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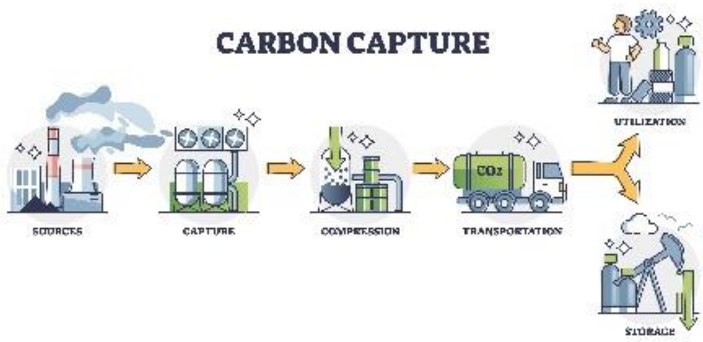
Carbon Capture and Storage (CCS) - Energy Hurdles

Carbon dioxide Capture and Storage (CCS) is an evolving technology aiming to enable the continuing use of fossil fuels (coal, natural gas, crude oil) while mitigating the global warming potential of the carbon dioxide produced by fuel combustion.

The goal of CCS is to capture and sequester the CO_2 from fossil fuel combustion while generating the smallest possible amount of additional CO_2. However, CCS has thermodynamic challenges – the energy required by the unavoidable physics of the CCS process.

The thermodynamic challenges can be considered as series of hurdles to feasible CCS operation:

1. **Capturing** CO_2 from the exhaust stream
2. **Compressing or liquefying** CO_2 to a feasible density for transport
3. **Transporting** CO_2 to the storage site
4. Securely **injecting** CO_2 into the disposal site.



Hurdle 1: Capture

The more concentrated the CO_2 is in the exhaust stream, the more efficient it is to capture and separate it from the other gas stream components (in terms of energy spent per kg CO_2 captured).

Consider an Acid Gas Removal Unit (AGRU) in a natural gas processing plant where the gas composition consists of 12 to 18 mol% CO_2. The other gas components are mostly methane, ethane and other hydrocarbons. Natural gas at the processing stage is very free of solids, dust and soot. The capture can take place at a pressure which increases efficiency for absorbing CO_2 into an amine solvent or pushing it through a separation membrane. Typical processing conditions are 60 barg (~60 times atmospheric pressure or 60 atm) and approximately 20 to 40 deg C.

Contrast that with extracting CO_2 from combustion exhausts where the CO_2 is not only more dilute but at low pressure. The other gases include inert nitrogen, some unburnt fuel, as well as fumes and soot from the combustion process, making it a dirty stream. The condition of the stream is difficult for CO_2 absorption – high temperatures and low pressures. With so much heat energy and room to move (that is what low pressure means), the CO_2 molecules are much harder to convince to get into an absorbent or move through the molecule-sized spaces in a membrane. Typical exhaust temperatures are 400 to 500 deg C, decreasing to 200 to 300 if there is waste heat recovery water cooling. Pressures are less than 1.5 barg under normal exhaust venting conditions. Higher pressures would cause the engine producing the exhaust to lose power and burn more fuel, resulting in more CO_2 being produced.

Some select situations may offer ideal CO_2 capture for efficiency, for example, high CO_2 concentration, large continuous volumes, access to extremely cold cooling water. However the great majority of fossil fuel combustion situations do not offer these conditions e.g. gas and diesel-fired power stations, diesel power ships, car, and truck exhausts.

Hurdle 2: Compression and/or Liquefaction.

Once the CO_2 is removed from the exhaust stream it must be compressed and or liquefied to make transport feasible. As a gas at atmospheric pressure, it is about 1000 times less dense than its liquid form. Compression takes energy. Above 5.1 bara (about 5 times atmospheric pressure), CO_2 can be cooled until it becomes liquid at -55.6 deg C. CO_2 is tricky to deal with because below 5.1 bar pressure, CO_2 sublimes from dry ice to a gas, and vice versa, skipping the liquid phase completely.

