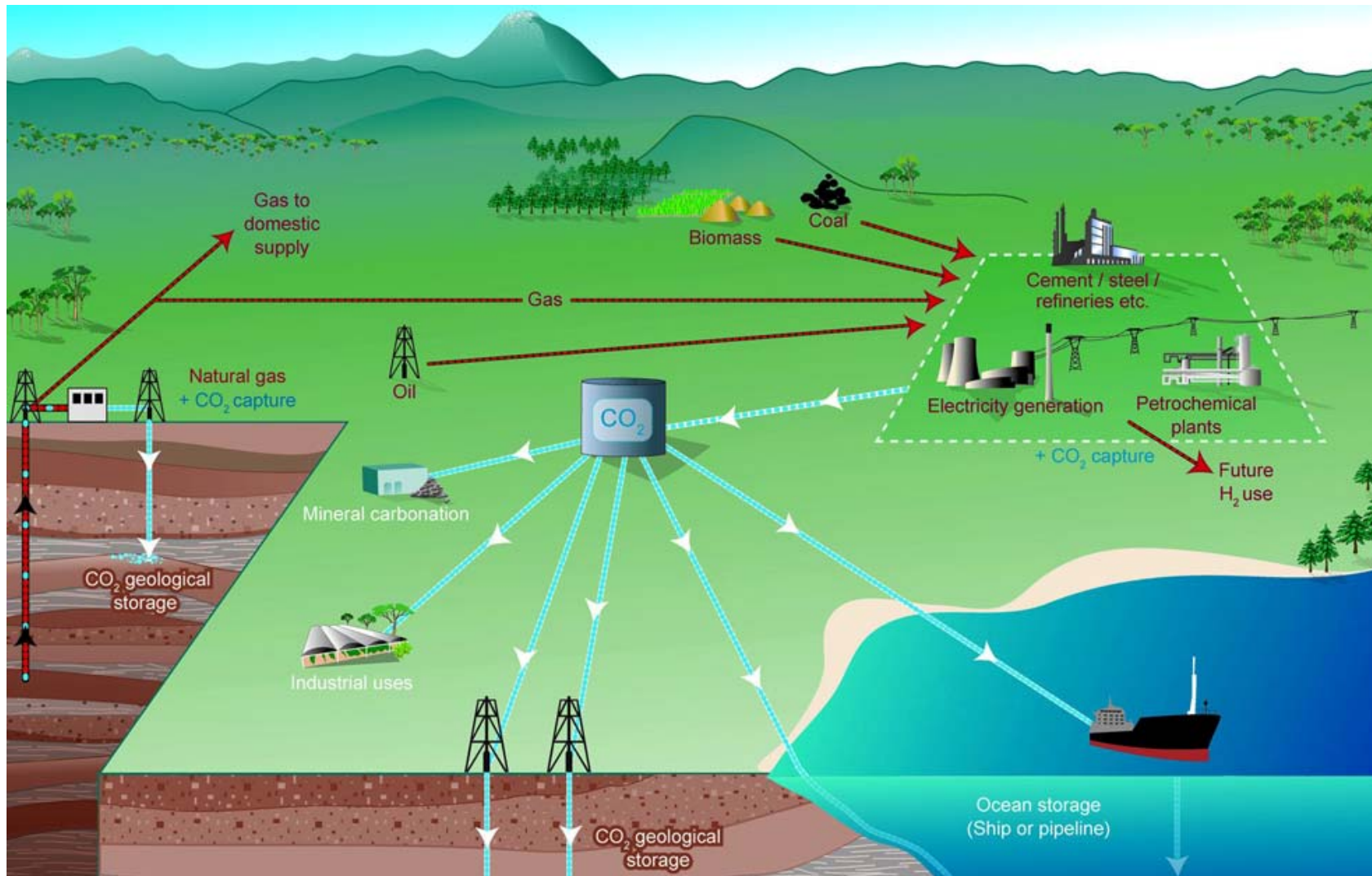


CO2 Capture and Pumping Tutorial



Ron Adams, Global Portfolio Manager – Petroleum

Sulzer Pumps Houston, TX

**Member API 610/ISO 13709, API 676, API 685 and
Intl Pump Users Symposium Advisory Committee**

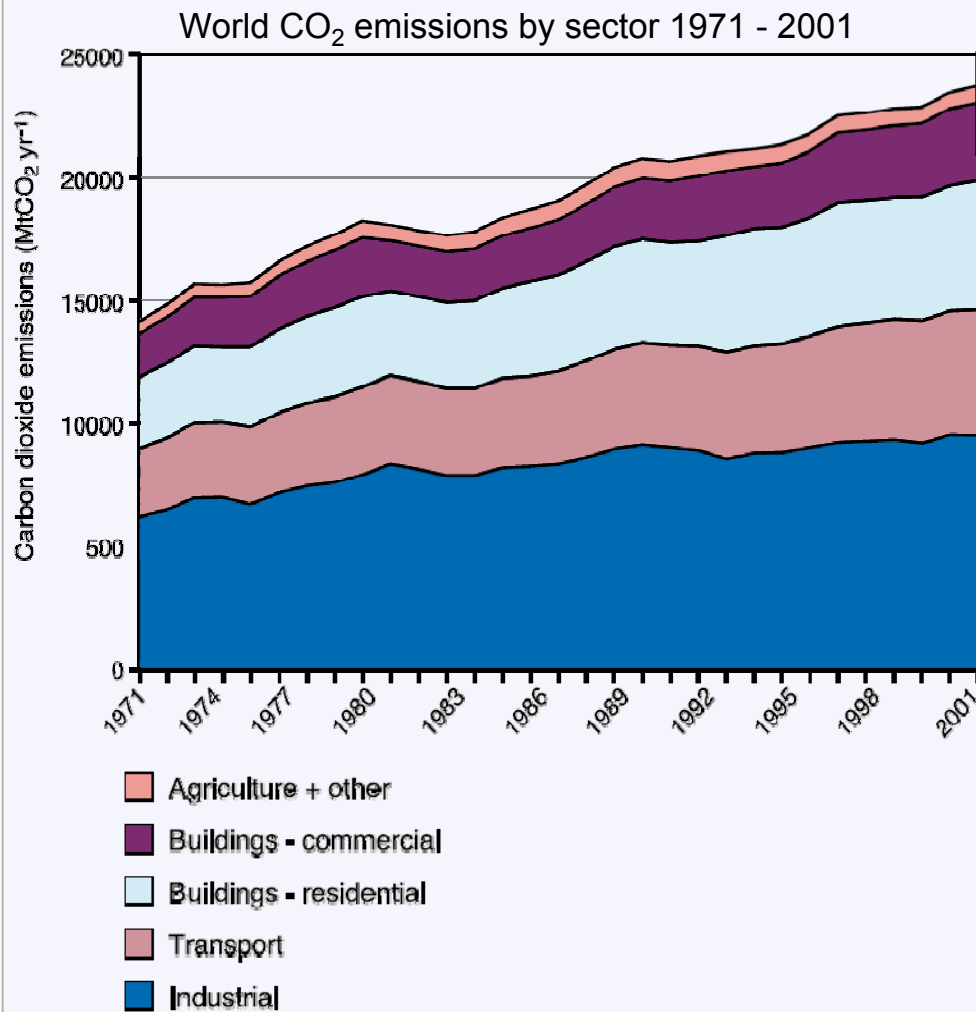
Contents

- CO₂ Value Chain and Scrubbing Methods
- Is it a Pump or Compressor application ??
- Super Critical CO₂ Applications
 - Experiences, Thermodynamics, Rotor Construction, Mechanical Seals
- Recent CO₂ application pictures
- Final Exam

CO₂ Emissions: Sources

Fossil fuels = dominant form of **energy** utilized in the world (**86%**)
and account for **75%** of current anthropogenic **CO₂ emissions**
CO₂ emissions have probably doubled in last 40 years

Total emissions from fossil fuel consumption
24,000 MtCO₂ per year (in 2001)



Large stationary sources
(> 0.1 Mt CO₂ per year)

Fossil fuels

Power	10,539 MtCO ₂ yr ⁻¹
Cement production	932 MtCO ₂ yr ⁻¹
Refineries	798 MtCO ₂ yr ⁻¹
Iron and steel industry	646 MtCO ₂ yr ⁻¹
Petrochemical industry	379 MtCO ₂ yr ⁻¹
Oil and gas processing	50 MtCO ₂ yr ⁻¹
Other sources	33 MtCO ₂ yr ⁻¹

Biomass

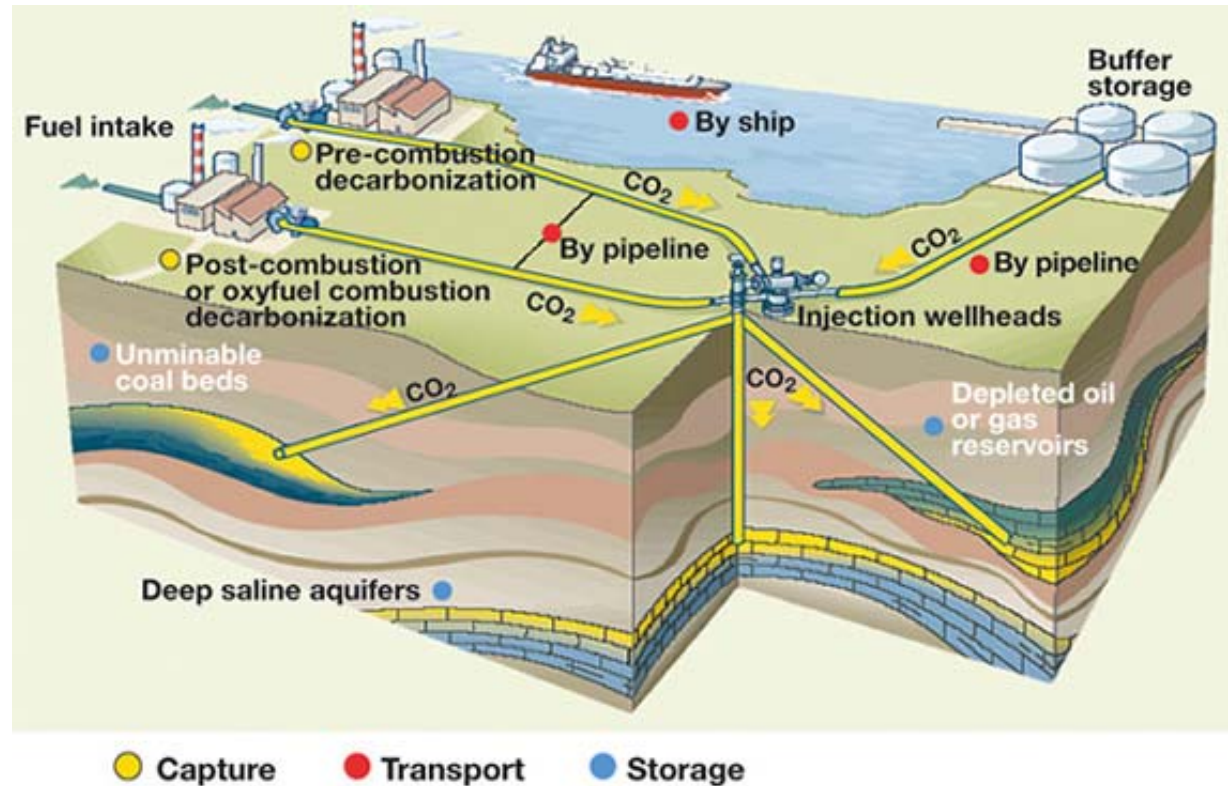
Bioethanol and bioenergy	91 MtCO ₂ yr ⁻¹
--------------------------	---------------------------------------

Total **13,466 MtCO₂yr⁻¹**

anthropogenic = derived from human activities

Getting Green is Expensive...

