CO_2-CAPTURE TECHNOLOGIES: AN OVERVIEW

With a Closer Look at Direct Air Capture
by ***Carbon Engineering***

North Jersey Section AIChE

April 17, 2018

YOUR PRESENTERS:

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- Member, Industrial Advisory Board, NJIT Otto York Dept. of Chemical and Materials Engineering
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  - Diamond Shamrock – specialty chemicals
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  - Henkel Chemical – specialty chemicals
  - Olin Hunt – microelectronics chemicals
  - EI Associates – A/E consulting
  - BOC Gases – industrial gases
  - Schering-Plough - pharmaceuticals
  - ALZO International, Inc. – specialty chemicals

YOUR PRESENTERS:

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ATTRIBUTION

Some information in this presentation was obtained (with permission) from:

- **Geoff Holmes,** Business Development Manager, Carbon Engineering Ltd., Squamish, British Columbia, Canada

- **"*New CO_2-Capture Approaches Push Against Cost Hurdles*",** Chemical Engineering magazine, August 2017

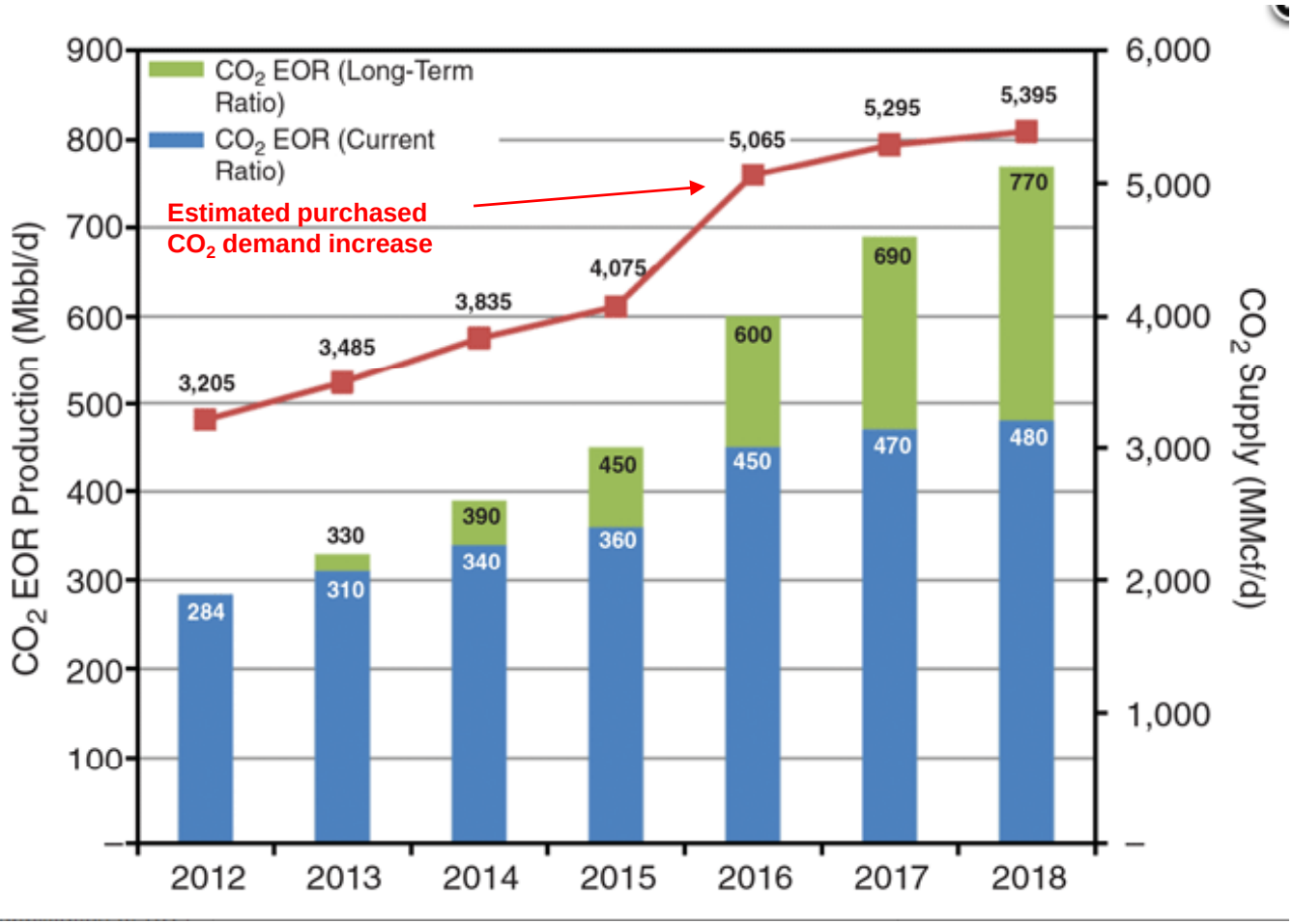
CCS (Carbon Capture & Sequestration): Driving Forces

