Carbon Capture and Sequestration: Possibility or Myth?

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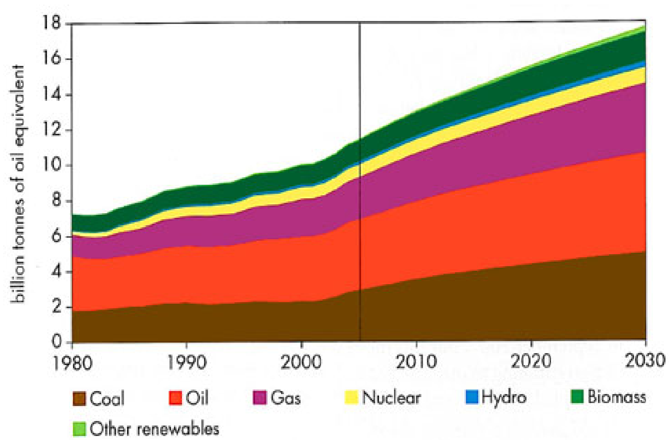
Abstract

GLOBAL carbon dioxide (CO_2) emissions are rising at levels higher than can be contained by the natural sequestering system, thus leading to climate change. Carbon Capture and Sequestration (CCS) has become a widely talked-about and speculated venture on behalf of cleaning up CO_2 generated from energy and industrial processes. As the amount of CO_2 in the atmosphere continues to increase each year, carbon sequestration projects have grown, but at a high cost. The viability of carbon sequestration is questioned due to its high cost, little research and development, and the inherent storage safety risks, primarily the threat of geological change in the rock formations once CO_2 is injected into the storage site. In order to attain greater energy output efficiency, it is necessary to create further carbon sink and sequestration sites. The following is a detailed analysis of the viability of carbon sequestration and some existing and pending projects.

What is sequestration and is there a need for it?

At present, 50 percent of the United States' energy output is produced from coal, since it is abundant and a seemingly cheap fuel source, given that environmental and health costs are not included in the price of coal, but are borne by society at large.[1] When burned, fossil fuels emit large quantities of CO_2, a leading greenhouse gas, as well as other noxious or toxic gases. Currently, coal and other fossil fuels, which produce vast amounts of carbon, continue to be used as the primary source of energy. As such, carbon capture and geologic sequestration is thought to be the way of the future. The idea calls for on-site capture of carbon, followed by geologic sequestration of that carbon into "unminable coal seams, abandoned natural gas reservoirs, deep saline reservoirs and depleted and marginal oil fields."[2] In the United States, there are approximately 3,000 miles of pipeline dedicated to CO_2, which are controlled and regulated to watch for CO_2 loss.[3] Common sources of CO_2 emissions are fossil fuel power plant stations, oil and natural gas processing plants, "cement manufacture, iron and steel manufacture, and the petrochemical industry."[4] See Diagram 1 for an overview of geological storage options and Diagram 2 for an illustration of the carbon sequestration process.

There is a vital need for geological sequestration of carbon due to the amount of carbon currently in the atmosphere, and because of future growth in demand for energy. The International Energy Agency states that by 2030, global energy demand will increase by 50 percent (70 percent of that coming from developing countries, a third of which is China).[5] The following chart shows the projected growth in fossil fuel usage and energy demand through 2030:



CCS is vital as the Earth reaches the point of no return with regard to atmospheric CO_2 saturation. The Intergovernmental Panel on Climate Change concluded in 2001 that countries "must reduce global greenhouse gas emissions to 25 percent below 1990 emissions by 2050 to reach climate stabilization at 450 parts per million (ppm), or 45 percent above 1990 emissions to reach 550 ppm."[6] Specifically for the United States, this means an 80 percent reduction of 1990 levels by 2050 to achieve

450 ppm or 60 percent reduction of 1990 to achieve 550 ppm.[7] However, CCS has faced challenges in getting off the ground because of the high cost of projects and their failure rates. Thus, to reduce carbon in the atmosphere, a generalized plan needs to be developed to include an increase in energy efficiency, using less carbon-emitting fuels, maintaining and broadening carbon sinks through vegetation, and through improving energy extraction and storage from renewables, which is beyond the scope of this paper.[8]

What is carbon capture?

