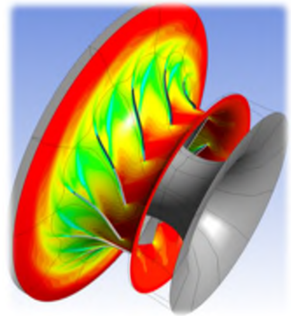
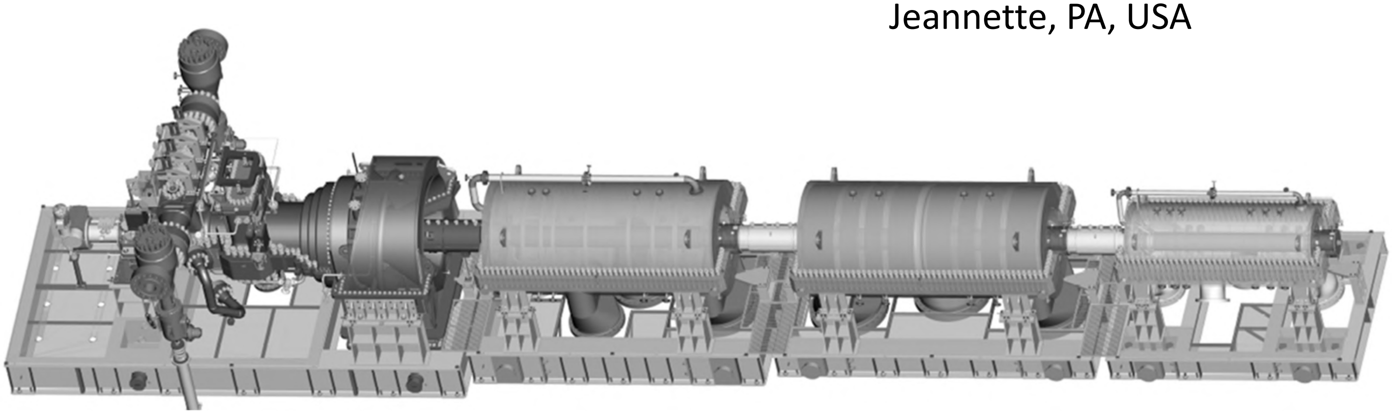


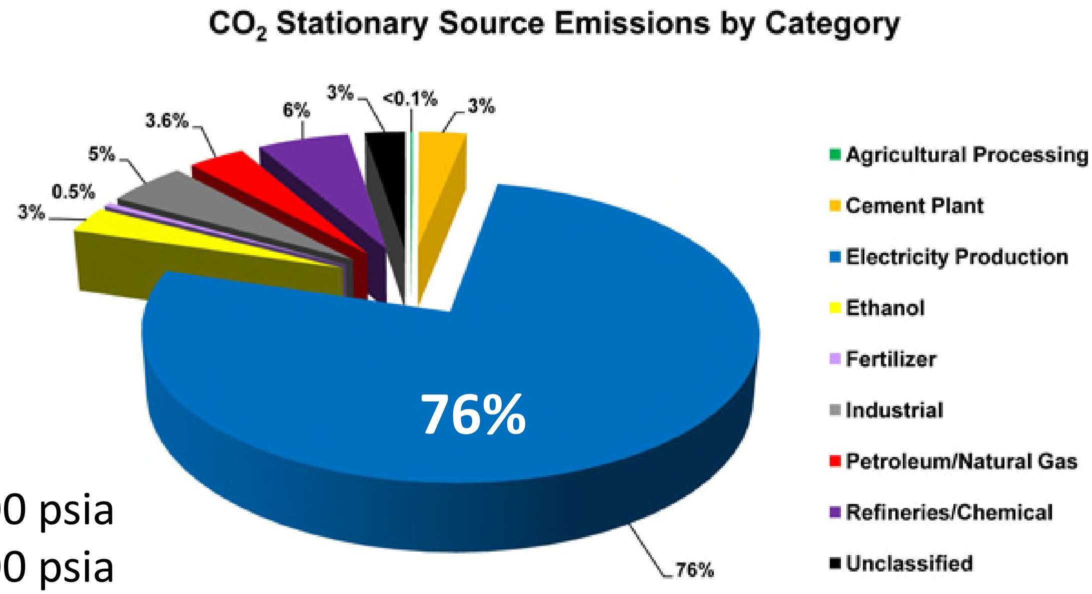
# Compressors and Pumps for $CO_2$ Transport


**Klaus Brun, Ph.D.**
Vice President Products & Technology
Ebara Elliott Energy
Jeannette, PA, USA

EBARA ELLIOTT ENERGY

# Industrial Sources of $CO_2$




Source: DOE/NETL

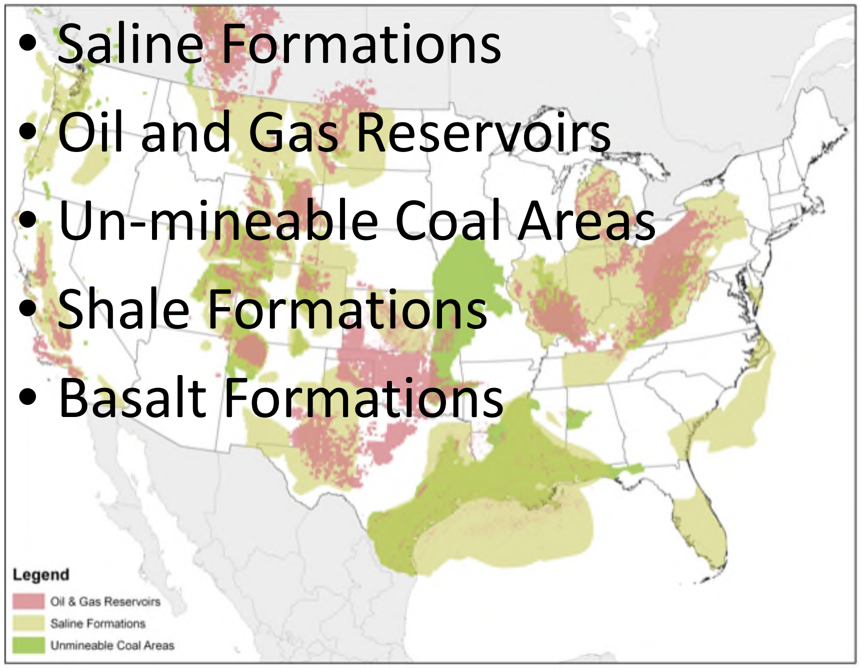
**Availability**:

- From Natural Gas Power Plants:
  - Steam Methane Reforming — P=20-100 psia
  - Gasification — P=50-400 psia
  - Oxyfuel Combustion — P=500-2000 psia
  - Combined Cycle Flue Gas — P=15-20 psia
- From Coal Power Plants:
  - Gasification Combined Cycle — P=100-500 psia
  - Stack Flue Gas Cleanup — P=15-20 psia
- From Oil & Gas Production
  - Associated Gas Separation — P=15-700 psia
- Other Industrial Sources ?