- It takes lots and lots of energy to capture CO₂ from stacks at power plants, cement kilns, refineries, etc
- It takes more energy to pipeline CO₂ to the point of injection
- Some people want to just pump it deep under ground or into the ocean bottom and let it sit there
- A few oil fields lend themselves to tertiary recovery using CO₂ as a miscible flood to break more oil loose from the sands.
- CO₂ has a surface tension a power of 10 less than propane and a viscosity that is a tiny fraction of the viscosity of water. It penetrates tiny pores or cracks and mixes readily with oils.

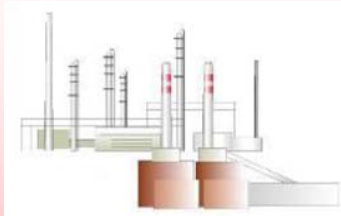


Non-metallic Pigs that have been in CO₂ pipelines grow to enormous size when removed. Orings can explode when decompressed.



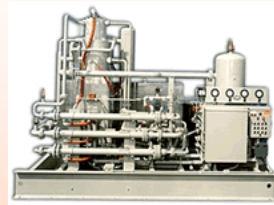
CO₂ Value Chain

Capture



Pre-combustion
Post-combustion
Oxyfuel

Compression / Liquefaction



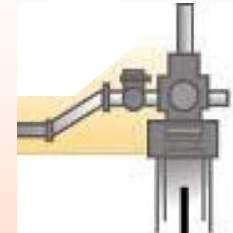
Supercritical fluid
or vapor (> 74 bar)
Last stage after
compressor

Transport



Booster pumps for
ambient ground
temperature

Injection



Pressure needed
depends on
storage location
**Pressure
gradient.**
~80 bar/km of
depth

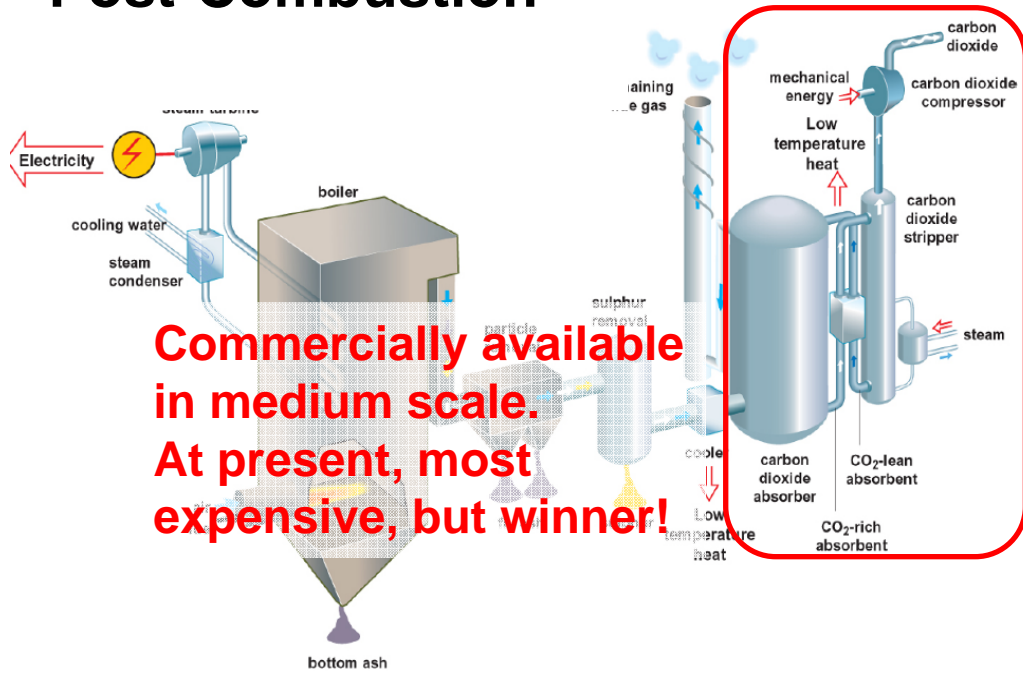
CO2 Capture

Pressure Boosting

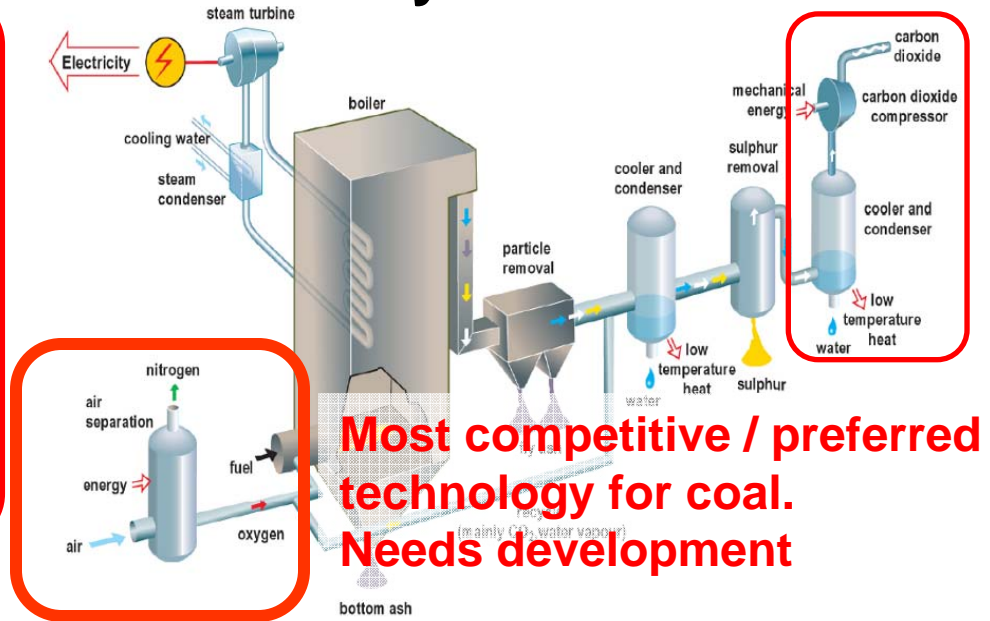
Pipelines & Oil Production or CO2 sequestration

