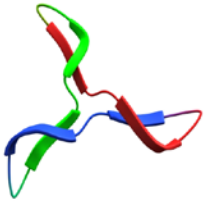

TRIMERIC CORPORATION

CO_2 Compression Options for CCUS

Presented at Carbon Management Technology Conference
July 18, 2019

Ray McKaskle, P.E.
Trimeric Corporation

Presentation Overview

- What CCUS CO_2 compression looks like
- How compression works (in simplest terms)
- Important factors in compressor selection
- Pros and cons of common compressor types for CCUS projects (by project size)
- Emerging technology
- CCUS CO_2 compression vs. liquefaction & pumping
- Takeaways

What CCUS CO_2 Compression Looks Like (1 of 3)

- This is NOT what CCUS CO_2 Compression looks like:

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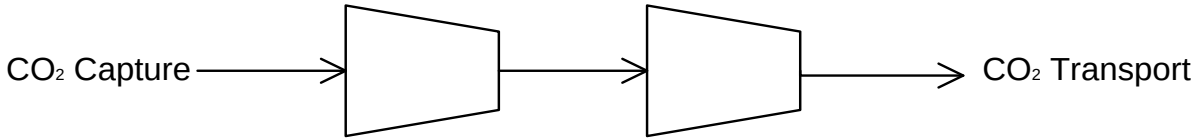


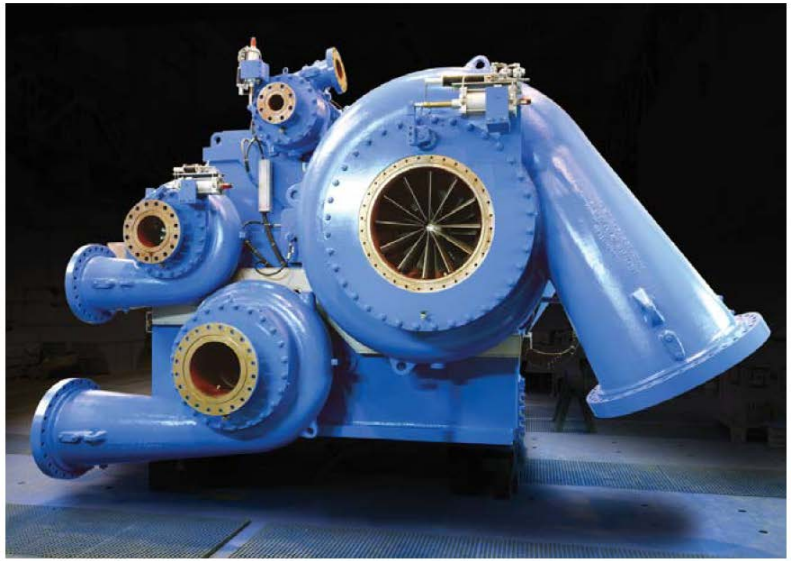
What CCUS CO_2 Compression Looks Like (2 of 3)

- This is what CCUS CO_2 Compression looks like:

Chaparral Coffeyville 50 MMscfd / 1 MM tonne/yr
19,500 hp (14.5 MW) CO_2 Compression and Dehydration Facility

What CCUS CO_2 Compression Looks Like (3 of 3)

- This is what CCUS CO_2 Compression looks like:

