The importance of high integrity centrifugal pump design for a robust, efficient and cost effective CO2 transfer process

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SPX ClydeUnion Pumps

Agenda

- Introduction to SPX Corporation
- Setting the Scene: Pumps are Energy Intensive and critical to all CCS processes
- Focus on CO_2 Transfer - Cost Reduction & Efficiency Improvement
- CO_2 Transfer: Key Considerations and Constraints
- Summary and Recommendations

An Introduction to SPX Corporation

SPX Corporation is a global, multi-industry manufacturer of highly specialized, engineered solutions with operations in over 35 countries and sales in over 150 countries around the world.

Headquartered in Charlotte, North Carolina , SPX, a Fortune 500 company, is publicly traded on the New York Stock Exchange, with annual revenues of ~$5.5 billion USD.

SPX employs more than 15,000 people worldwide.

SPX has 3 reporting segments: **Flow Technology, Thermal Equipment and Services** and **Industrial Products & Services.**

ClydeUnion Pumps is part of the **Flow Technology** segment of SPX Corporation.

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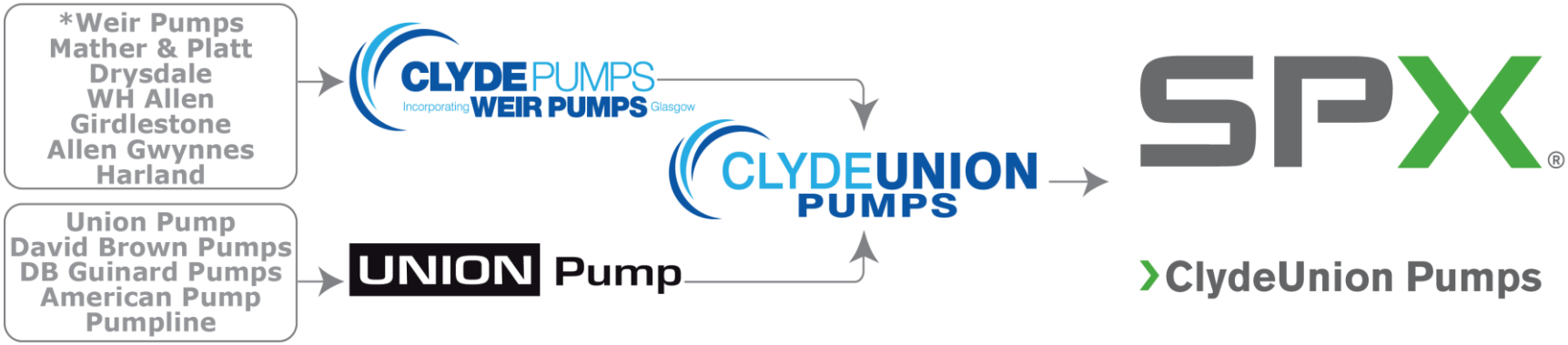
ClydeUnion Pumps, an SPX brand

- ClydeUnion Pumps was formed in November 2008 when the diverse portfolio of technologies, process knowledge and expertise of both Union Pump and Clyde Pumps (Weir) were brought together
- ClydeUnion Pumps incorporates the product heritage of Weir Pumps, Union Pump, Mather & Platt, DB Guinard Pump, David Brown Pumps and many other trusted names
- ClydeUnion Pumps is one of a handful of companies capable of supplying API standard pumps to the entire CCS system, end to end. We also have a full range of industrial standard pumps.



** This is a heritage product acquired when the Weir Pumps business transferred to Clyde Pumps in May 2007. Clyde Pumps re-branded as CLYDEUNION Pumps & was aquired by SPX in 2011*

Why are we here?

- First began pumping CO_2 in the 1960's, and pioneered high pressure injection in 1983*, some of our CO_2 pumps have been in service for more than quarter of a century.

- ClydeUnion Pumps have produced many CO_2 service pumps, including:
  - API610 Overhung and Between Bearings Centrifugal Pumps
  - API674 Reciprocating Pumps
  - Vertical ANSI Pumps

- ClydeUnion Pumps can provide any pump for CO_2 service from our established range, with key focus in CCS applications on:
  - CUP-BB1
  - CUP- BB2
  - CUP-BB5

Pumps: Energy Intensive and critical to all CCS Processes

Setting the Scene:
Pumps and pump systems are energy intensive

- Generally considered to be the highest auxiliary power consumption units within a plant or industrial facility – CCS is no different.

