What Is Carbon Capture, Utilization & Sequestration? Why Now, Why Here?

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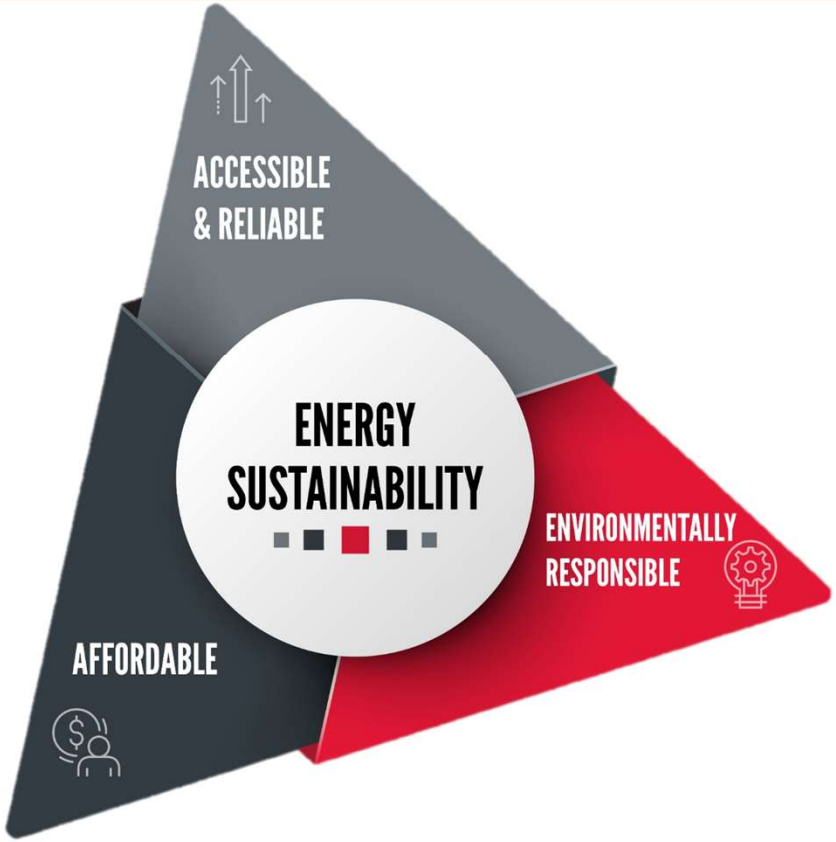
OUTLINE

- Underlying the Energy Transition: Energy Trilemma
  - Environmental & Climate Challenges
  - Global Demand & Supply Challenges
  - Capacity & Growth
- Technology Opportunities
  - Temporal & Spatial Applicability
  - Risk Tolerance & Capital Availability