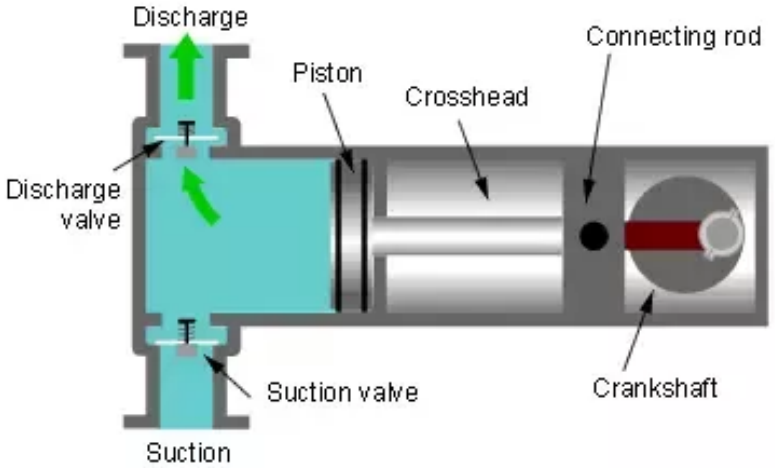


Seven-stage integrally geared turbo compressor with four-pinion technology.

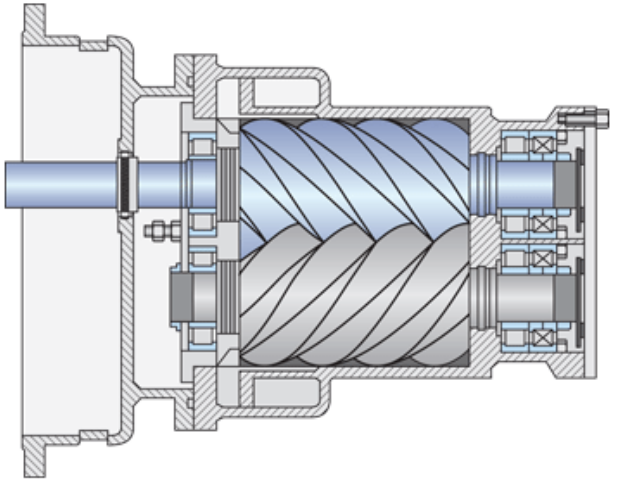
Images courtesy of Siemens

How Compression Works (In Simplest Terms) 1 of 3

- Positive displacement (PD) machines like reciprocating and screw compressors reduce the volume of the gas, which increases pressure



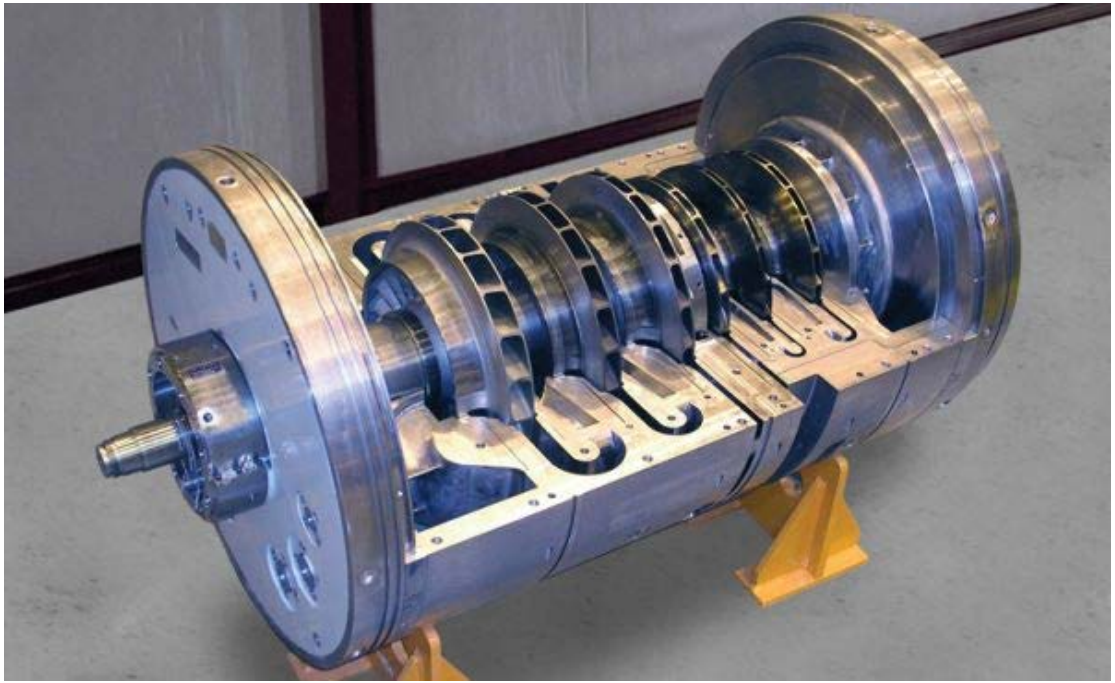
https://www.quora.com/Which-mechanism-is-preferable-for-reciprocating-compressors



