Large Scale CCS and Energy Storage

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What is CCS?

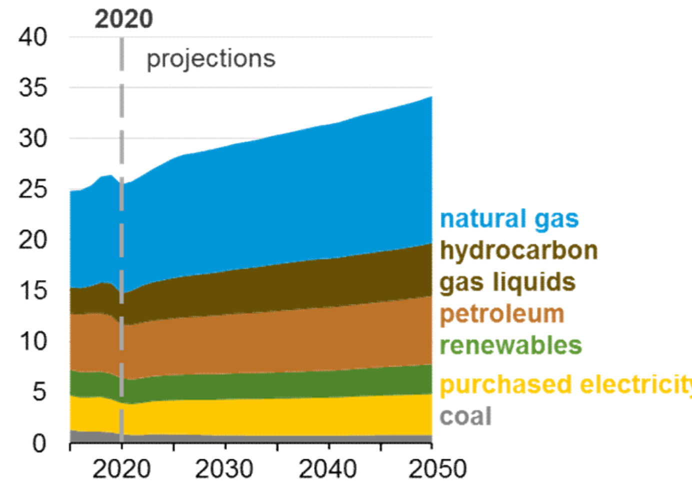
- CCS stands for carbon capture and sequestration (also called storage and not to be confused with energy storage)
- It can also be referred to as CCUS, which stands for carbon capture, utilization, and storage.
  - Recently, the XPRIZE Foundation announced the winners of the Carbon XPRIZE.
  - The competition required competing teams to capture CO2 from power plant flue gas and convert the captured CO2 into a useful product. There were 2 tracks: one for coal at a power plant in Wyoming and one for gas at a power plant in Calgary, Canada. The prize for each track was $7.5 million.
  - The winning team for the coal track passed the plant flue gas directly over uncured cement blocks. The blocks adsorbed some CO2. When cured the blocks were slightly stronger and weighed less.
  - The winning team for gas used wash water from the cement making process to capture CO2. The slurry was combined with fly ash and reduced amounts of lime to make a cement that contained the CO2 and was at least as strong as conventional cement. The reduced amount of lime also saved CO2 emissions.

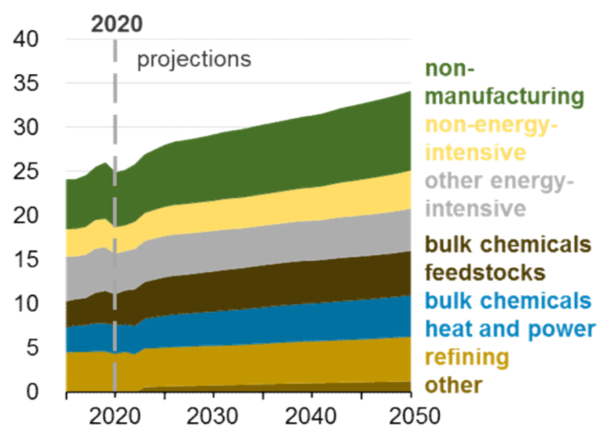
Why CCS?

- Most serious studies about getting to "net zero" carbon emissions recognize that the last 10 – 20% of reductions get to be extremely expensive.
- The alternative is to allow some fossil fuels to continue to be utilized as long as the CO_2 emissions are captured and prevented from returning to the atmosphere.
  - Sequestration is the most common approach.
  - Utilization is desirable. The problem is that there is way too much CO_2 to be utilized. The US alone generates 7 gigatons of CO_2 per year. We don't use 7 gigatons of anything. The closest is probably oil at 1.23 gigatons/yr.
- The UN and others expect that 15 – 20% of CO_2 reductions will likely come from CCS or CCUS.

Why CCS?

- Industrial Energy Use
- EIA 2021 projections
- Note that fossil fuel use is still substantial in 2050.
- If that is the case, net zero can only be achieved by CCS.





The Carbon Capture Part

- There are 3 main approaches to CO_2 capture.
- The first is to use a scrubbing solution to react with CO_2 in the flue gas and subsequently regenerate the solution to release the CO_2. Food grade CO_2 can be made using this process. Common scrubbing solutions include monoethanol amine (MEA), sodium carbonate, chilled ammonia, and various organic solvents (Rectisol, Selexol, and others). These are also used in natural gas processing before the gas is put into the pipeline. The energy requirements for these processes can be substantial. Early demonstrations consumed as much as 30% of the power plant power output (either in the form of steam or electricity). Process improvements have reduced that figure to 17- 20%.

