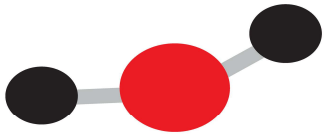
Process Hazards Associated with Carbon Capture and Sequestration

Carbon Dioxide

- Carbon Dioxide
  - Accounts for approximately 65% of greenhouse gas emissions in the US
  - Approximately 15% of the CO_2 emitted is from oil & gas operations/facilities (amine vent stream or engine exhaust)
  - Various rules, regulations and initiatives are in place that make it worth-while to reduce these emissions

Carbon Dioxide

- Carbon Dioxide
  - Naturally occurring portion of the atmosphere = 0.04%
  - Found in the gas state at room temperature
  - At normally-encountered concentrations it is odorless
  - Carbon dioxide is 53% more dense than dry air but is long lived and thoroughly mixes in the atmosphere
  - Carbon dioxide is soluble in water, in which it forms H2CO3 (carbonic acid), which is a weak acid
  - Atmospheric CO2 is the primary carbon source for life on Earth.
  - In the air, carbon dioxide is transparent to visible light but absorbs infrared radiation, acting as a greenhouse gas



CO_2

Carbon Capture

- Most industrial CO_2 emissions are the result of combustion of fossil fuels
- A major sources of CO_2 in the oil & gas industry are from fuel-fired equipment used in the production, treatment and transportation of oil & gas
  - Heater/treaters at the wellhead
  - Product pumps and gas compressors
  - Heat medium equipment at oil & gas treatment/processing facilitates
  - Amine treatment process*

Carbon Capture

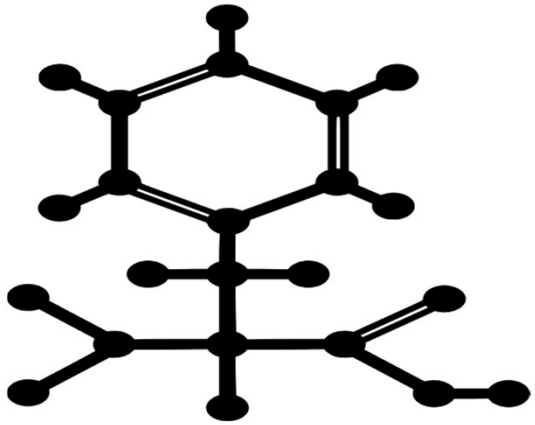
- Carbon capture, utilization and sequestration isn't new to the oil and gas industry
  - CO_2 has been separated from the production stream and used for enhanced oil recovery (EOR) since the 1970's
- Previous CO_2 inventories did not account for CO_2 generated from combustion sources
  - Companies can utilize low pressure capture, such as a vapor recovery unit to minimize release of combustion products to the atmosphere
  - These emissions can then be processed to separate gas components for reinjection

Carbon Capture

- CO_2 exhaust streams from fuel-fired equipment is typically high-temperature (600°F to 900°F), low-pressure (approximately 15 psig)
  - Higher temperature piping and equipment requirements than normal production, treatment, or compression
  - Increased worker heat stress around equipment
  - Oxygen evacuation around leaks

Carbon Capture

- CO_2 exhaust streams from fuel-fired equipment also contain a high level of impurities; such as oxygen and nitrogen compounds, and particulates
  - The higher level of impurities in the CO_2 stream requires lower temperature and higher pressure to transport efficiently



Carbon Capture

- High-temperature CO_2 needs to be cooled to effectively transport
  - Typically used for cross exchange in the treatment process
  - Can be used for onsite power generation
  - Worse case is release of heat to atmosphere
- Low-pressure CO_2 needs to be compressed to effectively transport
- Impurities in the CO_2 stream need to be removed
  - Typically done using chemical removal (catalytic reduction or absorption)

Carbon Dioxide Transportation

- CO_2 transportation
  - CO_2 can be transported in many ways, but using a pipeline is the most efficient
  - CO_2 can be transported In a gaseous state or in a supercritical state, with transport in a supercritical state preferred for longer distance transport due to higher volume capability and lower loss during transport
  - To get CO_2 to a supercritical state it must be kept at 88°F or lower and 1,010 psig or higher
    - With the higher level of impurities, the temperature and pressure requirements change (temperature goes lower, pressure goes higher)

Carbon Dioxide Transportation

- CO_2 transportation
  - A CO_2 pipeline is regulated by DOT PHMSA as a Hazardous Liquids Pipeline under 49CFR195 (>4,500 miles currently in existence)
    - Need to identify High Consequence Area
    - Decreased, automatic valve spacing
    - Increased inspections/surveys

Carbon Dioxide Transportation

- CO_2 transportation
  - Transport in a supercritical state requires components of the system must be chosen for the temperature and pressure environment in which the components will be used so that the pipeline will maintain its structural integrity
    - NOT typical Carbon Steel, however, can be used with appropriate ceramic/polymer coatings
    - 316 Stainless Steel (Cr, Ni, Mo) preferred
    - Polymer piping (pressure limitations)
  - Pipe joint welds must also be appropriate materials
  - May cause problems when converting existing systems

Carbon Dioxide Transportation

- CO_2 transportation
  - Increased transport distance also requires additional equipment and treatment to maintain the supercritical state (compressors, coolers and treatment skids)

Carbon Sequestration

- CO_2 injection and storage
  - Reservoir availability and compatibility
    - Depleted oil & gas reservoirs are perfect for sequestration
    - Regulated as Class VI injection wells under the Safe Drinking Water Act by USEPA and some states (LA, ND, WV, WY)
    - Requirements in place for plume impact analysis, well design, and operating procedures
    - Currently 11 EPA and 30 state permitted Class VI wells (>300 permit aps)

Carbon Sequestration

- CO_2 injection and storage
  - CO_2 can be used as a fracturing media.
    - CO_2 interacts with reservoir rock under higher pressure conditions, effectively changing the pore structure of the reservoir by dissolution of the rock matrix, and increasing the number and complexity of fractures
    - CO_2 has a higher solubility in formation fluid under high-pressure conditions and diffuses more deeply into the formation

Carbon Sequestration

- Alternative sequestration methodology
  - In Oman and Iceland collected CO_2 is being injected into peridotite and volcanic formations, a chemical reaction converts the CO_2 into solid carbonates

Carbon Sequestration

- The Bipartisan Budget Act of 2018 established a tax credit for carbon sequestration (Section 45Q)
  - Amount of credit is based upon date sequestration started and how it is accomplished (extended under the BBB)
  - Can range from $10/metric ton captured and sold to $85/metric ton sequestered/used
- Carbon offsetting:
  - Investing in carbon negative projects (Currently - EPA grant program, PA, CA; several other states considering)
  - Purchasing carbon offset credits

Thank You!

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