CO₂ Capture options

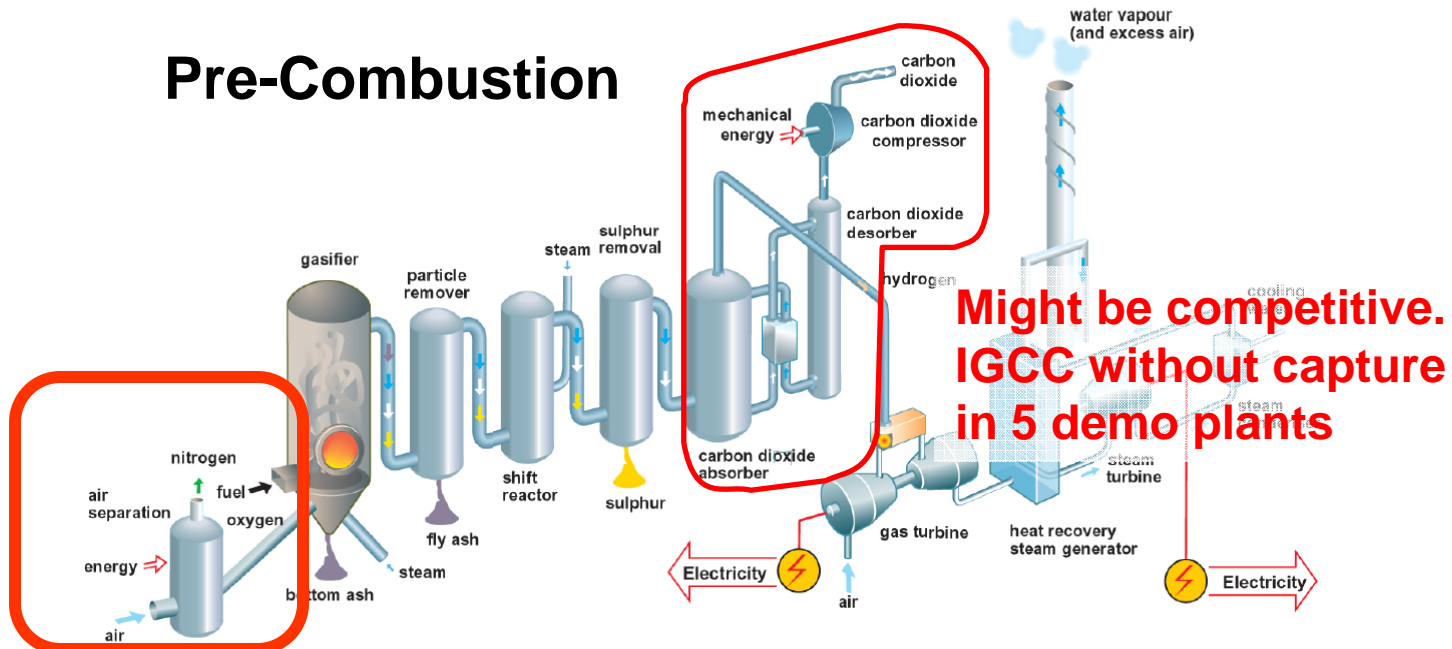
Post-Combustion



Oxyfuel

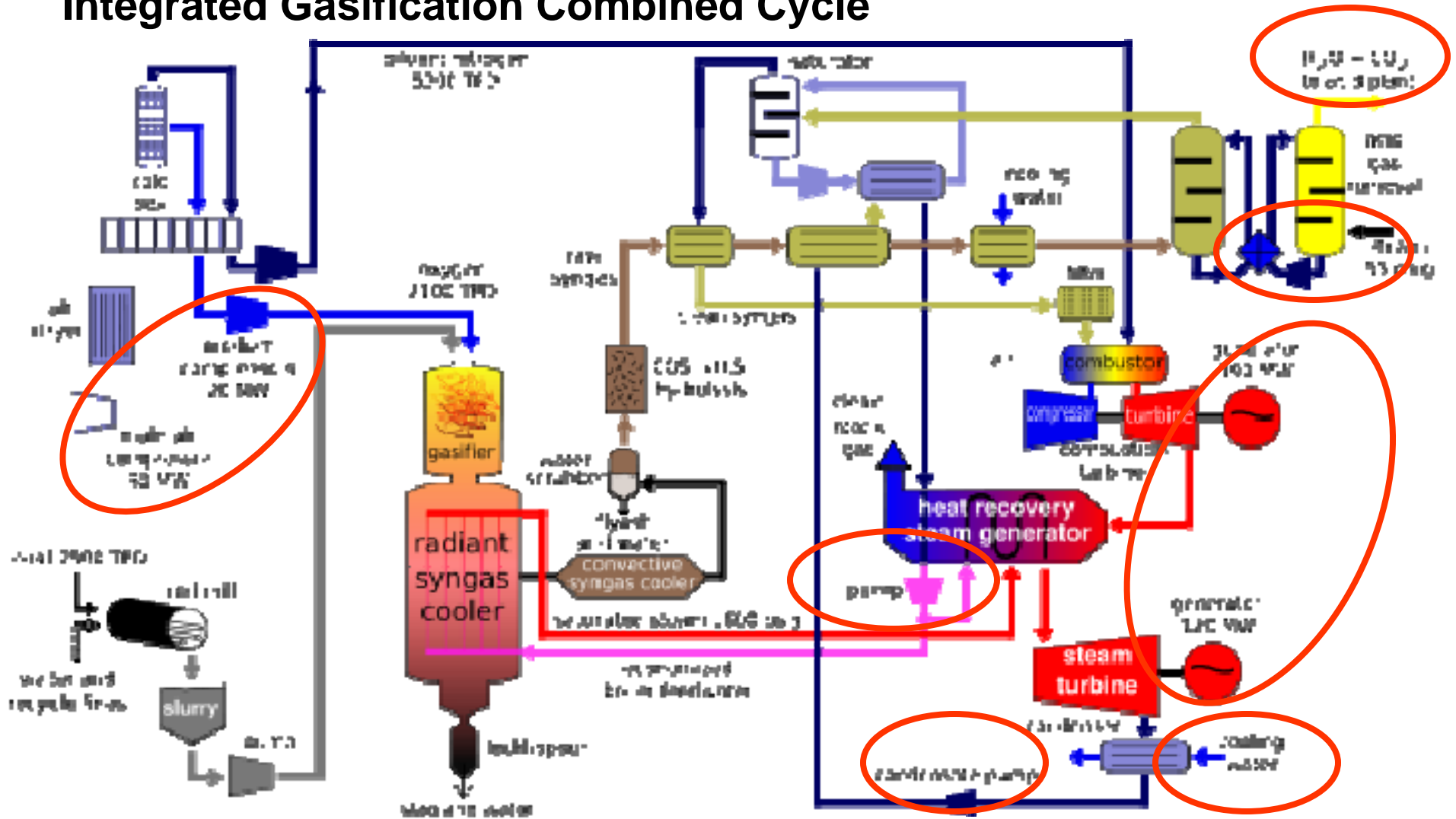


Pre-Combustion



Wikipedia IGCC schematic

Integrated Gasification Combined Cycle




Note 50 MW of compression in cryogenic gas plant on frontend for $190+120 = 310$ MW electric output. Power to run the Acid Gas Removal Plant power on backend, is not included

Cost of Plant and kWh estimates for CO₂ scrubbing

- Following 2 slides from this presentation




CO₂ Capture: Comparison of Cost & Performance of Gasification and Combustion-based Plants



Workshop on Gasification Technologies
Denver, Colorado
March 14, 2007

Jared P. Ciferno, National Energy Technology Laboratory



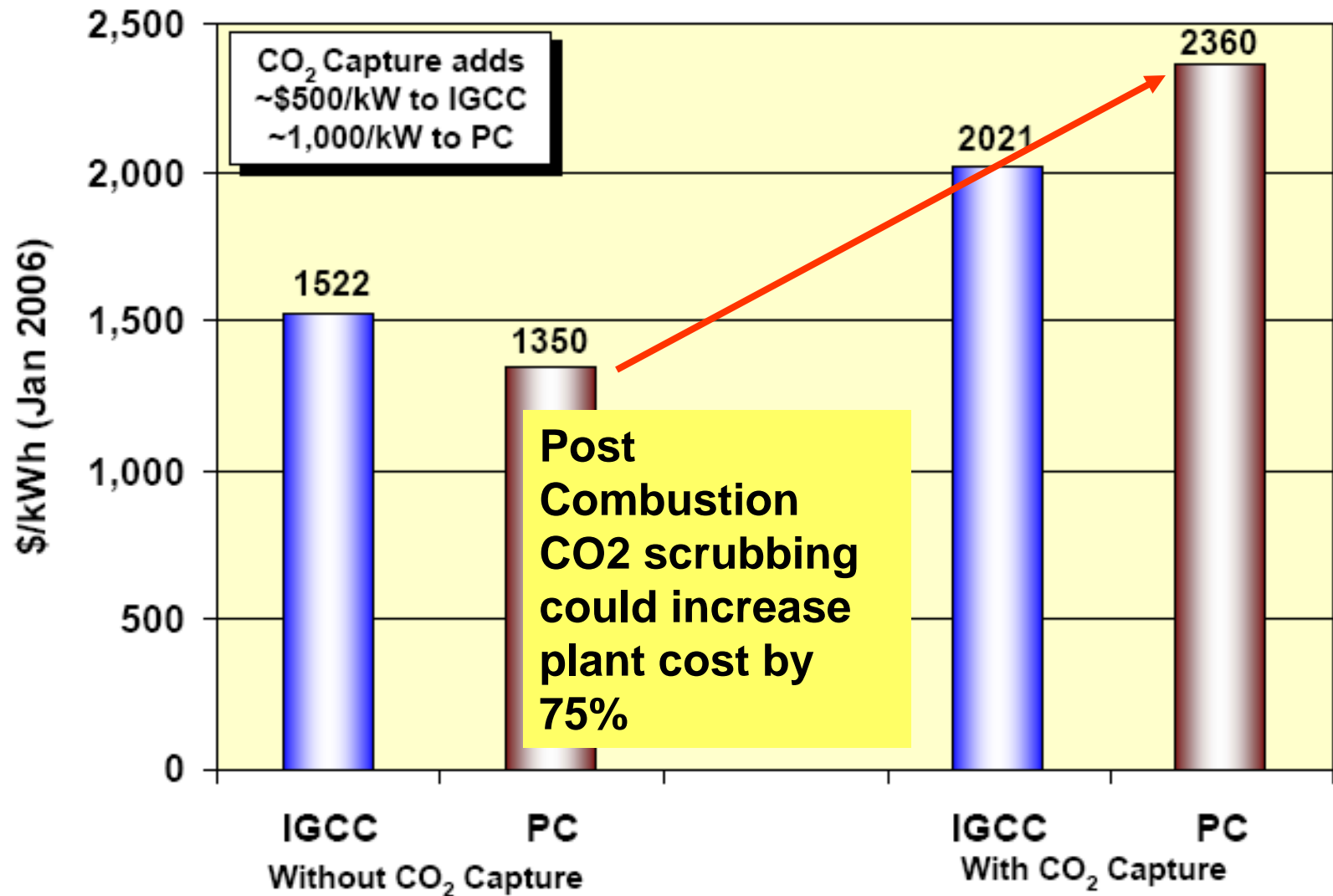
Email: Jared.Ciferno@netl.doe.gov
Phone: 412-386-5862

NETL Energy Analysis Link:
www.netl.doe.gov/energy-analyses

Model Links:
Power Systems Financial Model (PSFM):
Integrated Environmental Control Model (IECM):
www.netl.doe.gov/energy-analyses/technology/html