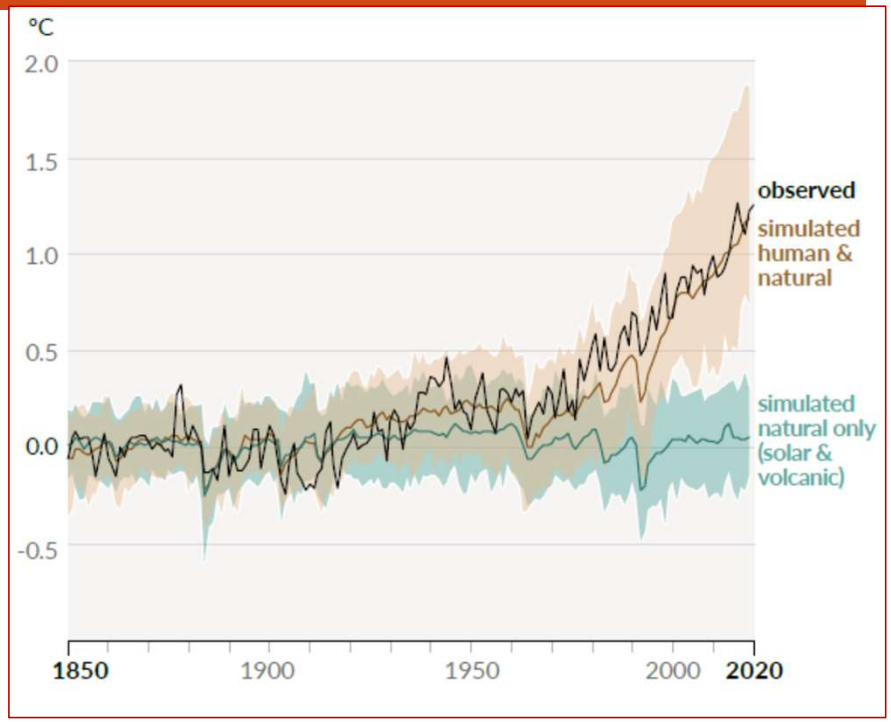
GLOBAL TEMPERATURE: HISTORY

- Temperature changes are considered relative to pre-industrial (1850-1900) climatology
- Key points:

❖ Already warmed by 1.1 °C (+/- 0.2 °C) and now warming at a rate of 0.2 °C /decade

❖ Warming > 1.5 °C has already occurred in some regions

❖ 20-40% of the global population lives in regions that have already warmed by more than 1.5 °C in at least one season