**Wide Range of Source Pressures**

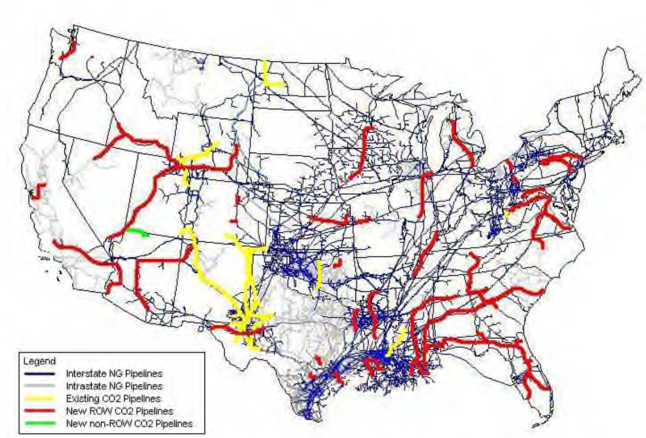
# Carbon Dioxide Storage Locations and $CO_2$ Pipelines

- Saline Formations
- Oil and Gas Reservoirs
- Un-mineable Coal Areas
- Shale Formations
- Basalt Formations

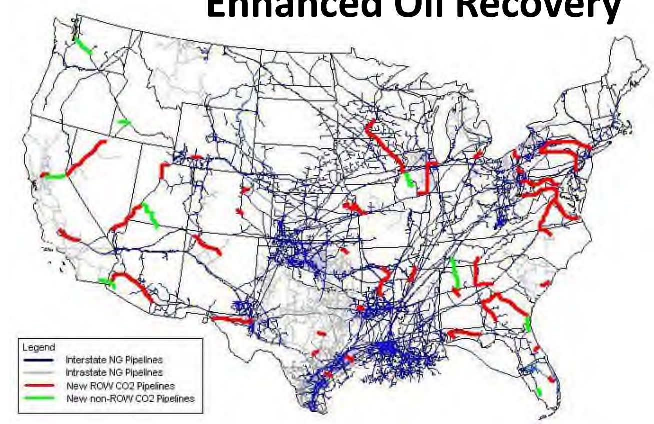



Source: National Carbon Sequestration Database and Geographic Information System

**Plenty of storage capacity and options, but do not align geographically with likely $CO_2$ production sites**



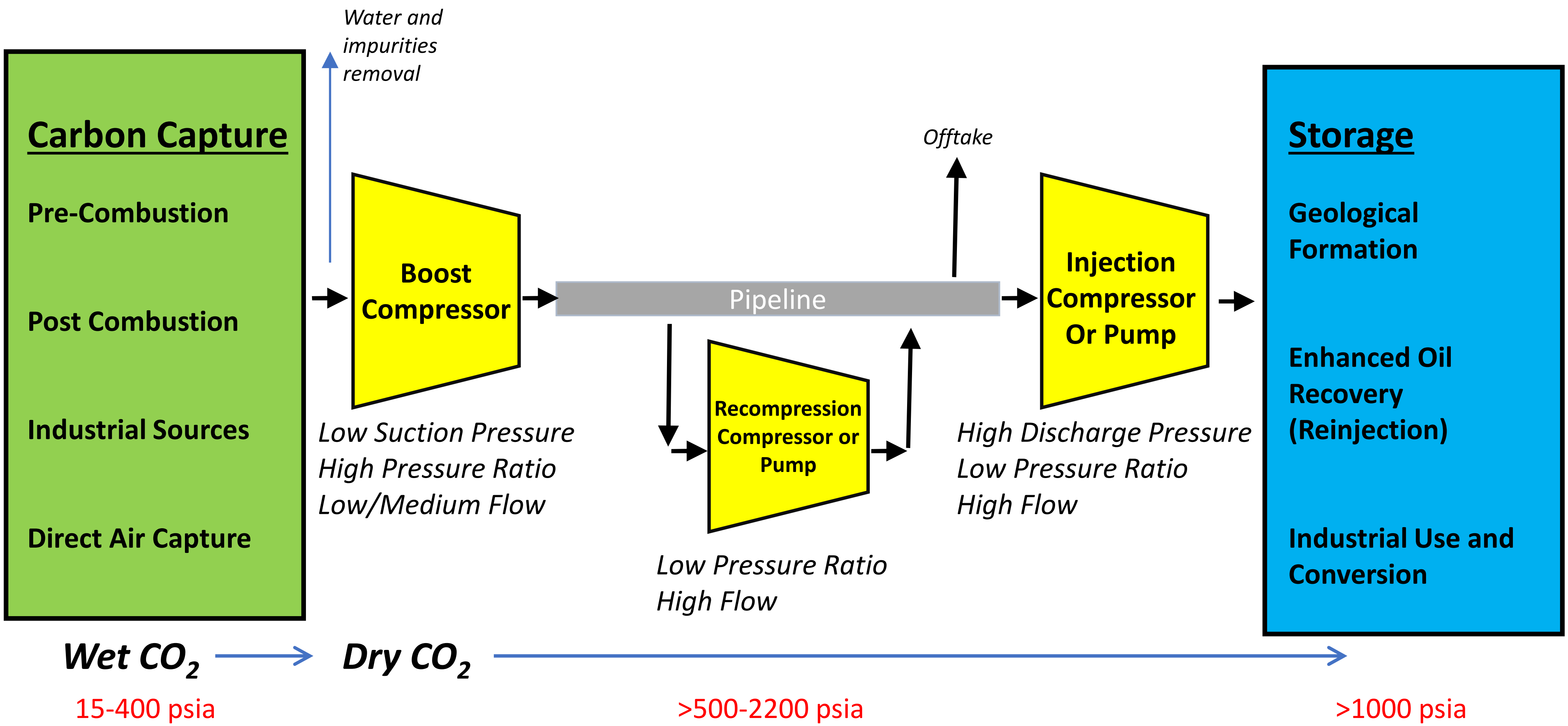

**Enhanced Oil Recovery**



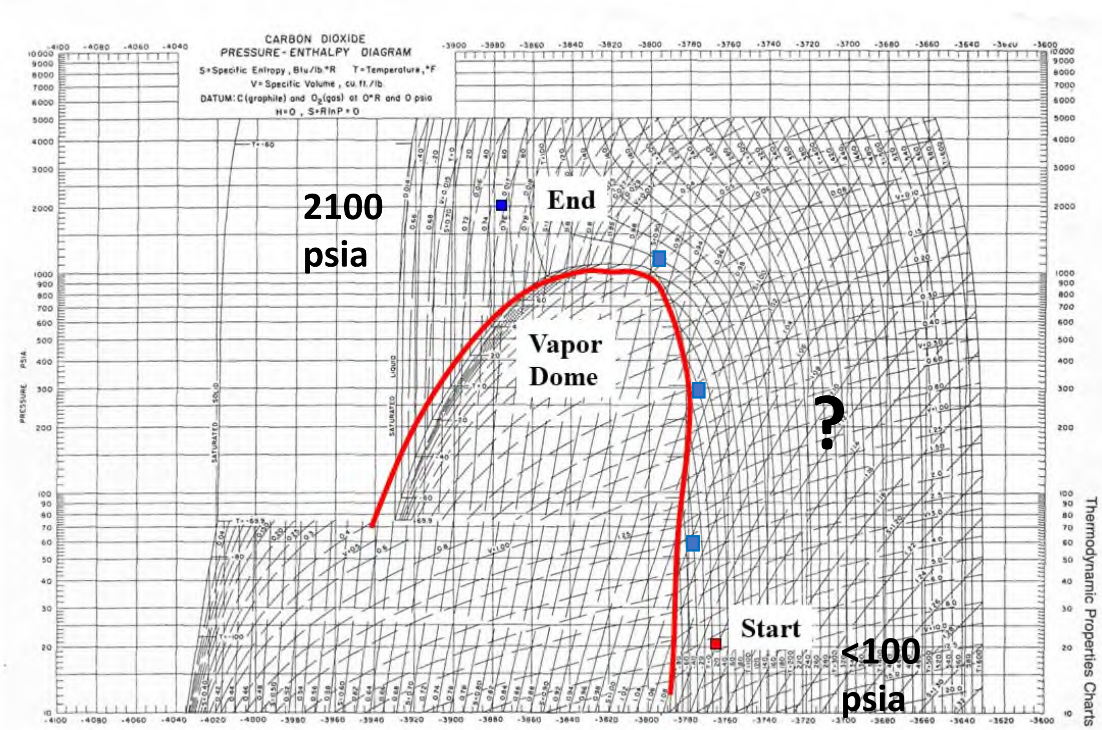

**Saline Formations**

**Injection pressure is 1800 psi for every mile of depth**

# Carbon Capture and Sequestration Value Chain



# Carbon Dioxide Compression versus Pumping




Carbon Dioxide Pressure-Enthalpy Diagram – Provided by Gulf Publishing Company-1972, Fig.8.2

