# Novel Concepts for the Compression of Large Volumes of $CO_2$

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# *Acknowledgement*

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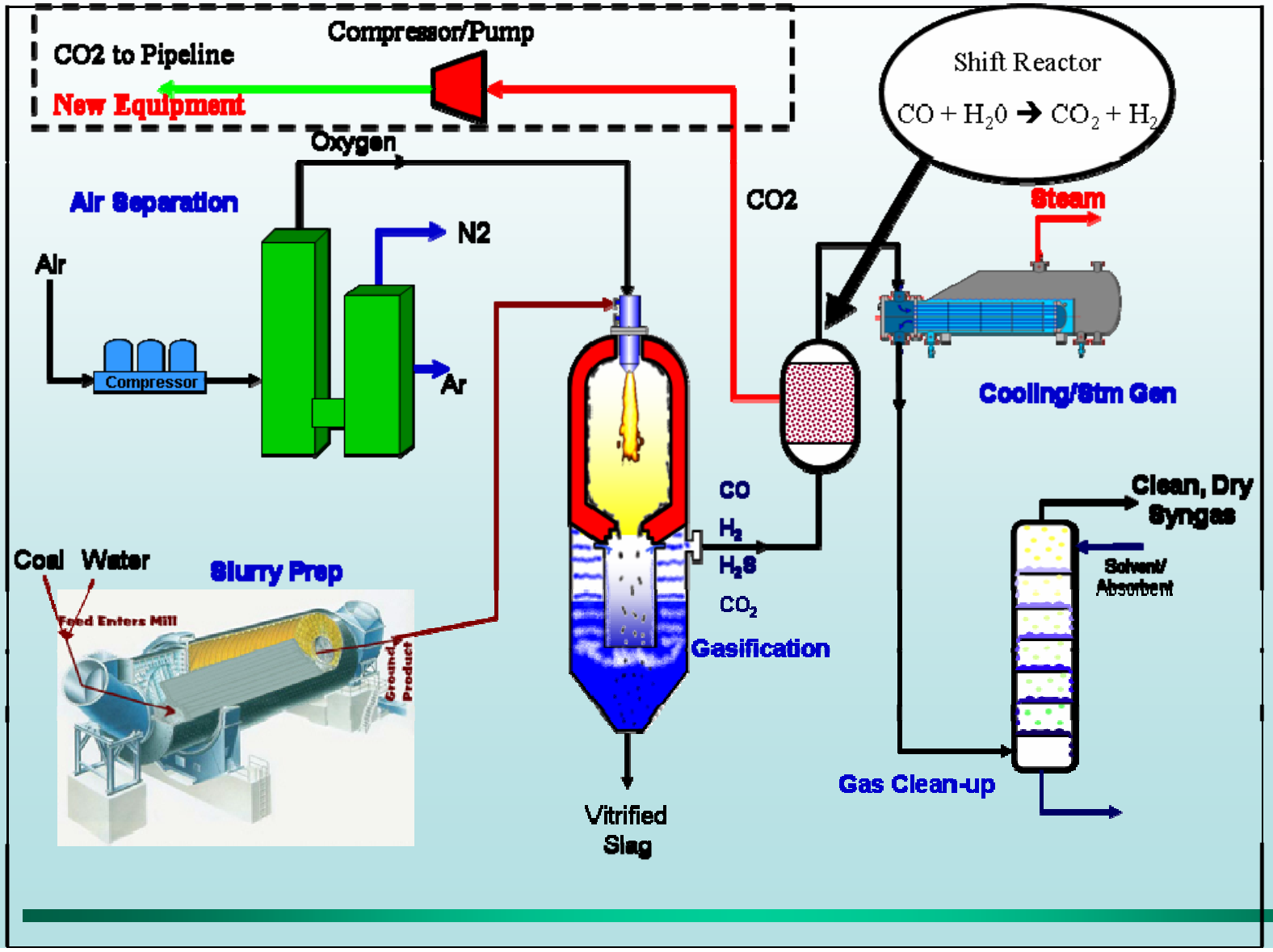
# Project Motivation

- $CO_2$ capture has significant compression penalty
  - As high as 8-12%
- Final pressure around 1500-2200 psi for pipeline transport or re-injection
- Typical flow rate 600,000 – 700,000 lbm/hr
  - Based on 400 MW IGCC plant
- Goal of this project is to minimize compression power penalty
- Many thermodynamic processes studied
- Several challenges with application discussed

# General Comments

- Type of compressor highly dependent on starting pressure (15 or 300 psia)
  - Approx 20-500 psia for $CO_2$ scrubbing of fuel stream (IGCC)
  - Approx 15 psia from CT or boiler exhaust scrubber
- High pressure ratio results in significant heat of compression
- Various compressor types considered
- Isothermal compression one concept considered to reduce power of compression
- Liquefaction of $CO_2$ also studied