As the second diagram shows, carbon capture is most easily attained from a stationary source such as a power or manufacturing plant. Three types of carbon capture exist: pre-combustion, post-combustion, and oxy-firing; however, improved technology needs to be developed to make the cost of carbon capture competitive.[9]

Pre-combustion capture involves a process through which coal is brought into contact with steam and oxygen, producing a synthetic gas called syngas (formed mostly of carbon monoxide, CO_2, and hydrogen).[10] This syngas is then used to create electricity in a turbine; the CO_2 is removed before electricity generation.[11] In post-combustion capture, the CO_2 is separated from the flue gas after the coal is burned.[12] Lastly, oxy-firing involves fuel combusted in pure oxygen, thus producing less flue gas and reducing the noxious gaseous emissions (75 percent less than air-fueled combustion, which is used by most major power plants and exhausts CO_2 diluted with nitrogen. The exhaust is made up of 80 to 90 percent water vapor, which eases the CO_2 capture process).[13] Diagram 3 shows the different methods of carbon capture and their chain: pre-combustion, post-combustion and oxy-firing.

The current cost of CO_2 capture is far too expensive for actual "carbon emission reduction applications" at $150 per ton of carbon.[14] SFA Pacific, Inc. also surmised that adding additional carbon capture technology could increase the cost of electricity from 2.5 cents to 4 cents/kWh.[15] The capture portion of the carbon capture, storage, transport and sequestration storage process account for approximately 75 percent of the cost of the process.[16] This is due to the extreme supercritical phase that the CO_2 must reach in order to be liquefied and put into the transit means. The cost of CO_2 capture as depicted in the following chart varies according to the type of plant and technology being used.[17] Carbon capture ultimately appears fruitless given the lack of R&D invested in developing more economical methods of carbon capture. Several types of programming can be developed to relieve the cost of carbon capture, such as: technology that separates the carbon and then stores it, such as chemical absorbents and membranes; and retrofittable CO_2 capture options for plants that are already in existence, such as ammonium carbonate slurry, which could be scalable and less energy intensive, thereby keeping the costs lowered.[18]

THE COST OF CO_2 CAPTURE FOR VARIOUS INDUSTRIAL PROCESSES
(see appendix for sources and assumptions)

Plant Type	Capture Process(es)	Cost Estimates for Capture & Compression	Factor(s) Driving Cost of Capture and Compression
Steam Rankine Power	Chemical Absorption (amines)	\$25–\$60/tCO_2	CO_2 content in flue gas stream, capital cost and energy requirements for solvent cycling
IGCC Power	Physical Absorption	\$25–\$40/tCO_2	CO_2 content in flue gas stream, capital cost
Refinery Flue Gas	Chemical Absorption/ Flue Gas Recycling	\$35–\$55/tCO_2	CO_2 content in flue gas stream and capital cost, energy requirements for solvent cycling (if applicable)
Steel	Flue Gas Recycling/ Chemical Absorption	\$20–\$35/tCO_2	CO_2 content in flue gas stream and capital cost, energy requirements for solvent cycling (if applicable)
Cement	Flue Gas Recycling/ Chemical Absorption	\$35–\$55/tCO_2	CO_2 content in flue gas stream and capital cost, energy requirements for solvent cycling (if applicable)

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CCS Projects: How viable are they?

There have been various technologies and projects attributed to CCS. Firstly, with regard to energy extraction from coal technologies, two specific technologies yield greater efficiency than the traditional pulverized coal plants: the supercritical pulverized coal (SPC) and the integrated gasification combined cycle (IGCC). The latter offers higher efficiency than the former.

IGCC technology is complex. It involves four major steps: gasification, syngas cleanup, power generation through a gas turbine combined cycle, and finally, a cryogenic air separation.[20] IGCC is proven to remove 90 percent of the carbon from its emissions, and does so pre-combustion. However, the process has not been commercialized. Thus, anyone who ventures to build an IGCC plant faces the possibility that the technology may not be what it seems and the costs may be much higher than the estimates.[21]

IGCC has been found to be more efficient than SPC. According to the EPA, at a cost of $7 or more per ton of CO_2, by 2012, IGCC CCS will emit lower levels of CO_2 than SPC. Also, adding CCS capabilities to IGCC is much cheaper than adding them to SPC (because capturing CO_2 in IGCC is much less energy-intensive than SPC).[22]

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An example of IGCC in action is the FutureGen project, which started in 2003 under President George W. Bush and was promoted as a zero-emissions coal-fired power plant. In January 2008, after selecting a site in Illinois due to the presence of deep saline rock formations and the lack of faults cutting through those formations to accommodate CO_2 storage,[23] the Department of Energy (DOE) announced that it would restructure the proposal and call for commercial involvement due to the high costs of the project for the government (the FutureGen alliance was also covering a share of the cost). The cost of the project is estimated to be 1.5 billion dollars, mostly concentrated in CCS.[24]