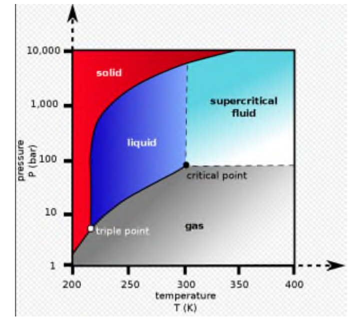
Issues:

- $CO_2$ available from separation at low (near atmospheric pressures (<100 psi). Header station is always compressor.
- Conventional assumption is that $CO_2$ is transported ("pumped") at supercritical pressures (2100 psi).
    - Requires very high pressure ratio compressors with intercooling
    - Large volume reduction
    - Multiple compression path options

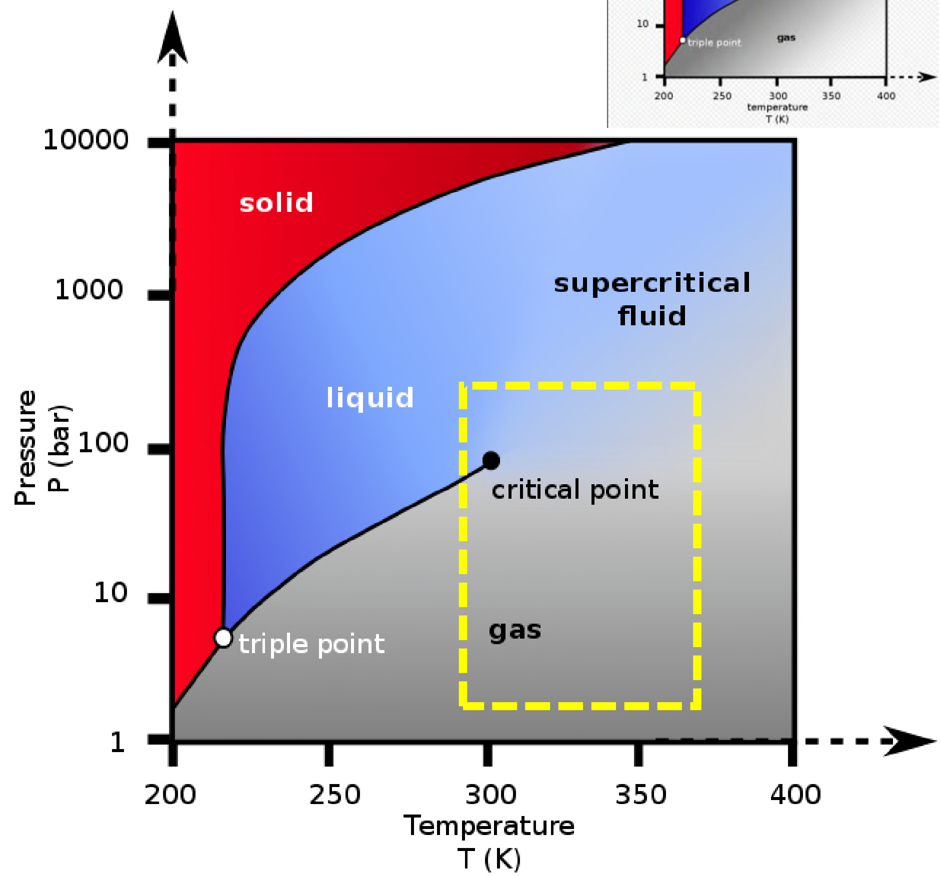
Pipeline operating pressure:

- **Not necessarily supercritical**
- Depends on transport distance, starting pressure and delivery pressure
- Injection pressure is not always supercritical (1150 psi per km of depth)

# Long Distance $CO_2$ Pipeline Operating Conditions

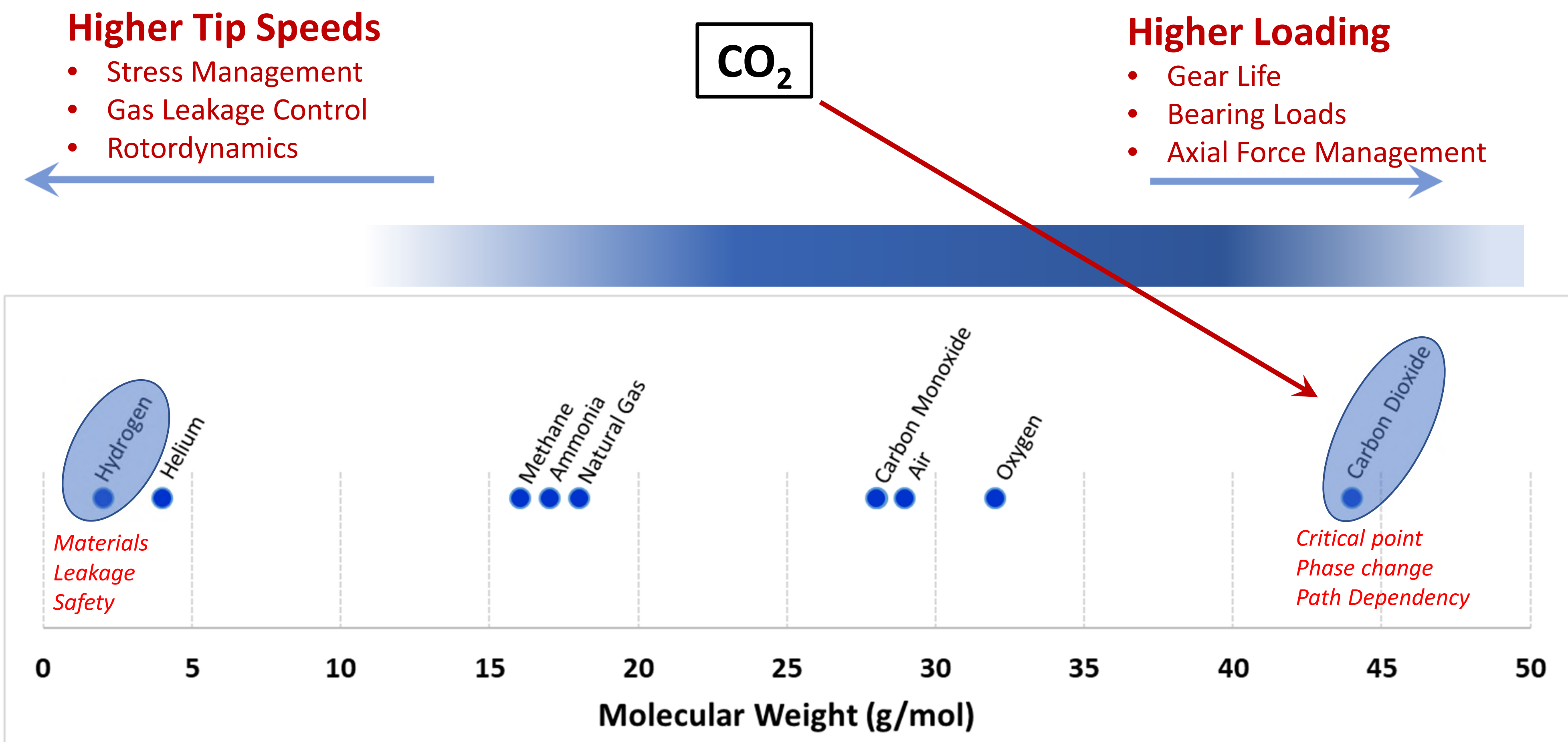



- Injection compression from near atmospheric
- Maintain dense phase operation
  - High density and low viscosity
  - Temperatures above 88˚F (30.9˚C)
  - Pressures above 1200 psi (73.3 bar), likely 1800-2300 psi
  - For pure $CO_2$
- Impurities alter speed of sound, vapor pressure, critical point, and compressibility factor
- <u>2100 psi is a typical pipeline pressure</u>
- Recompression is basically pumping