CO2 Capture – Power Plant Capital Cost increase

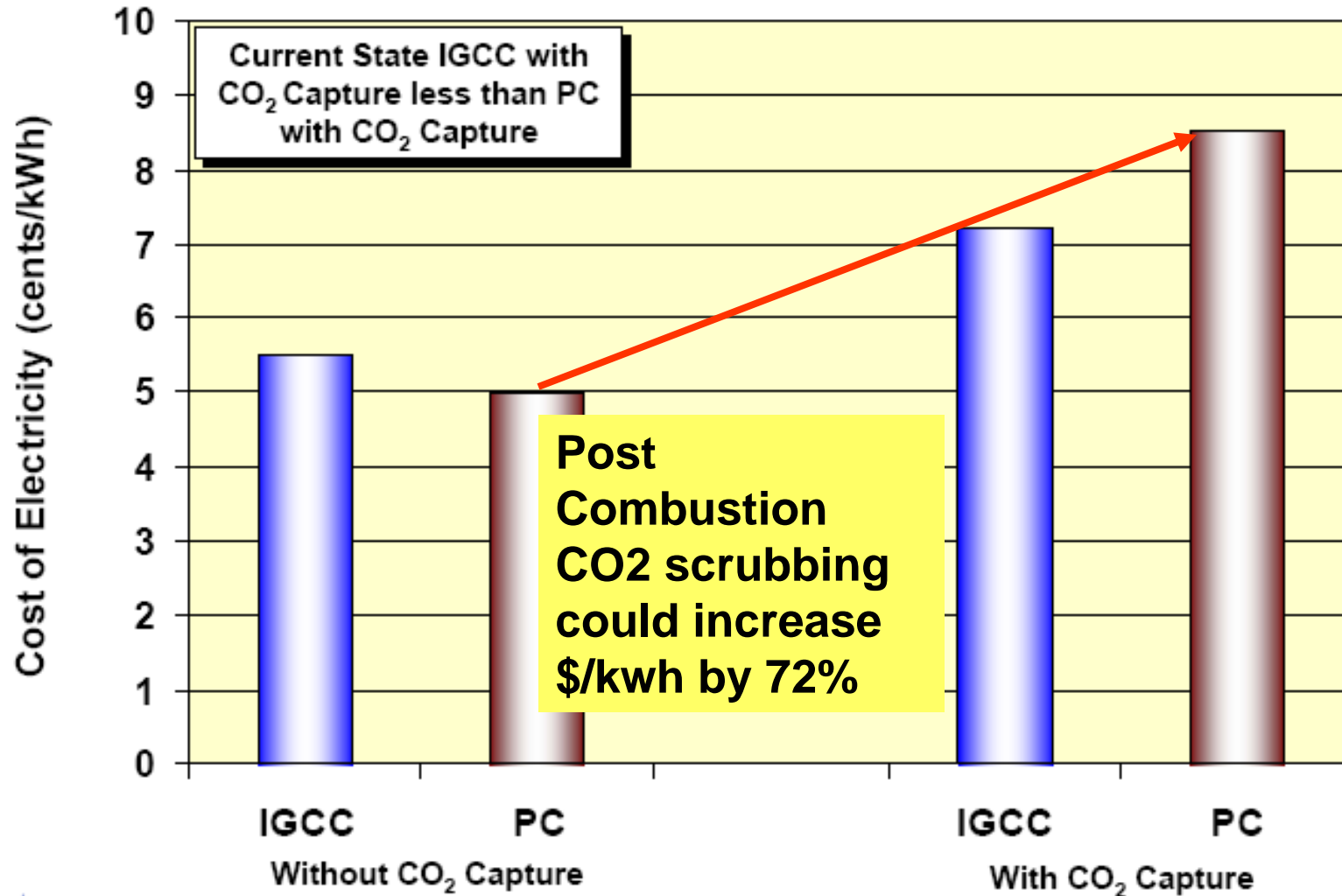
Average Total Plant Cost Comparison



Total Plant Capital Cost includes contingencies and engineering fees

CO2 Capture – Power Cost Increase

Average Cost of Electricity Comparison



History: Gas Scrubbing in the Oil Patch

Removing H₂S and CO₂ from natural gas, has been around a long, long time. Randall (now CBI), Ortloff (now UOP), Ventech, Howe Baker (now CBI), Petrofac, Pritchard (now B&V) were all players in that business. Diagram below from UOP paper.

Feed gas enters absorber at pipeline pressure – for effective contact of amine and feed gas

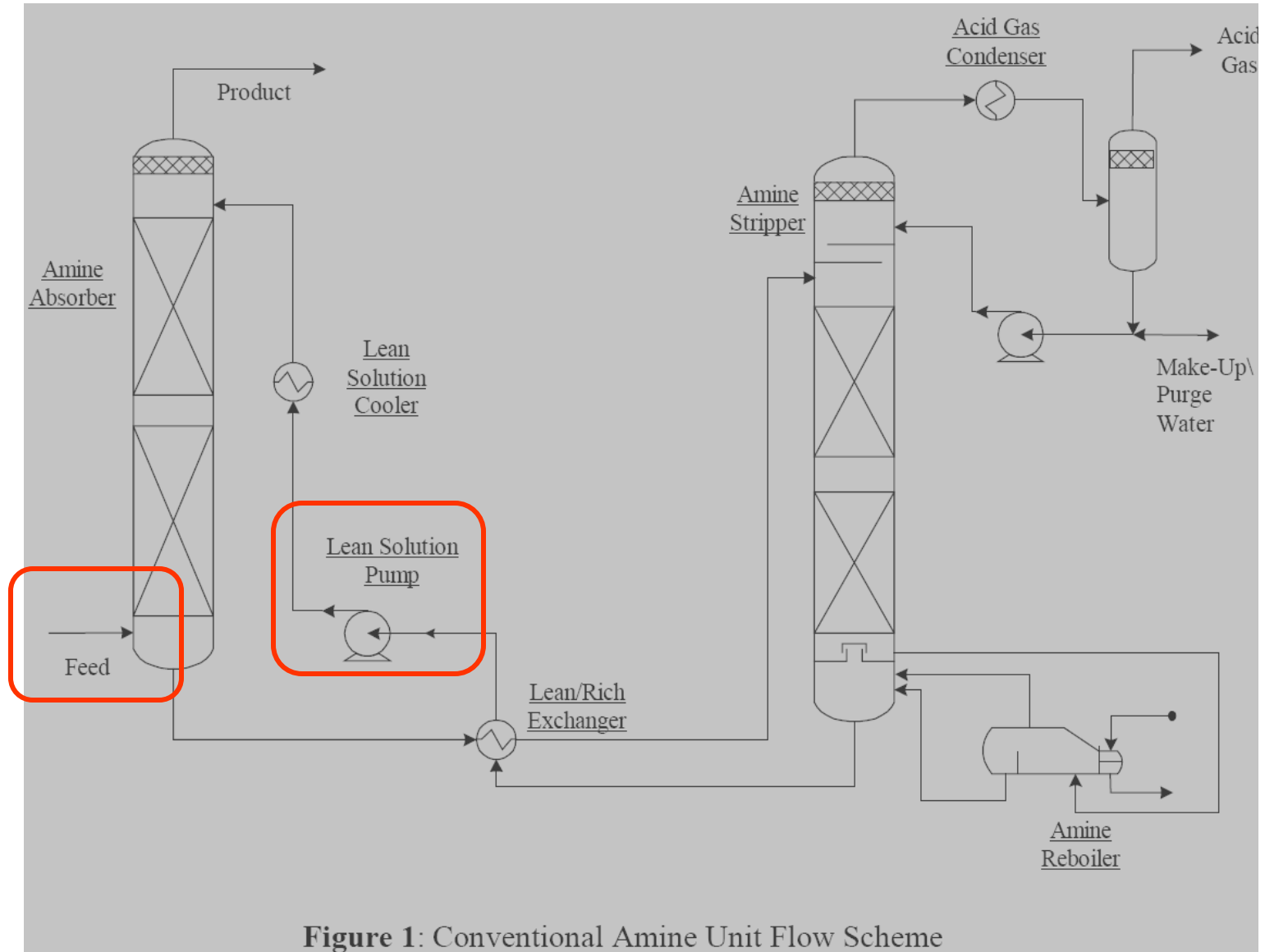


Figure 1: Conventional Amine Unit Flow Scheme

Membrane Separation in CO2 Recovery Plants

- Effluent (Oil, Gas, produced water and contaminants) from producing wells or lines enters plant. Liquids are separated out in separators
- Water vapor, Hydrogen, Helium and CO2 are allowed to pass through membrane
- dP across membrane is high so it takes energy, and thus is not a likely candidate for scrubbing stack gases

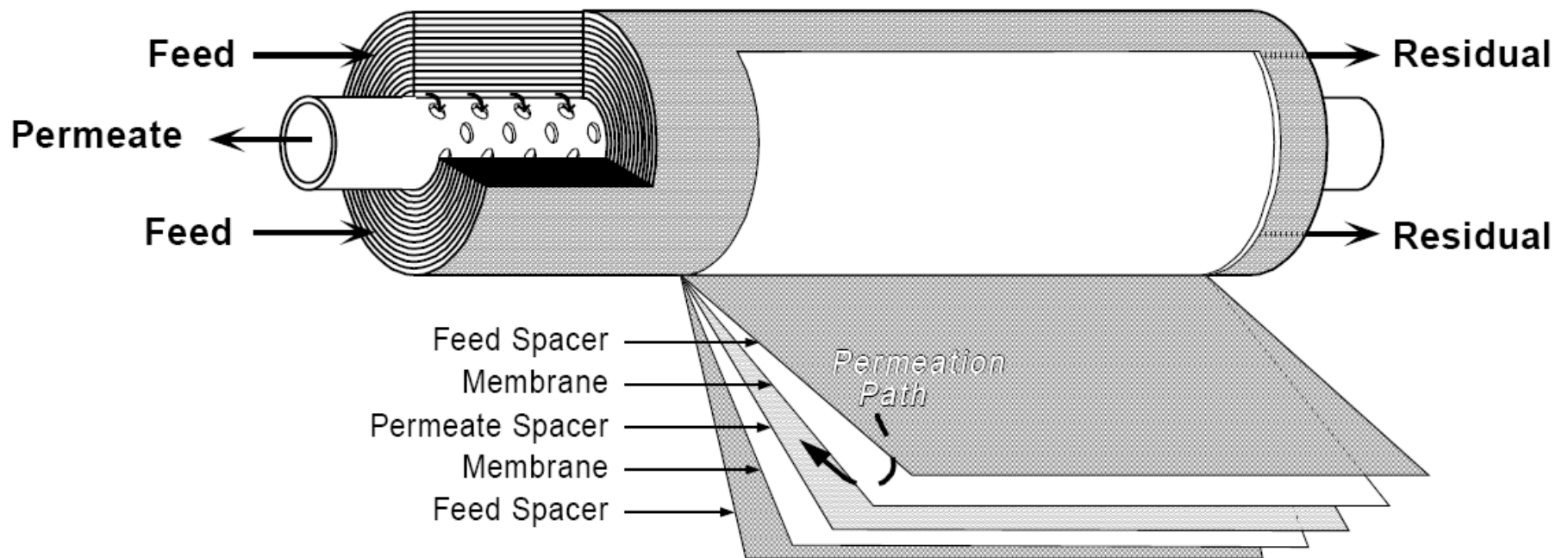
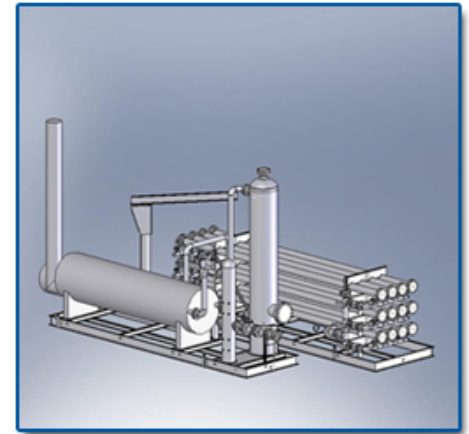


Figure 5: Spiral-Wound Membrane Element

Cryogenic Gas Plants & Air Separation

- Gas Treating is removal of hydrocarbon liquids and contaminants from natural gas
- Cold Box separation of butane, propane, ethane, nitrogen is accomplished by cooling the gas to near cryogenic temperatures where the lower vapor pressure components liquefy. Air separation is a similar process.
- Typical pump services are deethanizer, demethanizer and liquid CO₂. CO₂ & Ethane vapor pressure at -50C (-60 F) is only 6 to 8 Bar (90 to 120 psi). Ethane vapor pressure could be > 150 Bar (600 psia) at 25 deg. C (77 F)
- Pure gas seals with Nitrogen purge won't work at cold temperature because injected gas will get into pump and disrupt NPSHa
- Once the fluid gets to nearly critical pressure (and typically higher temperature), then a horizontal pump may be used with gas seals.

