ENERGY FOR HUMANITY

CARBON CAPTURE & STORAGE

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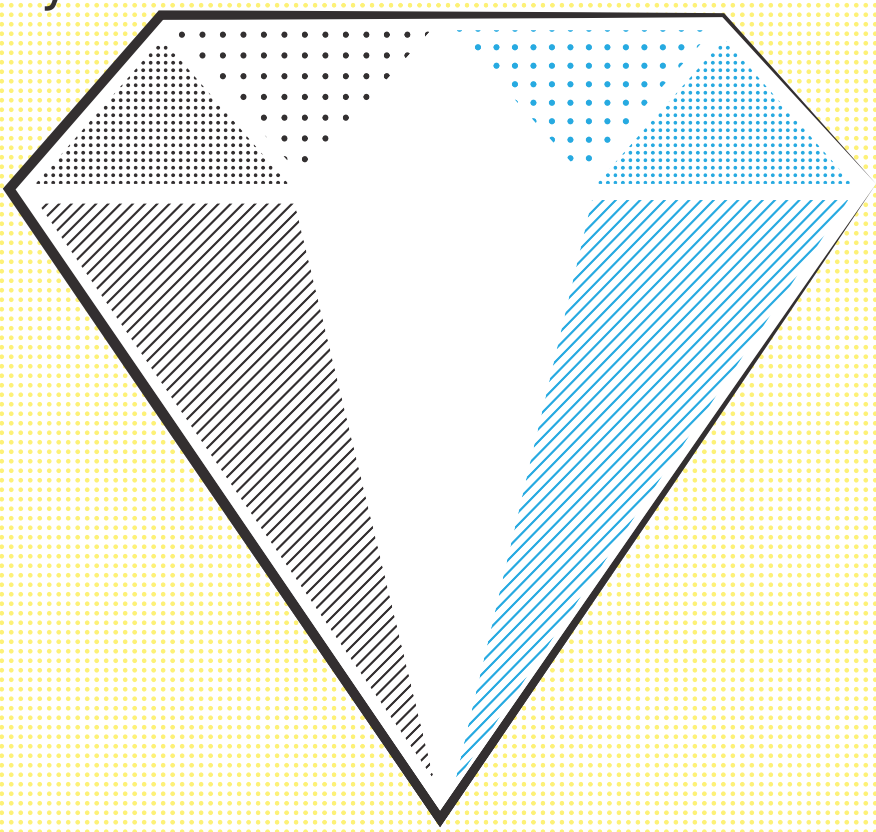
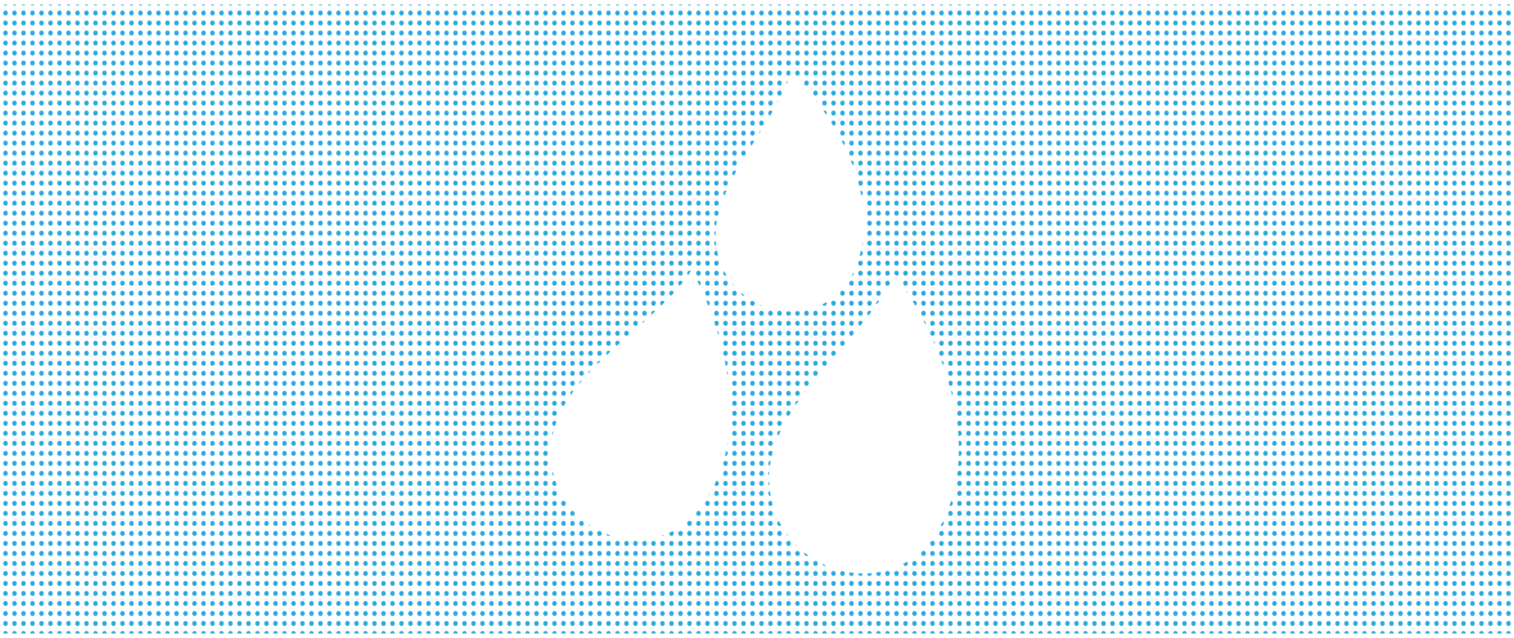