Carbon dioxide is very corrosive in the water/ aqueous phase. Wet CO_2 eats through carbon steel very quickly and is a primary form of steel corrosion. Also, if you are going to liquefy CO_2 it must be chilled to -55 degC, so any water would form ice and clog the process equipment. To enable cheap transport by pipe or ship it must be dehydrated. The dehydration process will again require energy incurring additional CO_2 emissions.

Hurdle 3: Transport

One of the great problems for CO_2 disposal is that most of the small number of available disposal sites are deep below ground, and rarely near the (proposed) point of capture. Disposal sites are predominantly known pressured aquifers with a proven pressure containment seal or depleted hydrocarbon reservoirs.

Getting the CO_2 from the point of compression/liquefaction to the disposal site will require energy, ie. to power a ship or push the CO_2 through a pipeline. That energy will need to come from burning fuel for the ship or power generation equipment, thus further CO_2 will be emitted.

Hurdle 4: Storage - Sequestration

Sequestration is the process of pumping the CO_2 into the below-ground aquifer or depleted hydrocarbon reservoir system (i.e. porous rock) that will hold the CO_2, hopefully for thousands if not millions of years.

To get it into the reservoir it will need to be pushed down a well-hole (50 - 525mm diameter) lined with steel tubing.

Most sensibly proposed reinjection sites are at least 1000m deep - any shallower, and the risk that the CO_2 will make it back to the surface is too high. The pressure at 1000m is normally around 100 bar (~100 times atmospheric pressure). The reason the pressure is so high is the concept of "hydraulic gradient" or "static head". The density of liquid CO_2 in the injection well tubing helps create pressure, improve injection and prevent backflow to surface.

However, the friction in the steel tubing and the friction in squeezing the CO_2 into the porous sands or rock will mean the surface pumping pressure is still considerable. Again, CO_2 will be generated while providing the energy for the pumping.

Industry specialists have estimated that coal-fired power stations will need to raise power prices by 50% to make CCS viable. The price increase will be for the capital and operating cost of the process equipment for CCS. The largest part of the operating cost will be the additional fuel required to power the CCS process. In broad terms, around 15% - 50% of additional CO_2 will be generated in producing the energy to power the CCS process. The lower limit, 15%, is where the situation is close to ideal – high pressure, high concentration CO_2 close to the disposal site. The 50% figure is not a limit. It could easily be exceeded if the CCS process is poorly designed and operated, to the point where the CCS process could even generate more CO_2 than is disposed!

Game Changers

There are several factors that could significantly improve the viability of CCS opportunities:

1. An efficient means to transport liquid CO_2 to distant injection sites, ie. via pipeline or an efficient CO_2 carrier ship. (Read more here: CO2-NH3 Carrier Design)
2. Processes that avoid compression – such as conversion of CO_2 to an insoluble solid such as Magnesium Carbonate. This replaces the compression step with a chemical reaction. Some mining companies have been investigating using their spent high magnesium oxide tailings to capture CO2 in just this way.
3. Use of renewables to power the CCS process. Obviously, this makes little sense for power generation (i.e. why not just use the renewable power directly and avoid the CO_2 generation?), but may be more logical where (for example) the CO_2 is coming from fertiliser production and CO_2 generation is not avoidable.

Conclusion

The capture, compression, transport, and final storage of CO_2 is typically an energy-intensive process that generates additional CO_2. Capture of all vented CO_2 from existing infrastructure and equipment is never going to be feasible; however, many CCS projects will be feasible with thoughtful opportunity identification and system design.

Participants in CCS projects should be mindful of the overall goal and efficiencies of the overall CO_2 capture-to-sequestration process, and challenge poor design and inefficiencies. The last thing anyone wants is a CCS process that fails to clear the hurdles and generates more CO_2 than it sequesters.