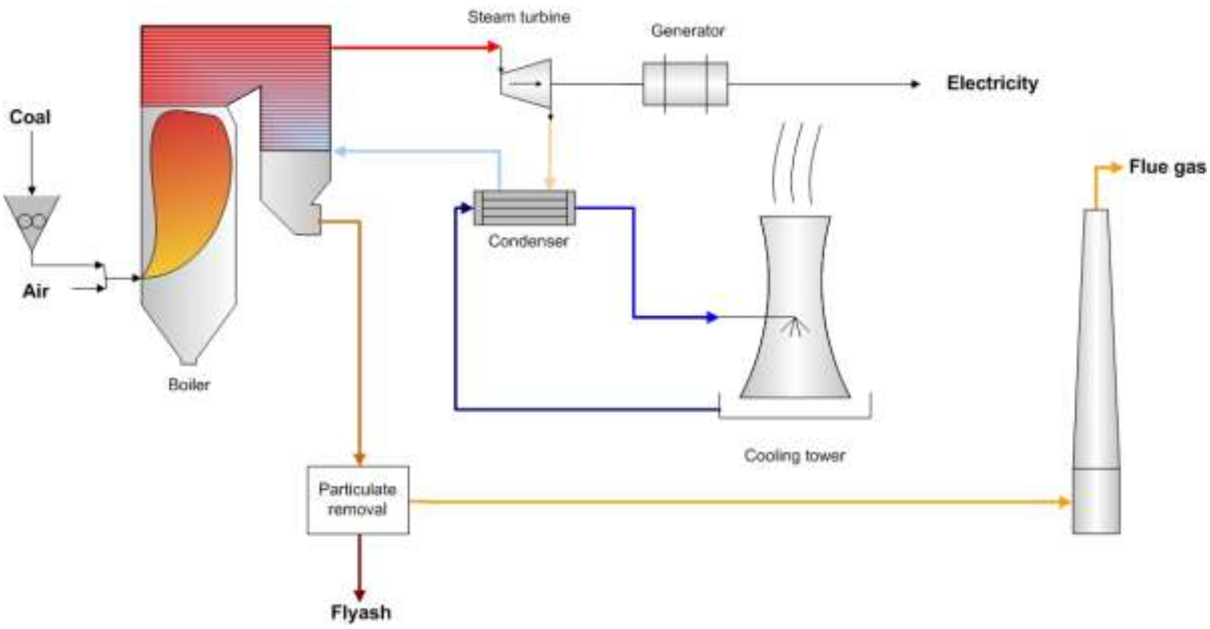
Other turbines

Flowing water can also be used to turn turbines such as in hydroelectricity plants. Wind is used to turn the blades of a turbine for wind power. Solar thermal energy may also be used to heat water to make steam or heat air to produce hot gas to drive a turbine.

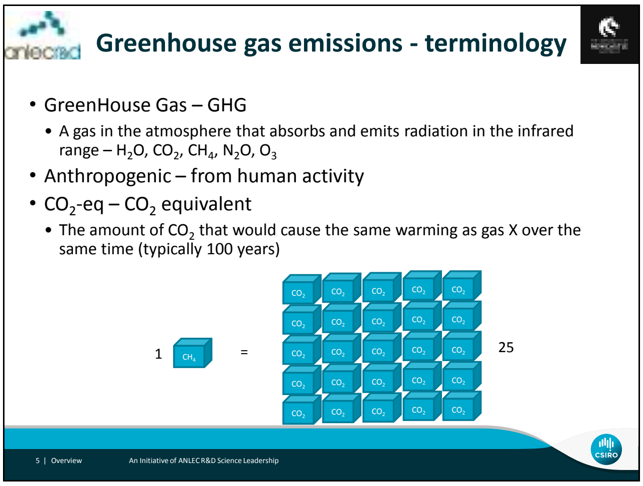
Electricity generation – a coal fired power station



Coal fired power stations are the most common type of power station in use the world over and generate most of our electricity (80% in Australia and about 45% globally). They work by burning coal in a furnace. Water is passed into the furnace in pipes and the water is heated to produce high pressure steam. The steam is then expanded through a turbine to turn the blades, which in turn turns the axle and coil of an electricity generator. Once the steam has passed through the turbine it is cooled and condensed back to water before being returned to the furnace. Because the coal is burned in air the resulting flue gas is about 80% N_2, 15% CO_2 and 5% O_2. Other gases such as sulfur and nitrogen oxides are present in small amounts as are some particulates containing heavy metals.



