Carbon Capture & Storage (CCS)

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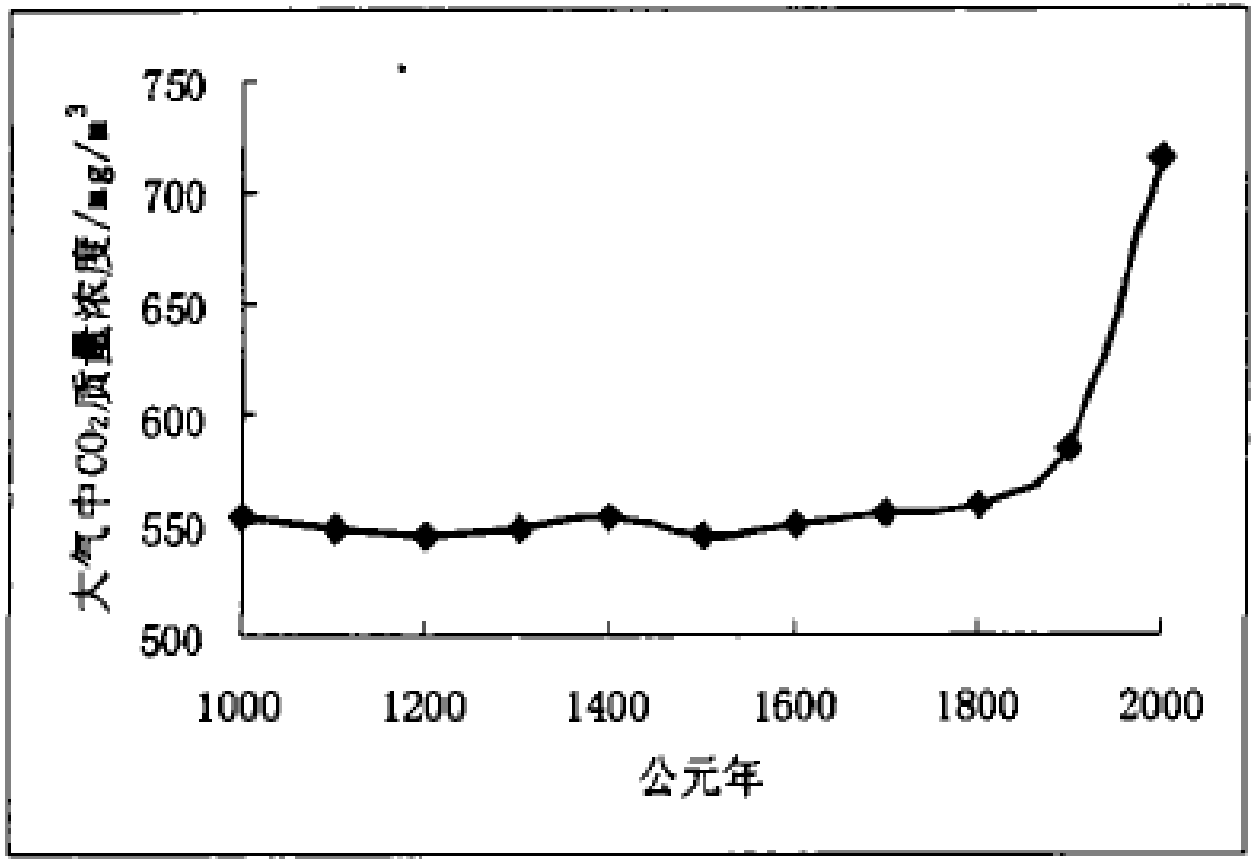
Introduction

- Global warming tied to excess carbon dioxide emissions is one of the most severe environmental problems currently.
- Kyoto Protocol for emission reduction
  - Treatment for carbon dioxide emission with economic ramifications
- 3 methods to control emissions
  1. Improve of resource use and energy conservation
  2. Develop methods to recycle energy
  3. Carbon Capture and Storage (CCS)

Carbon Dioxide Emissions Trend



The concentration of CO2 varies in recent 1000 years

What is CCS?

- CCS is the application of various methods to capture carbon dioxide and store it in various ways.
- Four main parts to CCS:
  1. Separate CO_2 from other waste gasses and concentrate them
  2. Transport the CO_2 to storage sites via pipelines or other means of transportation.
  3. Store the CO_2 in a location with good sealing properties
  4. Monitor the storage site for any leaks or geological issues.