# IGCC Process with Carbon Capture

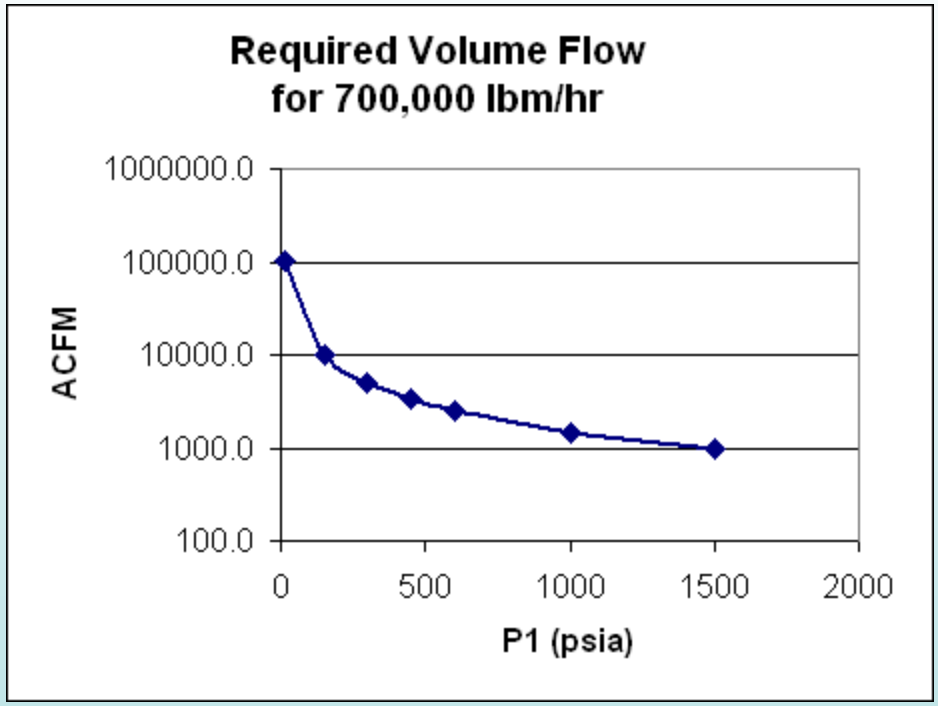


# *Required Inlet Volume Flow for $C0_2$ Compressor*

**Mass Flow = 700,000 lbm/hr**
**=144.89 MMSCFD**

| Pressure (psia) | Volume Flow ACFM |
|---|---|
| 14.7 | 100595.2 |
| 150 | 9858.3 |
| 300 | 4929.2 |
| 450 | 3286.1 |
| 600 | 2464.6 |
| 1000 | 1478.8 |
| 1500 | 985.8 |