The Carbon Capture Part

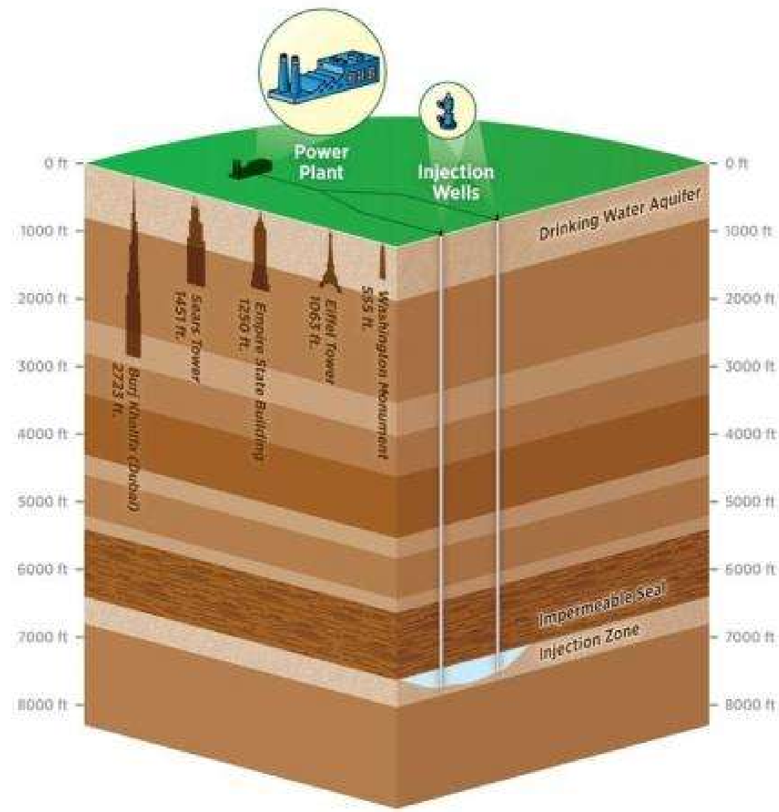
- The second approach is the burn fuels in pure oxygen. Flue gas recirculation is used to produce a synthetic air that is roughly 80% CO_2 and 20% oxygen. The resulting flue gas is anticipated to be over 95% CO_2. In this approach, the entire flue gas can be sequestered, thereby becoming a true zero emissions power plant.
- In order to generate pure oxygen, an air separation plant is needed. At 200 Kwhr/ton of O_2, the air separation plant consumes 20% of the fuel energy.
- The principal advantage of the oxygen firing approach is that for an existing boiler, no pressure part modifications are needed. Presuming oxygen can be purchased “over the fence”, this approach has the lowest capital cost to the power plant owner. The price of oxygen may not be to the owner’s liking, but capital is still a “scarce commodity”.

The Carbon Capture Part

- The third approach is to gasify a carbonaceous material to generate a synthesis gas, or syngas. Syngas is a mixture of CO, CO_2, H_2O, and H_2. Syngas can be used to create nearly any hydrocarbon. This approach was used by Germany during World War II to make synthetic fuels and was used commercially by South Africa in order to utilize domestic coal rather than import oil (SASOL plants).
- The use of a shift reactor can shift the composition to mostly CO_2 and H_2. By scrubbing out the CO_2, a relatively pure H_2 can be produced. If the captured CO_2 is sequestered, this hydrogen is referred to as "blue hydrogen".
- The DOE and EPRI were enamored with this approach to power generation, using the hydrogen in a gas turbine (which didn't exist). Nevertheless, the cost of a full IGCC (integrated gasification combined cycle plant) was roughly twice the cost of a conventional coal plant. A few demonstration plants were built that burned the syngas rather than converting it to hydrogen.

The Sequestration Part

- The DOE estimates that nearly 20,000 gigatons of CO2 can be safely stored in the US. Roughly 2.5 gigatons/yr comes from electric power plants. That would translate to 8000 years worth of storage.
- Saline aquifers that are over 1 mile below the surface of the earth are the prime targets. Over the course of time the CO2 is expected to convert to carbonates (ie become mineralized).
- Concerns include underground travel, leakage, and seismic activity.