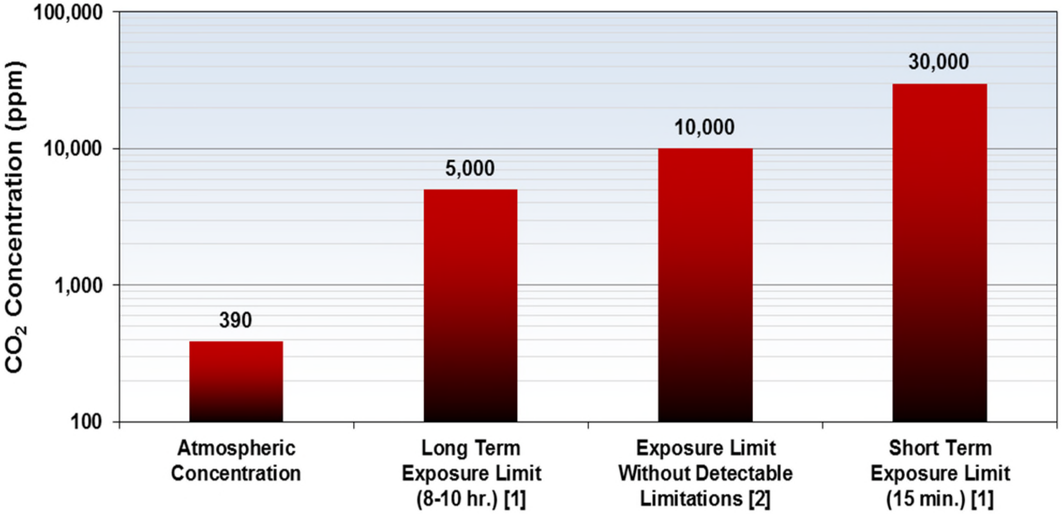
# Carbon Dioxide Compression Challenges

# Challenges Associated with $CO_2$ Turbomachinery Design

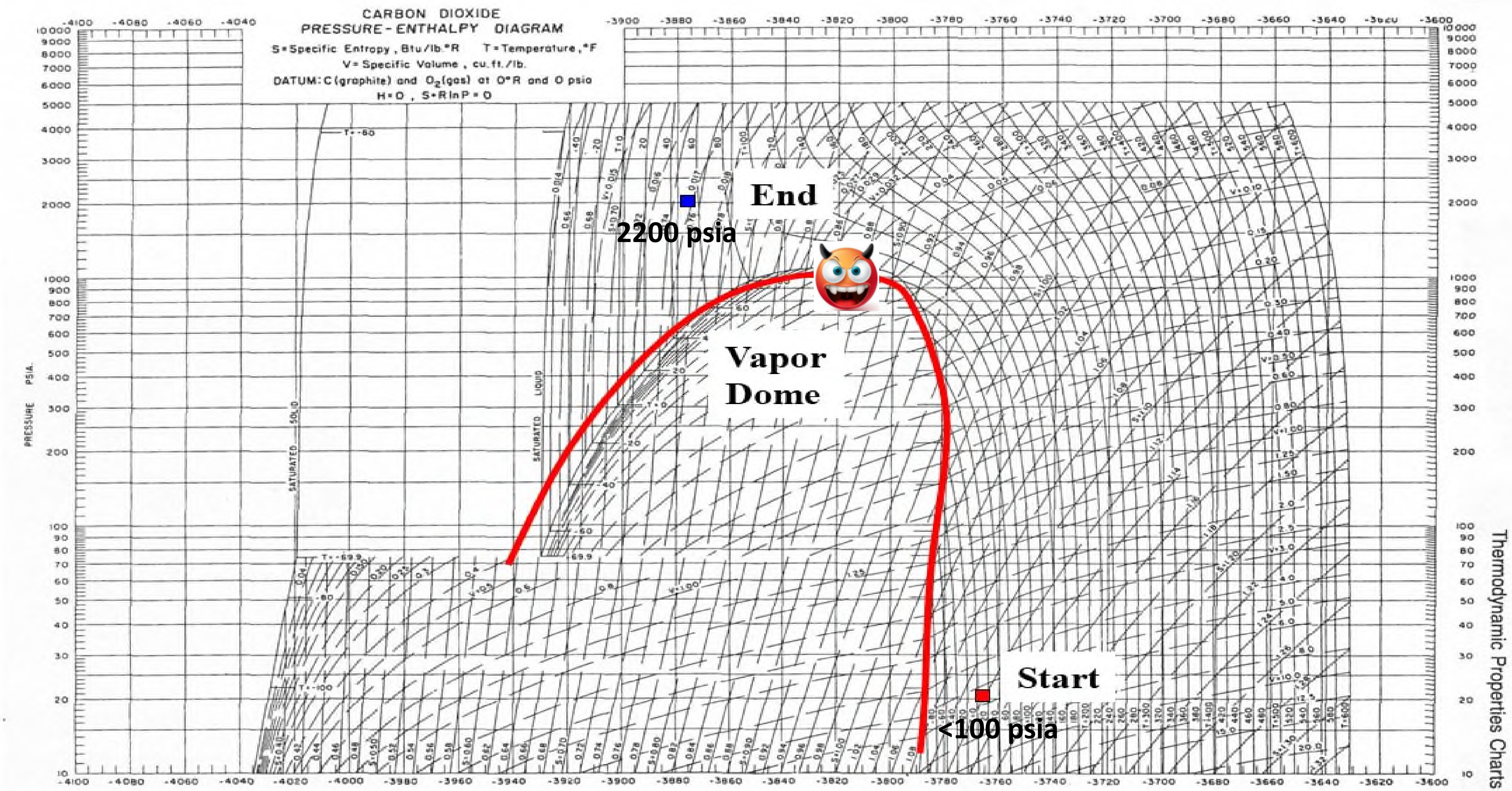


# Characteristics of $CO_2$

- Naturally occurring (0.04% of air)
- Odorless and colorless
- Mostly inert with gases
- Forms carbonic acid when mixed with water
- Non-toxic
- Asphyxiant
  - Sleepy at 1%, fatal over 7 to 10% concentration



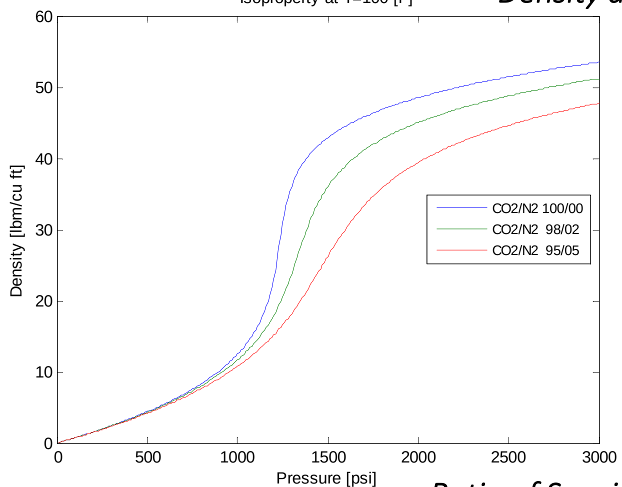
# Carbon Capture $CO_2$ Compression

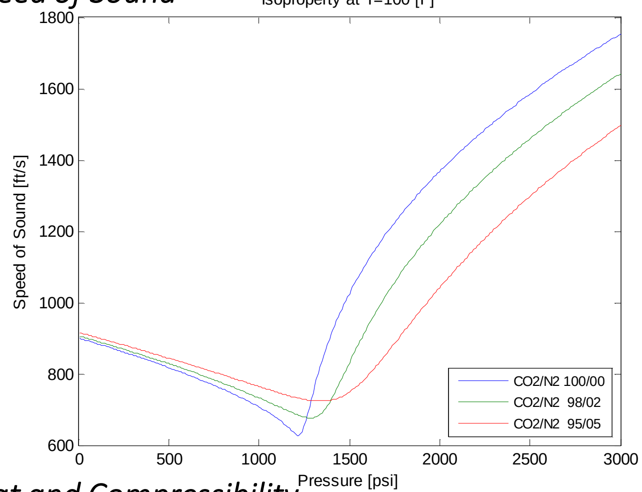



Carbon Dioxide Pressure-Enthalpy Diagram – Provided by Gulf Publishing Company-1972, Fig.8.2

