Process
Solutions
for a
Dynamic Market

CO2 CAPTURE & MARKETING

UPDATED JAN 2024

CANUSA EPC

AGENDA

- Carbon Capture Preface
- Carbon Sources for Oil & Gas Operators
- Process Technologies & Improvements
- Where is the Market for CO_2?
- Question & Answer



SOURCES

Point Sources

- Ethanol Fermentation
- Amine Units

Flue Gas

- Power Generation
- Cement
- Petroleum
  - Compressor/Generator Exhaust
  - Heater Exhaust
  - Flares

Production Gas

Atmosphere

CO2 Emissions Trends

- We are seeing an increase in CO2 from most sectors except Power

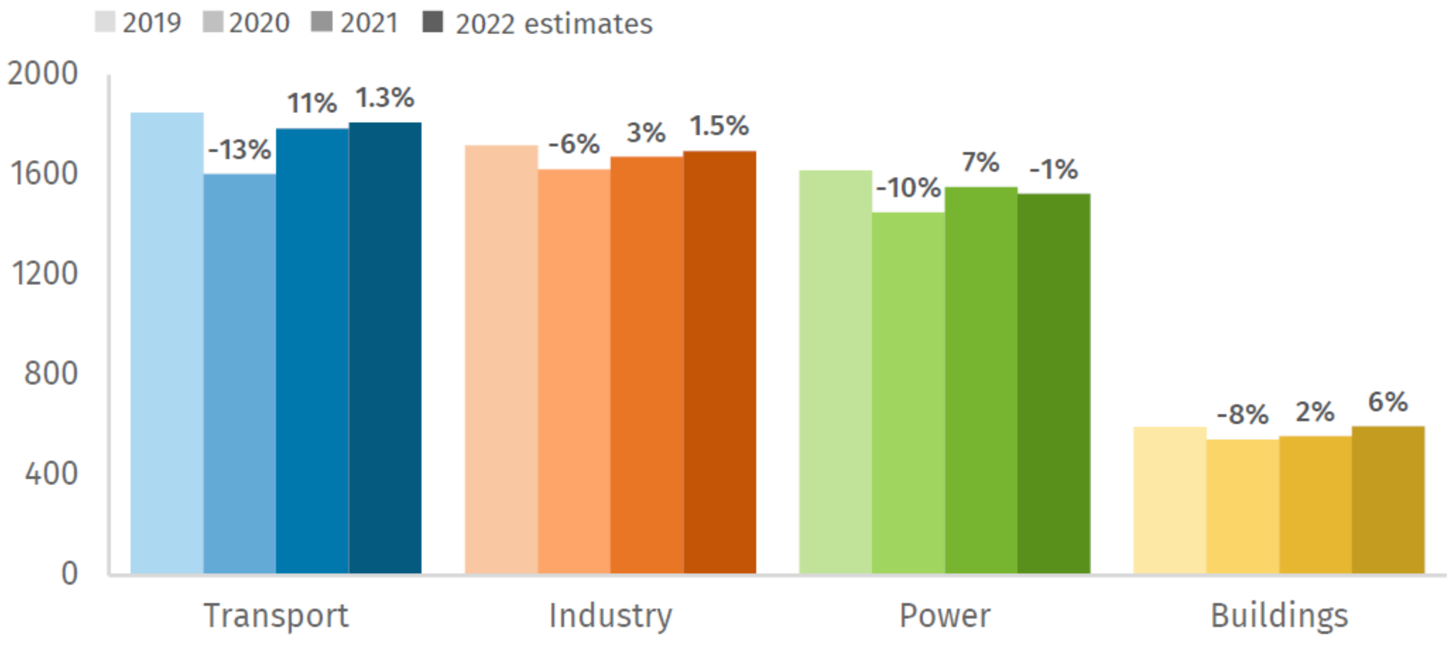
- Renewable Energy is displacing coal and natural gas generation

- More focus is on Methane in the short term related to abatement or conversion to CO2

FIGURE 3

Year-on-year change in net US GHG emissions by major emitting sector

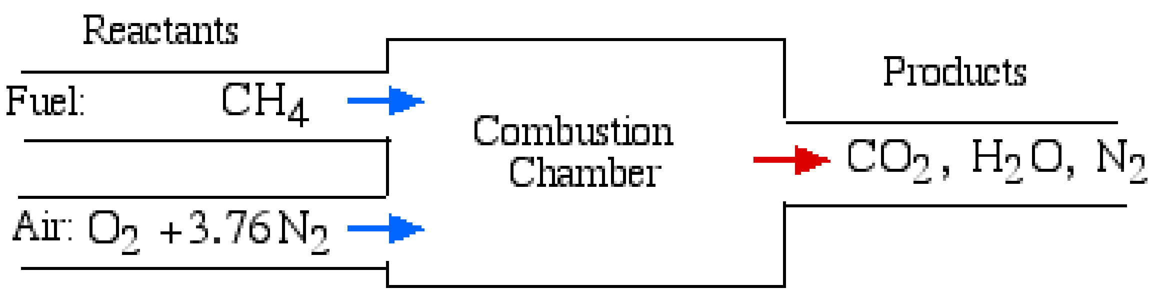
Million metric tons CO_2e and percent change yoy



Source: Rhodium Group

Flue Gas – Power Generation & Process Heat

- **Combustion** is a large source of CO2
- Large scale power generation has a long engagement of CCS efforts
- Onsite natural gas power generation is still common in remote gathering systems
- Process heat



$$CH_4 + 2(O_2 + 3.76N_2) \Rightarrow CO_2 + 2H_2O + 7.52N_2$$

U.S. electric utility and independent power electricity generation and resulting CO2 emissions by fuel in 2019