T=60 F




- High volume reduction adds to challenge in compressor selection

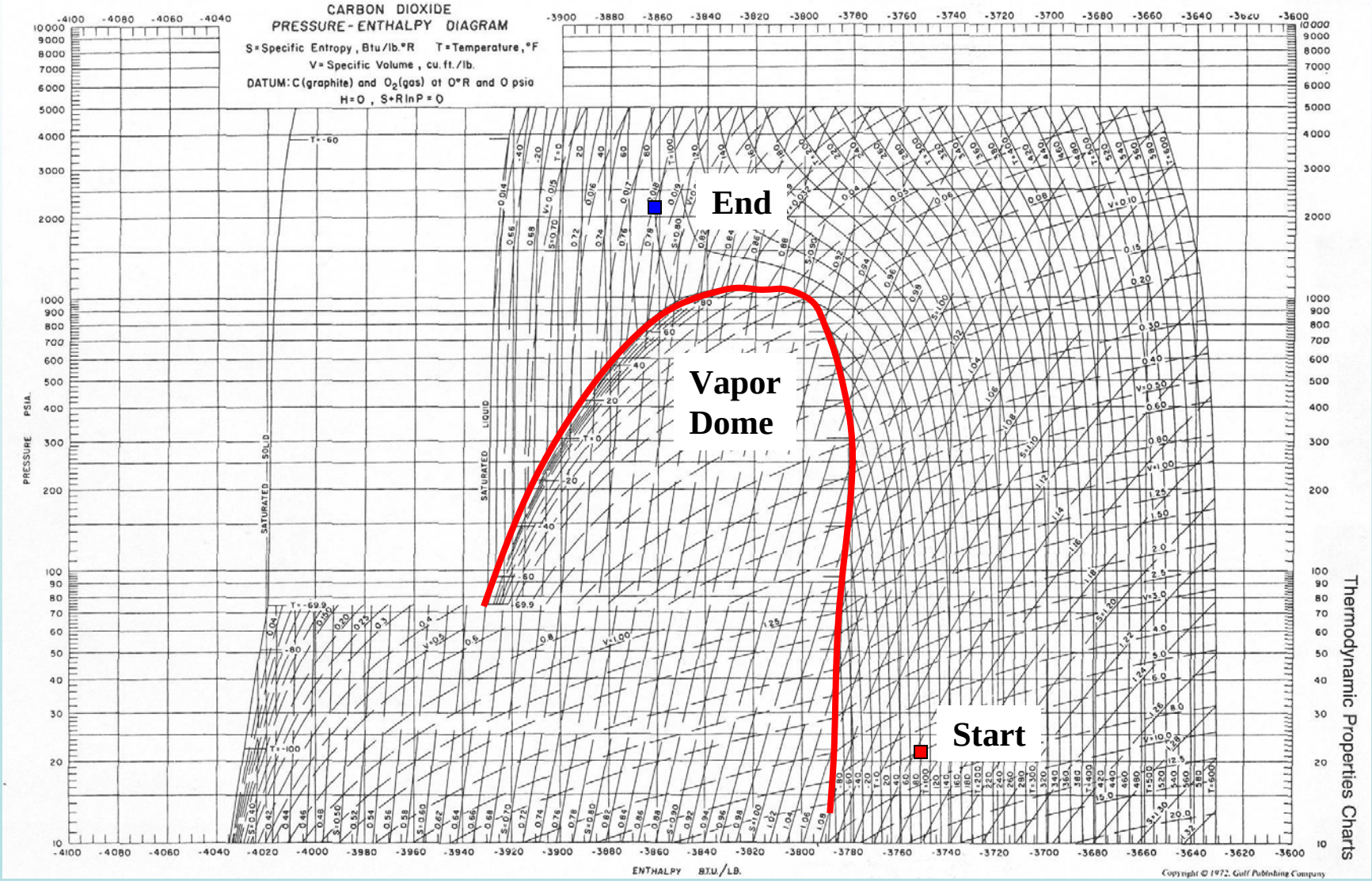
# *Example IGCC $CO_2$ Separator Conditions*

- Uncompressed $CO_2$ Streams in typical IGCC plant with physical absorption separation method using Selexol solvent.

| CO2 Gas Streams | LP | MP | HP 1 | HP 2 |
|---|---|---|---|---|
| Pressure (psia) | 21.9 | 160.0 | 250.0 | 299.0 |
| Temperature (°F) | 51.0 | 68.0 | 90.0 | 75.0 |
| Density ($lbm/ft^3$) | 0.177 | 1.3 | 1.87 | 2.088 |
| Flow Rate (acfm) | 33,257 | 2,158 | 3,374 | 1,073 |

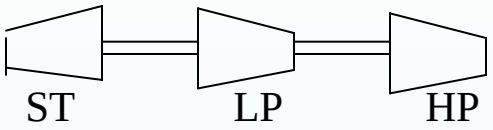
- Higher pressure streams help reduce volume reduction allowing more uniform frame size in compressor selection