- One of the most critical elements in all power plants and for any system which requires the movement of liquids

- A pumps structural integrity can significantly improve performance, therefore maximising efficiency and ensuring longer mean time between overhauls

- Important aspects to consider:
  - rotor dynamic design principles
  - pressure containment and optimising hydraulic & mechanical designs
  - cyclic operating regimes which are present in many plants and require pumps to operate at multiple speeds and flow rates

- High integrity pumping solutions which take into account system effects can **help both to decrease the carbon footprint of plants and systems while at the same time maintaining a reliable and effective process.**

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Average Operator's Costs

Industry Type	Pump Energy (% Total Motor Energy Usage)
Petroleum	60%
Forest Products	30%
Chemicals	25%
Food Processing	20%
Primary Metals	10%

A 200 Hp Pump ≈ 55,000 Euro / Yr Electrical Energy

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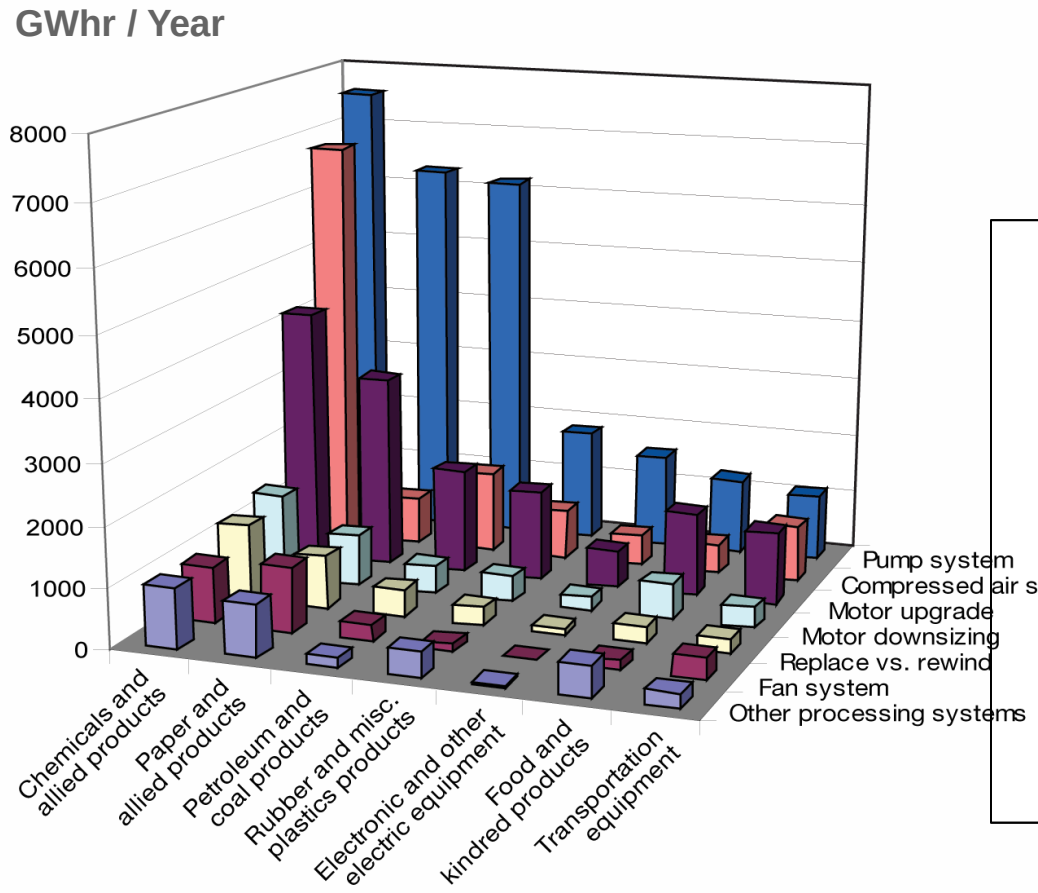
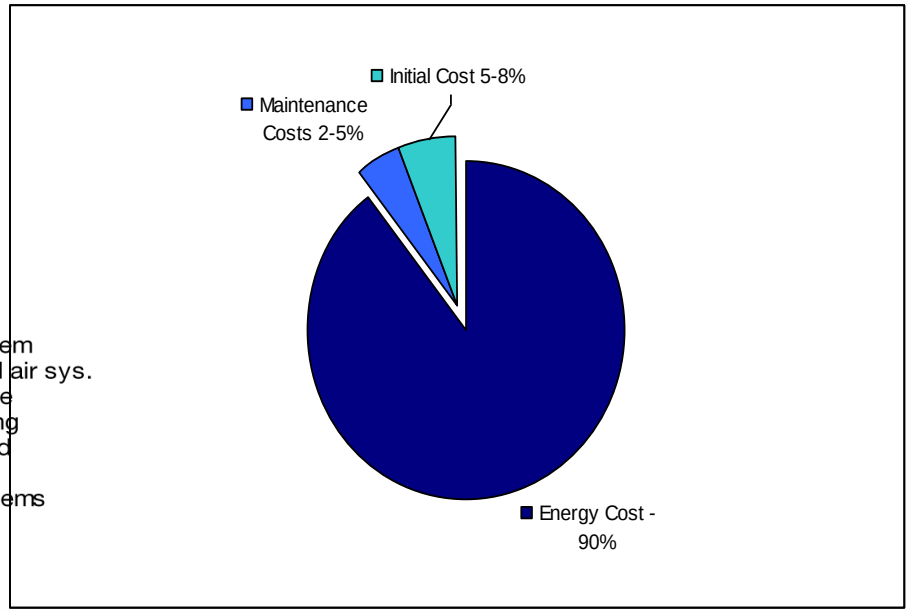
Energy + Cost Savings Potential