	Electricity generation	CO2 emissions		
	million kWh	million metric tons	million short tons	pounds per kWh
Coal	947,891	952	1,049	2.21
Natural gas	1,358,047	560	617	0.91
Petroleum	15,471	15	17	2.13

Flue Gas from Natural Gas Compression Engines

- Natural gas engines supply most of the installed horsepower in the oil and gas space
  - NOx, CO, THC, NMHC, NMNEHC, HCHO
  - Exhaust temperature at 822°F
  - Atmosphere pressure
  - 3608 CO_2 Emissions (2500 hp)
    - 423 g/hp-hr
    - 9,250 tonne/yr (25 tonne/d)
    - Small by capture projects standards

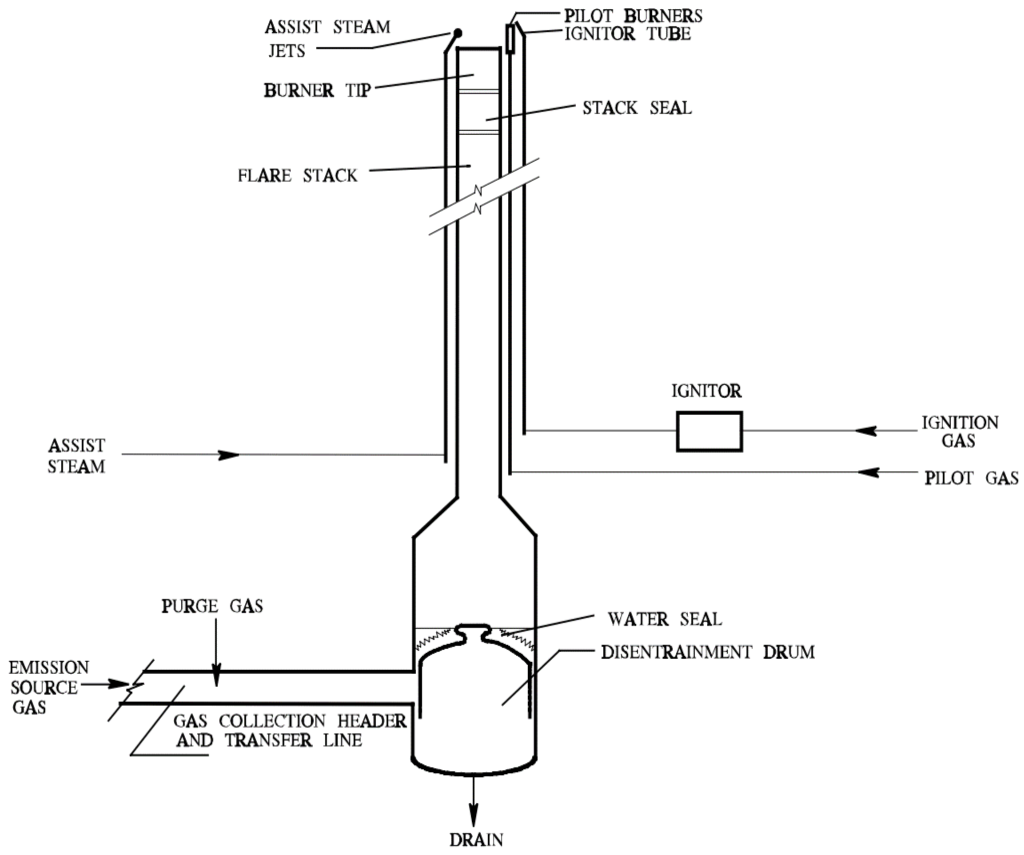
GREENHOUSE GAS EMISSIONS

2,012

Passenger vehicles driven for one year

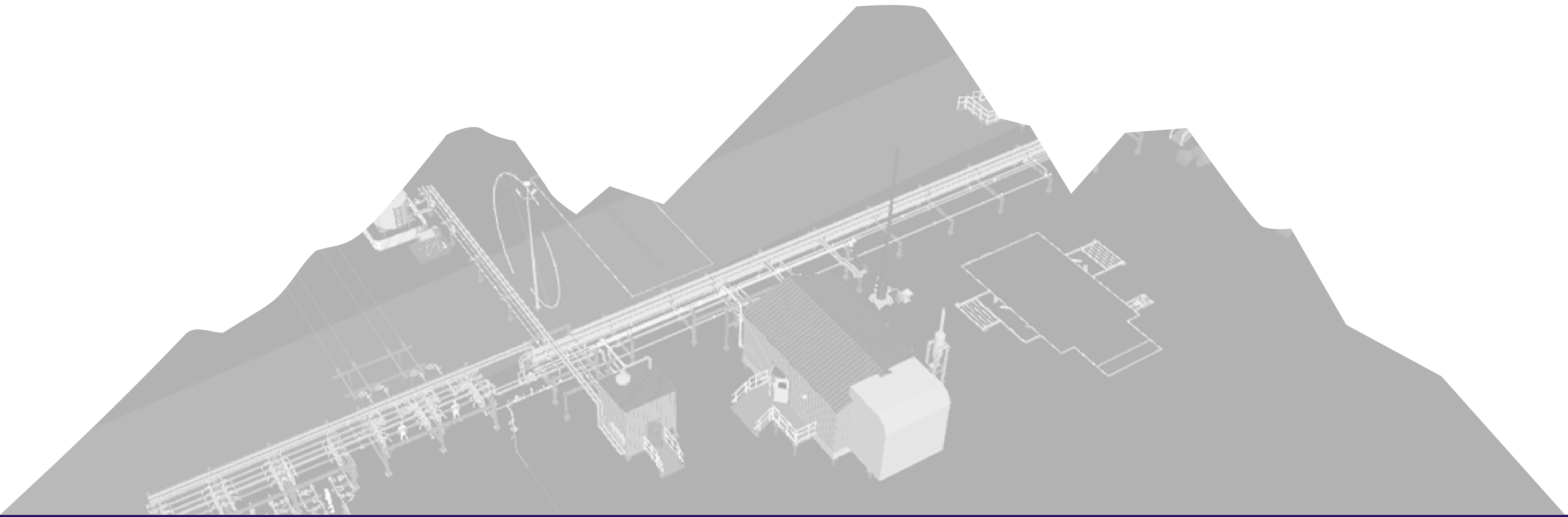
Methane GHG Emissions

- Combustors common in oil/gas facilities
- Reduce methane GHG reductions (still CO_2)
- High efficiency combustion
  - Properly operated flares combustors at least 98 percent combustion efficiency
- Capturing carbon versus reducing carbon