# Pressure-Enthalpy Chart for $CO_2$



# D-R Selection Using Conventional Centrifugal Compressors (Baseline)

- Requires 2 Parallel Trains
- Intercooling Between Each Section




**OPERATING CONDITIONS**

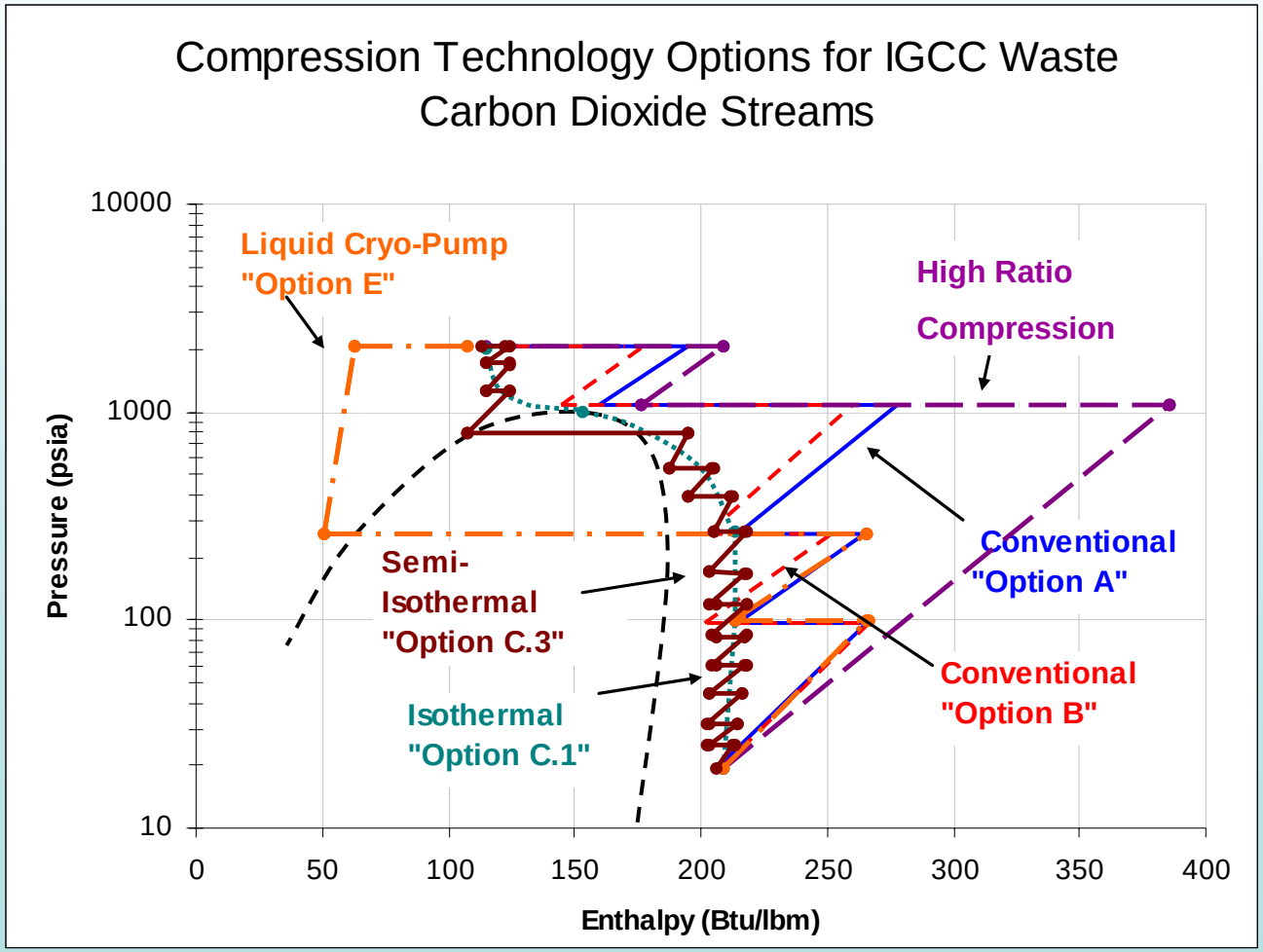
(ALL DATA ON PER UNIT BASIS)

| | Base | | | | |
|---|---|---|---|---|---|
| | D18R7B | | | D16R9B | |
| | SEC #1 | SS In | SEC #2 | SEC #1 | SEC #2 |
| ● GAS HANDLED (ALSO SEE PAGE ) | LP | MP | | Blend | |
| ● WEIGHT FLOW, (Lb/Hr) (WET) | 176,649 | 168,445 | 260,872 | 517,475 | 517,475 |
| **INLET CONDITION** | | | | | |
| ● PRESSURE (PSIA) | 21.90 | 170.0 | 96.58 | 248.0 | 1,087 |
| ● TEMPERATURE (°F) | 51.00 | 68.00 | 90.21 | 100.00 | 100.0 |
| ● MOLECULAR WEIGHT | 43.88 | 43.13 | 43.63 | 41.61 | 41.61 |
| ■ INLET VOLUME, (ACFM)(WET) | 16,634 | | 5,908 | 4,694 | 745.0 |
| **DISCHARGE CONDITI** | | | | | |
| ● PRESSURE (PSIA) | 106.6 | | 258.0 | 1,097 | 2,215 |
| ■ TEMPERATURE (°F) | 299.3 | | 258.1 | 369.8 | 231.4 |
| ■ Cp/Cv(Kavg) | 1.271 | | 1.272 | 1.274 | 1.230 |
| ■ COMPRESSIBILITY (ZAvg) | 0.9910 | | 0.9685 | 0.9334 | 0.6919 |
| ■ GHP REQUIRED (HP) | 3,684 | | 3,656 | 12,126 | 5,180 |
| ■ SPEED (RPM) | 5,166 | | | | |