Greenhouse gas emissions - terminology



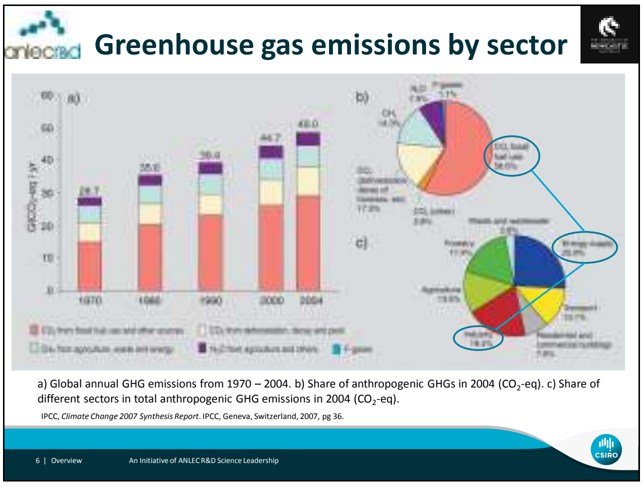
There are is some common jargon and abbreviations used when discussing greenhouse gases. The ones we will be using are given below.

GreenHouse Gas (GHG): A gas in the atmosphere that absorbs and emits radiation in the thermal infrared region. The name stems from the fact that these gases act to trap heat in the atmosphere much like a greenhouse traps heat. The most common GHG's are H_2O, CO_2, CH_4, N_2O and O_3.

Anthropogenic: This word refers to anything that is caused via human activity. It is used to distinguish the proportion of CO_2 and other GHG's whose emission is from human activity rather than natural environmental sources.

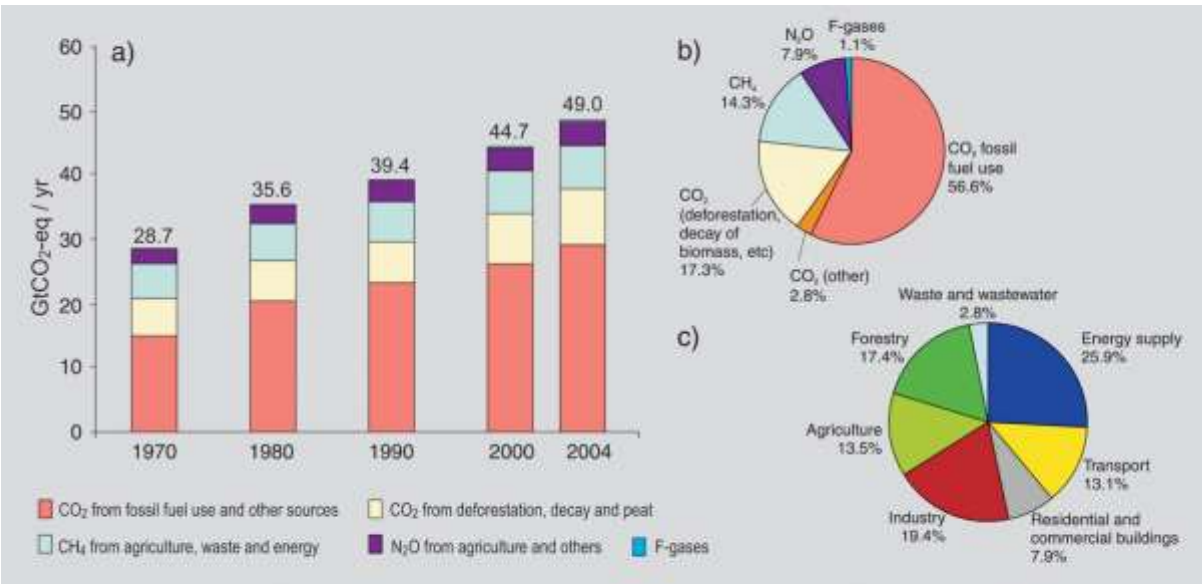
CO_2-equivalent (CO_2-eq): CO_2-eq is a measure of the warming potential of a GHG relative to CO_2. Specifically, it is the amount of CO_2 that would cause the same warming as gas X over the same time period (typically 100 years is used). For example the CO_2-eq value for CH_4 is 25. That means over 100 years 25 CO_2 molecules produce the same amount of warming as 1 CH_4 molecule.