  - VRUs and blowdown capture systems solve the problem (capture methane) and generate revenue
  - For other flue gases, still need CO_2 capture



TECHNOLOGY IMPROVEMENTS

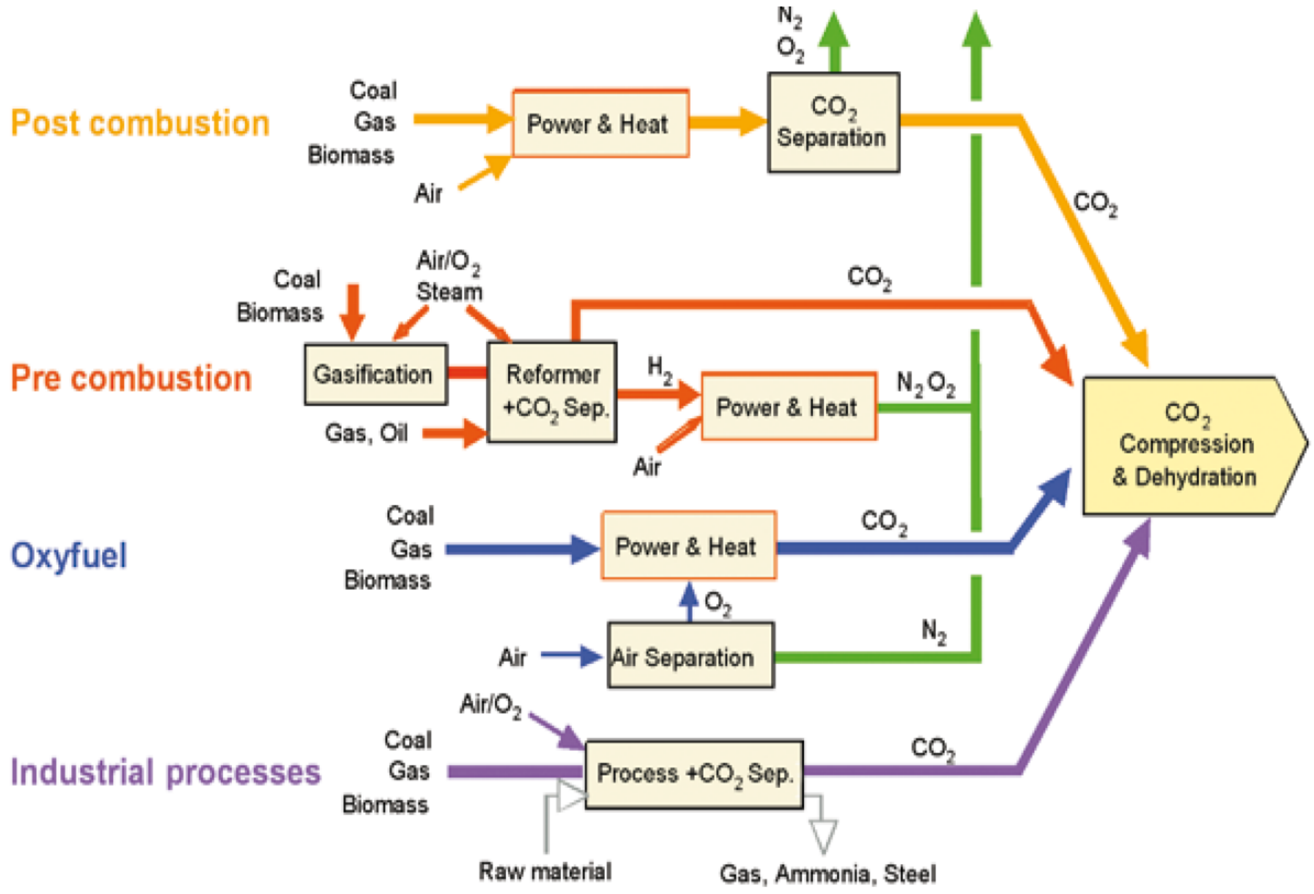
MAKING LOW CONCENTRATION SOURCES VIABLE



Capture Types & Technologies

- 4 Capture Types
  1. Post Combustion
  2. Pre-Combustion
  3. Oxy-Fuel Combustion
  4. Industrial

- First three dominant as applied to the electric power industry, where the CO2 capture goal is typically 90%



Post Combustion

Simplest carbon capture technology & most practical one for retrofitting existing plants

Carbon capture from power plant or industrial flue gas after combustion of fuel in air to make power or heat

CHALLENGES

Concentrations of 3-15% CO_2 + 70-75% N_2 + water

Contains O_2, NO_x, Sox

Low P (atmospheric), moderate to high T (50-150 C) → Cooling

TECHNOLOGIES

Absorption

Adsorption

Membranes

Cryogenics

Post Combustion – Solvents Based Capture

Most common technology?