https://blog.exair.com/tag/air-compresser/

How Compression Works (In Simplest Terms) 2 of 3

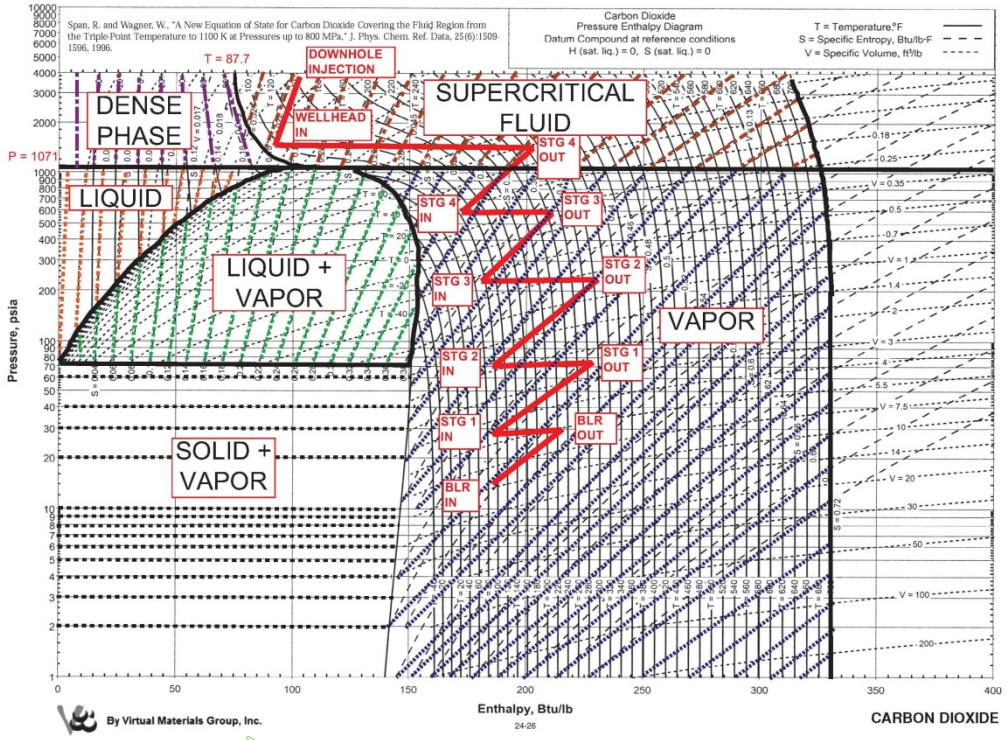
- Centrifugal blowers, compressors and pumps use one or more impellers to speed up, then carefully slow down the fluid, which converts the kinetic energy to pressure



https://www.turbomachinerymag.com/types-of-centrifugal-compressor-configurations/