Greenhouse gas emissions by sector

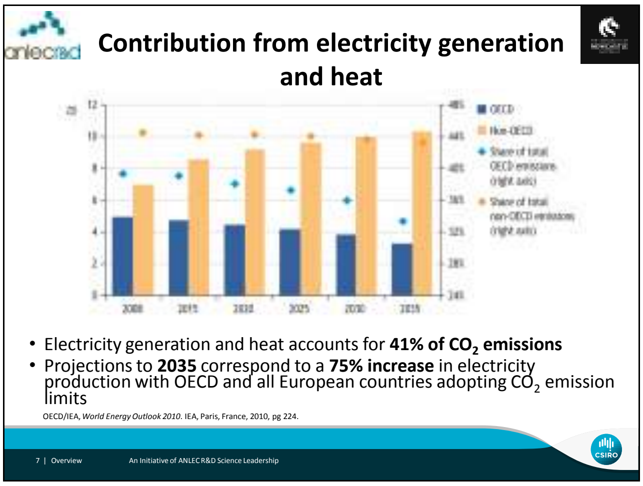


It is important to understand the sources of anthropogenic GHG emissions when thinking about the best way to reduce them. The figure below from the IPCC shows emissions for 2004. Chart a) is the total emissions of the main GHG's and chart b) is the share each gas represents of total emissions. Chart c) shows these emissions come from many different sectors in modern economies including transport (cars, trucks, planes, etc), the construction of buildings, industries like steel and cement manufacturing and the production of agricultural and forestry products. But the biggest single sector is energy supply. The second biggest source is industry. The CO_2 released by the burning of fossil fuels to provide heat and electricity for residential and industrial use accounts for almost half of global GHG emissions.

These sources are all possible targets for carbon dioxide capture and storage!



Contribution from electricity generation and heat

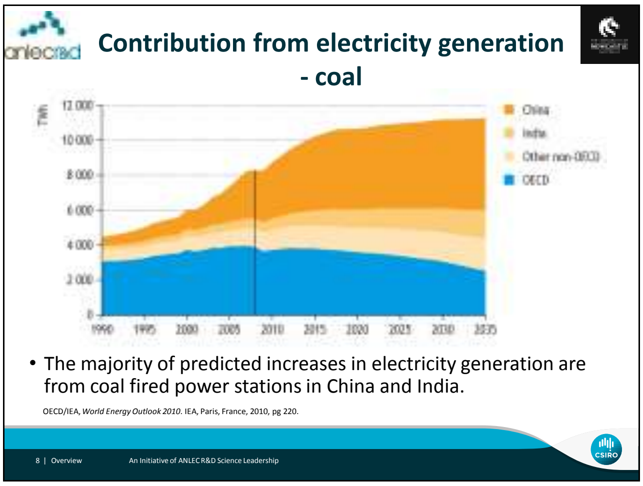


CO_2 accounts for 76.7% of total GHG emission as CO_2-eq. Since this value is in CO_2-eq the differing warming potential of the other gases has been taken into account. According to the International Energy Agency (IEA), in 2009 28 999 million tonnes of CO_2 was emitted. Of that 41% was for the generation of electricity and heat.

The reason electricity and heat are lumped together is because in many places around the world waste heat from electricity generation is used for district heating, in what are called combined heat and power plants. Also in colder climates large boilers burning fossil fuels are used just for heating.

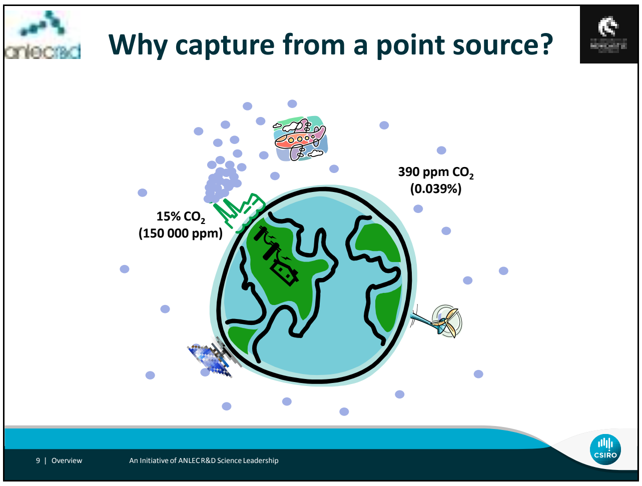
The IEA has done projections of the likely increase in electricity demand with rising population and increased electricity use in developing countries. They predict a 75% increase in electricity production by 2035. To maintain CO_2 emissions from electricity and heat near current levels would require all OECD and European countries to adopt emission limits. Since fossil fuels are likely to still be the biggest source of energy to meet this demand carbon capture and storage will have a major role to play.