LIFE CYCLE COSTS



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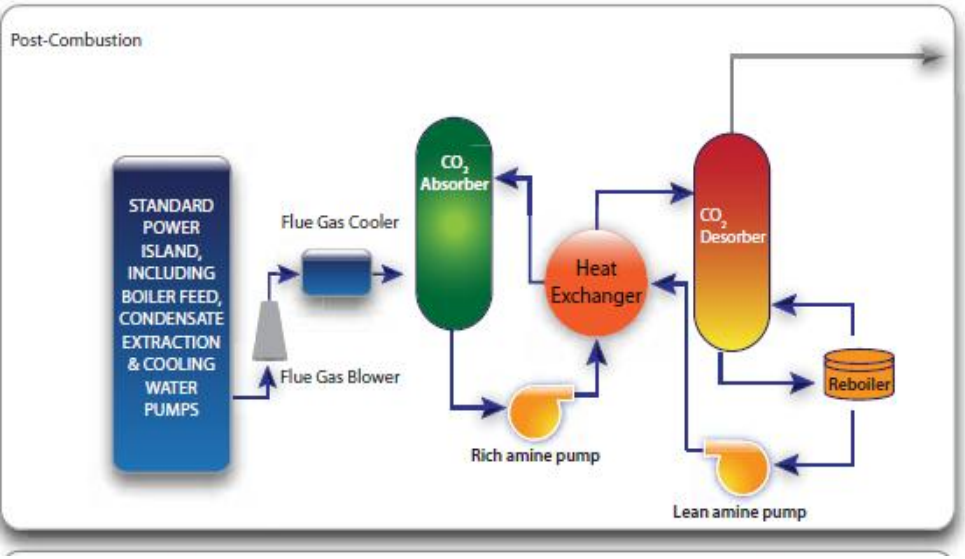
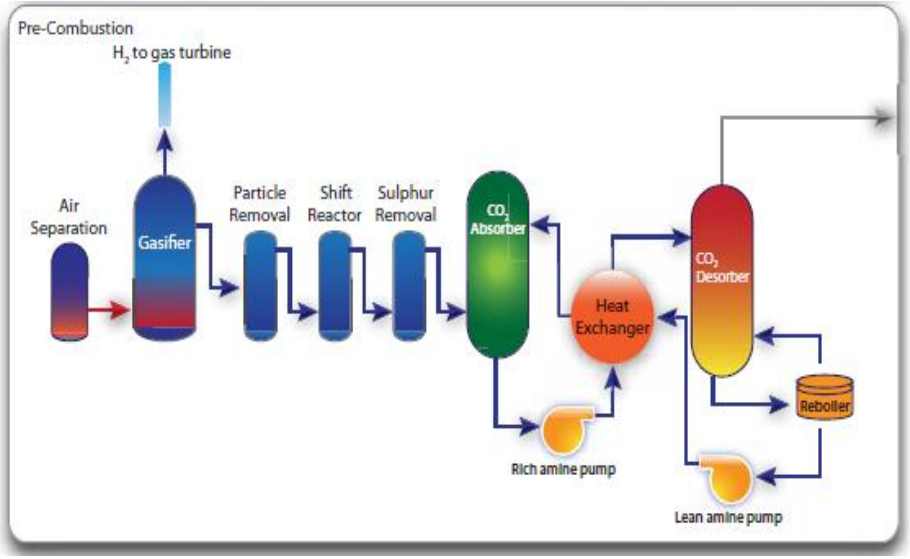
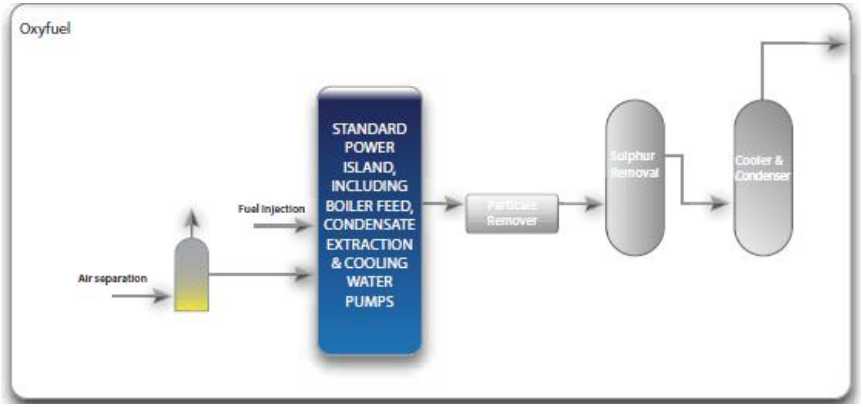
Source: U.S. Industrial Motor Systems, Market Opportunities Assessment, U.S. Department of Energy