- **Paris Climate Accord of April 2016**
  - **Temperature rise due to greenhouse gas emissions limited to 2°C or less above pre-industrial levels, by 2100**
- **Cost Model Results**
  - ***Costs of achieving this goal, (as well as the goal of less than 450 ppm atmospheric CO_2 concentration), would be considerably higher w/o widespread deployment of CCS***
  - ***Many believe it will only occur by establishing a price on carbon, (e.g.; taxes, cap-and-trade, etc.)***

CCS (Carbon Capture & Sequestration): Driving Forces, cont'd:

- **Currently, there is no financial incentive to permanently sequester carbon**
- **Consequently, carbon-capture projects have been carried out on a case-by-case basis**
- **HOWEVER: There is investment activity in ways to re-use the CO_2 after it is captured**
- **Sequestration is probable, but CO_2 recycling and re-use will be the real driver**

CCS (Carbon Capture & Sequestration): Driving Forces, cont'd:



American Oil & Gas Reporter, February 2014, http://www.aogr.com/magazine/editors-choice/industrial-co2-supply-crucial-for-eor

CCS (Carbon Capture & Sequestration): The "2nd Generation"

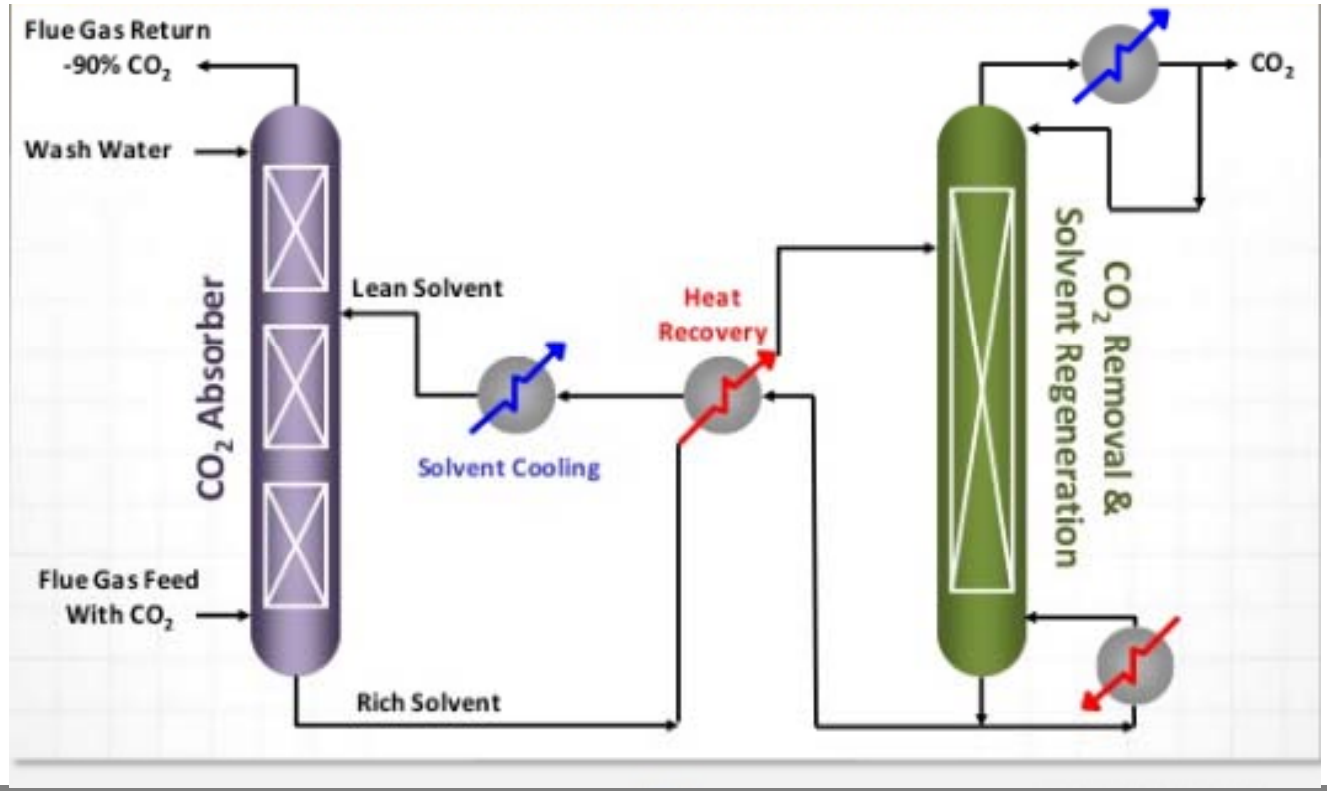
- **Major investments in 2nd Generation uses for CO_2, *(beyond enhanced oil recovery and carbonation…)***
  - **Conversion of CO_2 into bio-fuels**
  - **Incorporation of CO_2 into plastics and even concrete…**
    - *UCLA researchers are working on creating a closed-loop process to capture carbon from power plant smokestacks and use it to create a new building material - CO_2NCRETE - that would be fabricated using 3D printers.*