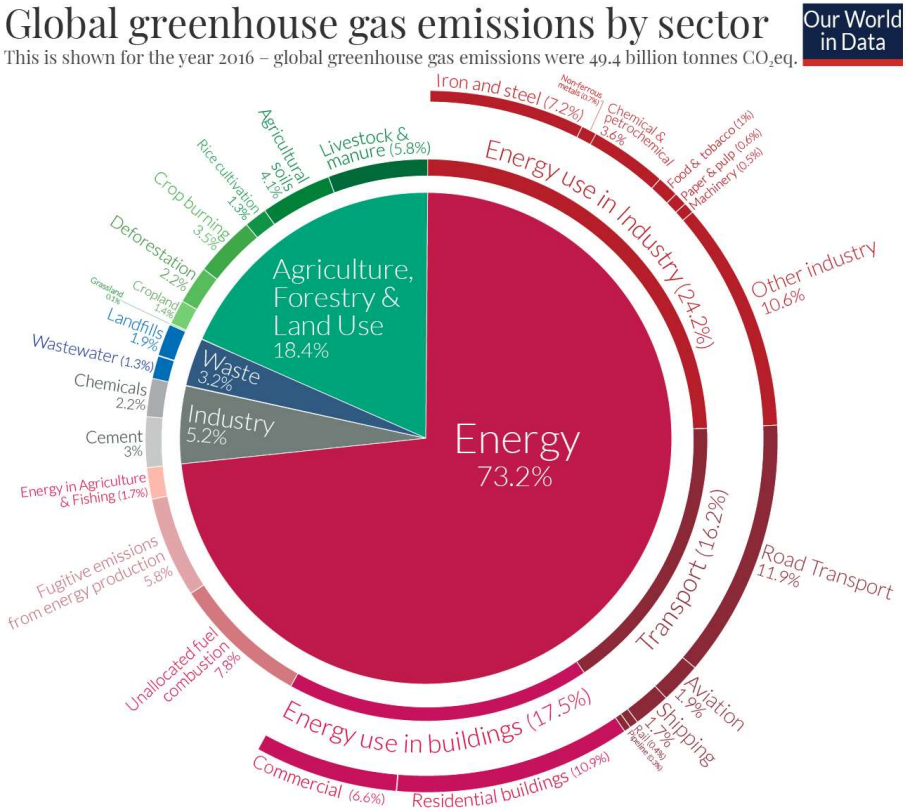


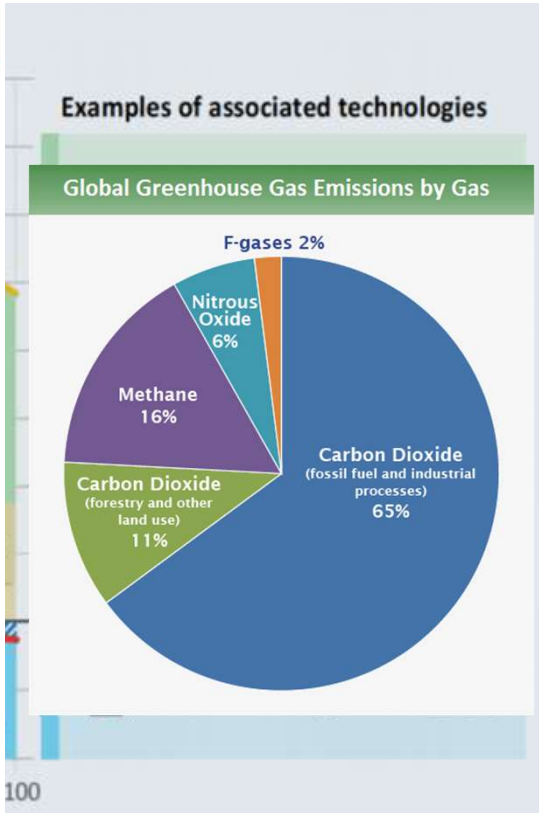
Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (1850-2020)

IPCC 2021

ADDRESSING THE ENERGY TRANSITION

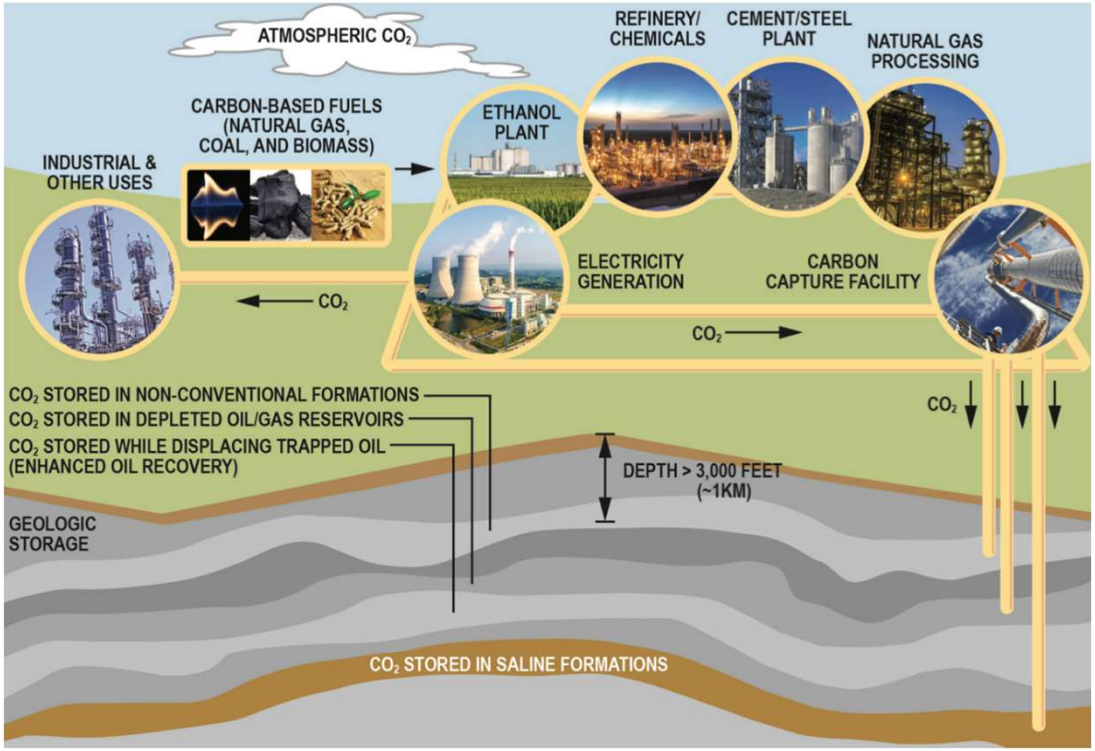
- Decarbonization deployed broadly is crucial
- Fuel Switching will be a significant portion of long term GHG emission reduction
- Energy sector must address decarbonization:
  - Transportation
  - Industry
  - Buildings
  - Materials





Source: OurWorldinData.org – Research and data to make progress against the world's largest problems.
Source: Climate Watch, the World Resources Institute (2020). Licensed under CC-BY by the author Hannah Ritchie (2020).