Pumps are Critical to all CCS Processes







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CCS usually involves gas stripping and transport of CO_2, which can involve a large number of high energy consuming pumps.

Key Requirements

- Reliability
  - Low failure rates necessary to avoid accruing extra costs for unplanned CO_2 emissions.
- Efficiency
  - Energy requirement of system should be minimised due to inherent revenue negative value nature of CCS.
- Safety
  - CO_2 leaks are dangerous and politically sensitive
- Cost Savings
  - Maximize the Mean Time Between Overhauls

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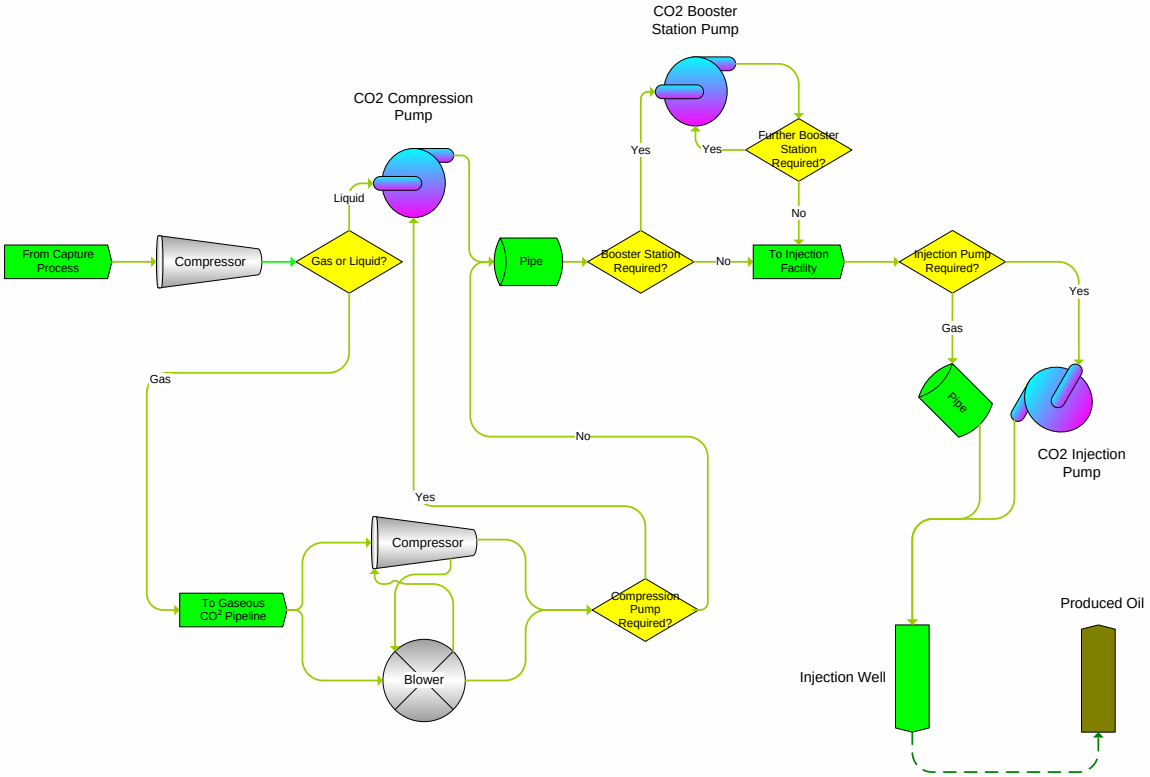
Key CO_2 Process Considerations