Post-combustion: CO₂ Stack Gas Scrubbing

Solvent circulation

Absorber

$T \sim 40\text{-}50^\circ\text{C}$ (105-120F)

$P_{\text{abs}} \sim 1$ bar (15 psi)

Stripper

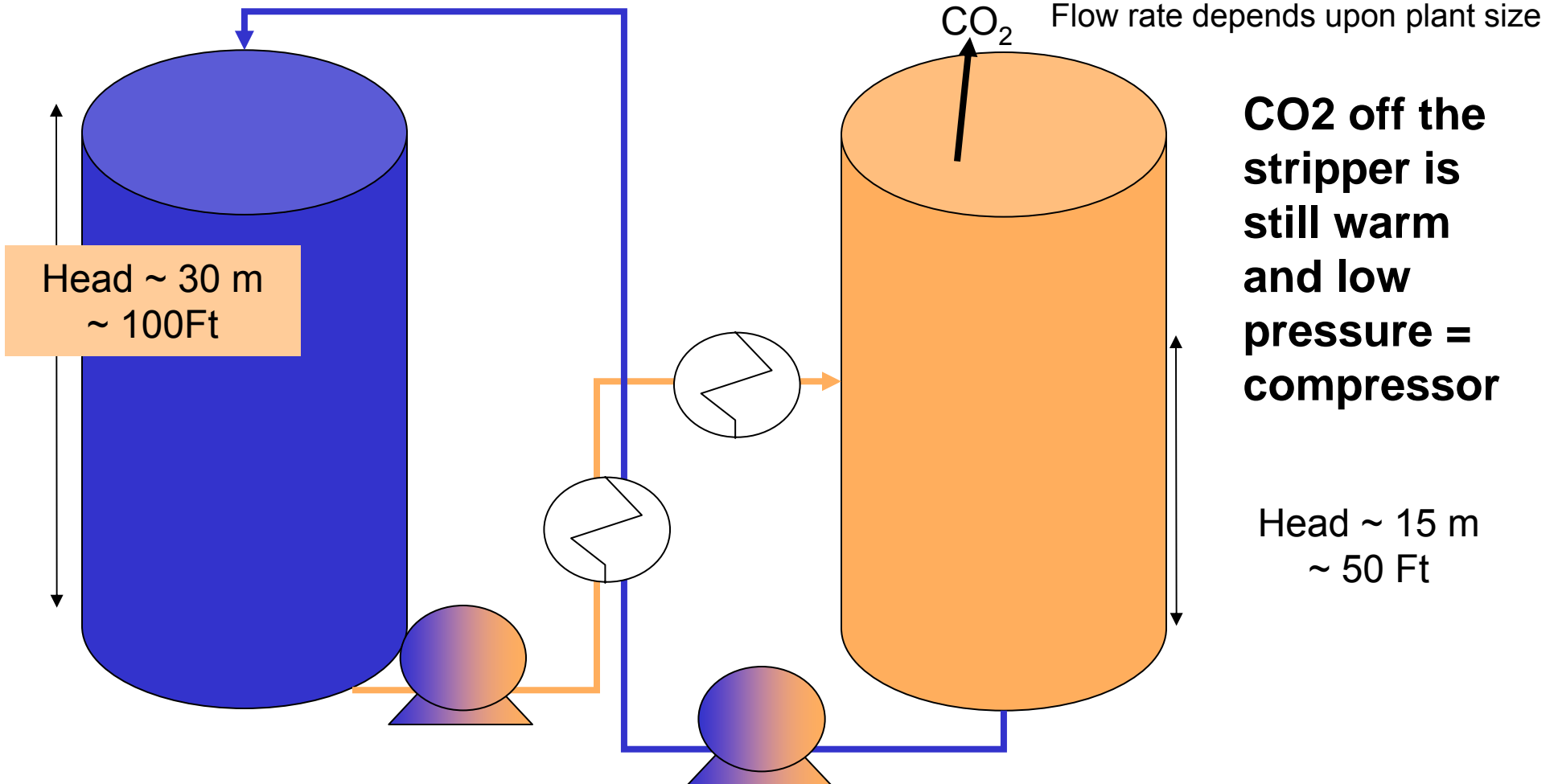
$T \sim 120^\circ\text{C}$ (250F)

$P_{\text{abs}} \sim 2$ bar (30 psi)

Pump: Absorber → Stripper
About 15 m (50 feet) of head

Pump: Stripper → Absorber
About 30 m (100 feet) of head

Flow rate depends upon plant size

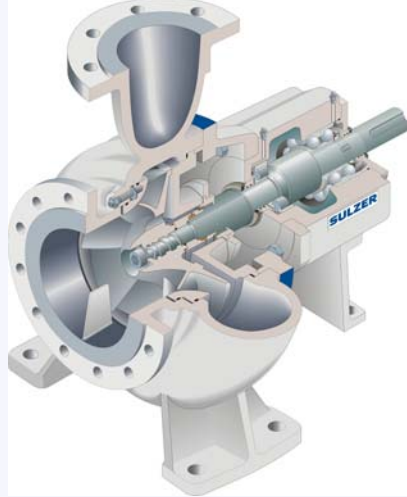


**CO₂ off the
stripper is
still warm
and low
pressure =
compressor**

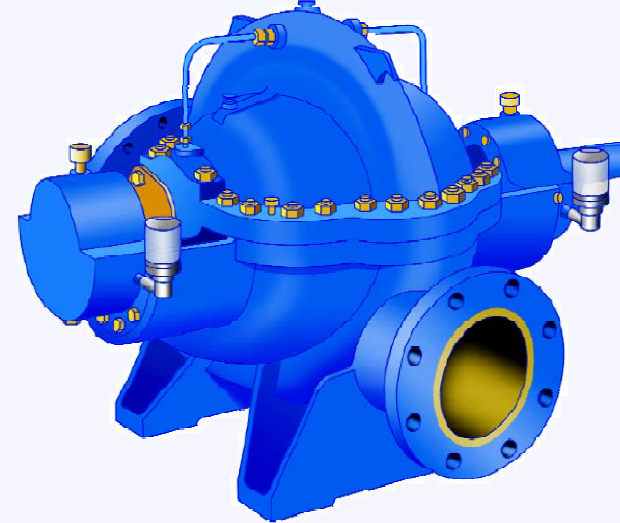
Head ~ 15 m
~ 50 Ft

Post-combustion: Pumps requirements

ANSI B73.1, ISO 5199



Single Stage



500 MW coal power plant (2-3 columns)

CO₂ emission ~2.5 Mt CO₂/year

≈> MEA flow rate: 3 200 m³/h (14 000 GPM)

Possible Pumps: 2 or 3 plus a spare

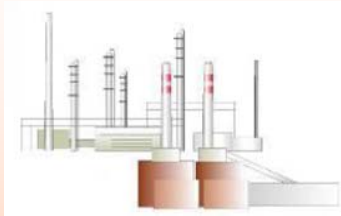
Materials:

CO₂ + Water = Carbonic Acid

300 series SS

CO₂ Value Chain

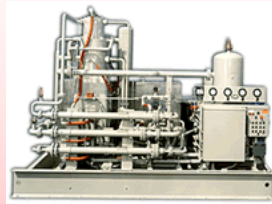
Capture



Pre-combustion
Post combustion
Oxyfuel

Still at low
pressure &
ambient temp =
compressor

Compression / Liquefaction



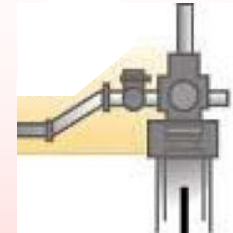
Supercritical
fluid or vapor
> 74 bara
(1080 psia)
Last stage after
compressor