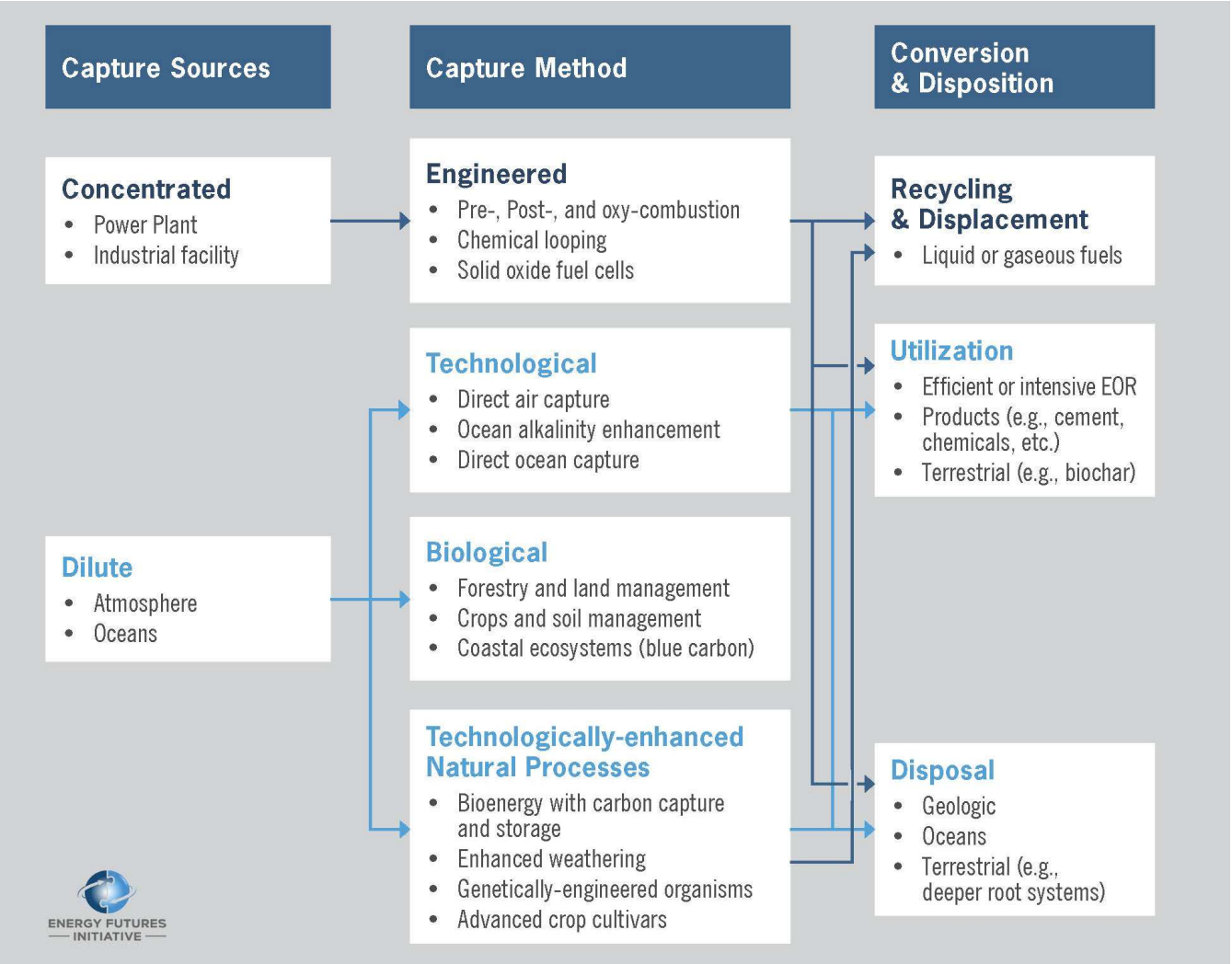
CO_2 MANAGEMENT SYSTEM



Rocky Mountain Coal Mining Institute, Atlas IV, as modified by NPC, 2019

- CO_2 emissions captured from industrial sources OR directly from the air.
- Compressed and transported via pipeline, truck, rail or ship.
- CO_2 injected underground for enhanced oil recovery or saline reservoir storage OR converted directly into products.