- Compression efficiency is greatest when pumps complete the process.
- Booster stations transport large, variable and increasing quantities of CO_2.
- Injection of CO_2, often supercritical, involves highly specialised duties.



A Typical CO_2 Pipeline System with Enhanced Oil Recovery

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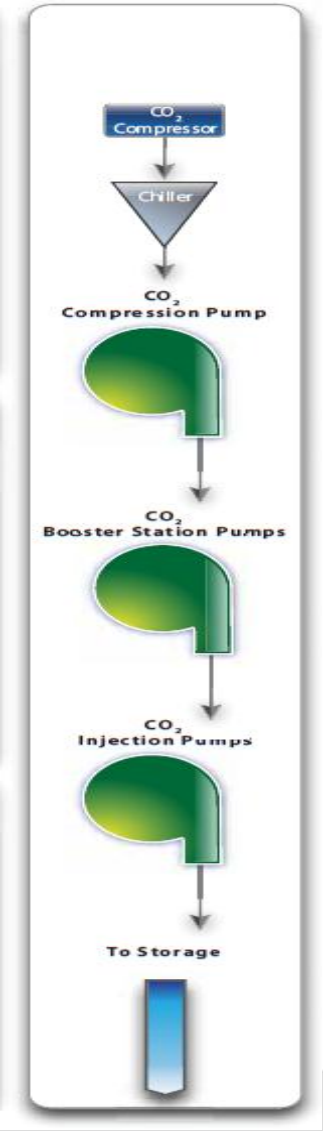
Focus on CO_2 Transport

CO_2 Transfer: Why does this matter so much?



- From a Pump perspective – the “Capture Process” has been tested
- Within the current infrastructure – entire project viability relies on the CO_2 being disposed/transferred out of the plant/facility. **This is the deal breaker!**
- Requires a new level of robust flexibility accounting for potential fluctuations in pressure and surge levels as new emitters come online

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Key Requirements

- Reliability
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- Efficiency
  - Energy requirement of system should be minimised due to inherent revenue negative value nature of CCS.
- Safety
  - CO_2 leaks are dangerous and politically sensitive
- Cost Savings
  - Maximize the Mean Time Between Overhauls and your Up Time

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CO_2 Transfer: Key Considerations and Constraints

Key Considerations

1. Properties of Liquid $CO_{2:}$: Considerations for CO_2 Transfer Application
2. Sealing/CP System
3. Additional Protection Considerations
   1. Flexible Pump System
4. Ancillary System Requirements