The longest-running carbon sequestration project in North America is in Saskatchewan, Canada: the Weyburn Enhanced Oil Recovery Project. The project, which started in 2001,[25] has stored five million tons of CO_2 and has a capacity of 30 million tons. As of 2005, there had been no reported CO_2 leaks.[26]

Another successful project is in Algeria: the In Salah project. Since 2004, it has injected 1.2 million tons of CO_2 per year into a sandstone reservoir 1,800 meters deep, and it has a capacity of 17 million tons.[27]

Another notable venture is the Otway Project. CO2CRC's Australian Otway Basin Project has successfully stored 10,000 tons of CO_2 greenhouse gas underground.[28] The gas was converted into liquid and then stored about two kilometers away in a depleted natural gas reservoir, where it is monitored by a geosequestration monitoring system.[29] Thus far, the liquefied CO_2 has behaved as predicted.[30] The cost of the Otway Basin has been approximately 30 million dollars.[31] The technology behind the project involves extracting the CO_2 and compressing it into a supercritical state in a compressor/refrigerator.[32] Diagram 4 shows two wells 300 meters apart. CRC 1 injects the CO_2 into the reservoir while Naylor-1 monitors the gas and fluids coming from the formation.[33] The project is expected to sequester 100,000 tons of CO_2 deep underground.

Looking at these projects, it would appear there is a large amount of CO_2 storage space even when the annual global CO_2 emissions rate is measured at about 23 to 28 billion tons.

Last but not least is the offshore and ocean storage of CO_2. The CO_2 from the stationary source is compressed and then transported via ocean or pipeline.[34] The major difference between offshore sequestration and ocean storage is that with offshore storage, the CO_2 is injected deep into a formation under the ocean seabed away from the water, while in ocean storage, CO_2 is injected into the water column at 1,500 to 3,000 meters to be dissolved, or below 3,000 meters to form a CO_2 lake.[35] An example of successful offshore sequestration is at Statoil's Sleipner Field in the North Sea, located 250 kilometers off Norway. The project has been ongoing since 1996. The CO_2 is separated from natural gas and then stored in a "deep saline formation" at 1,000 meters under the seabed.[36] Presently, there are no projects on ocean sequestration.

Is CCS an actual option?

CCS faces many obstacles. There are questions of monitoring and safety, of the susceptibility of rock formations to faults, and of course, the cost. Despite these concerns, there is a customer base for CCS. In Europe, 12 CCS plants using various technologies are in the works.[37] In Spremberg, Germany, a privately funded coal-burning power plant captures 95 percent of the CO_2 it emits.[38] The plant, which cost $100 million, liquefies the CO_2 and then transports it 220 miles to a depleted gas field in Northern Germany. Eventually, it will be transported by pipeline to improve efficiency.[39] German environmental groups have protested the building of the plant, stating that the building of any coal plant is not part of a sustainable future.[40] As far as customers in the United States, there is a viable market. For example, 95 percent of the 500 largest CO_2 emitting plants are within 50 miles of a "candidate CO2 reservoir."[41]

Another major viability issue is cost and research, which are ultimately related to the development of more efficient technology. The U.S. DOE's National Energy Technology Laboratory has a Carbon Sequestration Program, whose ultimate goal to decrease the cost of CO_2 capture from industrial sources and create knowledge on carbon storage, capacity, and safety.[42] One stage of the program is core R&D, working on the development of new technology for minimizing greenhouse gas emissions from industrial processes. This has ultimately resulted in computer programs modeling carbon sequestration and storage space.[43] Another stage is Demonstration and Deployment, which aids in the development of technologies through initiatives such as the DOE's Regional Carbon Sequestration Partnerships.[44] These are collaborations funded by the DOE among "government, industry, universities, and international organizations" to create regulations and infrastructure for carbon sequestration.[45] It would appear that the United States is betting on carbon sequestration; the amount of money and development being put into carbon sequestration at the DOE is impressive. The United States is attempting greater energy independence, which involves using more domestic resources. The most developed and abundant at present are fossil fuels.

"... who would want to live near a rock formation injected with liquefied CO_2?"

Carbon sequestration does have many obstacles. Of note are the cost of technology and pipelines, the lack of technological advances, and the safety of storing pressurized CO_2, a poisonous gas, anywhere near communities. IGCC has shown promise, but has ultimately failed in FutureGen. Additionally, who would want to live near a rock formation injected with liquefied CO_2?