**Total Power = 49,292 hp (37 MW, 5.2% of 700MW Output)**

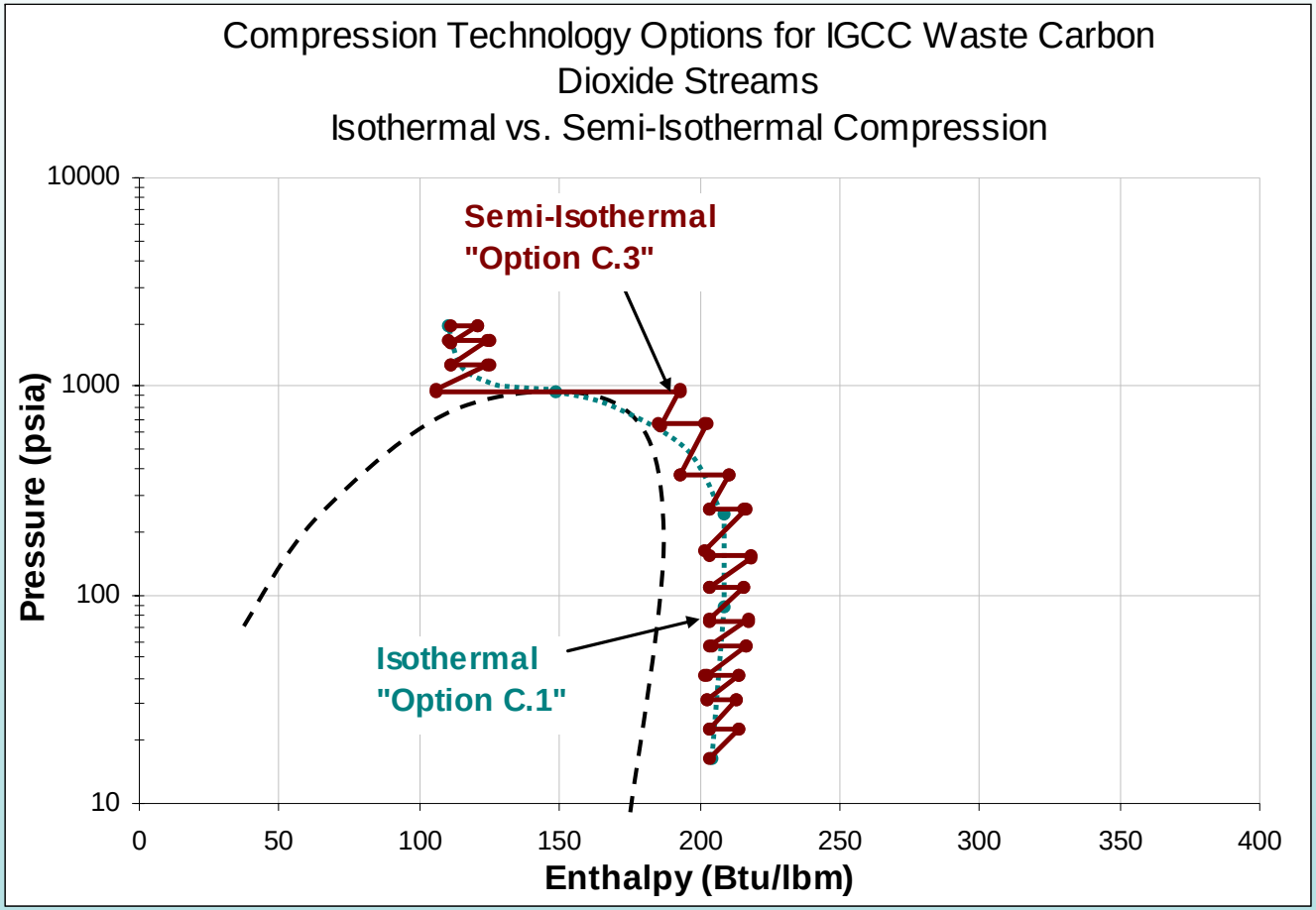
# Summary of Thermodynamic Analysis

- All Processes

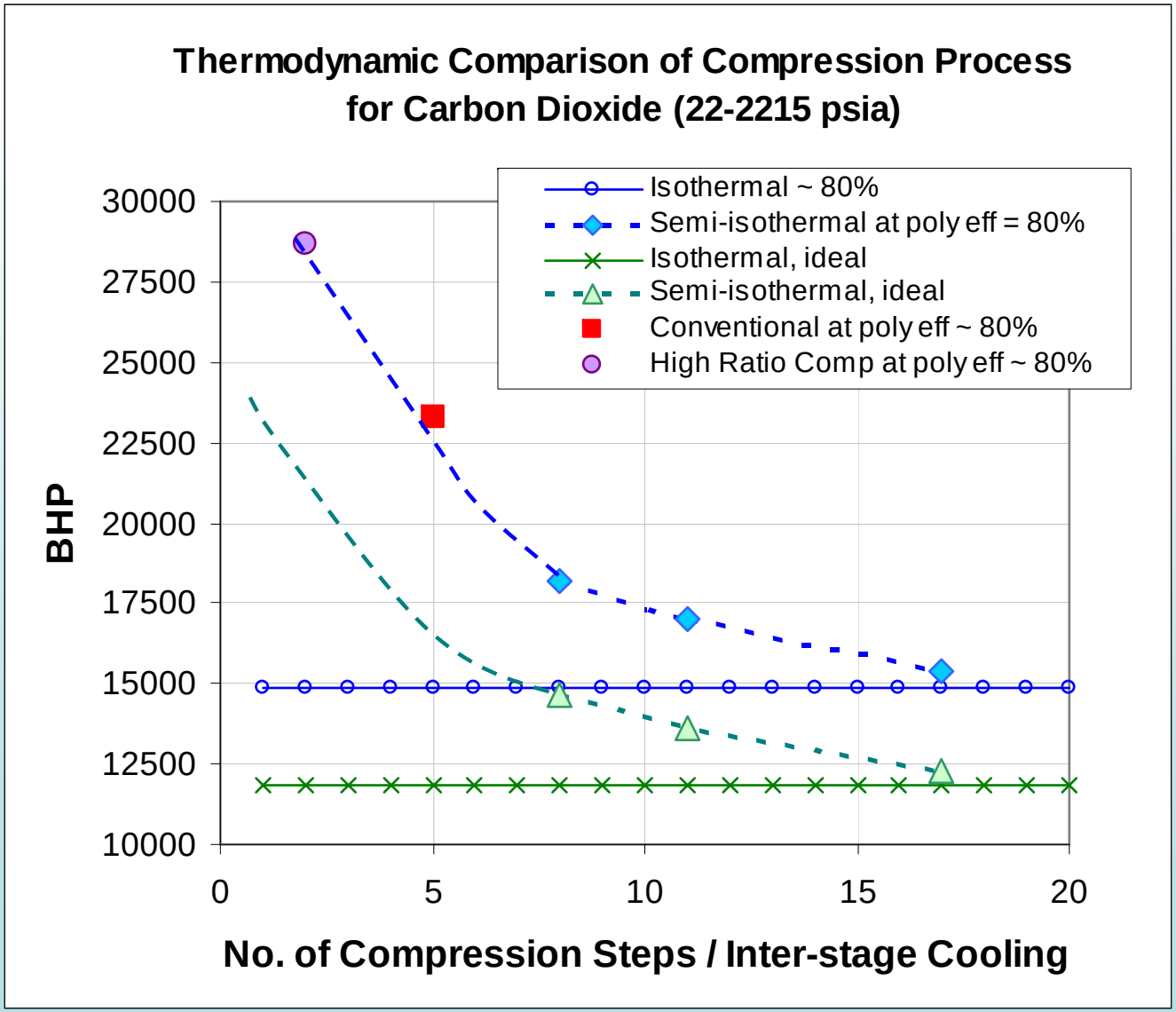


# Summary of Thermodynamic Analysis

- Semi-Isothermal Process



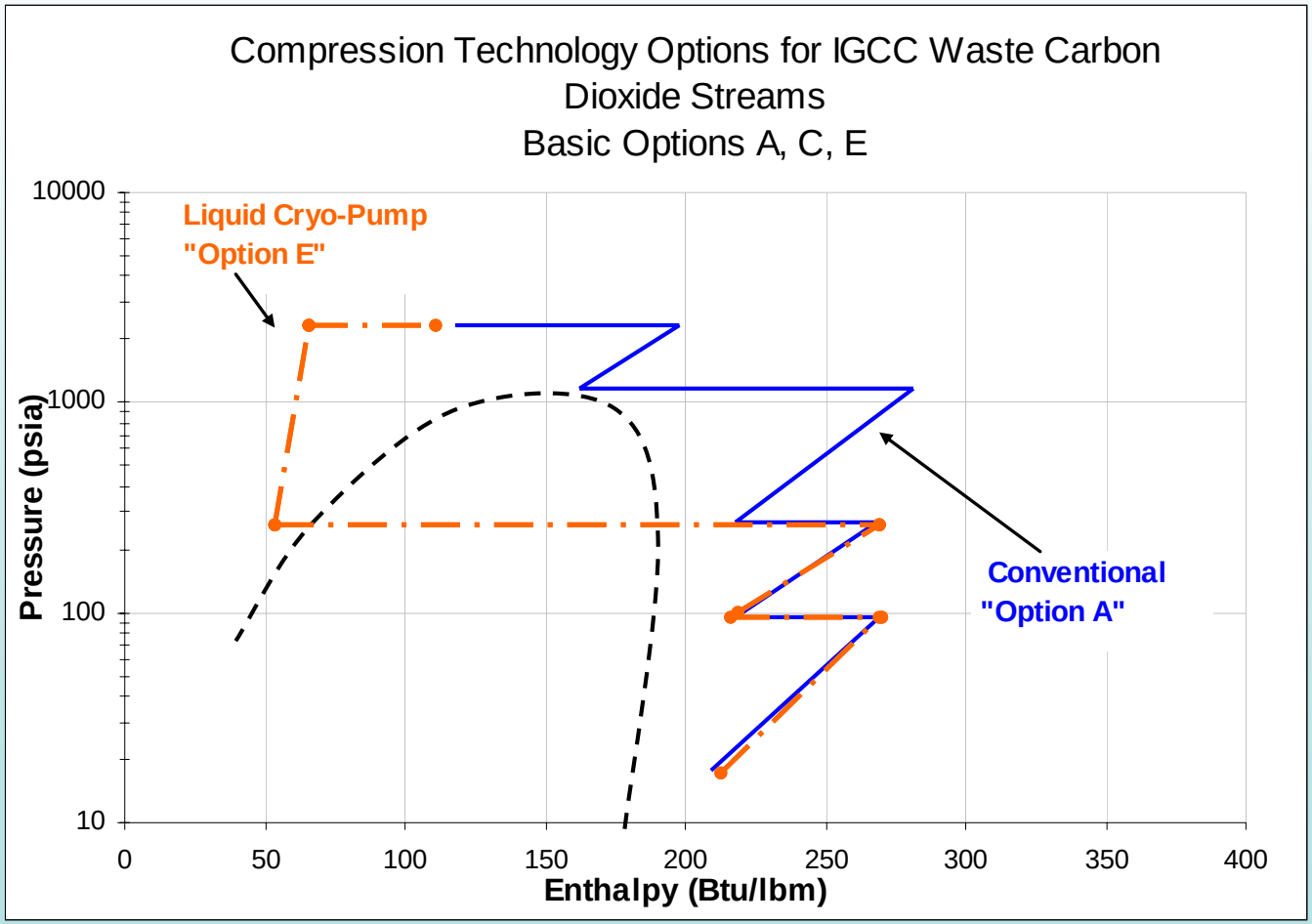
# Summary of Thermodynamic Analysis




- **17 intercooled stages provide near isothermal performance**

# Summary of Thermodynamic Analysis

- Liquefaction Process

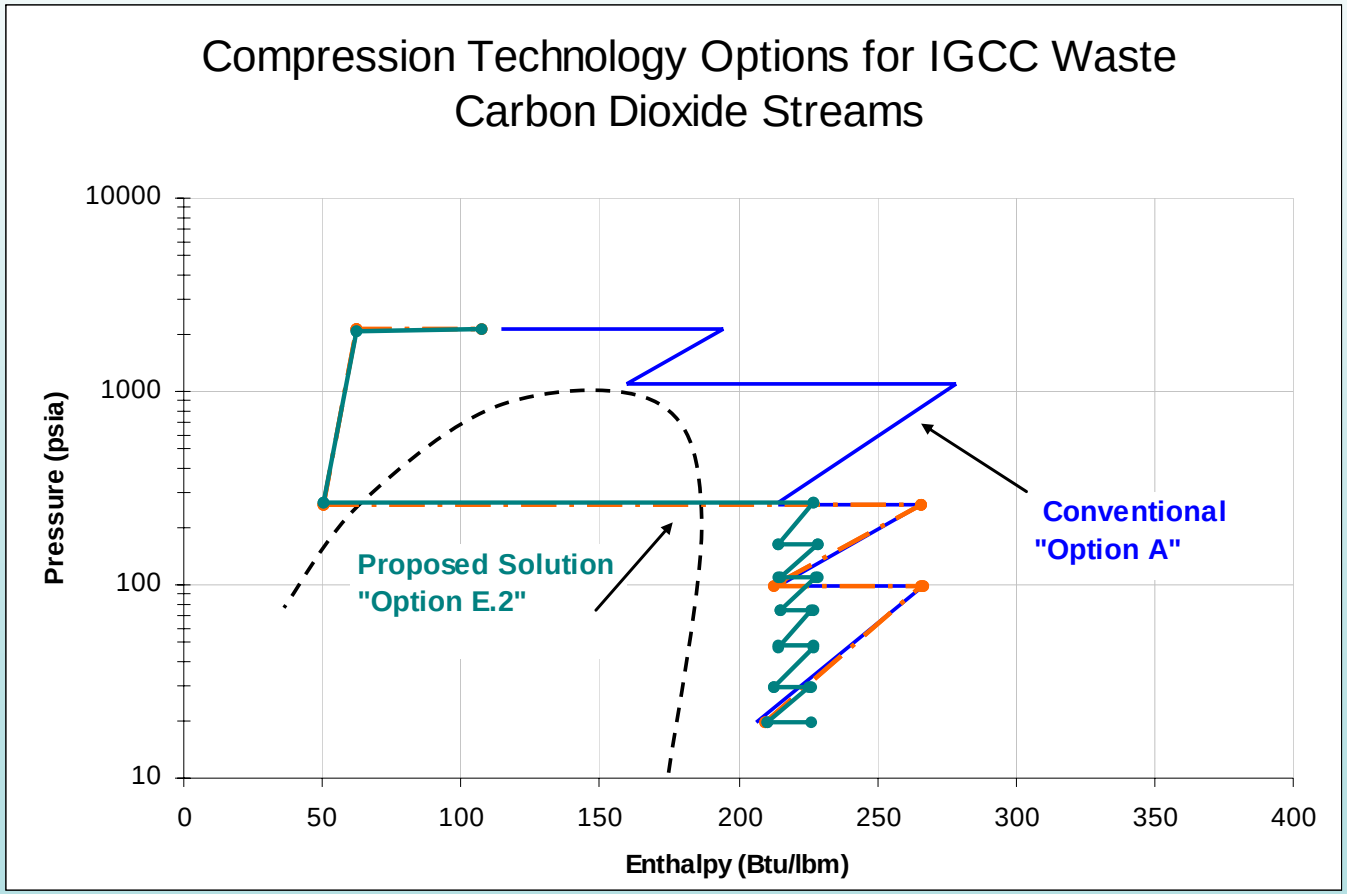


# *Summary of Thermodynamic Analysis*

- Liquefaction Process
  - Utilize a refrigeration system to condense $CO_2$ at about 250 psia and -20F
  - Liquid then pumped from 250 to 2215 psia
  - Requires significantly less power to pump liquid than compress a gas
  - Cost of refrigeration system must be accounted for

# Summary of Thermodynamic Analysis

- Proposed Optimal Solution