Interest in CCS

- From 2000 – 2019, there were roughly a few hundred papers on CCS. Since 2020, there have been well over 1000 papers.
- In the US, there were tax incentives provided by Congress in 2008. These were the 45Q sequestration incentives (roughly $10/ton) and the 48A investment tax credits. Neither were terribly effective.
- At the end of 2020, the Energy Act of 2020 tripled the RD&D funding for CCS projects.
- In Jan. 2021, the IRS finalized new rules for 45Q, increasing incentives to $50/ton.
- Since January, 5 bills have been introduced in both the House and Senate with "bipartisan support" promoting CCS.

Interest in CCS

- Access 45Q Act
  - Amends 45Q to include a direct pay option and extends 45Q to 2035
- Carbon Capture Modernization Act
  - Amends statutory language to allow coal fired power plant retrofits to CCS to access the 48A 30% investment tax credits.
- Storing CO2 and Lowering Emissions Act
  - Establishes a CO2 Infrastructure Financing Program
  - Establishes a Secure Geologic Storage Infrastructure Development Program
  - Increase funding for Class VI well permits
  - Provides grants for states and cities to buy low and zero carbon products made from CO2
- Carbon Capture, Utilization, and Storage Tax Credit Amendments
- Financing Our Energy Future Act
  - Allows the formation of MLPs to finance CCS projects

Large Scale CCS Projects

- There are now 38 commercial facilities in the Americas in development, construction, or operation, including 12 new projects announced in 2020.
- Nearly all of the 12 projects expect to qualify for the 45Q incentives. EOR will be used in 8 of the projects. The California Low Carbon Fuel Standards (LCFS) are driving 5 of the projects (one is using both).
- Coal fired power plants are involved in 4 of the projects. Biomass power is involved in 2 projects. Waste to Energy is involved in 2 projects. Natural gas power generation covers one plant. Methanol, fertilizer, and chemicals are products from the other plants.
- Operating facilities are currently capturing 30 million tons/yr.

Large Scale CCS Projects

- Great Plains Coal Gasification Project
  - This project was one of the original Synfuels projects promoted by the Carter administration.
  - The plant was built in 1984 to produce methane using Lurgi fixed bed gasifiers at a cost of $2.1 billion (1984 dollars). With the Reagan administration deregulation of natural gas, the plant went bankrupt and was auctioned off by DOE to Dakota Gasification company (a subsidiary of Basin Electric Power Co.). Basin Electric uses the coal fines that are not suitable for the Lurgi gasifiers in a nearby coal power plant.
  - In 2000, the captured CO2 started to be sold to Canada for EOR in a dedicated 205 mile pipeline in Weyburn.
  - Over 3 million tons/yr are being captured, shipped to Weyburn, and ultimately stored.
  - The plant processes about 750 ton/hr of lignite, or roughly enough for 1200 Mw(e).

Large Scale CCS Projects

- Boundary Dam Unit #3
  - This 120 Mw plant was retrofitted with carbon capture in 2014. (originally 150 Mw)
  - The CO_2 is mostly sold for EOR via pipeline 30 miles away
  - A portion is injected into an underground storage facility about 2 miles deep.
  - About 1 million tons of CO/yr are being captured and stored.
  - A fully instrumented test facility has been set up with a capacity of 120 ton/day CO_2.
  - SASK Power is "mandated" to share their expertise to support the full scale development of full scale CCS on power and other industrial facilities.
  - Amine scrubbing is used to capture the CO_2. (Shell Cansolv)

Large Scale CCS Projects

- Petra Nova
  - This 240 Mw plant in Texas began operation in 2016.
  - The plant is capable of capturing 1.9 million tons CO_2/yr.
  - The CO_2 is sold for EOR to a nearby oil field.
  - With the crash in the price of oil last year, the capture unit was placed in reserve in May 2020.
  - The project received a $195 grant from DOE.
  - The plant uses a Mitsubishi improved amine system for capture.
  - The project was able to get low cost financing from Japan and was aided by the part ownership of the nearby oil field.