Recommendations and Conclusion

CO_2 is a problem, and carbon sequestration is only a part of the solution. Ultimately, a future dependent on more coal plants is unsustainable specifically because there are available technologies today that can produce coal's energy output with less environmentally damaging results, particularly with much lower CO_2 emissions. Current coal plants must be retrofitted with scrubbers, and when they are to be decommissioned, the land should be reforested, thereby returning to carbon sinks rather than carbon producers. We advocate a future in efficiency, renewable energy, nuclear plants and, if necessary, hybrid natural gas-coal plants.

The recent March 2009 Waxman-Markey bill, otherwise known as the American Clean Energy and Security Act, puts a strong emphasis on U.S. energy independence. The bill calls for additional investment in energy technology and greater usage of renewables. Chairman Waxman said that "this legislation will create millions of clean energy jobs, put America on the path to energy independence, and cut global warming pollution...Our goal is to strengthen our economy by making America the world leader in new clean energy and energy efficiency technologies."[46] The new bill will require a renewable electricity standard that six percent of electricity must come from renewables by 2012, and 20 percent by 2020, of which five percent can be achieved through efficiency improvements. The types of renewables that can be used are solar, wind, geothermal, biomass, "marine and hydrokinetic energy, biogas and biofuels derived exclusively from eligible biomass, landfill gas, wastewater-treatment gas, coal-mine methane, hydropower projects built after 1992, and some waste-to-energy projects."[47] We recommend that R&D funds be put towards finding a way to store renewably-produced energy for longer periods of time so that they are more easily dispatched. In addition to major storage issues, R&D funding should support renewable technologies such as solar-thermal energy in order to replace coal's baseload capability.

"We recommend, as a hedge against CCS failure, that hybrid plants using natural gas and coal become the default in place of coal plants."

The bill also requires emission cuts that would start in 2012 and a cap-and-trade program to be implemented by 2016. This program would phase in energy permits, of which only five percent would go to merchant coal generators that have long-term contracts with electricity generators (which would eventually be phased out from 2026-2030).[48] Another two percent would go to electric utility companies from 2014-2017, with another five percent coming in once CCS technologies are developed and implemented (if that ever comes to fruition).[49]

The bill directs 60 billion dollars to CCS technology by the year 2025. New coal plants would be built up to the year 2020, although they are expected to have CCS technology. By 2025, the coal plants would be required to capture 50 percent of their emissions (coal plants built after 2020 would have to capture 65 percent of their emissions). This bill places a heavy bet on the outcome that CCS will become a likely technology; however, it is neither viable nor feasible.

We recommend, as a hedge against CCS failure, that hybrid plants using natural gas and coal become the default in place of coal plants. Natural gas burns more cleanly than coal and is a much more efficient producer of electricity. If fossil fuels must continue to be used, then natural gas is the cleanest route. Furthermore, we advocate investment in improving energy efficiency output through nuclear energy and in the development of storage cells, so that renewable energy can increase its share of the energy market and help replace the use of coal.

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Diagram 1

Geologic carbon sequestration through carbon injection at various storage sites. [1]