How Compression Works (In Simplest Terms) 3 of 3

- Most often, multiple stages of compression and cooling are required



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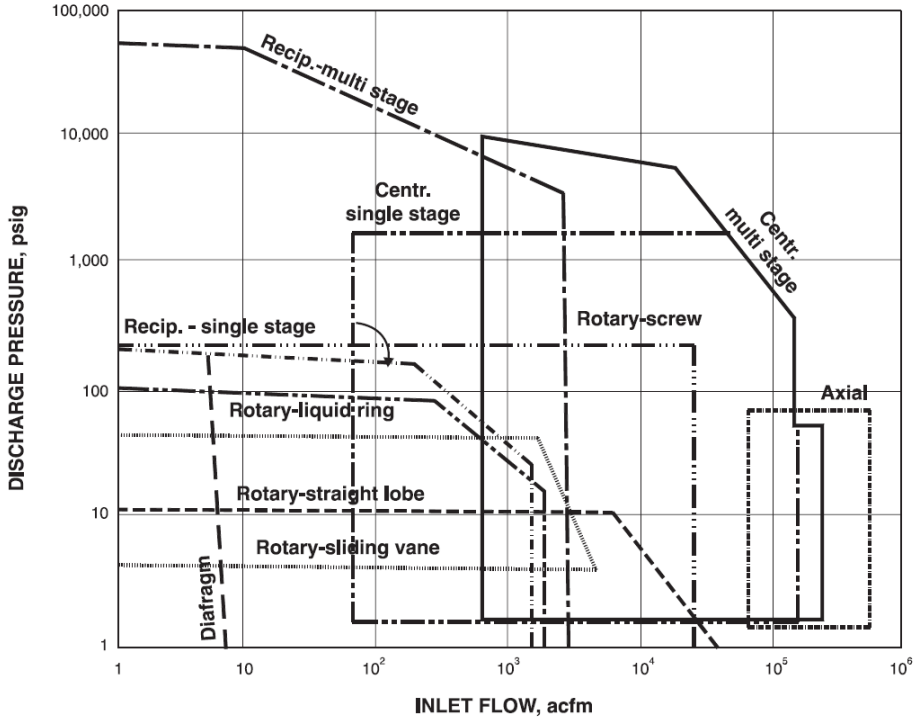
Important Factors in Compressor Selection (1 of 2)

- Money ! – Capital costs, operating costs (power)
- Project duration
- Mass flow rate
- Suction pressure – impacts *actual* volumetric flow rate
- Discharge pressure
- Turndown and sparing requirements
- Driver options – electricity, steam, gas engine

Important Factors in Compressor Selection (2 of 2)

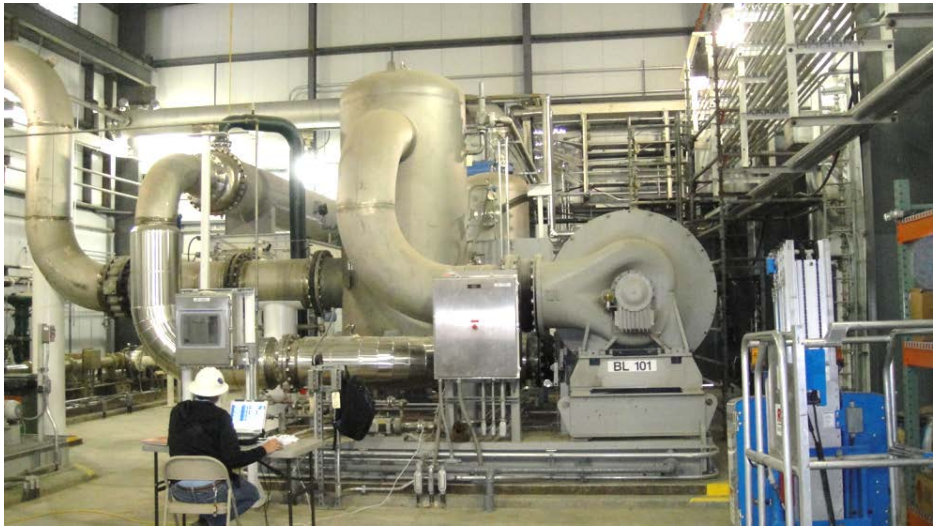
- Actual suction volumetric flow rate and discharge pressure impact compressor selection