Liquid solvent absorption

Absorption in solvent liquids

Chemical — Physical

Chemical solvents rely on… **solubility** + **chemical reaction with CO_2** to form salts that can be regenerated with heat

Physical solvents rely on… solubility only with an example like Selexol (a poly glycol ether), among several others
(since the latter rely on pure partial pressure, it is challenging to remove 90% CO_2 at atmospheric pressure)

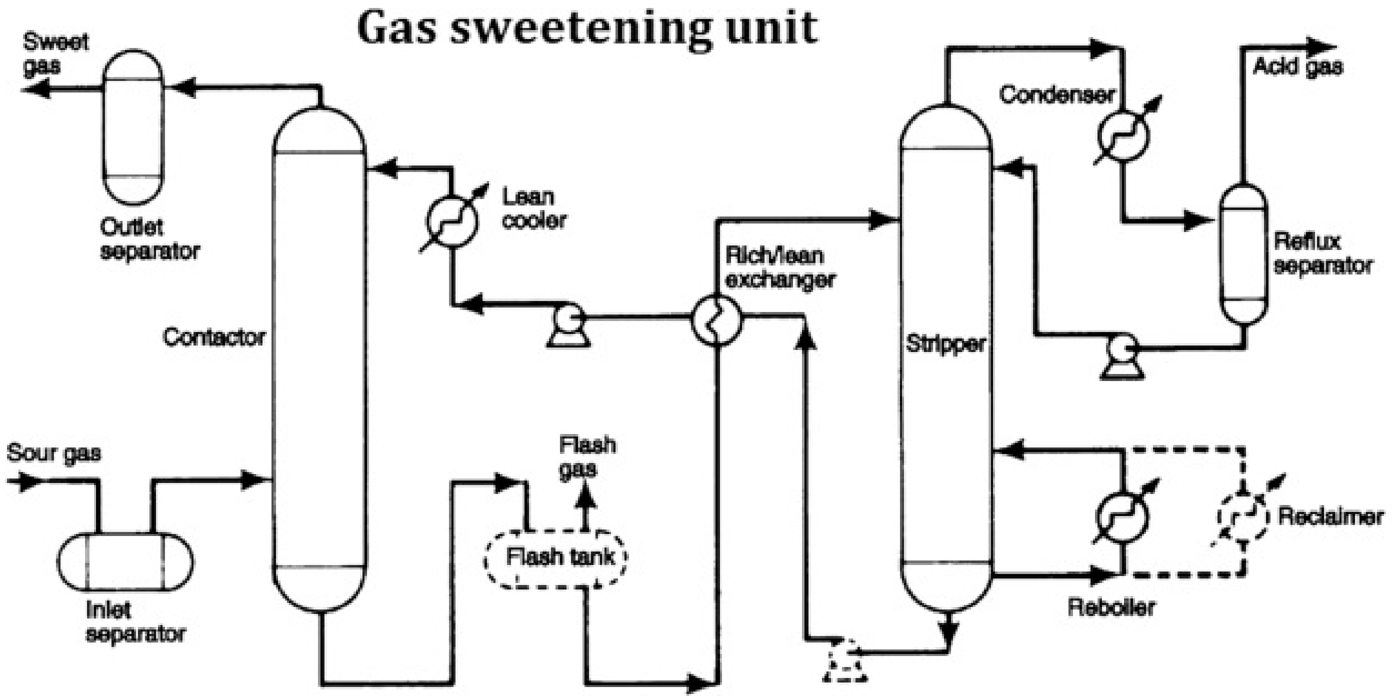
Post Combustion – Solvent Technology

Most mature technology?

90% CO2 Removal

Chemical solvents!

Amines, Aqueous Ammonia, Potassium or Sodium Hydroxides



Post Combustion – Solvent Technology

Waste Stream from Solvent Process

- Around 120°F
- 90+% CO_2, with some water and a 1-2% light HC

Equipment

- Low P + Mod-Hi T = Low Density
- REQUIRES LARGE EQUIPMENT (BLOWERS, PACKED CONTACTORS)

Post Combustion

- Other technologies that can be utilized are adsorption on solid materials such as activated carbon, zeolites or others
- Membranes can also be utilized, but challenging due the low pressure and membranes requiring partial pressure as a driving force
- Cryogenic separation can also be utilized but the challenge is again low pressure
- For all these technologies, higher pressure removal is obviously easier but substantial compression power required → cost

Pre-Combustion & Oxy Fuel

- Pre-Combustion carbon capture utilizes the concept of making synthetic gas (CO, H_2) with some CO_2 from gasification and/or reforming of hydrocarbons, similar to hydrogen production
- After reforming and shift reaction, the gas is then put through a PSA purification process to produce high purity H_2
- The CO_2 is a waste gas stream from the H_2 purification, where it can be recovered, before using the waste gas as fuel
- Mostly associated with large power plants, H2 production
- Oxy-Fuel combustion is carbon capture that is simply combustion using enriched air (95% O_2) instead of normal air (21% O_2) to make heat or power; low or high pressures
- Advantage: smaller flue gas stream due to the absence of N_2; mainly water vapor and CO_2 (up to 80%) → subsequent CO_2 removal is easier than post combustion as it is mostly H_2O condensation
- Combustion temperature is higher and requires moderation of some kind; can be done by having slightly lower O_2 content with more N_2 or with CO_2 by recycling of flue gas, resulting flue gas rate can still as low as 20% of an air combustion flue gas; can also be done with water
- Since 95% oxygen is utilized, this process requires an air separation unit of some kind, typically cryogenic for larger applications and PSA units for smaller applications, increases cost