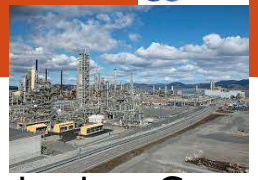
Technical Pathways for CO_2 Removal & Use / Storage



Source: Energy Futures Initiative

THE HISTORY OF CO_2 CAPTURE

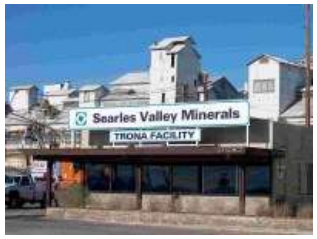
1st fertilizer



1st direct air Technology Center Mongstad

1st oxy-fuel

1st patent



1st coal power

1st gasification

1st gas processing

1st offshore

1st petchems

1st ethanol

National Carbon Capture Center

1st iron and steel

1st cement

1st hydrogen

1st BECCS

1930 1972 1978 1982 1996 2000 2006 2009 2010 2011 2012 2013 2016 2018 2019

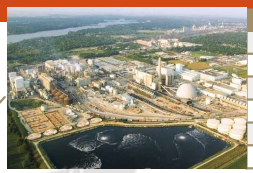
High Pressure | High Purity | Dilute | Very Dilute | Extremely Dilute

Images from the Baker Hughes digital library and courtesy ZeroCO2.no, Statoil, Google Earth, CO2 Norway, DOE/NETL and US Patent office
Adapted from Howard Herzog / MIT Energy Initiative using information from ZeroCO2.no and the GCCSI

TOP 10 US CO_2 CAPTURE EXAMPLES

Lost Cabin Gas Plant, Fremont County, WY	
Operator	ConocoPhillips
Start date	2013
Size	0.9 Mtpa
CO2 Source	Natural Gas Processing
Transport	232-mile pipeline
Storage	EOR in Belle Creek fields in MT

Great Plains Synfuels Plant, Beulah, ND	
Operator	Dakota Gasification Company
Start date	2000
Size	3 Mtpa
CO2 Source	Coal gasification
Transport	205-mile pipeline
Storage	EOR in fields in SK, CAN



Illinois Industrial CCS, Decatur, IL	
Operator	Archer Daniels Midland
Start date	2017
Size	1.1 Mtpa
CO2 Source	Ethanol Production
Transport	2-mile pipeline
Storage	Mount Simon Saline Formation

Shute Creek Gas Plant, La Barge, WY	
Operator	ExxonMobil
Start date	1986
Size	7 Mtpa
CO2 Source	Natural Gas Processing
Transport	142-mile pipeline
Storage	EOR in fields in WY, CO, MT

Coffeyville Gasification, KS	
Operator	Coffeyville Resources
Start date	2013
Size	1 Mtpa
CO2 Source	Fertilizer production
Transport	68-mile pipeline
Storage	EOR in North Burbank Unit field, OK

Century Plant, Pecos County, TX	
Operator	Occidental Petroleum
Start date	2010
Size	8.4 Mtpa
CO2 Source	Natural Gas Processing
Transport	100-mile pipeline
Storage	EOR in fields in West Texas

Enid Fertilizer, OK	
Operator	Koch Nitrogen Company
Start date	1982
Size	0.7 Mtpa
CO2 Source	Fertilizer production
Transport	120-mile pipeline
Storage	EOR in fields in OK

Terrell Natural Gas Processing, Fort Stockton, TX	
Operator	Occidental Petroleum
Start date	1972
Size	0.5 Mtpa
CO2 Source	Natural Gas Processing
Transport	220-mile Val Verde pipeline
Storage	EOR in fields in West Texas