Used with Permission from GPSA Engineering Data Book

Multistage Centrifugal Blowers

- Common in ethanol and fertilizer CCUS applications
- Simple, low cost way to double low suction pressure
- Cuts downstream volumetric flow rate in half
- No oil in contact with process gas
- Controls needed to maintain sufficient flow and discharge pressure



ADM Decatur / MGSC 400,000 tonne/yr CCS Plant
1,250 hp (933 kW), 4-Stage, Centrifugal Blower

Screw Compressors (1 of 2)

- Workhorse of food / beverage CO_2 and frozen food industries
- Lower capital cost than reciprocating and centrifugal compressors
- Great turndown with slide valve even without VFD
- Low noise and vibration compared to other PD compressors
- Oil mixes with process gas - Important to separate properly after compression
- Must manage water dew point carefully to prevent water condensation

Photograph courtesy of GEA FES

Screw Compressors (2 of 2)

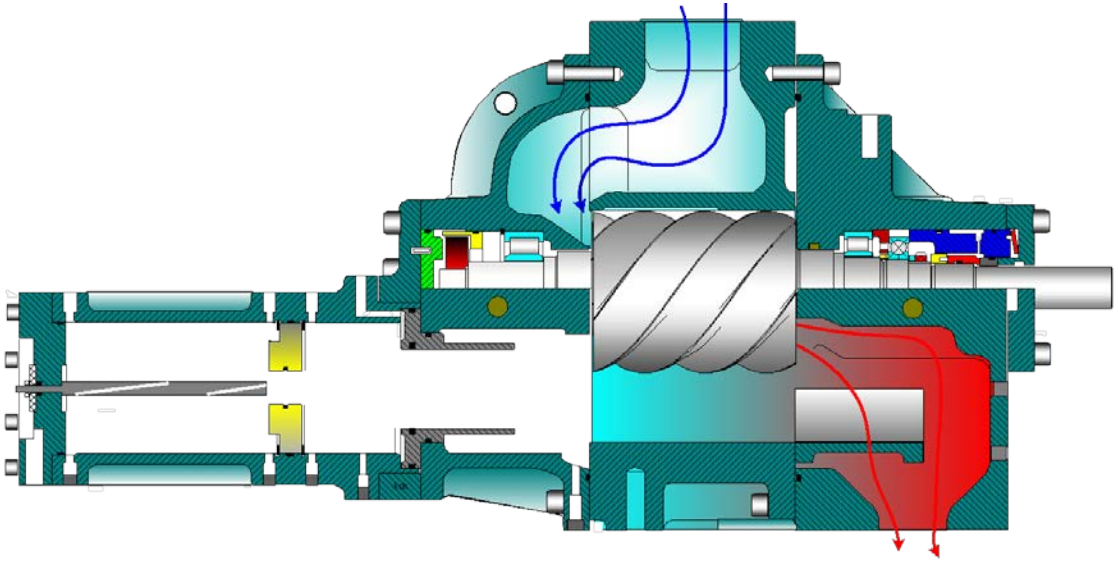


Image Courtesy of York Process Systems

Animation Courtesy of Howden Compressors

Reciprocating Compressors (1 of 2)

- Workhorse of CO_2 Enhanced Oil Recovery industry
- Several turndown options without VFD – head unloader, variable volume clearance pocket
- Economic to spare compared to large centrifugal compressors
- Vibration requires piping support and thick foundations
- Lots of piping and moving parts
- Cylinder lubrication oil gets into process gas

ADM Decatur / MGSC 400,000 tonne/year CCS Plant
3,250 hp (2,425 kW),
4-Stage, Reciprocating Compressors (x 2)

Reciprocating Compressors (2 of 2)

- Chaparral Coffeyville Compressor Building
- Approaching a point at this scale where higher capacity centrifugal compressors make more sense
- But, this plant had to run at 50% turndown for first year, which requires recycle with centrifugal machines