Contribution from electricity generation - coal



As mentioned electricity generation is predicted to have increased by 75% in 2035. The majority of this increase is from coal fired power stations in China and India. The reason is predominantly an economic one. Building power stations is a large investment as they typically cost $1 billion+ depending on their size. More than anything, it is this predicted increase in coal fired power stations that makes it crucial to have technology available that can reduce their CO_2 emissions.

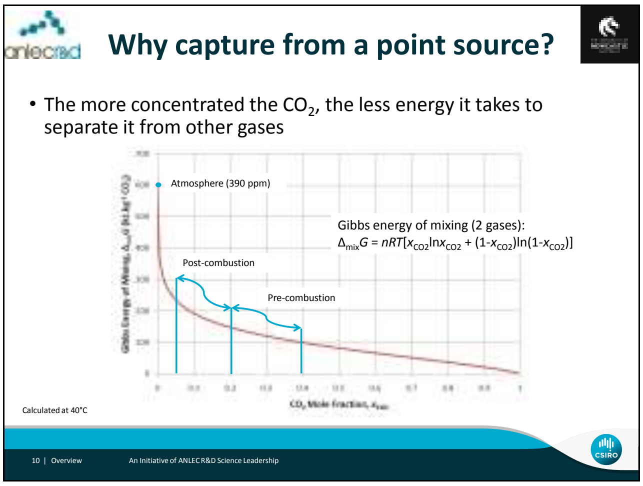
Why capture from a point source?



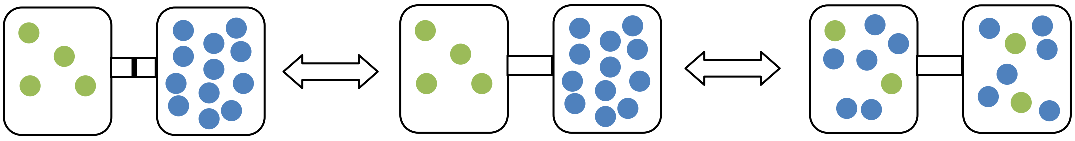
A point source is a power station, steel smelter, etc, where large amounts of CO_2 are being emitted in one place. For example the gas that goes up the chimney at a coal fired power station is 15% CO_2 (that is 150 000 ppm). Carbon capture and storage is focused on capturing CO_2 from these types of sources, but why? In principle it's possible to capture CO_2 directly from the air rather than from a power station chimney. This would have the advantage of being able to be done anywhere meaning you could easily locate your capture plant near good CO_2 sequestration sites.

It comes down to concentration. The concentration of CO_2 in air is only 0.039% (390 ppm) and this low concentration means you have to put a lot more energy in to capture the same amount of CO_2.

Why capture from a point source?



So why do you need less energy to separate CO_2 from a concentrated point source than the air? It's simple thermodynamics! The minimum amount of energy you need to separate 2 gases is the change in the Gibbs energy when they are mixed. Consider the illustration below where we have 4 molecules of a green gas and 12 molecules of a blue gas separated by a valve. We open the valve and let the gases mix. If the Gibbs energy of mixing is $\Delta_{mix}G$ Joules per molecule (we have 16 molecules) then for the green gas we get an energy of mixing of $16 \times \Delta_{mix}G$ / 4 (Joules / molecules green gas) and for the blue gas $16 \times \Delta_{mix}G$ / 12 (Joules / molecules blue gas). So the more concentrated the CO_2 source the less energy we need per molecule of CO_2 to do the separation.



2 gases in separate containers with a valve in-between | open the valve and let them mix | now they are mixed

The chart below is the Gibbs energy of mixing in kJ per kg of CO_2 for two gases as a function of the CO_2 mole fraction in mixture. The value at 390 ppm is more than 3x greater the value at 15% CO_2 (a mole fraction of 0.15).

Why capture from a point source?