Can we use continue to use fossil fuels and capture the CO_2, with retrofit or low cost improvements to current technology? This note outlines three leading ways to capture CO_2 from power generation.

If we can electrify transport and heating, and make electricity zero carbon, we can substantially decarbonise industry and domestic energy.

Land use change and agriculture will still be emitters but there are other routes to tackle these. While renewables create nearly CO_2 free power, they do not produce at all times and storage is not capable of smoothing out their biggest excursions in countries with significant seasonal variability.

Nuclear is a leading contender for zero carbon energy but existing nuclear technology is expensive and slow to build. Very much more promising, 100% safe technologies are in development but may not be deployed for a while.

We would really like to be able to continue to use fossil fuels and capture the CO_2, with retrofit or low cost improvements to current technology.

There are three leading ways to capture CO_2 from power generation, some of which also apply to cement and/or steel production:

Oxyfuel combustion burns coal or natural gas with oxygen separated from air, often diluted with CO_2 to control temperature. The exhaust gas is mostly CO_2 and water, which condenses on cooling. The CO_2 is dried, compressed to around 70 atmospheres and transported by pipeline to geological storage or use such as enhanced oil recovery. The air separation and CO_2 compression both use additional power and hence reduce the efficiency of generation. Both processes usually need expensive additional equipment, although a novel oxyfuel cycle under development by NetPower may be able to produce pipeline ready CO_2 with effectively the same capital cost and efficiency as a conventional top quality gas fired power station.

> It is very likely that CO_2 removal from the atmosphere will ultimately be needed to stabilize the climate.

Integrated Gasification Combined Cycle (IGCC) converts coal to a mixture of hydrogen, CO_2, carbon monoxide and hydrogen. This 'syngas' is cleaned up to remove particulates and sulphur, and the carbon monoxide with added steam is catalytically converted to more CO_2 and hydrogen. Once the CO_2 is stripped out and compressed for pipeline transport, the hydrogen can be burnt in a combined cycle power plant, with some of the waste heat used for drive the gasification (hence the 'integrated'). The energy losses and additional equipment both add to the cost of the electric power produced.