Capture Technologies – Improvements

- Capture in Solids and Membranes
  - Low, Medium & High Temperature Solids; can work at all pressures
  - Low: Activated Carbons, Zeolites, MOFs
  - Medium: LDH; High: Calcium Based
- Though MOFs show promise, still some optimization required, and costs must decrease to compete with liquids
- Membranes can also capture CO2 but require partial pressure driving force; still require improvement for both high permeance/selectivity
- As in natural gas treating, case study comparison reports are needed

Capture Technologies – Improvements

- Most mature technology is solvent absorption but regeneration energy and equipment size are challenges + degradation

- What have we done to address solvent regeneration energy?
  - Solvent formulation
  - Process optimization - heat integration
  - Catalytic regeneration

- Other major issue is oxygen degradation → HSS; dealt with through formulation/reclamation; water wash helps nitrosamines and other volatility issues

Capture Technologies – Improvements

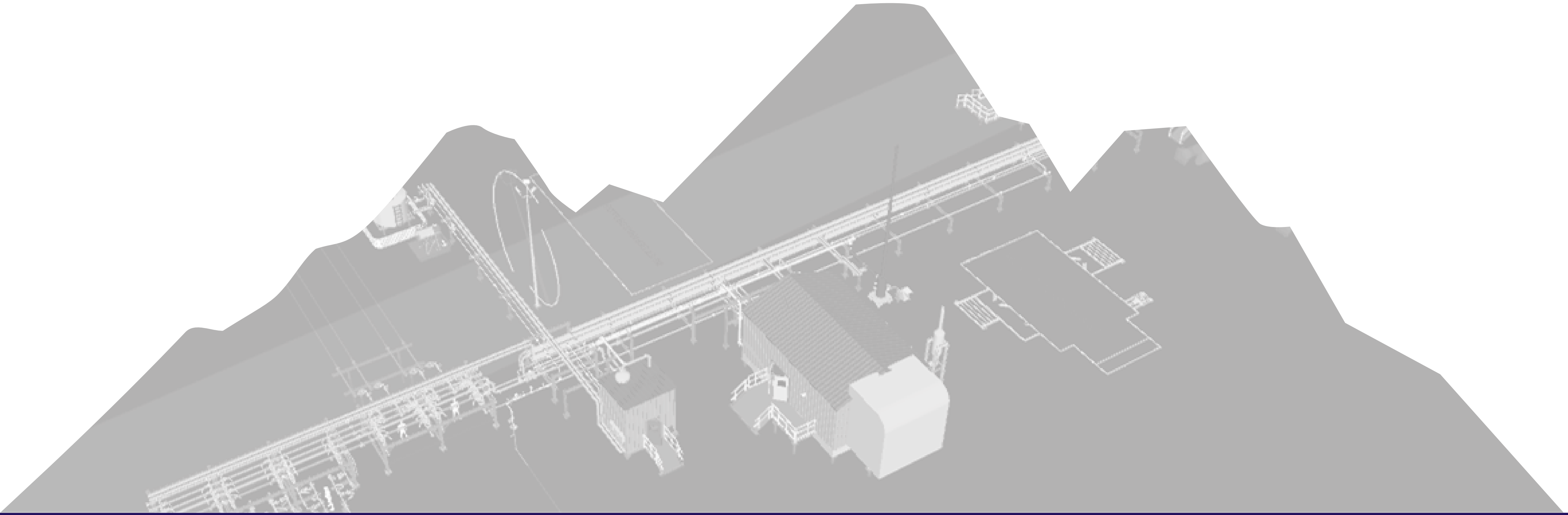
- Have we done anything to address equipment sizes?
  - Use packed contactors to reduce diameter required (2 m/s)
  - Development of new internals types that allow higher velocities and better mass transfer
  - Though usually considered uneconomic, some work suggests compression to 3 atm

- Few consistent studies on process optimization; lower OPEX → higher CAPEX; some studies agree that absorber intercooling & rich split should be used

- <u>Consistent study needed</u>

ONCE I PURIFY THE CO2, WHAT IS IT WORTH?

DEPENDS ON THE APPLICATION



HOW TO MARKET CO2

- No universal open market for carbon dioxide – yet
- Revenue from carbon dioxide will rely on political policy and individual contracts - the former still developing
- Short Term Developments
  - Sequestration/EOR
  - Industry Uses – concrete, chemicals → small compared to emissions
- Long Term Markets are not established beyond industrial gas supply needs

Where is there proven value?