Why is the Development of CCS Important?

- Climate change has recently become a global threat
  - Reducing CO_2 emissions must be a priority of every country
- Improve the energy efficiency, cannot dramatically reduce CO_2 emissions
- Recycling energy through win and solar energy haven't been efficient enough in the U.S., very difficult in other countries.
- If 90% of CO_2 emitted by fossil fuel energy, then the threat of global warming would be reduced drastically.
- Developing a low carbon use economy will take time.

Carbon Capture & Storage-Capture

- Accounts for 80% of the overall CCS process
- Easiest to be done at the source
  - Done directly outside facilities
- 3 methods of capture
  1. Post-Combustion
     - Extract CO_2 from flue gas immediately after combustion.
     - Capacity to capture high amount of CO_2, no requirements or economic incentives currently.
  2. Pre-Combustion
     - Air or Steam used to separate CO_2 and H_2 before combustion.
     - Not required under the Clean Air Act, cost not justified
  3. Oxy-Fuel Combustion
     - Pure O_2 used to separate CO_2 and H_2
     - Results in waste that's mostly CO_2 and water.
     - Under development due to O_2 needing a temperature of ~3500 °C to combust
       - Extra filtering of boiler exhaust can remove pollutants that can be used to maintain temperature needed for O_2
     - Most current boilers can be retrofitted with oxy-fuel systems

Carbon Capture & Storage-Transport

- Transport of CO_2 involves concentrating and compressing it into a supercritical state, at which is becomes a liquid. Several methods involved.
- Pipelines
  - Main mode of transport
  - Similar to oil and natural gas pipelines
  - Must be constantly monitored for leaks and over pressurization
  - Many factors play a role in the cost:
    - Onshore/offshore
    - Surrounding population
    - Environmental features- mountains/rivers
    - Climate
  - ~3600 miles of CO_2 pipelines active
- Other methods available include marine tankers, rail cars and trucks
  - Not thoroughly explored, shipping costs unknown for large scale

Carbon Capture & Storage-Storage

- Ideally should be stored as quickly as produced.
  - Difficult to accomplish due to various economic issues.
- 5 Storage Methods
  - 3 Geological methods
    1. Depleted oil and gas reserves
    2. Deep saline reservoirs
    3. Un-mineable coal seams
  - 2 Other Methods
    1. Deep ocean sequestration
    2. Mineral carbonation

Carbon Capture & Storage-Storage cont.

- In geological formations
  - CO_2 injected into ground at super critical state
  - Depths >800 keep CO_2 in liquid state due to pressure
- <u>Depleted Oil and Gas Reserves</u>
  - CO_2 typically used in Enhanced Oil Recovery (EOR)
    - Removes oil/gas while injecting CO_2
    - Oil/Gas production offsets CO_2 storage costs
    - Current issue is companies use mainly natural CO_2
  - Projects like In Salah (Algeria) and Weyburn Project (Canada) using sites like this
  - Advantage: Storage capacity already there, Oil/Gas extraction tech can be used for injection
  - Disadvantage: Improperly plugged sites can leak, over pressurization can cause fracturing

Carbon Capture & Storage-Storage cont.

- Deep Saline Reservoirs
  - Contain brine/aqueous solutions that are unfit for human or agricultural use
  - More of these sites, so higher chance of being close to CO_2 sources
  - Aqueous solutions can dissolve CO_2 to help keep it from escaping
  - Disadvantage: This dissolving can form carbonic acid and erode the storage site, either causing the CO_2 to leak out, or toxic minerals to escape into the surrounding environment
- Un-mineable Coal Seams
  - Coal mines that cannot be dug out
    - Structural issues or other hazards
  - Contain methane which binds to the coal
    - CO_2 binds to coal tighter
    - Can extract methane for profit while injecting CO_2
  - Mines need to have methane
  - Many are close to power plants
  - Highest storage capacity in the U.S.

Carbon Capture & Storage-Storage cont.