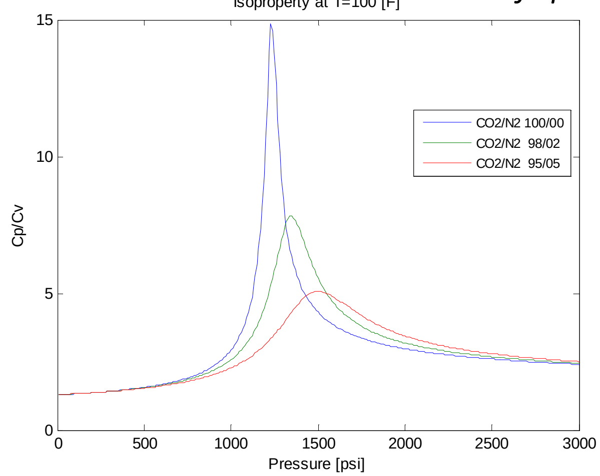
# $CO_2$ Physical Property Variation Near Critical Point

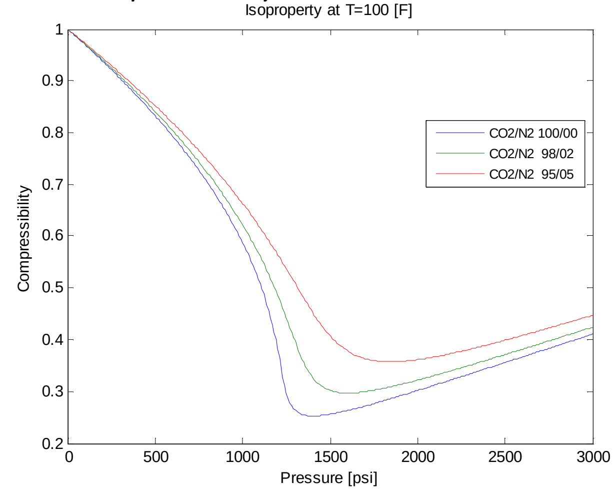
*Density and Speed of Sound*




*Ratio of Specific Heat and Compressibility*



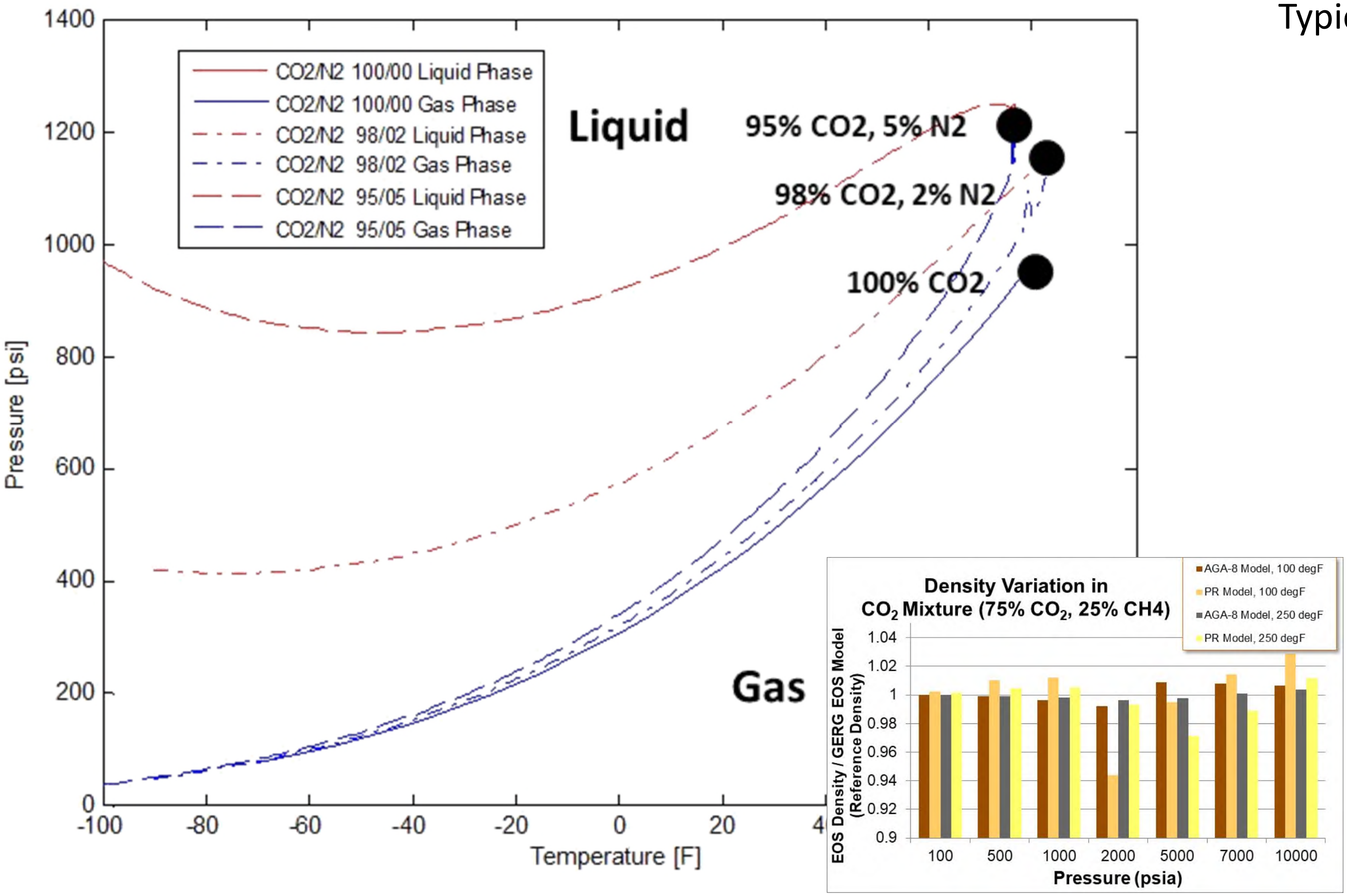

<u>Near Critical Point</u>:

- Enhanced thermal conductivity
- Sharp density decrease
- Increased thermal conductivity
- High ratio of specific heats

<u>Above Critical Point</u>:

- Small density increase (i.e., small volume decrease) with P
- Drastic speed of sound increase with P

# Change in Critical Point with Mixture



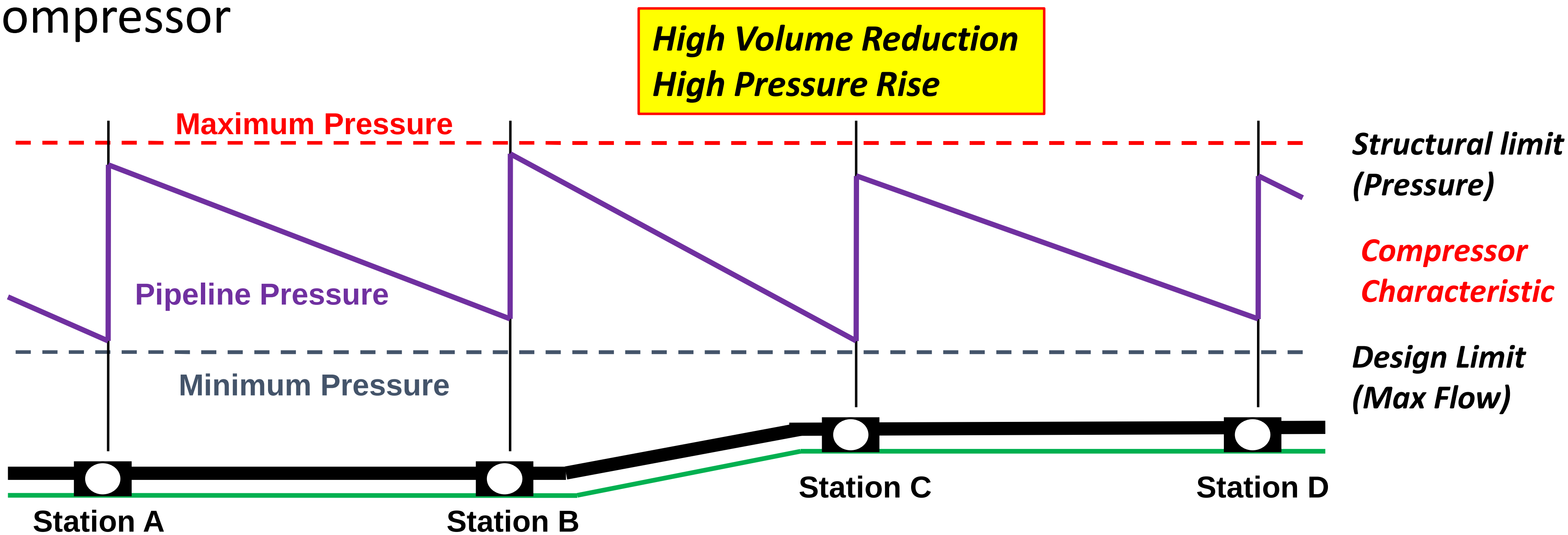

Typically trace impurities:

- $H_2O$ – Water
- $H_2S$ – Hydrogen Sulfide
- CO – Carbon Monoxide
- $O_2$ – Oxygen
- $CH_4$ – Methane
- $N_2$ – Nitrogen
- $NH_3$ – Ammonia
- Ar – Argon
- $H_2$ – Hydrogen
- $SO_x$ – Sulfur Oxide/Dioxide
- $NO_x$ – Nitrogen Oxide/Dioxide

***+ EOS Uncertainties***

# Are Gas Properties Important?

- Gas properties determine operating characteristics of your compressor

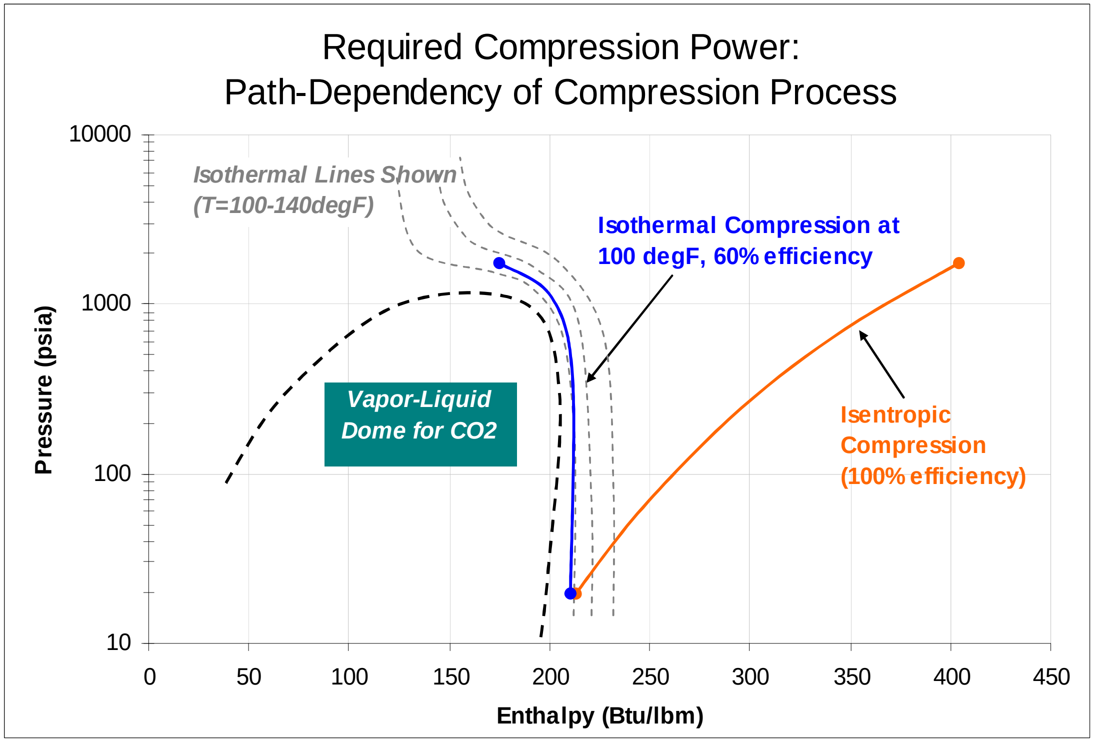


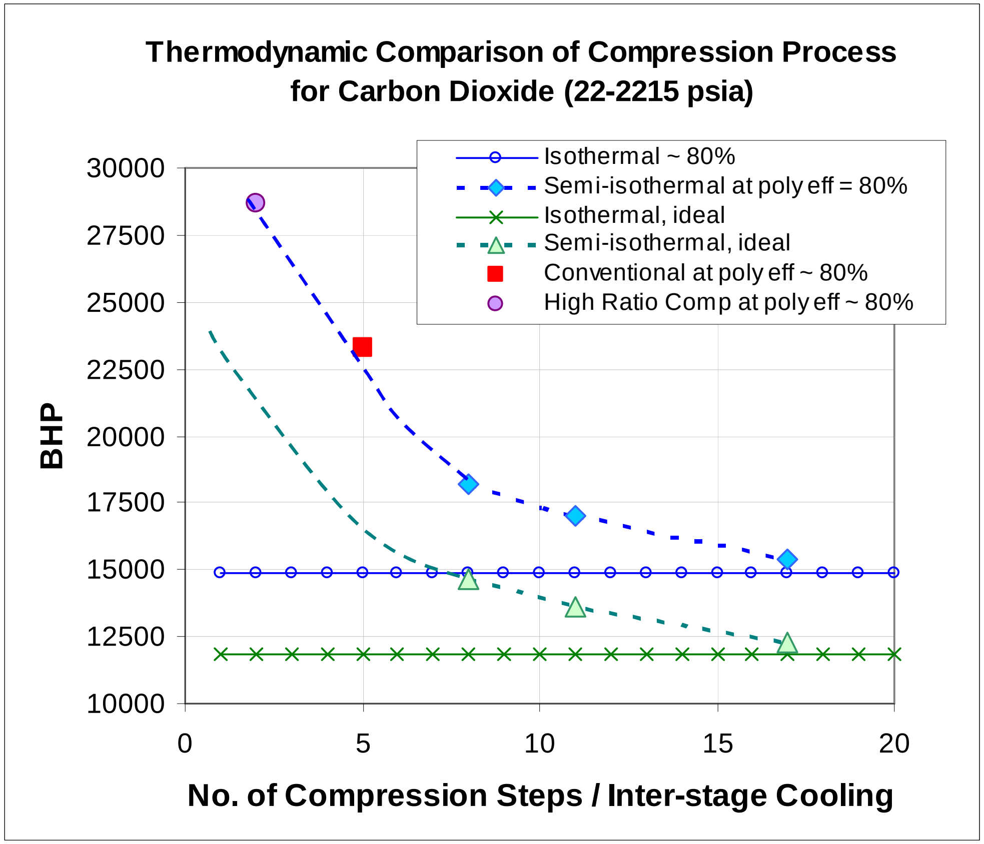

**Compression:** $$\frac{P_2}{P_1} = \left(1 + \frac{\eta}{c_p \cdot T_1} \cdot H\right)^{\frac{\gamma}{\gamma-1}}$$

$$Power = (dV/dt) \cdot \rho \cdot H$$

$$\frac{T_{Cold}}{T_{Hot}} = \left(\frac{P_{Hot}}{P_{Cold}}\right)^{\frac{1-\gamma}{\gamma}}$$