- Enhanced Oil Recovery
- Liquid CO2 for Food and Beverage

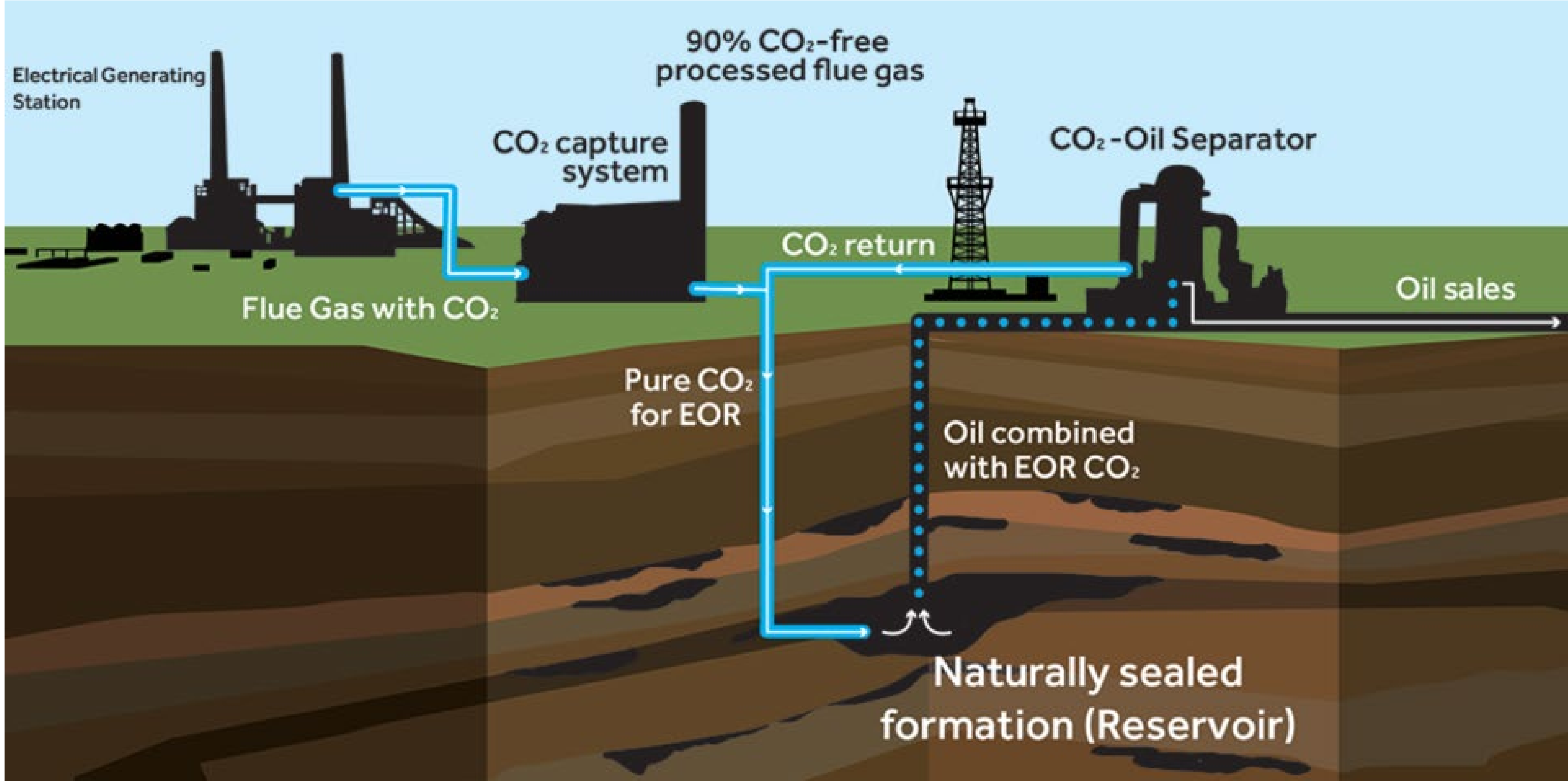
EOR (Tertiary Injectant)

Proven method for generating value from CO2

Improves performance of well production with a “waste” gas

Carbon credits available
$60 Per Metric Ton
Requires a Class II Well

Who is doing it?
Exxon – Rockies/Gulf Coast
Oxy – Gulf Coast
Kinder Morgan
Canada – Encana – Weyburn, SK



Sequestration – Permanent Storage

Available to take advantage of now

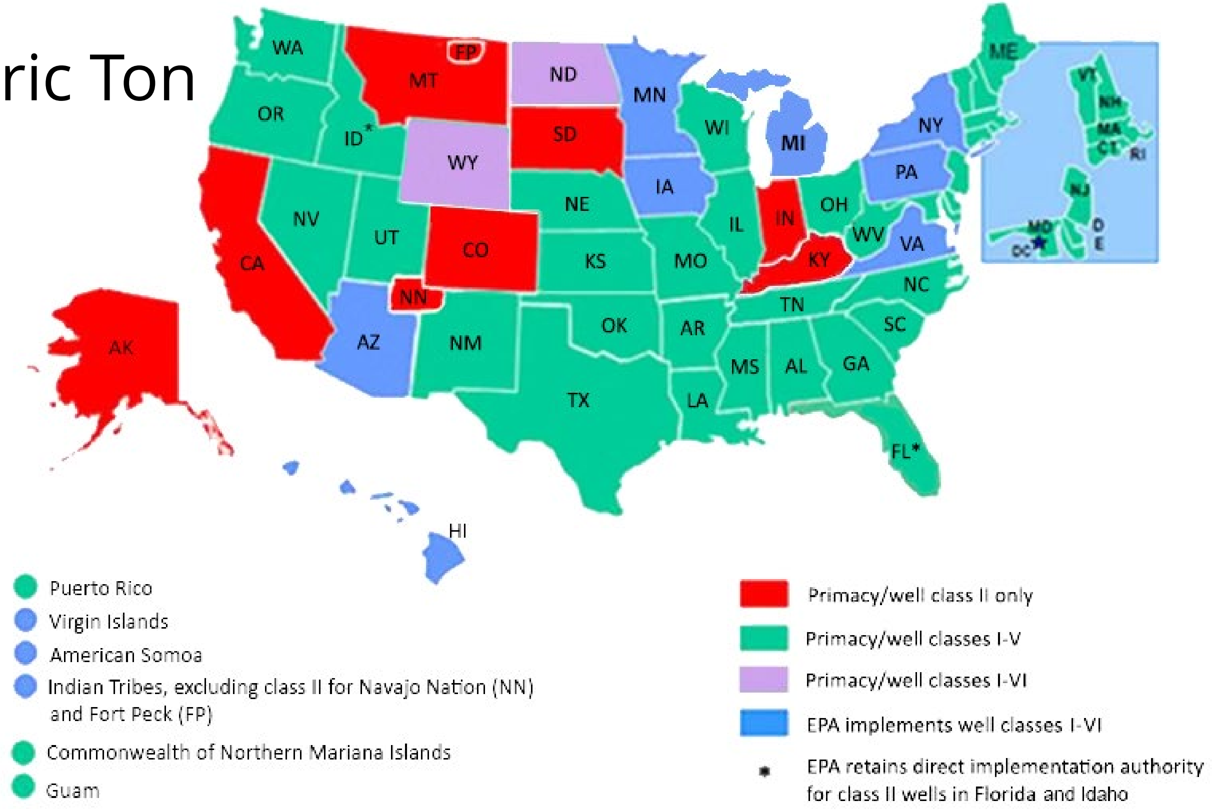
45Q Credits are available - $80 Per Metric Ton