Large Scale CCS Projects

- Alberta Carbon Trunk Line
  - The Trunk Line became fully operational in June 2020.
  - CO_2 captured from a refinery and a fertilizer plant is compressed and sent to a 150 mile pipeline to an oil field in southern Alberta for EOR.
  - The pipeline can carry 14.6 million tons/yr CO_2. Right now, only 1.6 million tons/yr are being transported. The concept is for other capture plants to send CO_2 to the Trunk Line.
  - The project cost $900 million CD. Alberta provided $495 million and the federal government provided another $63 million.
  - Emissions credits and CO_2 sales provide sufficient revenue to support the project.

Large Scale CCS Projects

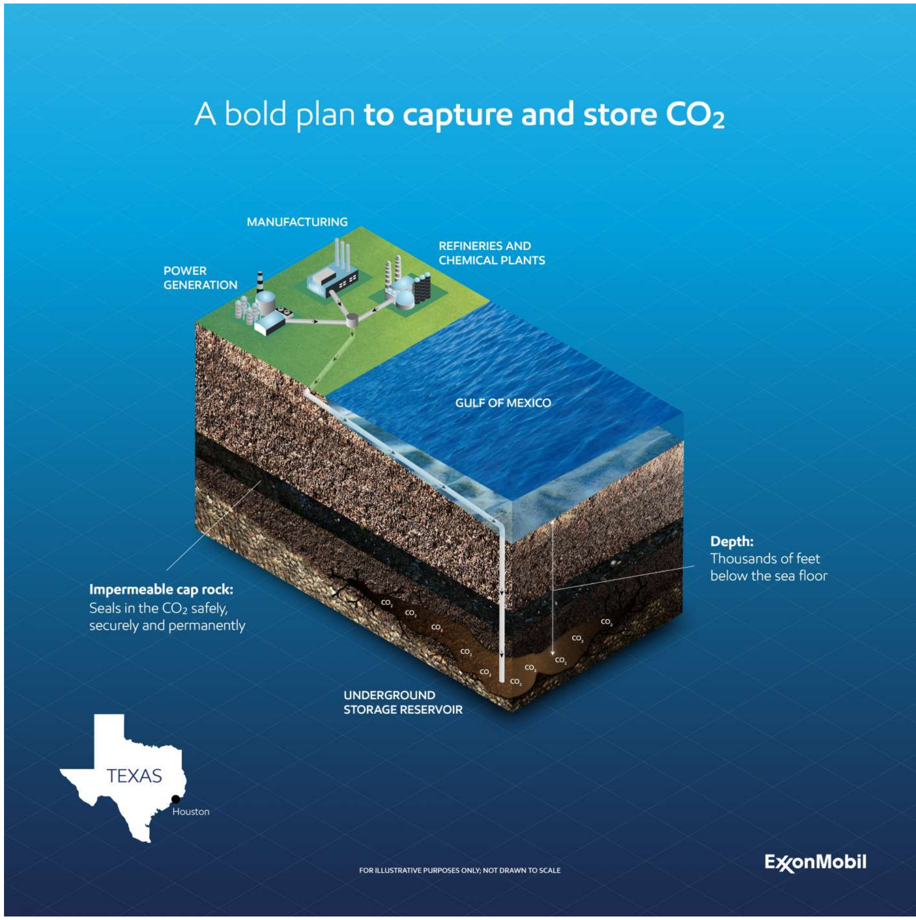
- Shell Quest Carbon Capture and Storage Project
  - The project was the first ever at a bitumen upgrader plant.
  - The plant became operational in 2015.
  - The CO_2 is sent 40 miles to storage in a deep saline aquifer (1.5 miles deep).
  - The plant captures 1.2 million tons/yr. Over 5 million tons have been captured.
  - Project cost was $811 million.
  - Shell Cansolv amine technology is used for scrubbing the CO_2.
    - This is a two stage process with SO_2 capture first and CO_2 capture second.

Large Scale CCS Projects

- Recent Announcements
  - Elon Musk announced that he is putting up $100 million in prize money for teams that can remove CO2 from the atmosphere or the oceans. He has designated the XPRIZE Foundation to manage the competition. Teams must build a pilot scale facility to demonstrate their technology at 1000 tonne/yr and model their process at the megatonne scale. After 1 year of competition, in which the competing teams provide "proof of principle" testing, 15 teams will be selected to continue and be granted $1 MM each to assist in development. After the pilot scale demonstration, a winner will be selected and will receive $50 MM. The next 3 teams will receive $10 MM each. The remaining $5 MM will be awarded to selected student teams in the early competition.