CCS (Carbon Capture & Sequestration): The Cost Problem

- **Currently, fossil-fuel-powered electric generation plants are outfitted with carbon-capture systems that use a lot of steam:**
  - **15% to 25% of generated steam is typically used for regenerating CO_2 from the amine capture solvent**
  - **This means electricity production is reduced**
  - **This puts the lowering of energy usage and fighting parasitic power losses front-and-center of the challenges facing CCS**

CCS (Carbon Capture & Sequestration): What's Already Out There?

- **Amine-based carbon capture technology has been around for a while**



Improving Amine-based Carbon Capture Technology

- **Aker Solutions ASA (Norway) is working on improving amine-based capture**
  - **Their design requires 35% less energy compared to a standard amine plant**
  - **They have developed a non-toxic, biodegradable and non-corrosive amine solution** *(significantly reducing stainless steel equipment requirements and cost)*

http://akersolutions.com/what-we-do/products-and-services/carbon-capture-utilization-and-storage/

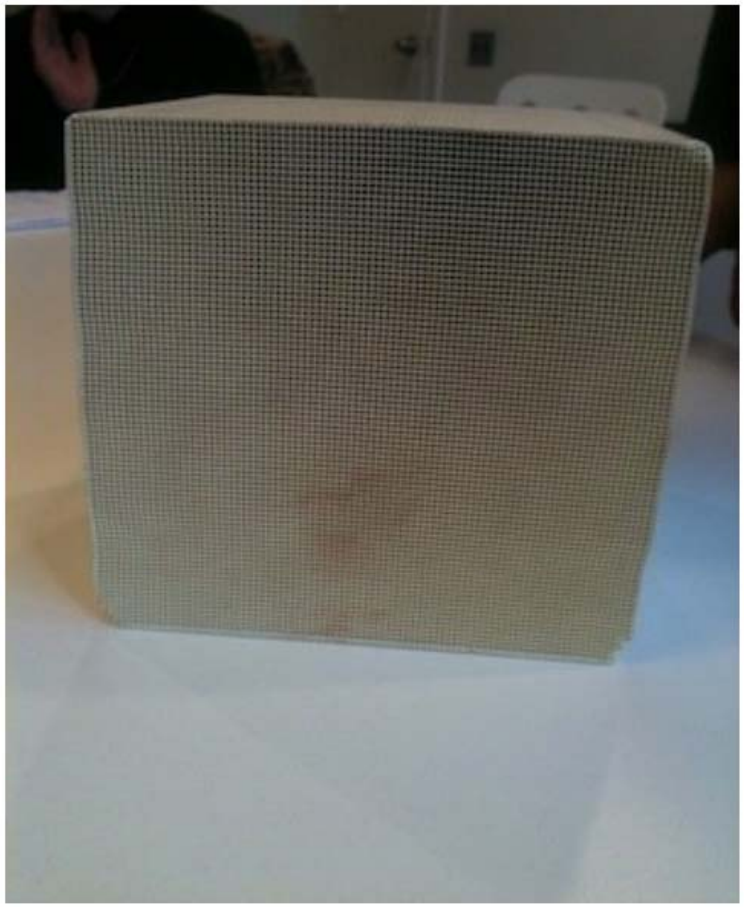
Improving Amine-based Carbon Capture Technology