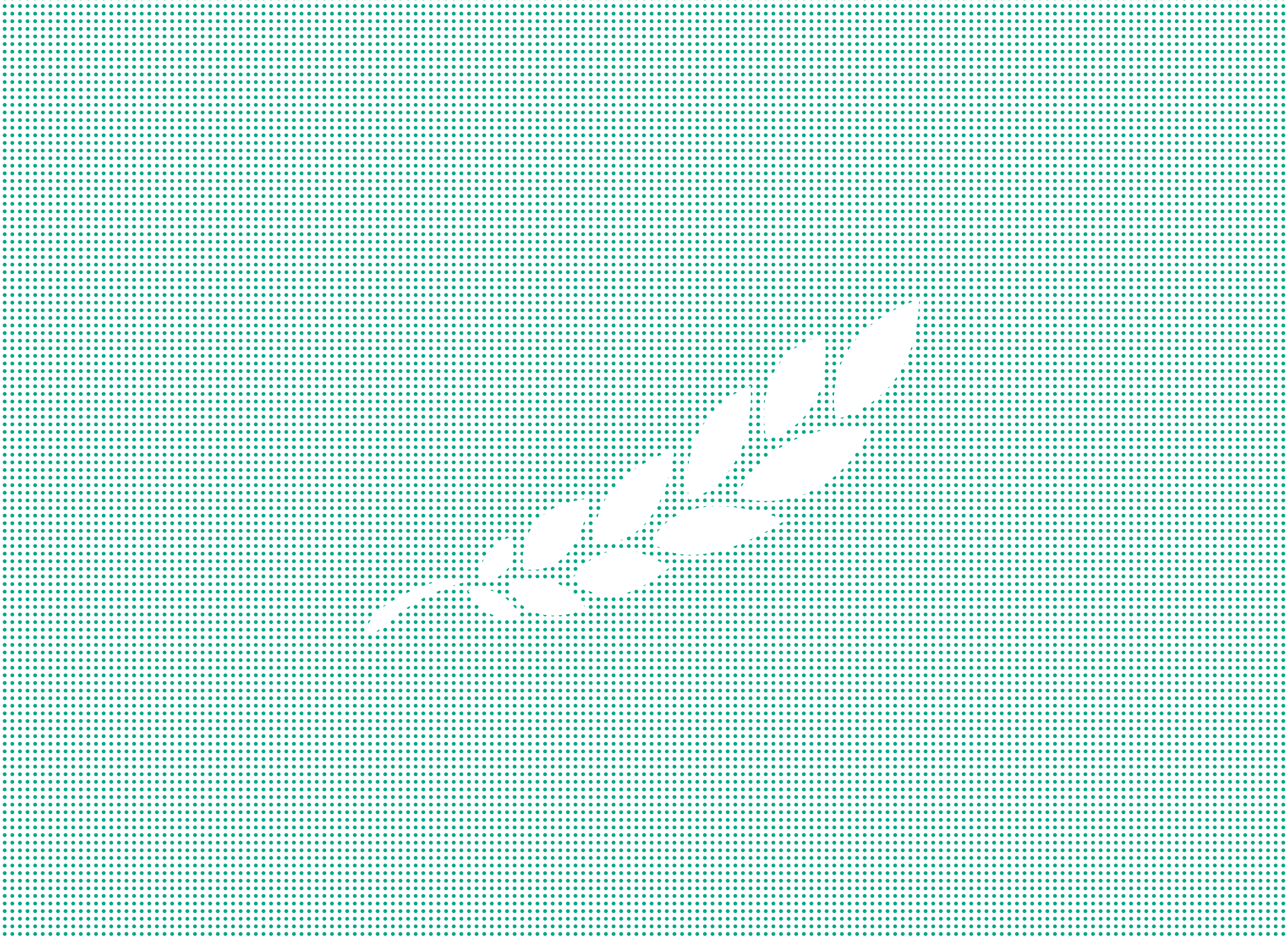
'**End-of-pipe'** typically can be retrofitted to existing coal and gas fired power plants. The flue gas is 'scrubbed' by drizzling a CO_2 absorbing liquid through it. The saturated liquid is then confined and heated, which releases the CO_2, ready for compression. Once again, the required heat and compression energy reduce the efficiency of the power generation and add capital costs.

Oxyfuel and end-of-pipe appear most promising at the moment and both are under intensive development. IGCC is a combination of known technologies but it is challenging to integrate all the components. Gas is typically easier to clean up than coal. It burns cleaner, so CO_2 separation is easier and, compared to coal, less than half the CO_2 per MWh of power must be captured and transported.

One company www.skyonic.com is working on CO_2 mineralization as part of the capture process. At small scales, the products are valuable and can displace more CO_2 intensive variants of the same material, Eventually, they will swamp the market and, like everyone else, Skyonic will need to be paid to capture CO_2.

CCS projects usually make economic sense at very large scale and hence the absolute amounts of money needed to build them are large. Governments have subsidised wind and solar at levels which could make CCS economic, but the total subsidy is much less obvious, hence more palatable than it would be for a CCS project. New technologies such as Netpower (https://netpower.com) may reduce costs to the level where CCS is substantially lower cost than renewables, once the costs of grid integration at high penetration are taken into account.

It appears very likely that CO_2 removal from the atmosphere will ultimately be needed to stabilise the climate. Reducing the amount of CO_2 going into the air is currently less expensive than taking it out and so should be deployed until cost effective projects are all done. But very little research into CO_2 removal has been done and we have little idea about what is possible.



There are three main routes:

Direct absorption by some kind of solvent: this is quite inefficient since the the CO_2 concentration in air is 1/100th of that in flue gases.

Via biomass, which not only captures the CO_2 but converts it to carbon. Biomass could be used in conventional CCS generation, thereby generating CO_2 negative power. Alternatively, biomass can be converted to biochar (similar to charcoal), which improves soil quality and is stable for centuries to millennia. But (see note on biomass to power) there are some not well understood constraints on large scale biomass production which may make the biomass approach invalid or scale limited.

Out of seawater, where the CO_2 concentration is many times higher than in air. The seawater concentration is in equilibrium with air at the surface, but it takes many centuries for the deep ocean to come into balance. Note that the acidification of seawater may have catastrophic effects on the marine food chain and hence fisheries, so direct CO_2 removal from seawater will probably have beneficial consequences.

Is Carbon Capture and Storage Geoengineering?

Some see CO_2 removal from air as geoengineering and therefore a bad thing. However, arguably putting CO_2 into the atmosphere is geoengineering, while reversing it is not. Given the lack of progress to date on emissions reduction, it appears very likely that CO_2 out of the air will be needed, even if we completely carbon neutralise the power system in the coming decades. Hence CCS technology is a necessary part of every low carbon scenario.