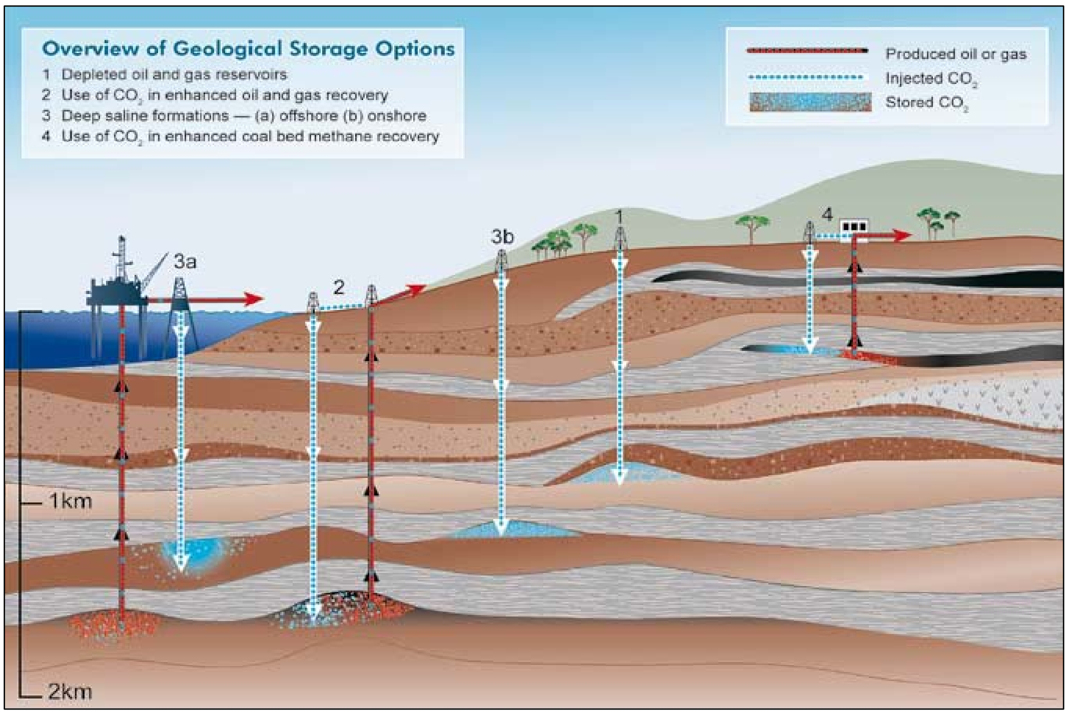


Diagram 2

On-site capture of carbon followed by its transport (usually by pipeline, sometimes by road, rail or ship) and sequestration. [li]

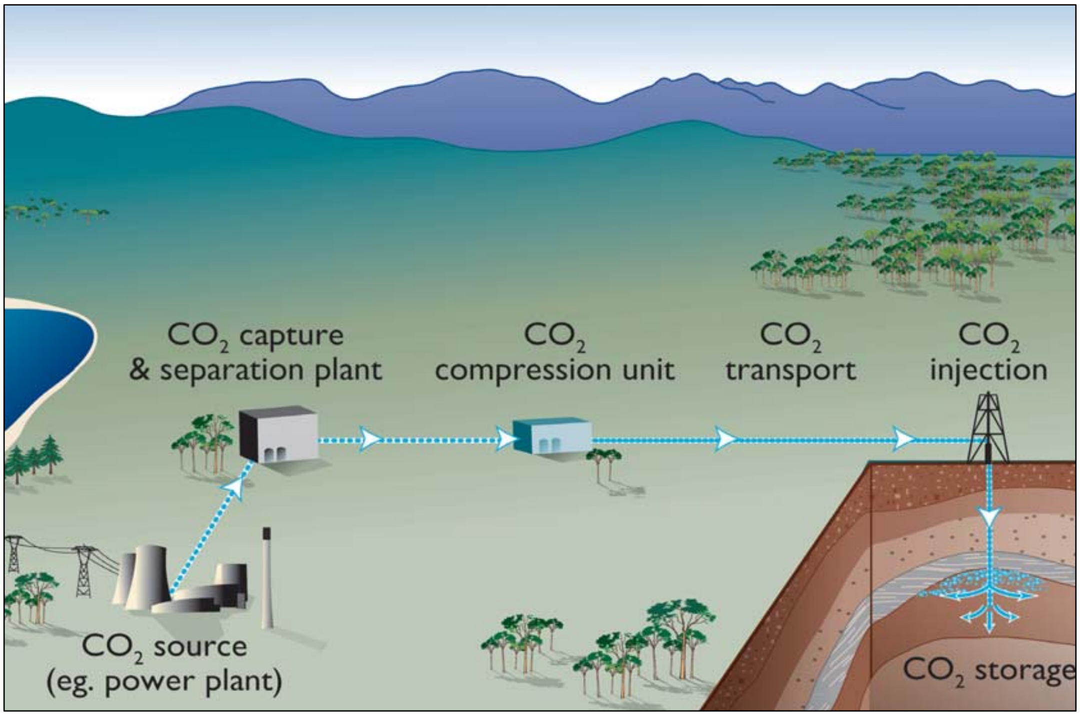


Diagram 3

The various methods of carbon capture and their chain: pre-combustion, post-combustion and oxy-firing. [lii]