  - Combines interstage cooling and liquefaction approach



# Summary of Thermodynamic Analysis

| Option | Compression Technology | Power Requirements | % Diff from Option A | Cooling Technology |
|---|---|---|---|---|
| **A** | Conventional Dresser-Rand Centrifugal 10-stage Compression | 23,251 BHP | 0.00% | Air-cool streams between separate stages |
| **B** | Conventional Dresser-Rand Centrifugal 10-stage Compression with additional cooling | 21,522 BHP | -7.44% | Air-cool streams between separate stages using ASU cool N2 stream |
| **C.1** | Isothermal compression at 70 degF and 80% efficiency | 14,840 BHP | -36.17% | Tc = 70 degF inlet temp throughout |
| **C.4** | Semi-isothermal compression at 70 degF, Pressure Ratio ~ 1.55 | 17,025 BHP (Required Cooling Power TBD) | -26.78% | Tc = 70degF in between each stage. |
| **C.7** | Semi-isothermal compression at 100 degF, Pressure Ratio ~ 1.55 | 17,979 BHP (Required Cooling Power TBD) | -22.67% | Tc = 100degF in between each stage. |

# Summary of Thermodynamic Analysis

| Option | Compression Technology | Power Requirements | % Diff from Option A | Cooling Technology |
|---|---|---|---|---|
| **D.3** | High ratio compression at 90% efficiency - no inter-stage cooling | 34,192 BHP | 47.06% | Air cool at 2215 psia only |
| **D.4** | High ratio compression at 90% efficiency - intercooling on final compression stage | 24,730 BHP | 6.36% | Air cool at 220 and 2215 psia |
| **E.1** | Centrifugal compression to 250 psia, Liquid cryo-pump from 250-2215 psia | 16,198 BHP (Includes 7,814 BHP for Refrigeration) [1] | -30.33% | Air cool up to 250 psia, Refrigeration to reduce CO2 to -25degF to liquify |
| **E.2** | Centrifugal compression to 250 psia with semi-isothermal cooling at 100 degF, Liquid cryo-pump from 250-2215 psia | 15,145 BHP (Includes 7,814 BHP for Refrigeration) [1] | -34.86% | Air cool up to 250 psia between centrifugal stages, Refrigeration to reduce CO2 to -25degF to liquify |

# *Program Benefits*

- Provide enabling technology to compress $CO_2$ from a coal fed IGCC power plant cost effectively minimizing the financial impact of $CO_2$ sequestration
- Supports carbon capture to eliminate green-house gas emissions from power plants, which make up 35% of total $CO_2$ emissions
- Minimize financial impact to US industry and consumers of electricity
- This program identified up to 35% power savings over a conventional $CO_2$ compression solution
- Thermodynamic process more important than compressor efficiency
- Program proceeding into Phase 2 to perform validation testing

# Questions???

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