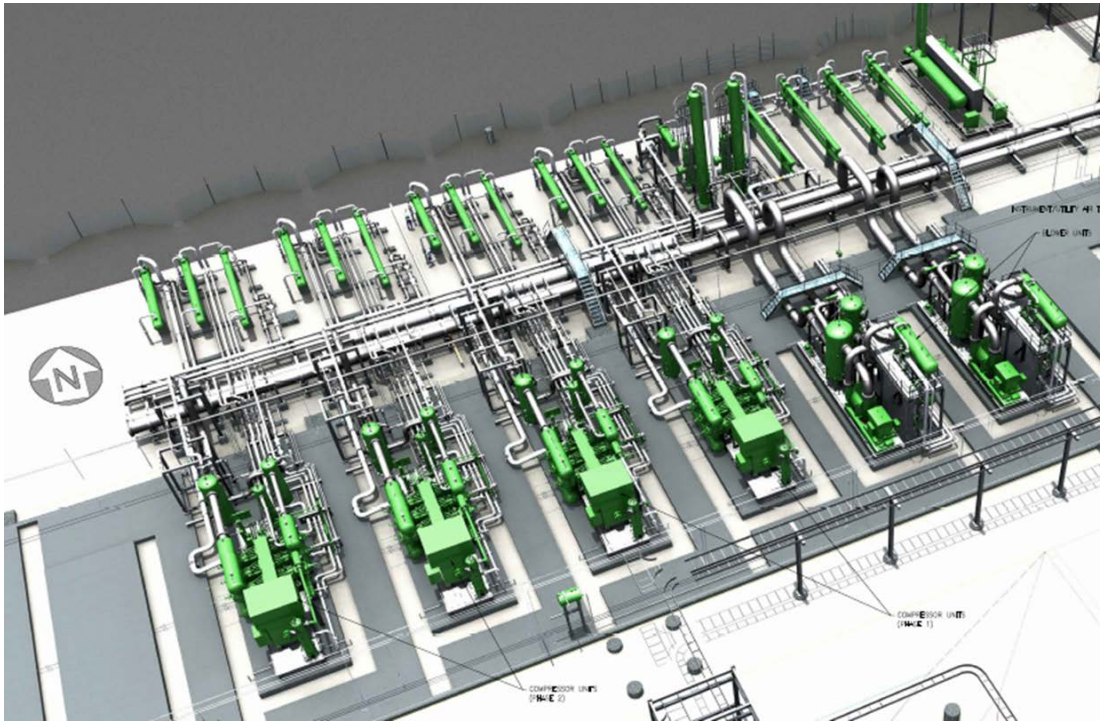


Image courtesy of Willbros Engineering

Single Shaft / Barrel Style Centrifugal Compressors

- Very high capacity and reliability
- Fewer moving parts (vs. recips)
- No oil in contact with process gas
- Same speed for all impellers
- Limited options for interstage cooling and dehydration pressure
- Limited turndown
- Long lead time (~ 2 X recips)
- More expensive to spare
- Controls needed to maintain sufficient flow and discharge pressure