- **KOCH Modular Systems (U.S.A.) is utilizing their expertise in gas recovery systems and modularized construction to drive down costs as well:**
  - **Modularization of amine-based carbon capture plants can reduce costs 15% to 20% by reducing construction labor requirements and compressing construction schedules**

https://www.youtube.com/watch?v=qf0Mi6iw6Jg

Improving Amine-based Carbon Capture Technology

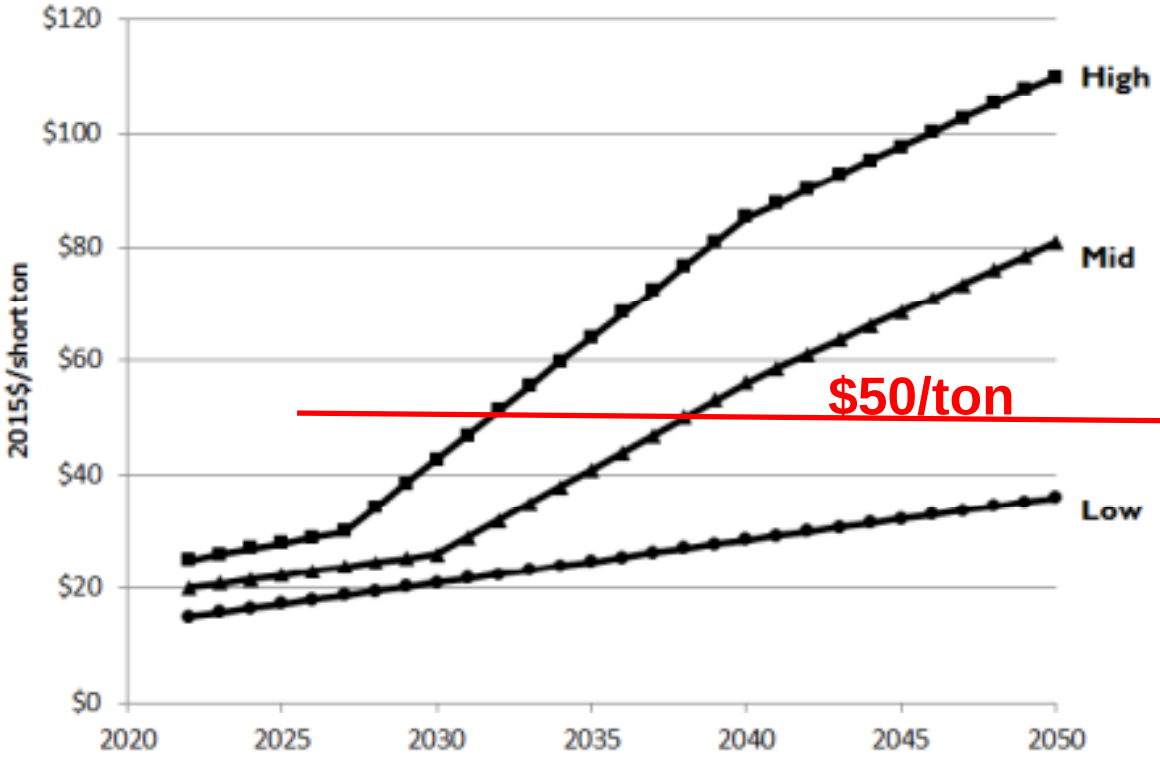
- **Global Thermostat, LLC (U.S.A.) is developing technology around solid amine absorbents:**
  - ★ **Solid, amine-based sorbent material-coated monoliths utilize capture and desorption process**
  - ★ **Capable of producing CO_2 at $50/ton or less *(why is this figure so interesting?)***