Transport



Booster pumps

Injection



Pressure
needed depends
on storage
location

**Pressure
gradient:**
~80 bar/km
(1900 psi /
mile) of depth

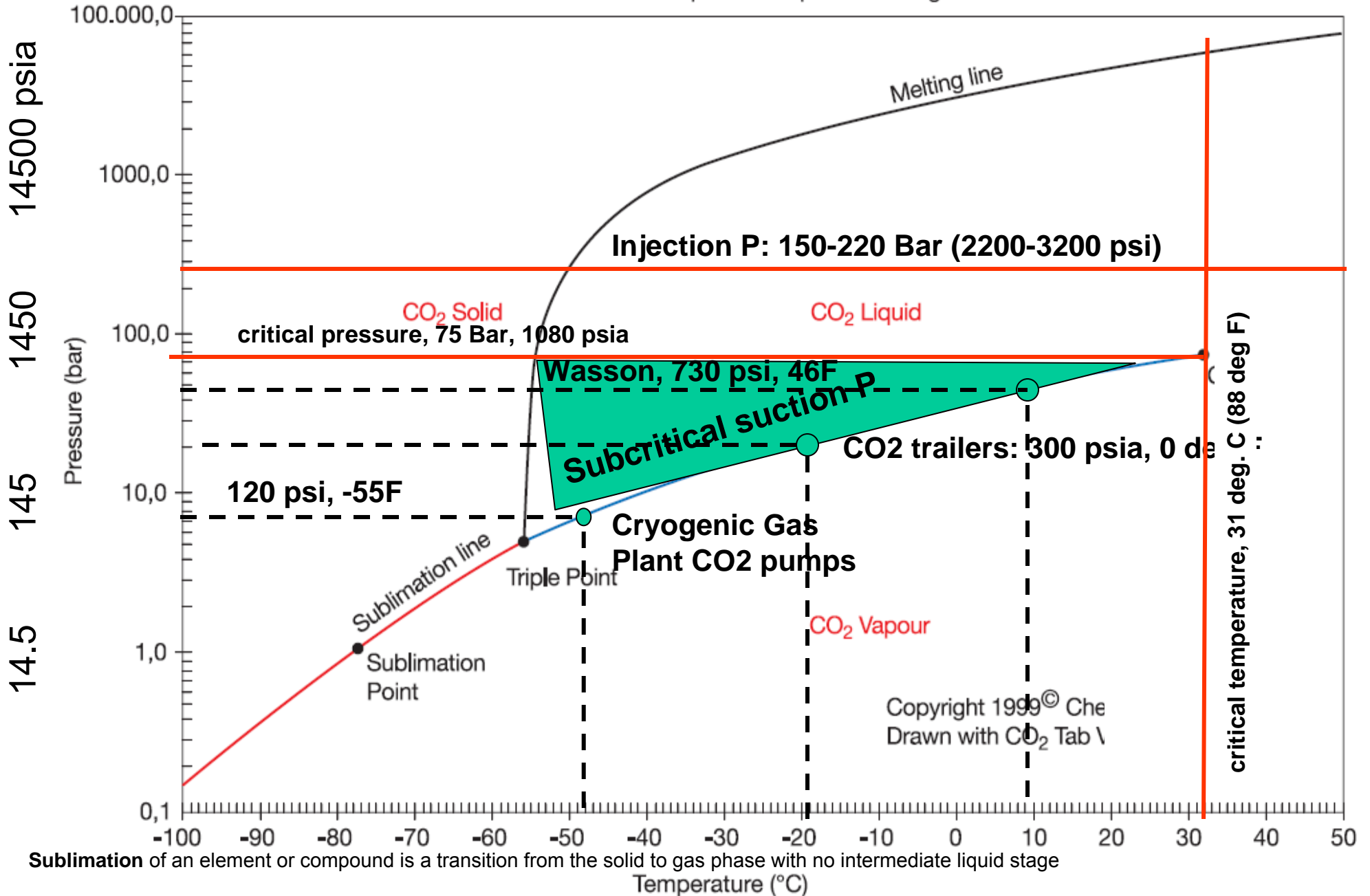
CO₂ Capture

Pressure Boosting

Pipelines & Oil Production or CO₂ sequestration

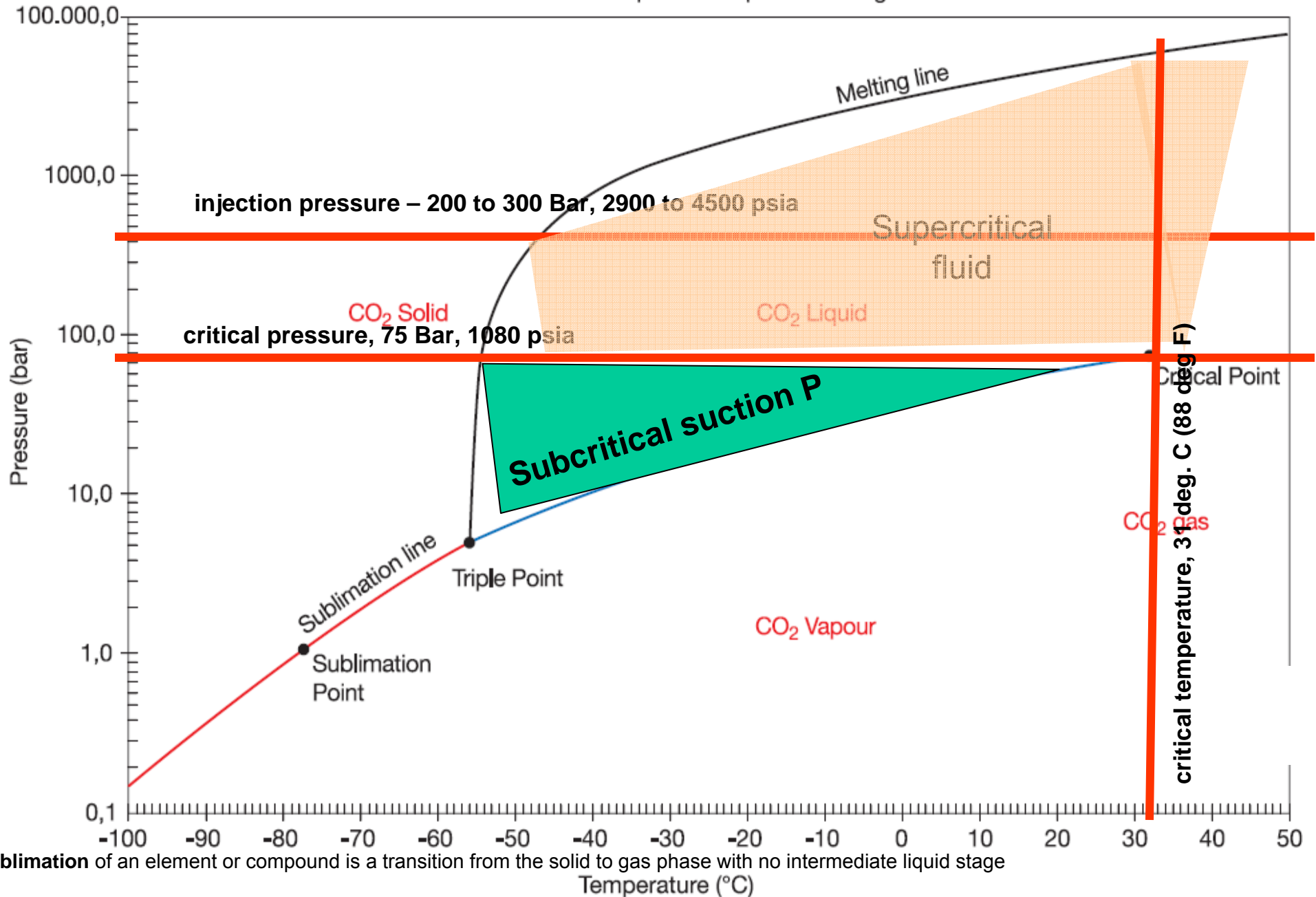
CO2 Liquid Pumping

Carbon dioxide: Temperature - pressure diagram



Compression to Supercritical Fluid

Carbon dioxide: Temperature - pressure diagram



Sublimation of an element or compound is a transition from the solid to gas phase with no intermediate liquid stage

Pressure – Enthalpy Diagrams

Pressure - Enthalpy Diagrams provide graphical evidence of equation of state values.

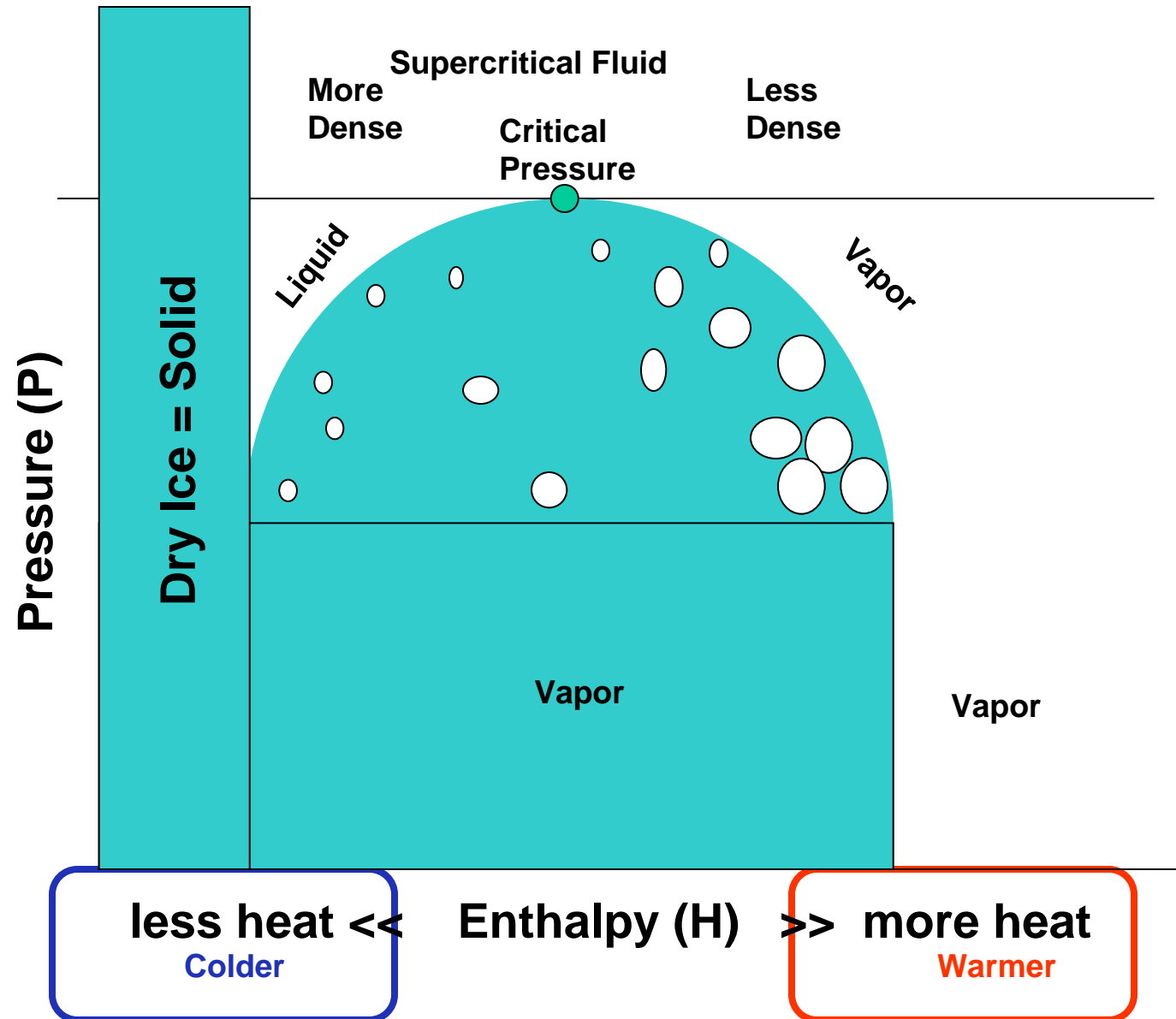
3 states: Solid, Liquid, Vapor

For CO₂, Colder = more dense

Really cold = dry ice

Warm = vapor (gas)