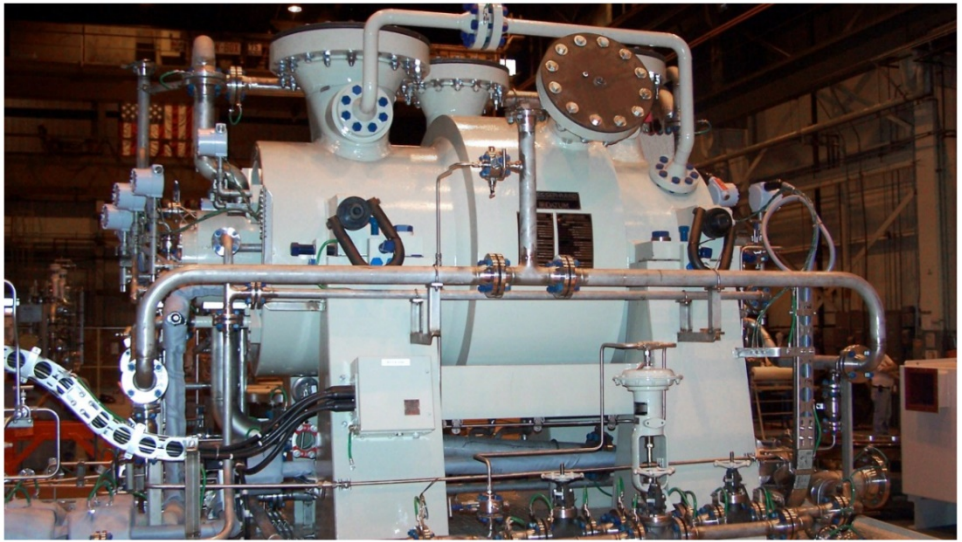


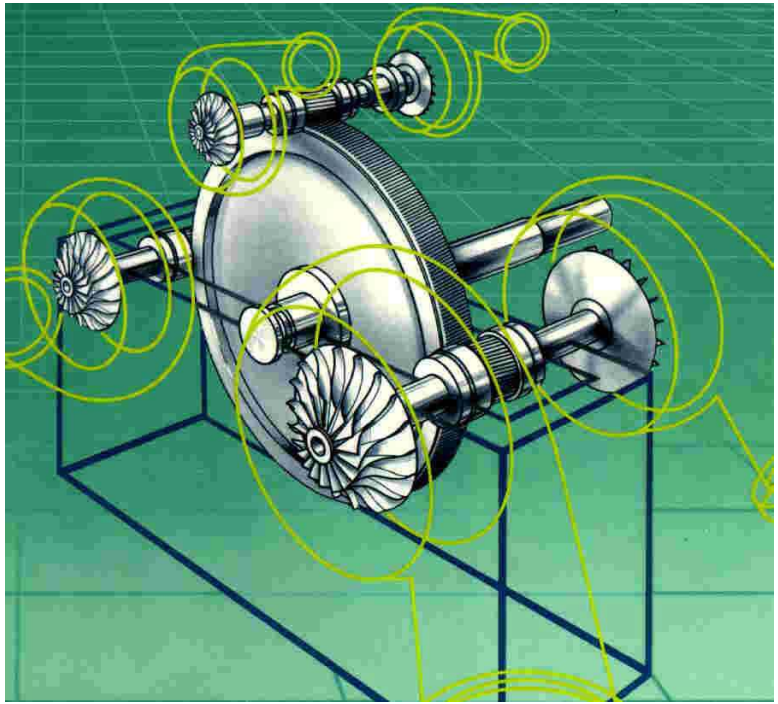
Image courtesy of Siemens

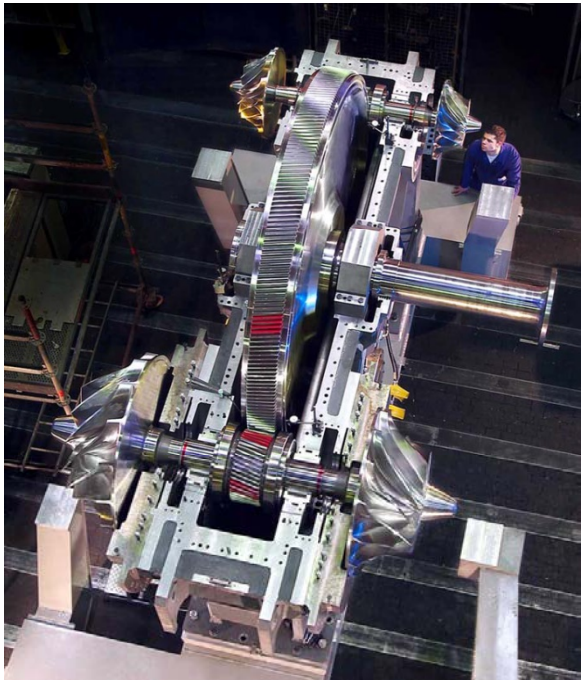
Integral Gear Centrifugal Compressors (1 of 2)