# $CO_2$ Compression Path Dependence



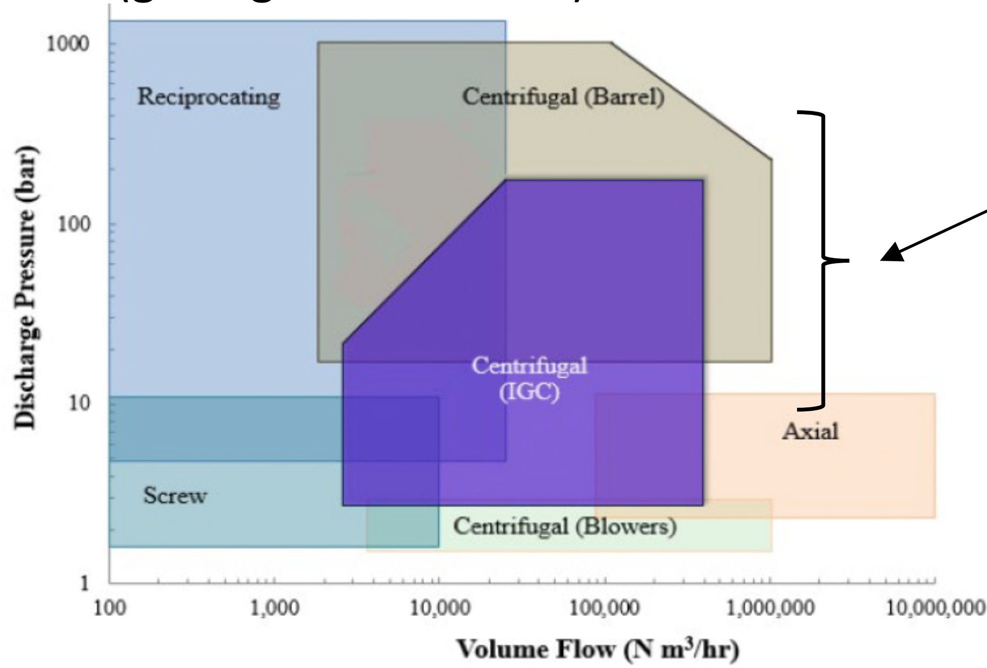




*Courtesy SwRI and DOE [Moore et al.]*

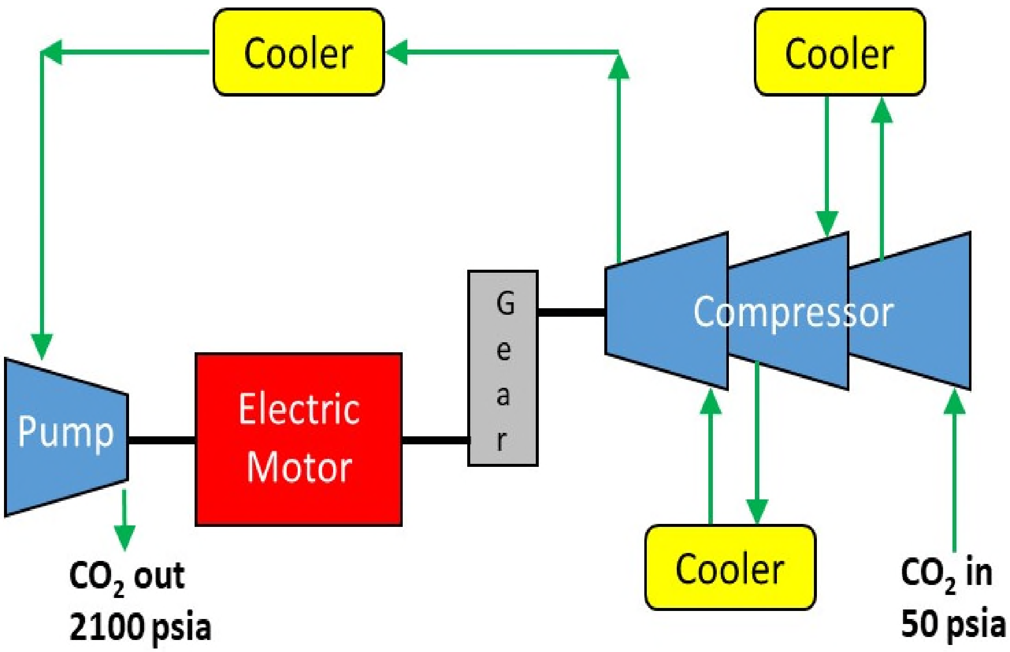
# Carbon Dioxide Compression

Compression Applications:

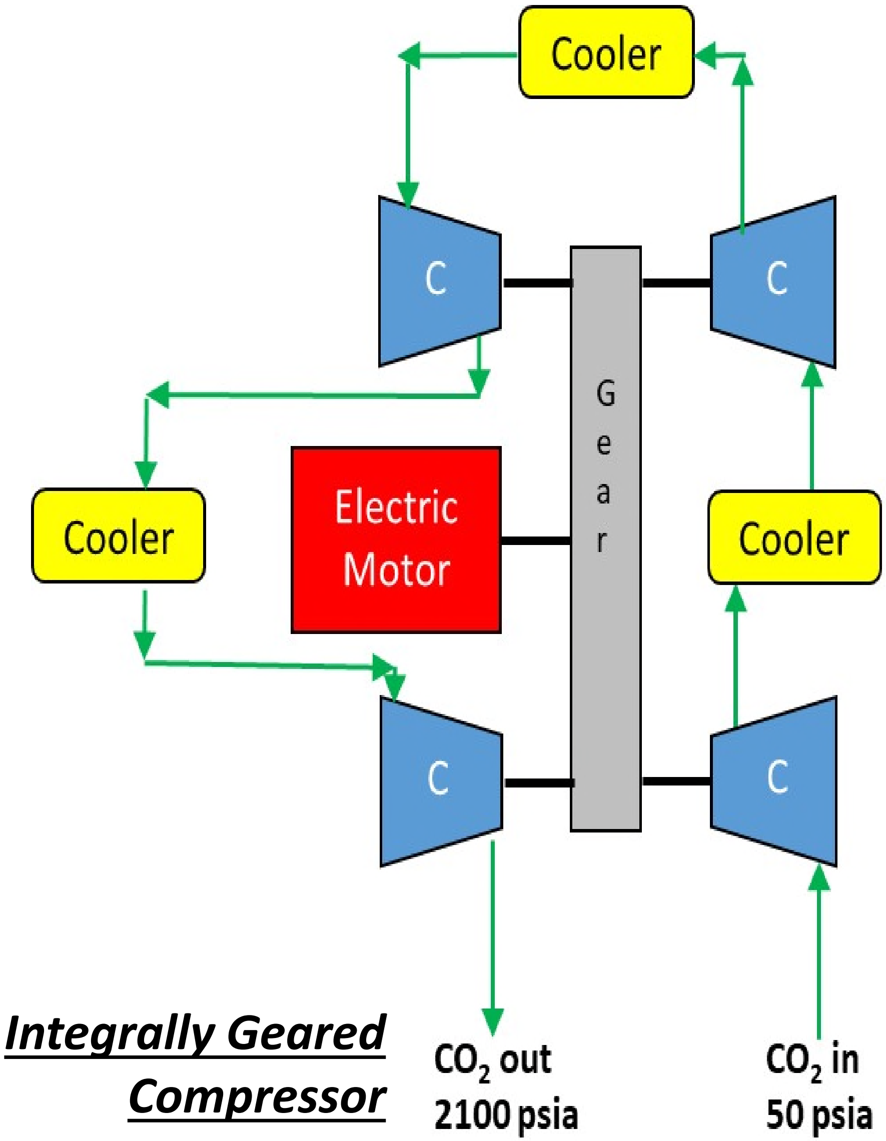
- Pipeline re-compression/re-pumping (2100 psi) — PR 1.2-1.6
- Steam reformer to Pipeline Pressure (2100 psi) — PR 40-70
- Gasifier to Pipeline Pressure — PR 5-20
- Flue Gas to Pipeline Pressure — PR 100-130
- Boost into sequestration (geological formation) — PR 1.2-30