Sample of Global Thermostat's carbon capture cube.

Projected CO_2 Price Trajectories

Figure ES-1: Synapse 2016 CO_2 Price Trajectories



Source: Synapse Energy Economics, Inc. 2016.

Very attractive price point !

What About Non-Amine-based Carbon Capture Technologies?

- **CO2 Solutions, Inc. (Canada) employs the enzyme carbonic anhydrase (CA) into their technology, allowing the use of low-grade (i.e.; low cost) heat, and avoiding toxic chemicals**
  - **Ubiquitous in nature, CA converts CO_2 to bicarbonate in respiration**
  - **CO2 Solutions has essentially developed a method of "directed evolution" in a host microbe to adapt the natural version of CA to industrial purposes**

https://www.youtube.com/watch?v=Y_1QkqBSEeA&feature=youtu.be

What About Non-Amine-based Carbon Capture Technologies?

- **GEOENGINEERING - the deliberate large-scale intervention in the Earth's natural systems to counteract climate change.**

  - *There is wide range of proposed geoengineering techniques. Generally, these can be grouped into two categories:*

Geoengineering, cont'd

1. **Solar Radiation Management (SRM) or *Solar Geoengineering:*** aim is to reflect a small proportion of the Sun's energy back into space. Some proposed techniques include:

   - ***Albedo enhancement***. Increasing the reflectiveness of clouds or the land surface so that more of the Sun's heat is reflected back into space.
   - ***Space reflectors***. Blocking a small proportion of sunlight before it reaches the Earth.
   - ***Stratospheric aerosols***. Introducing small, reflective particles into the upper atmosphere to reflect some sunlight before it reaches the surface of the Earth.

Geoengineering, cont'd

2. **Carbon Dioxide Removal (CDR) or *Carbon Geoengineering* -** CDR techniques aim to remove carbon dioxide from the atmosphere, directly countering the increased greenhouse effect and ocean acidification. Some proposed techniques include:

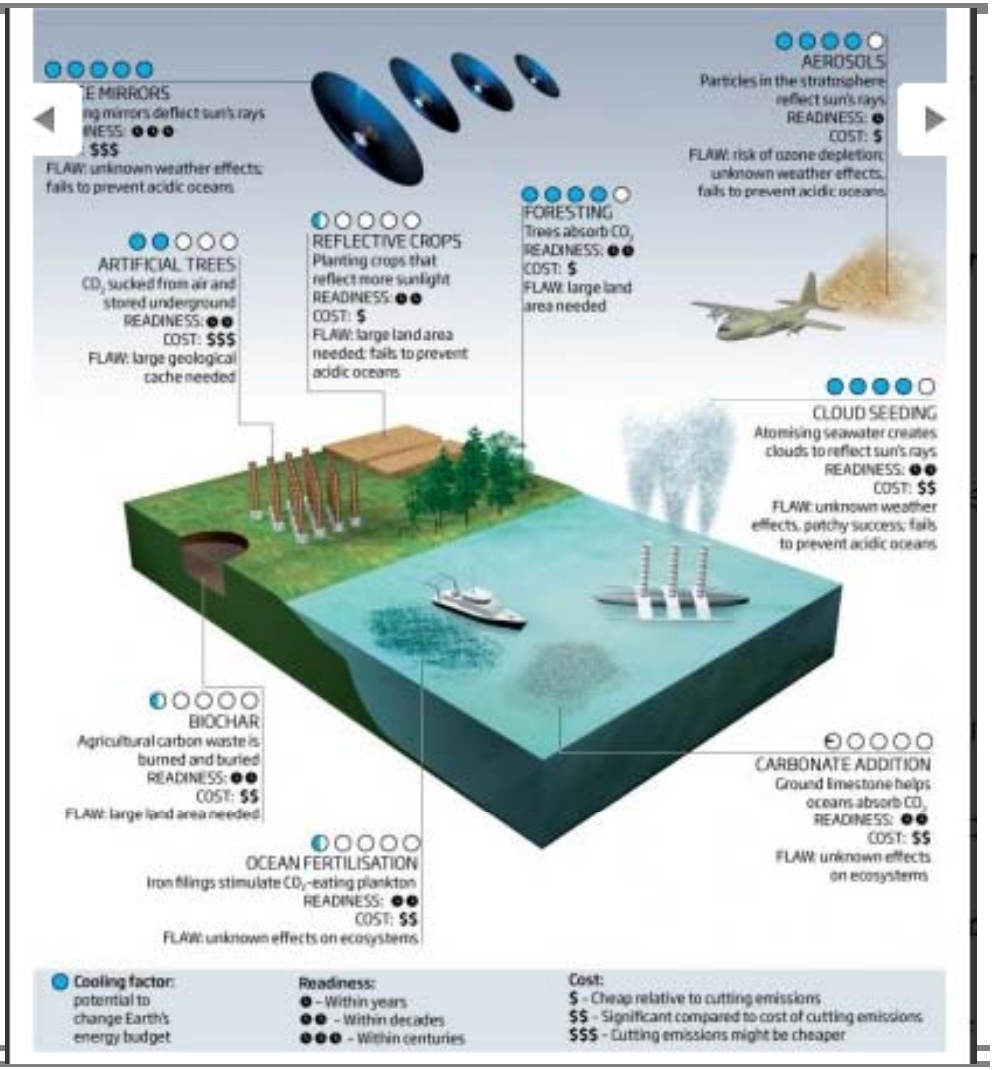
   - ***Afforestation***. Engaging in a global-scale tree planting effort.
   - ***Biochar***. 'Charring' biomass and burying it so that its carbon is locked up in the soil.
   - ***Bio-energy with carbon capture and sequestration***. Growing biomass, burning it to create energy and capturing and sequestering the carbon dioxide created in the process.

Geoengineering, cont'd

- ***Direct /Ambient Air Capture***. Building large machines that can remove carbon dioxide directly from ambient air and store it elsewhere.
- ***Ocean Fertilization***. Adding nutrients to the ocean in selected locations to increase primary production which draws down carbon dioxide from the atmosphere.
- ***Enhanced Weathering***. Exposing large quantities of minerals that will react with carbon dioxide in the atmosphere and storing the resulting compound in the ocean or soil.
- ***Ocean Alkalinity Enhancement***. Grinding up, dispersing, and dissolving rocks such as limestone, silicates, or calcium hydroxide in the ocean to increase its ability to store carbon and directly ameliorate ocean acidification.

Geoengineering, cont'd

These geoengineering technologies are in various stages of development, with varying estimated costs and potentials for success. Let's take a look in more detail at one of them, DAC (Direct Air Capture)……



Introducing Direct Air Capture

- **Direct Air Capture (DAC) is a technology that essentially "scrubs" CO_2 directly from the air at commercial scale.**

- **Direct Air Capture - Defining the Baseline:**

  – *Greenland ice cores recovered in 1993, and subsequent analysis, revealed atmospheric CO_2 non-anthropogenic (man-made) concentrations in the pre-industrial age "near-past" (110,000 to 15,000 YA) varied between 160 to 290 ppm. This represents recent, and normal, planetary "breathing".*

  – *The current (2018) global average CO_2 concentration is 406 ppm which reflects anthropogenic accumulation since the intellectual advent of Homo sapiens about 35,000 YA.*

Defining the baseline, cont'd:

- *Many scientists believe the planet is already experiencing noticeable climate change impacts at the current 406 ppm level and these impacts may have started years ago at the 325 ppm level.*
- *The Paris Climate Accord goal of not exceeding 450 ppm CO_2 by 2100 correlates to a 2°C temperature rise. The scientific basis for this goal was based on the then most recent report of the UN's Intergovernmental Panel on Climate Change (IPCC).*
- *The IPCC created 116 scenarios (algorithms) that tested a global temperature rise outcome of <u>< 2°C</u>. 101 of those scenarios concluded that "negative CO_2 emissions" were required to meet the mandated global temperature rise outcome.*
- *The IPPC initially determined that at a 450 ppm CO_2 concentration in 2100, the total atmospheric CO_2 content should <u>not exceed</u> 1,000 Gigatons. The current <u>annual</u> anthropogenic emission rate is 40 GTY.*

Defining the baseline, cont'd:

- *At 40 GTY, it would only take 25 years (about 2040) to "break the budget" of 1000 GT total content so reaching the ultimate goal would result in a total collapse of the global fossil fuel based economy.*
- *This is obviously not a tenable solution which is why the IPCC concluded "negative CO_2 emissions" are needed to attain the $\leq$ 2°C goal by 2100 without reverting mankind to the Stone Age.*

- *The only known negative CO_2 emissions technique is **Direct Air Capture** followed by sequestration.*

Direct Air Capture Technology

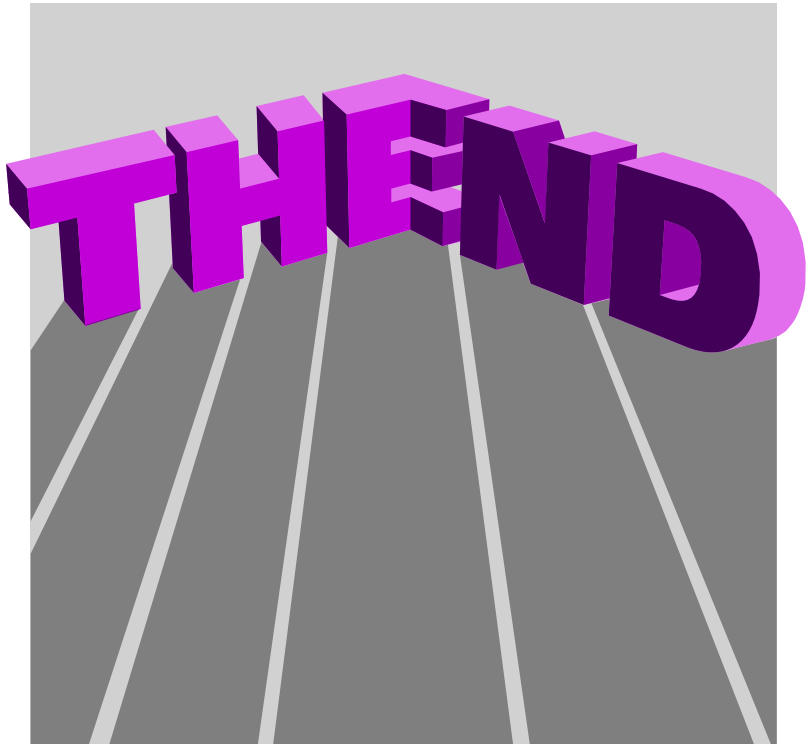
- **Several companies are developing this technology. One of them is:**
- **Climeworks AG -** A Swiss company, Climeworks' DAC technology is based on a cyclic adsorption and desorption process utilizing a new material that specifically adsorbs CO_2

https://www.youtube.com/watch?v=63S0t4k_Glw

Direct Air Capture Technology, cont'd

- **Another DAC company is:**
- **Carbon Engineering -** a Squamish, British Columbia-based company commercializing technology to capture CO_2 directly from the atmosphere, as well as technology to use that CO_2 along with renewable electricity to make clean transportation fuels.

At this point, I'd like to turn this presentation over to Mr. Robert Rossi, consultant to Carbon Engineering, who will go into more detail about their particular technology…


THE END

"There is no expedient to which a man will not resort to avoid the real labor of thinking."

Sir Joshua Reynolds

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