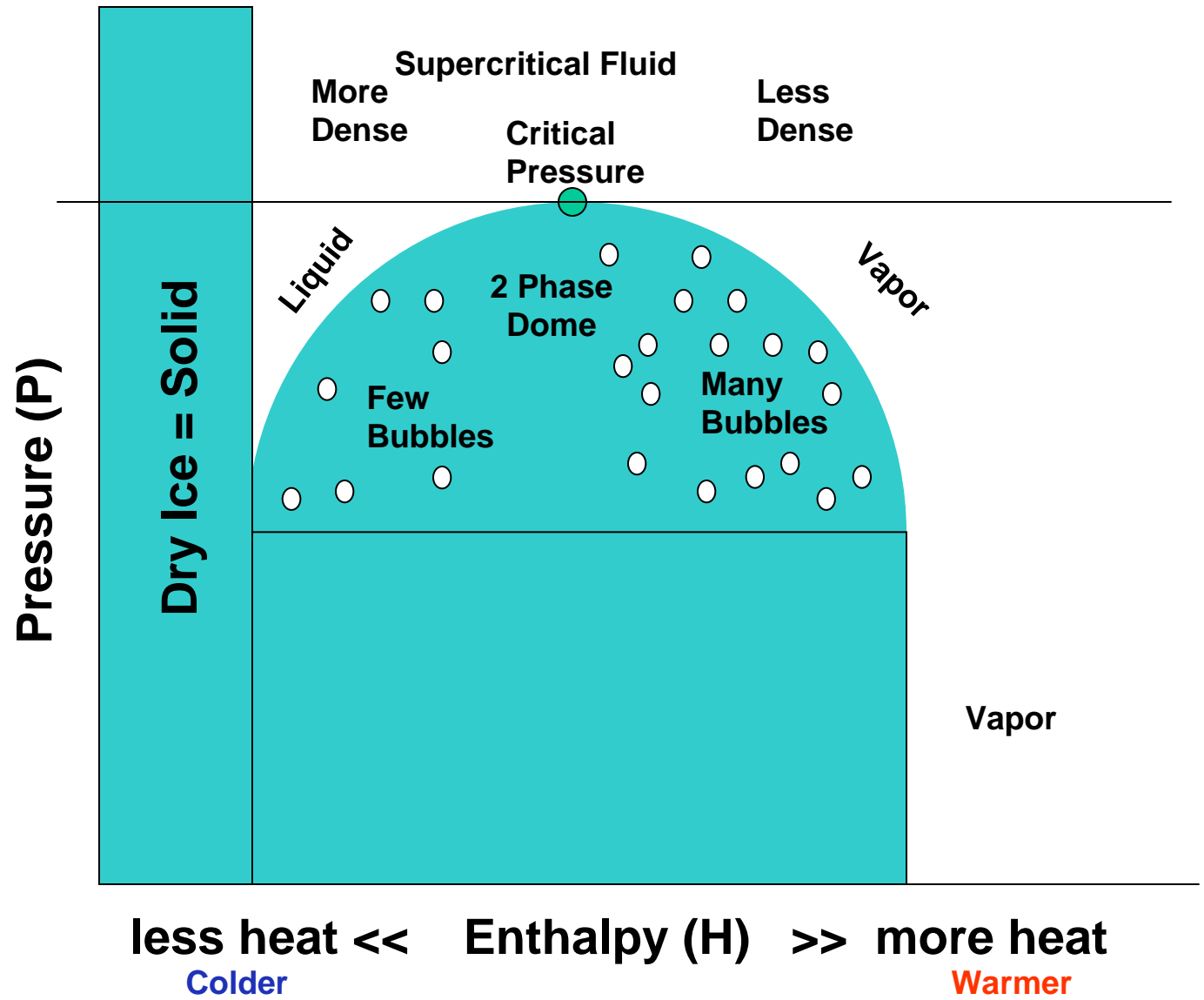
2 phase dome is demonstration of boiling when heat is added to liquid



Pressure – Enthalpy Diagrams

CO2 Pipelines typically run at supercritical pressure to increase density. That allows a smaller diameter pipeline for same mass flow = lower installed cost

It also helps keep the line from surging and reduces chance of hydraulic shock



Constant Entropy Compression

Constant entropy lines are nearly flat to right of dome

That means there is much temperature rise with little change in pressure

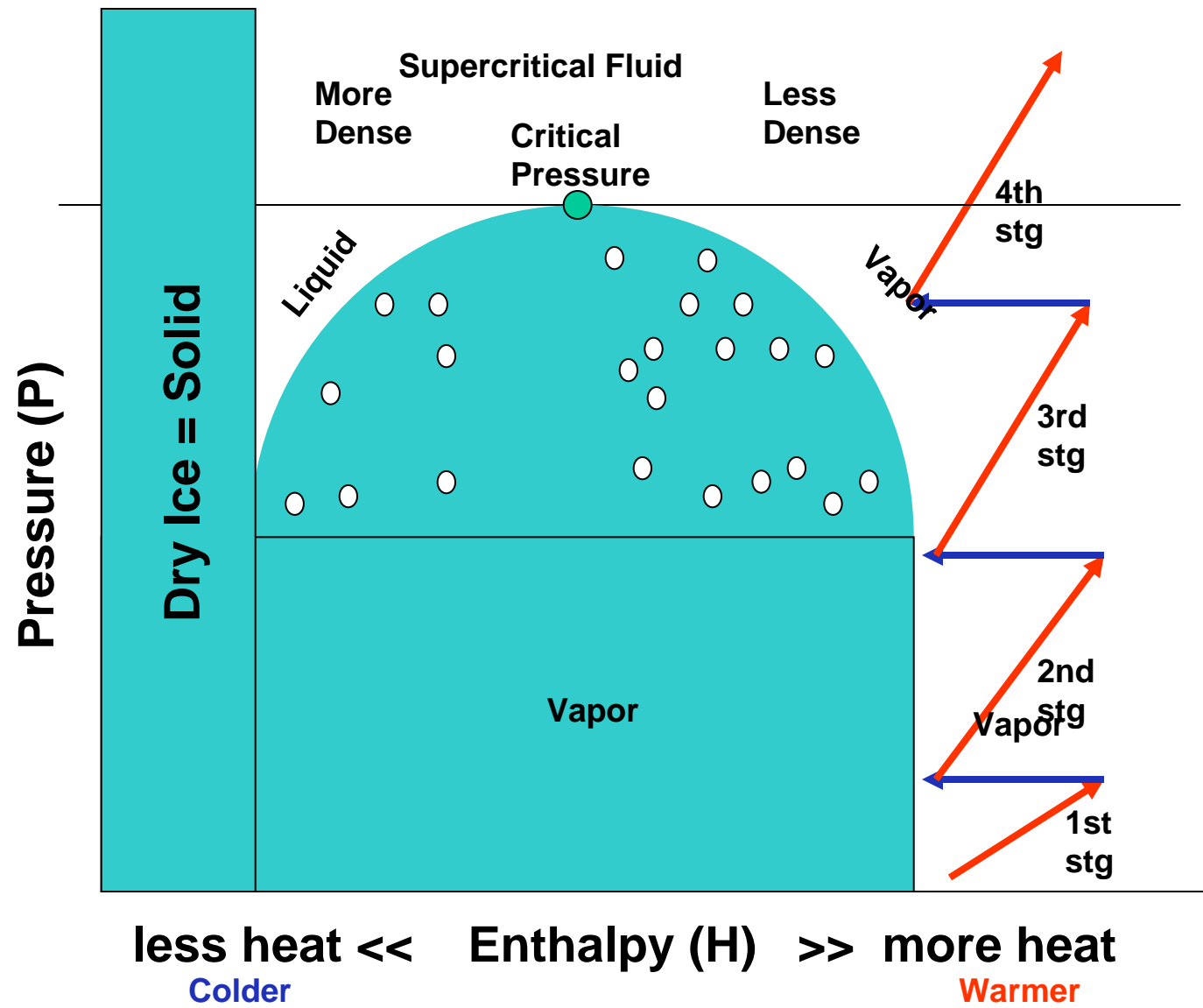
Before the next stage, the gas is intercooled