# Compressor Solutions

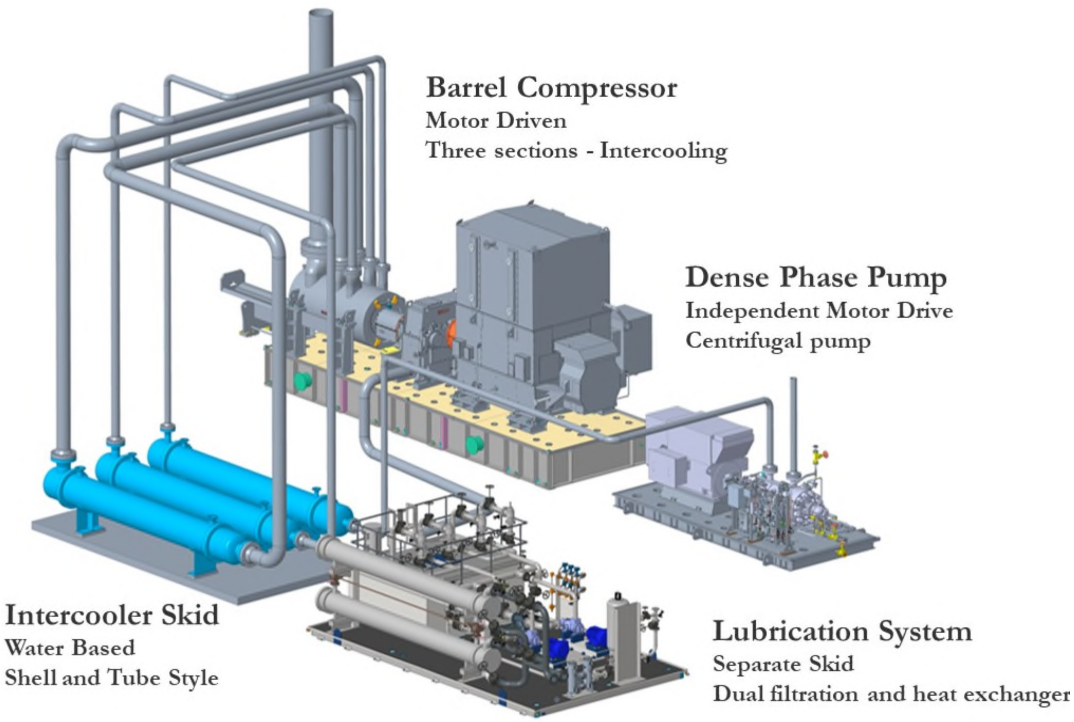


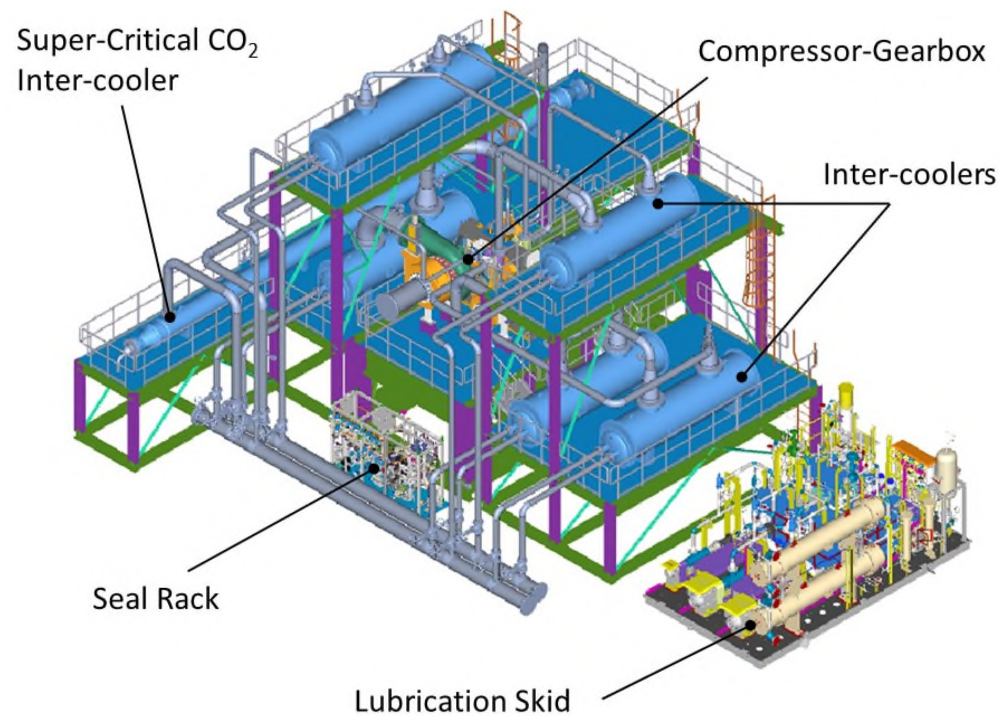

***Barrel Compressors and Pumps***




***Integrally Geared Compressor***

# Compression Solutions



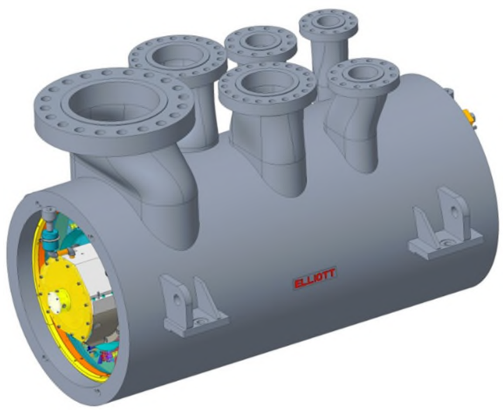




***Barrel Compressors and Pumps***

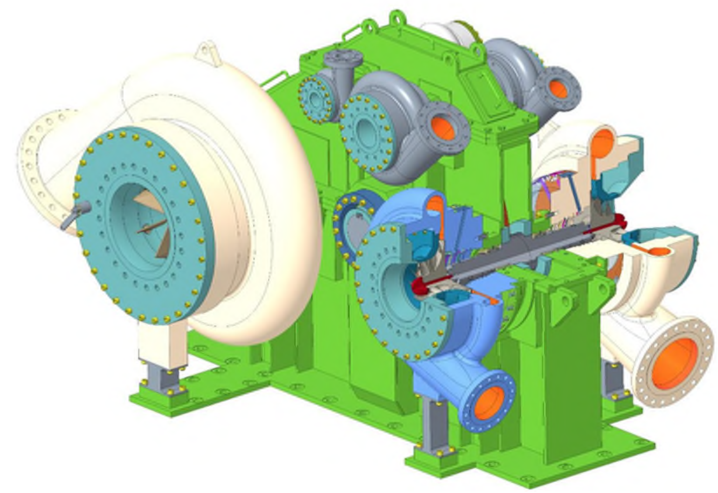
***Integrally Geared Compressor***

# Technical Options Impact on Performance and Reliability

**LP Section**



**HP Section**



**2 Beam Style Compressors (or Pump)**

1 Parallel Shaft Gearbox

3 inter-coolers

**4 Gas Seals / 4 Journal Bearings**

**Drive Power = 12,863 kW**

**IG Compressors**

1 Gearbox with 4 Pinions

8 Stages

7 Inter-coolers

**8 Gas Seals / 18 Journal Bearings**

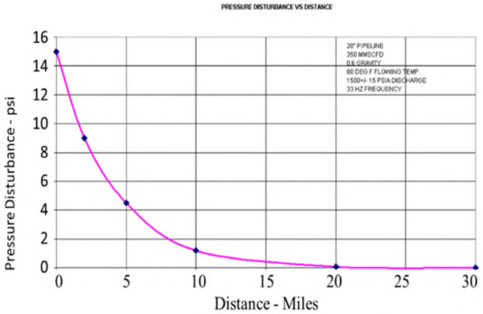
**1-4 Variable Guide Vanes**

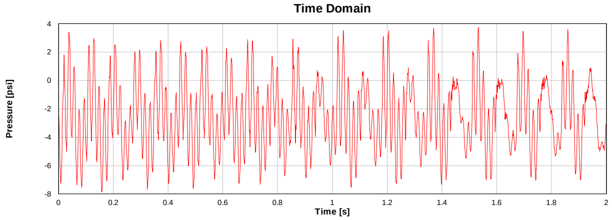
**Drive Power = 10,925 kW**

# Aside: Reciprocating Compressors for $sCO_2$

Issues:

- Pulsation control
- Lube oil-gas contamination
- Leakage
- Flow Limited
- Reliability




# Questions and Comments?

**Klaus Brun**
Global Director, R&D
Ebara Elliott Energy
Jeannette, PA, USA

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