Large Scale CCS Projects

- ExxonMobil proposed Houston Hub project
  - ExxonMobil has announced a potential $100 billion project to capture CO2 in the Gulf Coast region, pipe it offshore, and sequester it under the sea floor.
  - Infrastructure could be in place to capture 50 million tons CO2/yr by 2030 and 100 million tons/yr by 2040.
  - The Dutch Government and Royal Dutch Shell have announced support in the form of $2.4 billion for the project.
  - A public-private funding scheme will be needed to make this project proceed.



Energy Storage

- Energy storage has been the “holy grail” of the power industry for decades.
- Pumped hydro have been the mainstay of storage for generation.
- Fuel storage has been the primary source of storage for the entire energy system, along with a reserve margin (excess capacity) for generation equipment.
  - Reserve margins of 20 – 25% for generating equipment
  - 90 day coal pile
  - Oil storage tanks
  - Gas pipeline storage as well as salt caverns.
- Batteries have been in use for very short term storage (ie plant trip to emergency generator to safe shut down).

Energy Storage

- The intermittent nature of renewables increases the need for energy storage, particularly wind and solar.
- For solar plants, night time represents over half the operating time that needs to be covered, along with cloudy days, inclement weather, and seasonal variations.
- For wind plants, there can be over 2 weeks at a time when the wind speed is too low to turn the wind turbine.
- The average capacity factor for roof top solar PV in the Northeast is 11%
- The average capacity factor for on shore wind plants is 30 – 35%.

Energy Storage

- Batteries are not a source of energy. They need an energy source to charge up the battery.
- That implies excess capacity that needs to be built in order to charge the battery when the intermittent power source is available.
  - For roof top solar PV with an 11% capacity factor, at least 10 MW has to be built to get one continuous MW, plus the cost of the battery and the various circuitry. These costs are not being considered when advocates claim the solar is competitive with current grid power.
- Fuel storage of some kind will still be needed for longer term intermittency and seasonal variations.
  - The typical battery has about 4 hours of storage. Thus, 2 or 3 batteries might get you through the night. If you need 2 weeks, fuel storage will be needed.

Energy Storage

- Infrastructure will play a critical role in the amount of additional capacity and the amount of storage that will be needed.
  - There are currently 11 planning areas for power in the US (ISOs or RTOs). They typically balance demand and generation within their planning region. If they were more interconnected, less reserve margin will be needed, as power could be generated in another regions and transmitted to the region in need.
  - There are some concerns on this approach. California resorted to partial blackouts last summer when they were not able to purchase from out of state as the heat wave covered neighboring states as well as California.
  - Location of large scale generating facilities will become more difficult as the amount of renewables continues to increase.
    - The easy sites are already taken
    - The land area requirements per Mw of power produced are much greater for renewables.

Energy Storage

- Fuel storage will be needed for longer term storage and seasonal variations.
  - Already New England is planning on extra oil storage in the event of another “polar vortex” in order to avoid building a new pipeline or importing more electricity from Canada (with the associated power lines).
- Two potential fuels that are being considered are hydrogen and ammonia.
- Biofuels are also a consideration. The problem becomes one of land area use. In the Northeast, it takes 15 years to grow a tree to some reasonable size. In order to support a 100 Mw power plant with biomass (wood), a circle 75 miles in diameter would be needed, where by 1/15th of that circle would be cut down and replanted each year to feed the plant. That would be sustainable, in that the replanting would sustain the needed supply each year. However, for a state like CT, which is only 60 miles north to south, this was deemed unacceptable. The state government vetoed the application for a 100 MW wood fired plant.

Energy Storage

- Recognize that energy storage only solves the intermittency part of the problem, not the cost part of the problem or any of the ancillary services.
- Excess capacity still needs to be built and adequate infrastructure needs to be planned and built along with the extra capacity.
- Today, batteries are primarily used for emergency operations, voltage control, and short term storage. Even power arbitrage (ie store cheap power for when the grid is expensive) has not been profitable.
- Decarbonizing the last 15 – 20% gets to be very expensive. That drives the system to consider and apply CCS. That allows conventional equipment to operate and provide the real base load capacity that is needed to stabilize the system.