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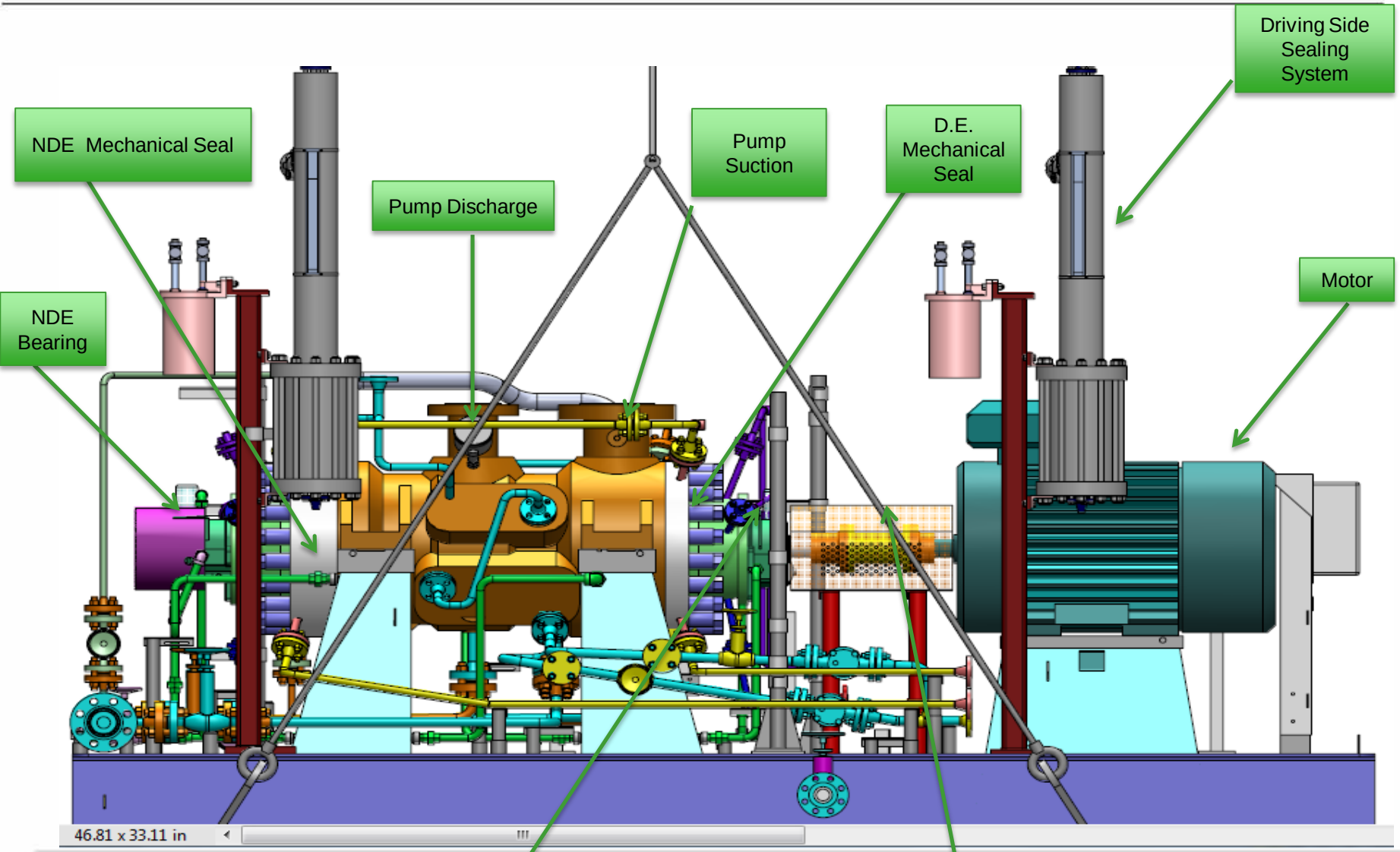
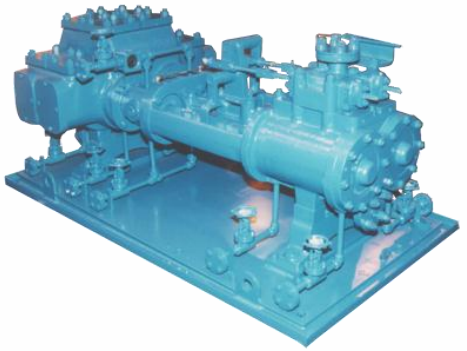
Pump Diagram



Properties of Liquid CO_2 : Considerations for Pumping Applications

- Whether CO_2 is transported as a gas or a liquid, it will often need to be further pressurised at one or more booster stations along the pipeline.
  - Where injection is offshore, this is likely to be at the shoreline.



- The flow passing through booster stations will vary considerably:
  - Variable load plants, e.g. gas plants on spinning reserve, will only produce CO_2 at irregular times for irregular periods and this must pass through these stations.
  - Moreover, as more plants are added to CCS Cluster, the maximum flow will increase.

- Consequences:
  - Each booster station will, over time, require a fairly large number of pumps
  - These pumps (or at least the earlier ones) must have variable speed
  - It may be desirable to offer hydraulic change out after a certain period of time – in this way increasing the flexibility of the plant, while standardising the casing and auxiliary systems.