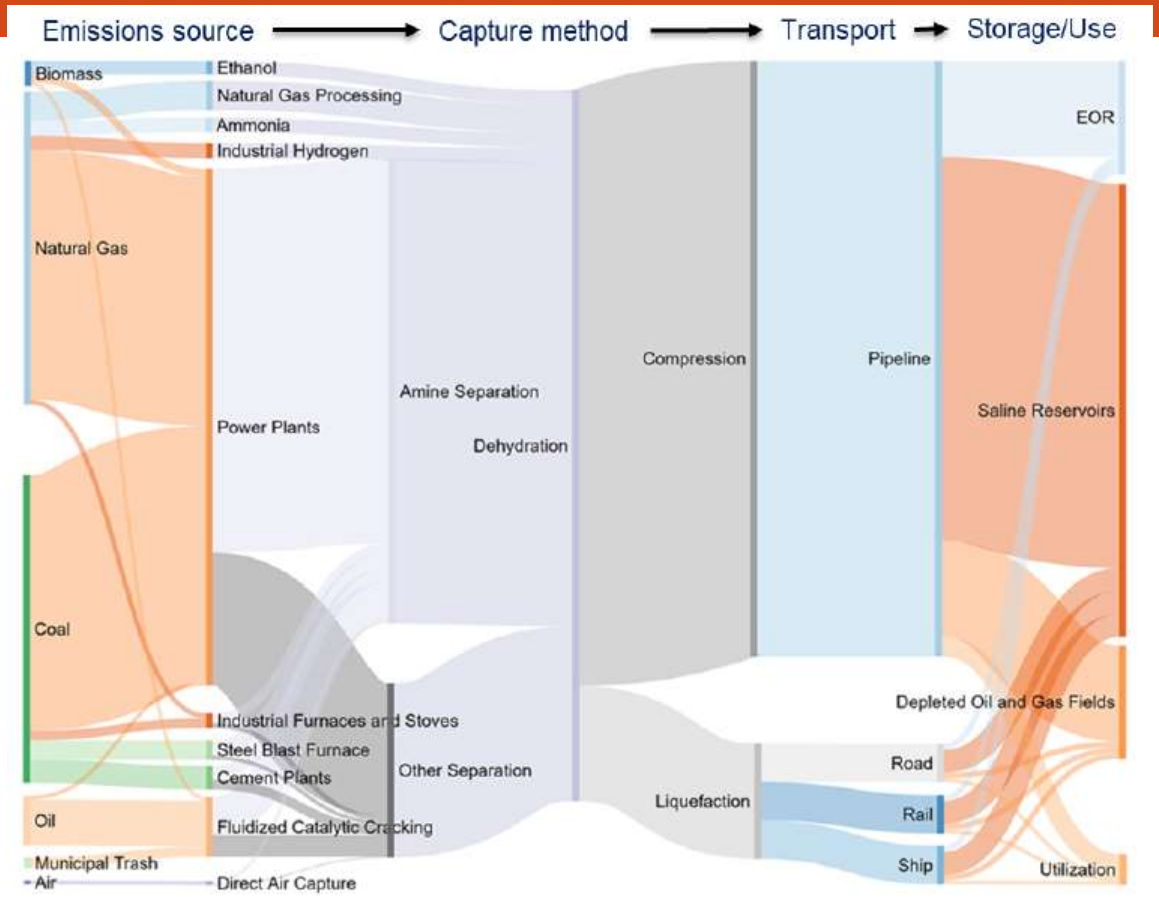
Petra Nova (WA Parish), Houston, TX	
Operator	NRG Energy
Start date	2017
Size	1.4 Mtpa
CO2 Source	Coal-fired power generation
Transport	80-mile pipeline
Storage	EOR in West Ranch field, TX

Air Products SMR, Port Arthur, TX	
Operator	Air Products
Start date	2013
Size	1 Mtpa
CO2 Source	Hydrogen production
Transport	13-mile pipeline
Storage	EOR in fields in TX