Class VI well required

- EPA is the primary entity
- Some states are being given primacy Wyoming/North Dakota/Louisiana

Current hurdles

- Ambiguity in state oversight
- Substantial monitoring (Underground Injection Control)
- Liability for 50 years of storage



Liquefaction for Food/Beverage & Medical

COMPRESSION → DEHYDRATION → REFRIGERATION → STORAGE → LOADING

- Feasible with off the shelf packages
- Varying grades may require additional purification
  - Beverage 99.9
  - Food 99.9
  - Medical 99.5

Liquefaction

Sensitive to liquifying CO2 based on contaminant concentrations

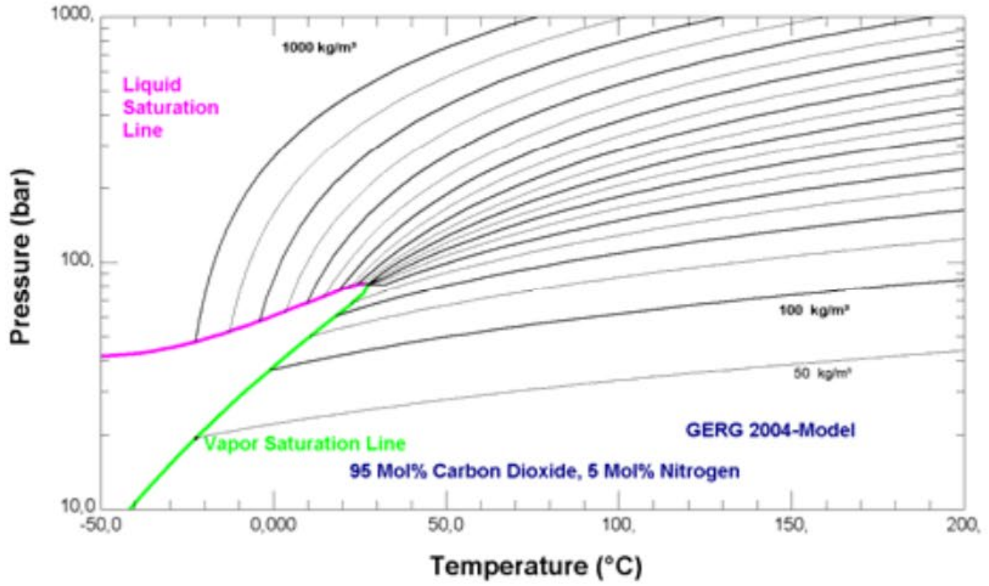


Fig. 3a. Phase diagram 95 Mol% Carbon Dioxide 5 Mol% Nitrogen calculated with accurate GERG 2004 equation [10]
Critical Point: 27.12 °C, 81.13 bar [10]