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Our Assumptions

- The transfer process can occur either as a gas or liquid (similar process to handling liquefied gases in the oil & gas industry)

- Over a certain volume, gas compression will most likely become cost prohibitive (due to cooling element)

- Pumping is more efficient/cost –effective over gas blowers or compressors (energy savings of c6%.*)

- At higher volumes: Conversion to liquid for transportation becomes highly cost effective

- At these higher pressures; there are common environmental considerations both for gas and liquid transfer

- **Typical CO_2 transport duties involve high suction pressures between 100 – 135 bar, high flow and varying quantities.**
- **Temp range 16-23'C**
  - Suction conditions are sensitive to temperature changes due to CO_2 phase changes at different temperatures
  - Small temperature increases may cause CO_2 to flash
- **Typical specific gravity of 0.8**
  - There is a difference between specific gravity at 16'C vs. 23'C . The system is less volatile with respect to changing duty pressures at 16'C
- **Requirement for high reliability & integrity at these suction pressures**

**http://www.ecomagination.com/technologies/integrated-co2-compression-pumping*

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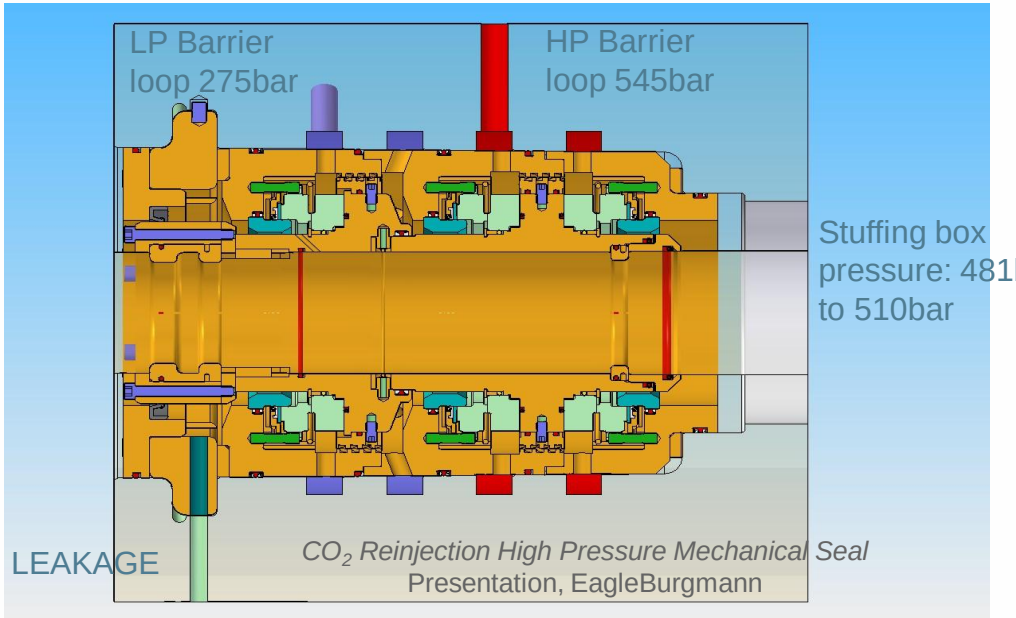
<u>Recommendation</u>: API610 pumps (ex. BB5) for higher pressures and fluctuating conditions . Provide 25 years operating life and 3 years MTBO.

Sealing

- The inherent abrasive/poisonous properties of CO_2 **demand 100% containment**

- As a result of the varying inlet pressures, leakage is more of a concern and can result in:
  - Seal wear issues
  - Dry ice formation with major leaks
  - Solidification of the liquid CO_2 in the pump

- Seal features include:
  - Elastomer free seals or those using suitable elastomers can be rated for > 500bar
  - Double (and triple) configurations available
  - Mineral Oil Barrier Fluid to remove risk of carbonic acid formation.
  - Conservatively sized + selected to ensure reliability (bearings and seals)