High Pressure | High Purity | Dilute | Very Dilute | Extremely Dilute

Source: Adapted from National Petroleum Council Report on Meeting the Dual Challenge, 2019, Chapter 5 "CO2 Capture". Additional photos from SPE, DOE/NETL/ZeroCO2.no

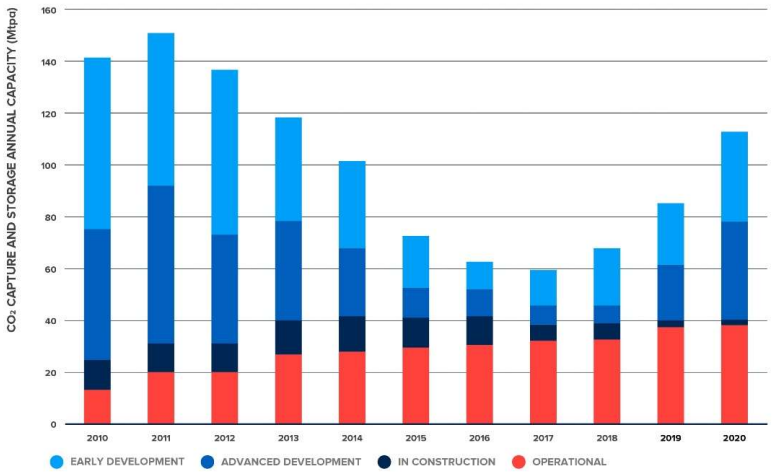
CCUS SUPPLY CHAIN SANKEY DIAGRAM



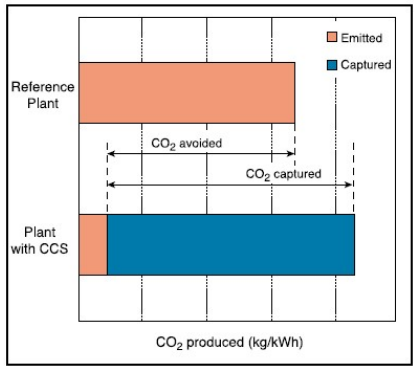
Source: National Petroleum Council Report on Meeting the Dual Challenge, 2019, Chapter 5 "CO2 Capture"

CCUS: CAPTURE PHASE

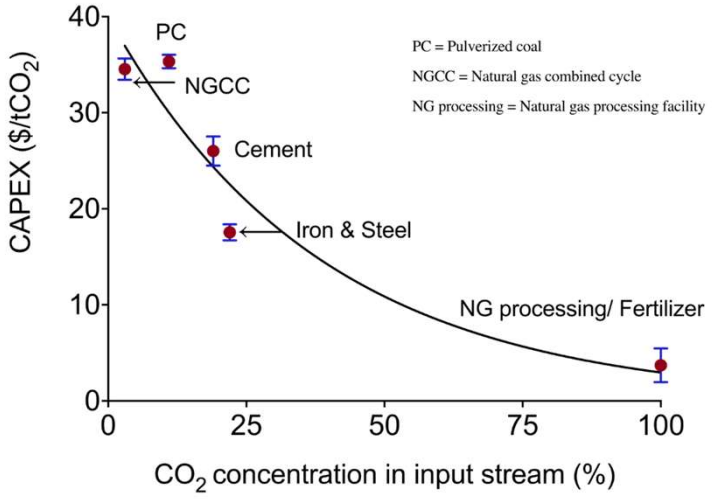
- Globally 26 projects capture ~ 40 MM tons of CO_2 annually (captured and sequestered or utilized)
  - 0.1% of annual anthropogenic CO_2 emissions
- Critical challenges for capture technologies
  - Cost-effective capture
  - Energy efficient capture
  - Parasitic load
  - Scaling-up
  - Retrofit and application to existing infrastructure and fleet