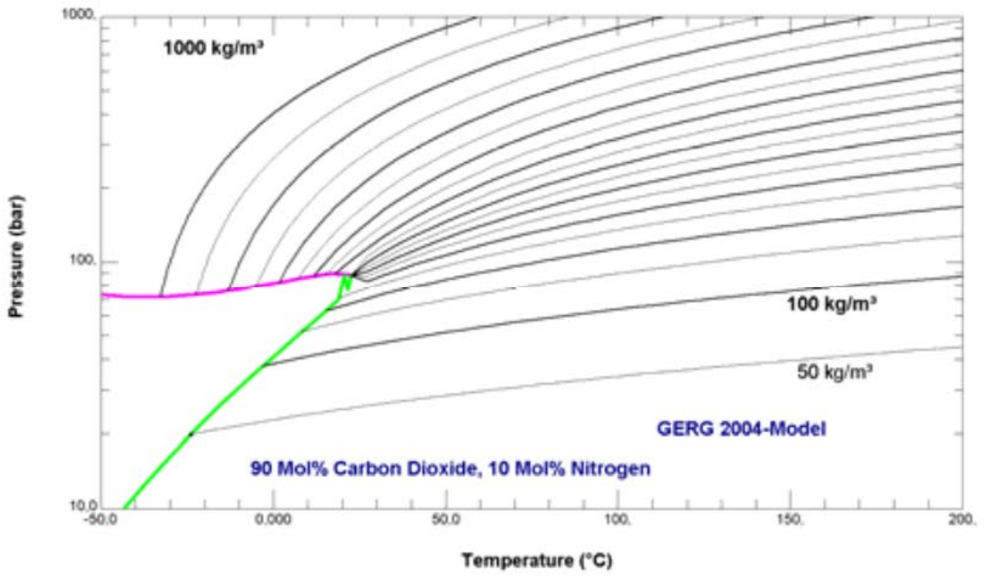


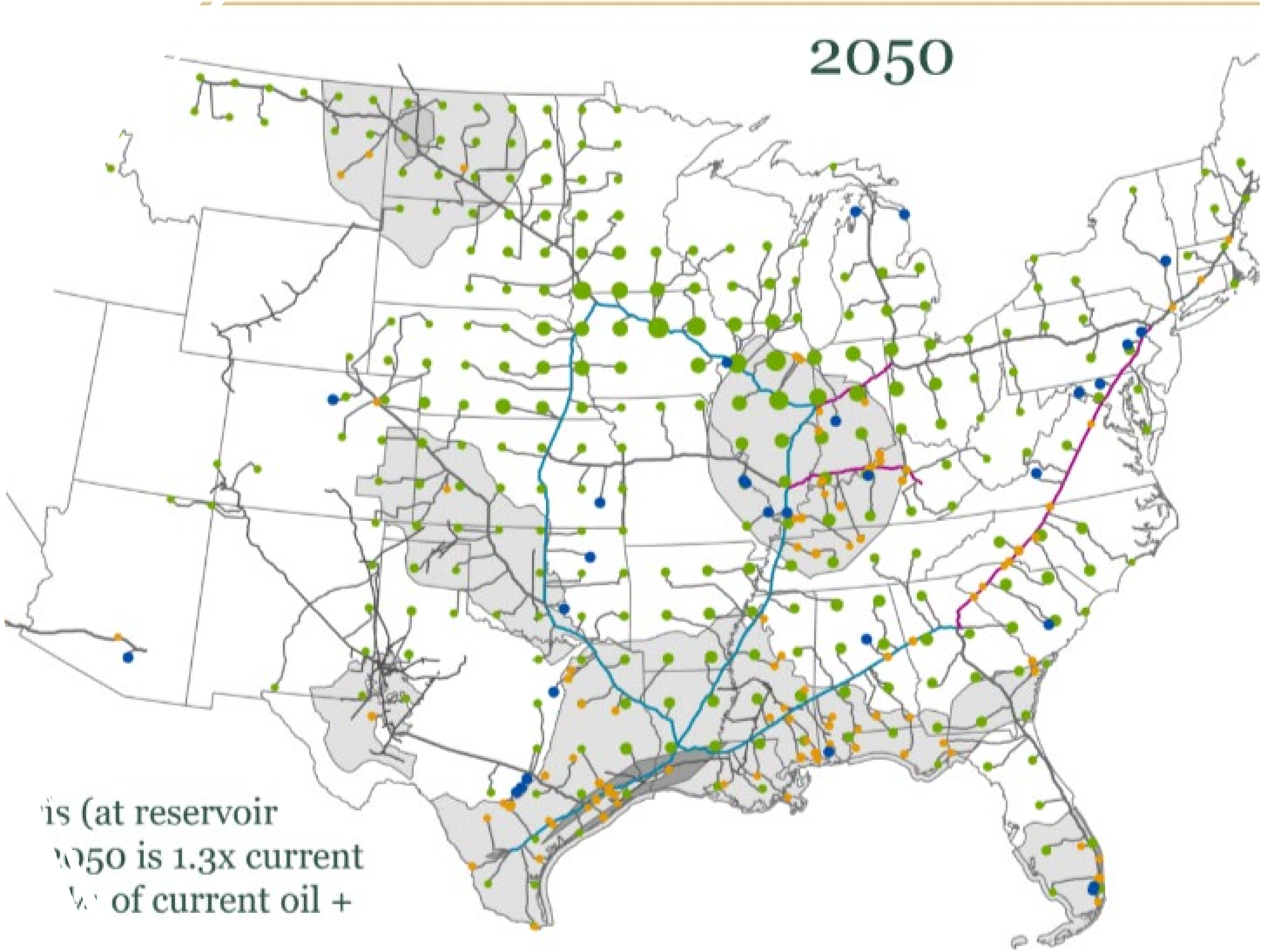
Fig. 3b. Phase diagram 90 Mol% Carbon Dioxide 10 Mol% Nitrogen calculated with accurate GERG 2004 equation [10]
Critical Point: 22.51 °C, 87.70 bar [10]

Pipelines – The Midstream Way

- 50 existing systems transporting
  68 million tonnes annually to EOR/Sequestration

- New developments are being discussed
  - Summit Carbon Solutions
  - Wolf Midstream
  - Tallgrass Trailblazer Conversion
  - Wyoming Pipeline Corridor

- Pipelines will have sales quality requirements
  - Low water content
  - No O2



Net - Zero America: Potential Pathways, Infrastructure, and Impacts Report, October 2021. https://netzeroamerica.princeton.edu/the-report

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Geoff Amon
Principal, Operations and Engineering
403-519-0152
geoff.amon@CANUSAEPC.com

Forrest Churchill
Principal, Sales and Marketing
720-346-5464
forrest.churchill@CANUSAEPC.com

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