- Deep Ocean Sequestration
  - Oceans have always acted as a sink for CO_2
  - Can store up to 90% of carbon from humans
    - Will take thousands of years
  - Oceans natural currents can bring surface CO_2 to bottom of ocean
  - Depths <500 m: CO_2 stays gaseous but some can dissolve
  - Depths: 500 m < x <3000 m: still gaseous but more likely to dissolve
  - Depths:>3000 m: will remain in liquid state, either slowly dissolves or forms underwater pools/lakes
  - Could store CO_2 for thousands of year, however causes acidification which can have drastic effects on the ocean environment
- Mineral Carbonation
  - Reactions high concentrations of CO_2 with minerals
  - Forms compounds like calcium carbonate (CO_2)
    - Naturally happens, known as weathering
  - Have not yet been tested on large scale
    - Flood basalts could be used

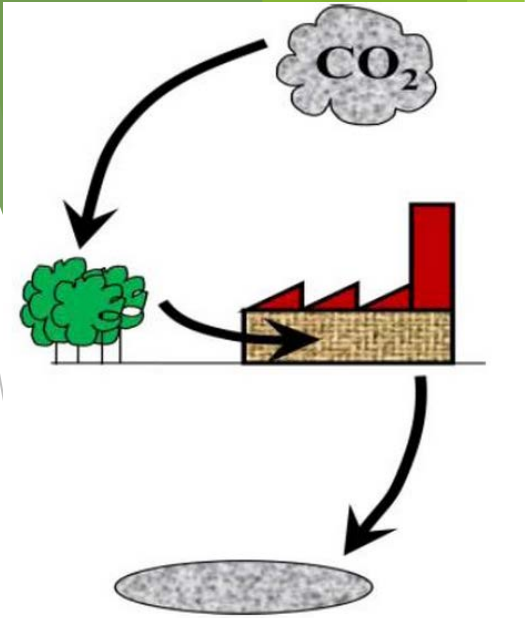
Where Do We Go From Here?

- The main limiting factor to the growth of CCS is cost and legislation.
  - Transportation, pipe building costs, adding capture methods onto existing facilities, injection process, monitoring the storage etc…
- There is currently no federal law in the United State that inhibits the amount of carbon dioxide companies can inject into the air.
  - European Union has developed a Cap and Trade policy.
- Although 9 out of 10 scientist agree that climate change is real and needs to be addressed the media portrays that the scientific field is split 50:50.
  - Climate of Doubt
- The international Energy Agency estimates that for CCS to have a significant effect in flowing global warming there must be 6000 CCS projects each storing a million tons of CO_2 per year in operation by the year 2050.
  - Still research on going as to how much can a underground reservoir can holds and its potential health risks.
- One limit is that technologies do not deal with the carbon dioxide already in the atmosphere.

Continuing Research

- An easier method for the synthesis of a porous azo-linked polymer (ALP) has been reported in 2014.
  - The ALP is considered to be a porous organic polymer (POPs).
  - Synthesized by a homocoupling of aniline-like building units in the presence of Copper (I) bromide and pyridine.
  - This POP has high surface areas, physiochemical stability and significant gas storage abilities.
    - The interaction between CO_2 and the ALP is weak meaning easily rengerated from adsorption to the POP.
    - High uptake of CO_2 at moderate conditions 273 K and 1 Bar (153-236 mg g^{-1})
      - This is has a greater capacity then BILPs (12-235 mg g-1) which are seen among the best on the market for CCS.
  - The uptake has been attributed to the high internal molecular free volume, high surface area, and high nitrogen content.
  - At higher pressures the ALP can adsorb even more.

Carbon Capture and Bioelectricity



- A research has been developing to converge biomass energy with carbon capture and storage technology (BECCS).
- Using the renewable energy (biomass).
  - The biomass combustion is a neutral process in that the biomass includes carbon entirely from the atmospheric CO_2 (by photosynthesis).
    - Leads to negative emissions over time.
  - Bio-energy production includes biomass fuel-power stations, pulp mills and bio-fuel plants.
- Adds another green component to CCS.
  - Problems with using biomass with the processes used in supplying biomass and the potential for decreasing land used for crops.

Conclusions

- There is a real demand for the growing Carbon emissions building up in our atmosphere.
  - While there are efforts to use carbon there is still a need to supply companies with CO_2
- Carbon Capture and Storage is a credible way to slow the effects of global warming and give the world more time to seek out new energy sources.
- Research conducted now is trying to increase the ease from which we capture carbon and hopefully someday capture the carbon already in the atmosphere.
- The End!