- State of the Art for Largest CCUS projects – Petra Nova, Air Products Port Arthur, Dakota Gasification
- Very high capacity and reliability
- Highest efficiency
- Optimal speed for each set of impellers
- No oil in contact with process gas
- Most options for interstage cooling and dehydration pressure
- Limited turndown
- Long lead time (~ 2 X recips)
- More expensive to spare
- Controls needed to maintain sufficient flow and discharge pressure

8-Stage, 15 MW Wet CO_2 Compressor
Image courtesy of MAN Energy Solutions

Integral Gear Centrifugal Compressors (2 of 2)





Images courtesy of MAN Energy Solutions

Multistage Centrifugal Pumps

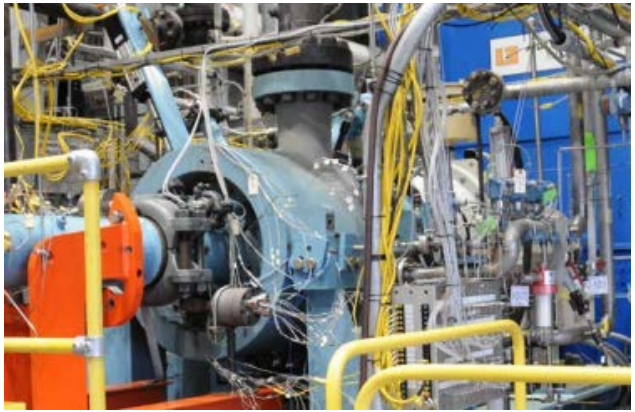
- Common for CO_2 pipeline booster stations
- Very low equipment costs
- Very low power requirements
- Affordable to equip with VFD for wide turndown range
- These pumps can take swings in pipeline / injection well pressure and let more expensive upstream compressors run at their “sweet spots”
- Controls needed to maintain sufficient density, flow, and discharge pressure.

26-Stage, 200 hp (149 kW) Centrifugal Pump

Centrifugal Pumps at CO_2 Pipeline Booster Station

Emerging Technology – Shockwave Compression

- Development work by Dresser-Rand / Siemens continues (see DOE FE0026727)
  - Low Pressure machine from atmospheric pressure to 200 psi in one stage
  - High Pressure machine from 200 to 2,000 psi in one stage
- Expected Benefits
  - Smaller footprint, less piping, fewer coolers
  - Discharge temperatures exceeding 550°F (290°C) creates better waste heat recovery opportunities
- Challenges / Remaining Work
  - Move from lab to plant environment
  - Integrating with dehydration pressure (typ. ~ 550 psi)
  - Slightly less efficient than some other compressors
  - Finding heat integration opportunities to increase overall system efficiency relative to other CCS approaches



Datum S Compressor. Image courtesy of Siemens.

www.netl.doe.gov/sites/default/files/event-proceedings/2013/co2%20capture/A-Koopman-Ramgen-Supersonic-Shock-Wave-Compression.pdf

Compression vs. Liquefaction & Pumping

- Have to evaluate on case-by-case basis
  - Important factors include CO_2 mass flow rate, project duration, power costs, pipeline length, and water content in feed stream
- Factors that make liquefaction & pumping more attractive
  - CO_2 is available at pressure needed for liquefaction (> 300 psi)
  - CO_2 liquefaction is required for purification (e.g., oxygen removal)
- Trimeric hypothetical comparison for ethanol plant CO_2 showed 38% more power required with liquefaction & pumping

Conclusions

- There are many options for CCUS CO_2 compression
- Careful analysis for each project considering CO_2 source, capital costs, operating costs, project duration, product requirements, and other factors is needed to select optimal compression approach
- Mass flow rate, suction pressure / actual volumetric flow rate, discharge pressure, and other factors impact compressor selection
- Integral gear centrifugal compressors are state of the art for the largest CCUS projects