CO_2 Reinjection High Pressure Mechanical Seal
Presentation, EagleBurgmann

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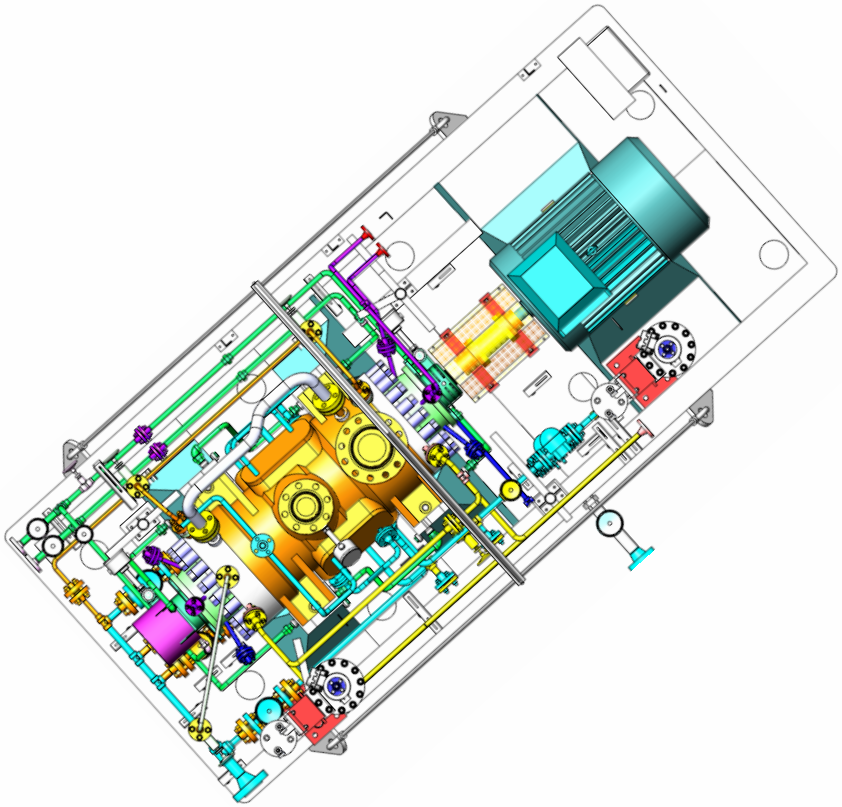
<u>Recommendation:</u> Inclusion of a CP system, which improves seal life, especially under varying suction pressures

CP System

- The purpose of a CP System, and its associated pipework, is to provide a supply of cooled barrier fluid to a dual pressurised or double mechanical seal with minimal leakage
- Provides an excellent mechanical sealing environment in the most demanding process conditions
- CP system was designed specifically for such applications to provide the absolute minimum amount of sealing fluid escaping into the pump liquid, (dual protections)…



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Additional Considerations

FLEXIBLE PUMP SYSTEM

- **Current CO_2 transfer requirements are very low compared to expected growth when new emitters come online (estimated at 20x current levels)**
  - Example: a typical system (with several emitters) estimated at 2 million Tons/year at initial design phase to 20 million Tons/year (10 year estimated timeline)

- **Need flexible pump system design, to bring on and off as required while maintaining appropriate pressure levels and managing surge levels**
  - Levels can be at the minimum flow rate or the design flow rate or anywhere in between

- **Involves multiple pumps working in parallel and variable system hydraulics evolving from different emitters entering the process at different times**

- Under all conditions any given pump must always be kept full and at correct suction pressure to ensure there is no possibility of changing phase within the line.

- Ensure to match fluctuating demand with an optimised number of pumps designed to operate in parallel as and when required to match the demand.

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<u>Recommendation</u>: Surging -> Flexible Station design using VSD

Additional Potential Ancillary System Requirements

- Depending on site conditions - Other Ancillary System Requirements may include:
  - Lube Oil Systems
    - To maximise bearing life
  - Cooling Systems
    - c/w air cooling (self-contained – no auxiliary service requirements)
  - Noise Protection
    - Consider selection of low noise motors (with special cowling)
    - noise blanket wrapped around pump casing and deck covering system (dampens any noise which might reverberate from steel baseplate)
  - Condition Based Monitoring (CBM) for prior indication of any machinery issues to prevent catastrophic failure
    - pump and motor vibration levels
    - Bearing temperatures
    - Seal barrier system levels

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Recommendation: Remote Monitoring & Healthcare Contracts with Supplier

Summary and Recommendations

CO_2 Transfer: Summary Recommendations

API – High Integrity, Reliability & Efficiency….but Why?

- Reliability
  - Handling supercritical CO_2 requires pump design that guarantees reliability and can handle high suction pressure requirements
  - High integrity bearings (sleeve tilted bearing not traditional ball bearing). Bearing design system lasting for 25 years
  - highest possible availability of plant – as near as possible to 100% operational
- Efficiency
  - Rotor design , run out, vibration levels very low – keeping seal faces at optimum orientation and maintaining the seal integrity
  - Optimum efficiencies across all operation points (reduced losses at all points)
- Safety
  - The transfer process must function within our current urban infrastructures, API pumps address additional risks including sealing, recirculation protection and surging
- Cost Savings
  - extended MBTO (3 years) – reduced intervention issues

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THANK YOU FOR YOUR ATTENTION

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