Global status of CCUS as of 2021



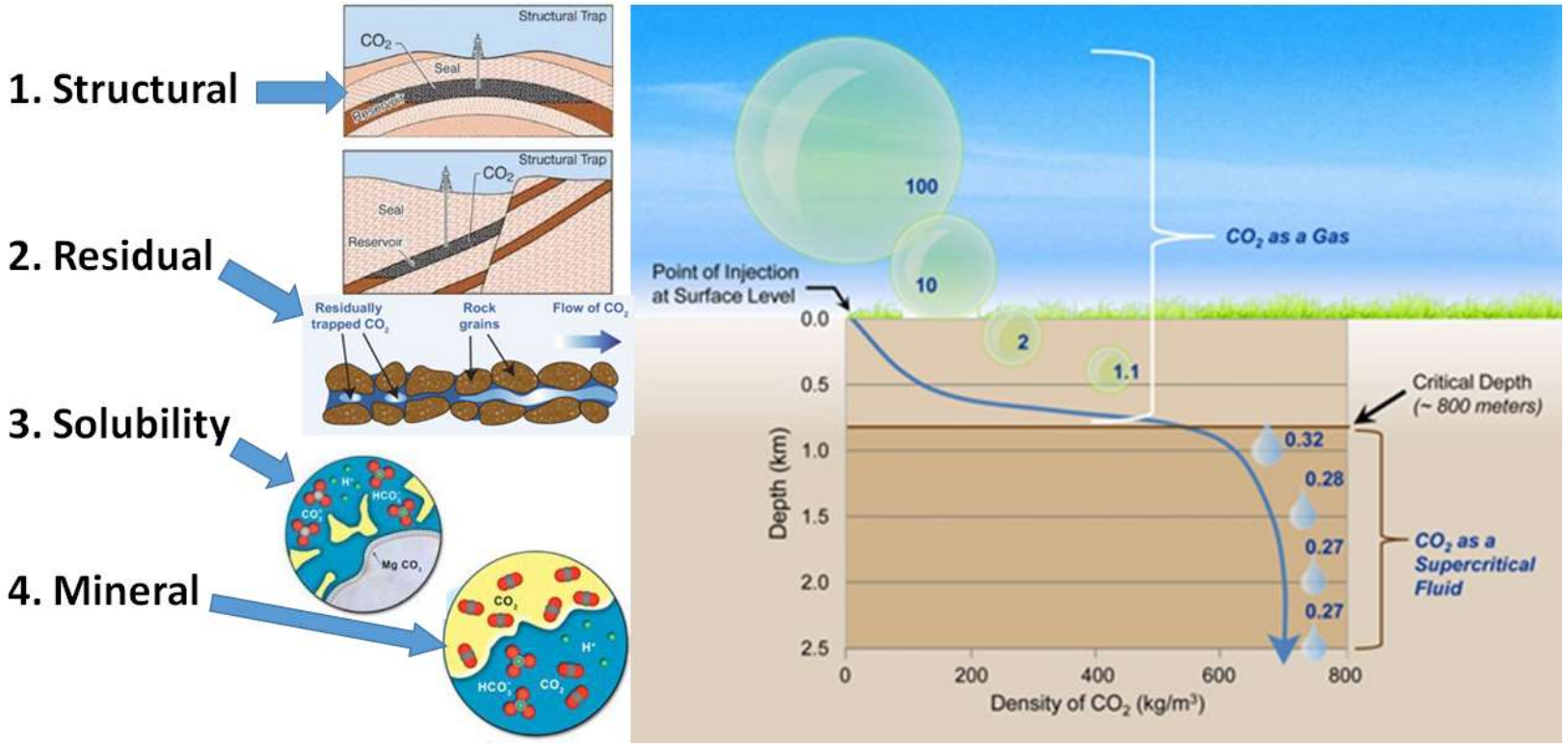
Parasitic energy load of CCUS



CAPEX for CO_2 separation as a function of CO_2 concentration in input stream

Sources: Global CCS Institute, IPCC Special Report on Carbon dioxide Capture and Storage

LIABILITY MANAGEMENT: TRAPPING MECHANISMS SURFACE GAS VS. SUBSURFACE FLUID MANAGEMENT



KEY POINTS

- Carbon Capture and Carbon Sequestration are mature fields
- Carbon Valorization is key
- Need to keep global leadership here in GHA