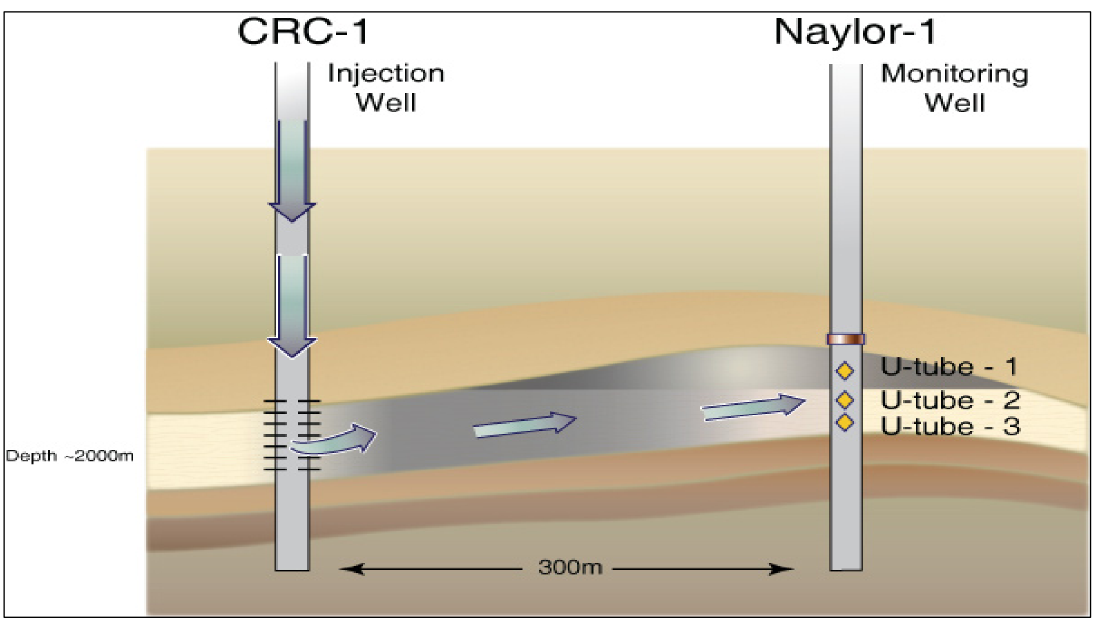
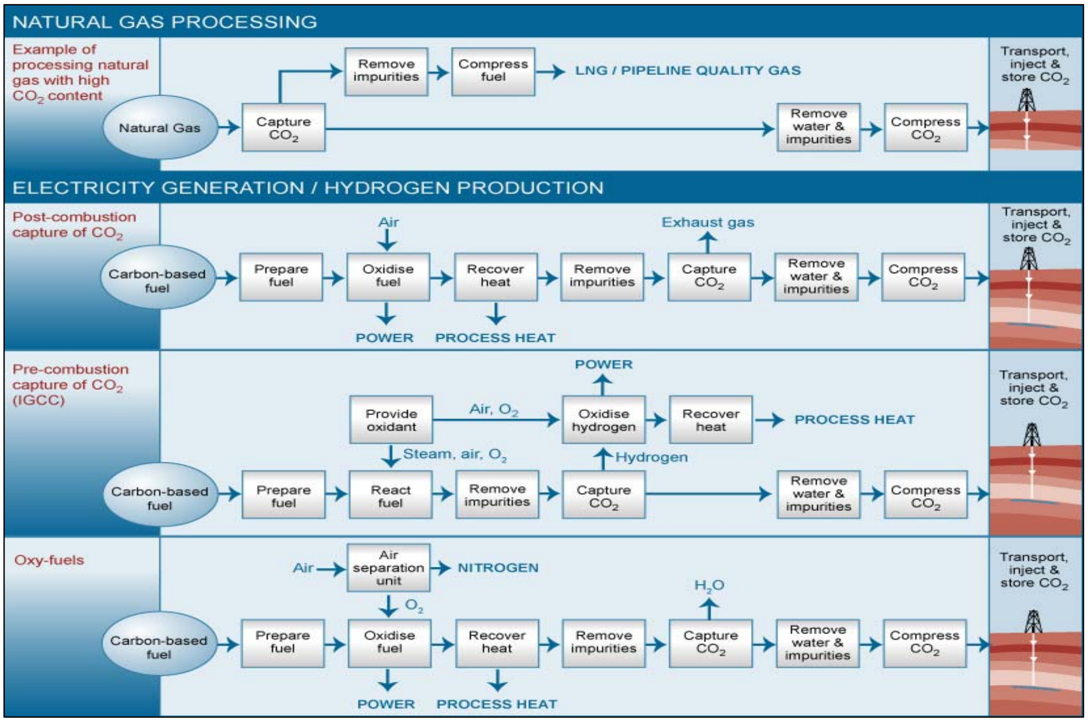


Diagram 4

[liii] Two wells 300 meters apart: CRC 1 injects the CO_2 into the reservoir while Naylor-1 monitors the gas and fluids coming from the formation.



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