2nd stage adds more dP and dT

More intercooling

Another stage, intercooling

The compressors at DGC use 8 intercooled stages

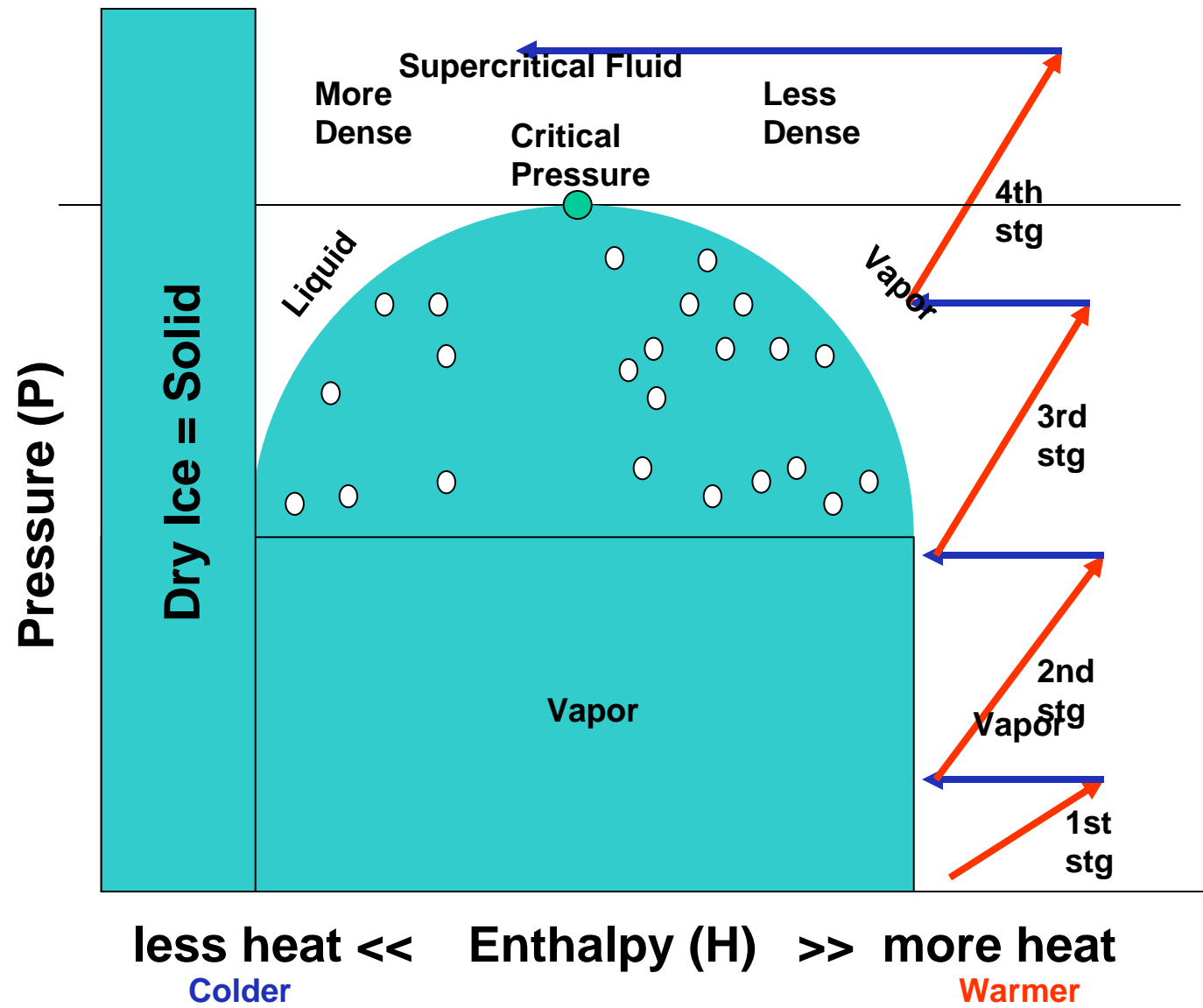


Aftercooling and pipeline size

The CO₂ may be aftercooled to reduce its volume

Temperature is limited by the temperature of the cooling medium (air, water, etc) and the heat exchange effectiveness

Final CO₂ temperature is seldom lower than 6 deg. C (11 deg F) warmer than the air or water temperature on a particular day



Supercritical CO₂ Pump Applications

- Super Critical CO₂ Applications
 - Experiences,
 - Thermodynamics,
 - Rotor Construction,
 - Mechanical Seals

Super Critical CO₂ Applications

Once we have scrubbed the CO₂ out of the stack gas or other source, we then compress it, or pump it, to pipeline pressures – typically between 100 and 150 Bar (1440 and 1900 psi)

CO₂ has very little viscosity and thus is non-lubricating

Warm CO₂ is compressible – more m³/h (GPM) will go into the pump than will come out. Mass flow rate stays the same

When we compress CO₂, it get warmer if we start at ambient temperatures

That leads us to focus on our

- Experience with CO₂
- Understanding of performance on CO₂ (Thermodynamics)
- Experience with non-lubricating hydrocarbons
- Rotor construction
- Bearing systems
- Mechanical seals

CO₂ – Early Days in West Texas

- Water floods had been in place for many years and the oil production was declining.
- The first trial CO₂ floods were a few trailers of CO₂ at 0F and 300 psia (-18C and 20 Bara) on an pile of dirt (to make enough NPSH). The CO₂ flowed from the trailers into triplex or quintiplex recip pumps and was injected into the wells.
- Sealing the plungers was a learning curve since the CO₂ flashed and formed dry ice crystals abrading the plunger packing.
- Tandem stuffing boxes with automatic transmission fluid in the secondary packing enhanced plunger packing life.
- The CO₂ bubbled out through the transmission fluid and packing life improved to acceptable months between repair



In late 1970's and early 1980's CO₂ became the hot topic as oil companies tried to extend the life of the Permian Basin in West Texas (**because it helped fund the state university system including TAMU!!**)

CO₂ for well fracturing – 1980's

- Each CO₂ trailer had a small vane type pump to pump the liquid CO₂ out of the trailer to refill tanks. They were limited on flow and pressure differential
- Early trials using single stage centrifugal booster pumps didn't work well because the seals would fail from the dry ice crystals
- In about 1982, we installed a set of dual lip seals outboard of a single primary seal and filled the cavity between with brake fluid. The CO₂ bubbled out thru the brake fluid. That allowed us to run centrifugal pumps on CO₂ trailers and in larger booster pumping trailers to supply 15 to 20 well fracturing pumping units.



CO₂ – Well Fracturing – 1980's

- It was common to pump 1400 tons of CO₂ into the well with Hydrochloric acid in less than 4 hours – and the frac pressure was over 800 Bar (> 13000 psi).
- Several days before the frac job, a steady stream of trailers brought in the CO₂ and transferred it to large temporary onsite storage tanks.
- The onsite CO₂ storage tanks at -18C (0 F) and 20 Bar (300 psia) saturation point provided suction to the boosters which boosted to about 27 Bar (400 psia). The recip frac pumps made the rest of the dP. Commonly, there were over 15,000 hp (11 MW) in diesel engines running simultaneously around 1 wellhead.
- By the end of the day, the site was clear of people and equipment



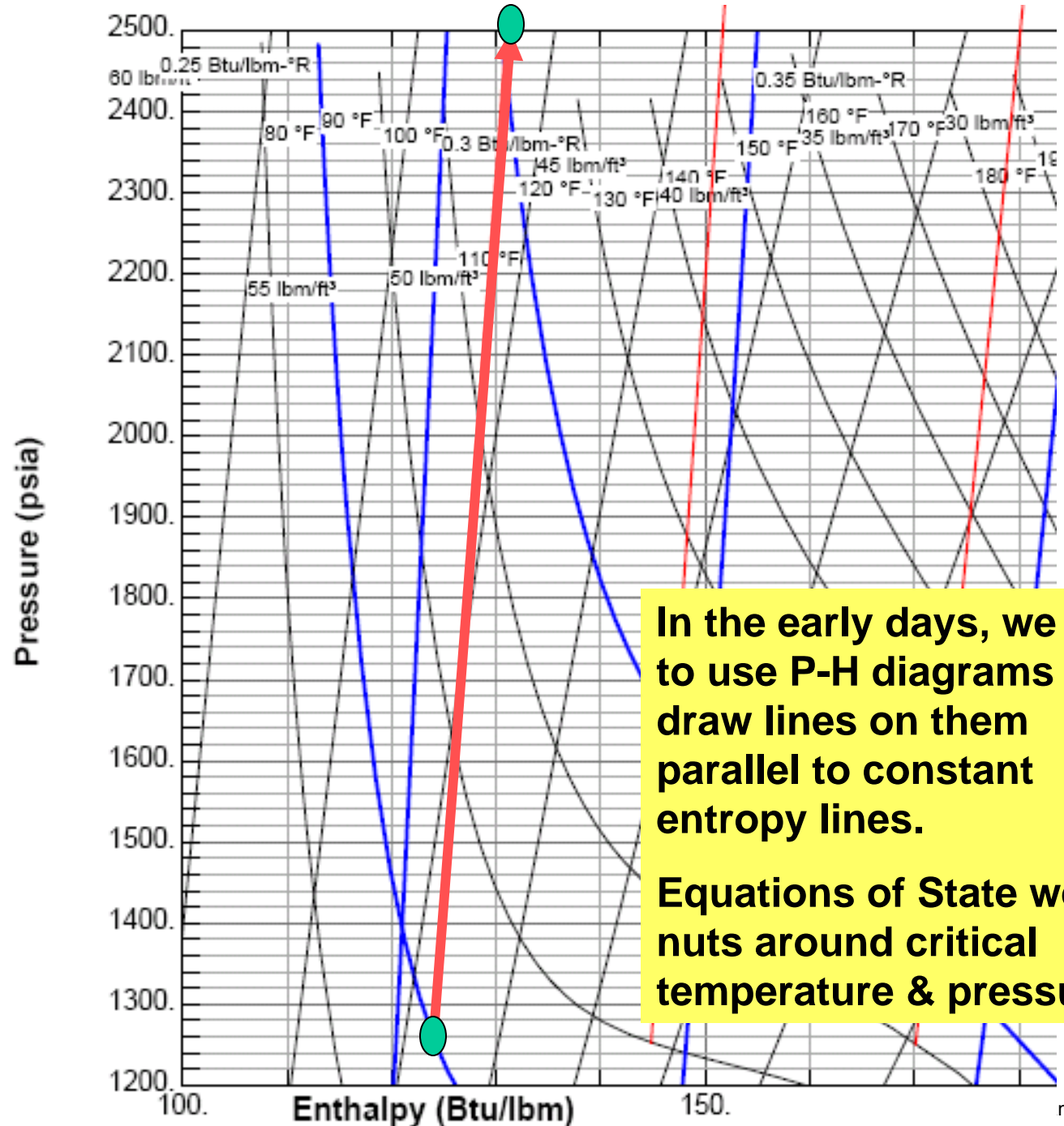
We wore our shirt collars up, not because we were cool, but because the dry ice flakes burned our necks during pump cool-down venting.

CO₂ – Thermodynamics: Pressure Enthalpy diagram

For constant entropy pressure rise, from Ts/Ps, follow constant Entropy line to discharge pressure.

Read density and temperature

Example: Ts/Ps
90°F, 1250 psia /
43 lbm/ft³ to 2500
psia: 47 lbm/ft³,
123°F
(32°C, 86 Bar, 690
kg/m³, to 172 Bar,
50°C, 754 kg/m³)



In the early days, we had to use P-H diagrams and draw lines on them parallel to constant entropy lines.

Equations of State went nuts around critical temperature & pressure.

CO₂ Applications – Thermodynamics

- We start with Ts and Ps from customer. For estimating, we divide the dP by about 4 or 5 and add that increment to Ps.
- We use recognized software for equations of state
- We assume constant entropy pressure rise to Pd
- We then average sp.gr. and sp. heat. Sp.Gr. is used to calculate head. Sp. Heat is used to calc dT due to pump inefficiency

Temperature deg. F	Pressure (psia)	Density (lbm/ft ³)	Enthalpy (Btu/lbm)	Entropy (Btu/lbm-R)	Cv (Btu/lbm-R)	Cp (Btu/lbm-R)	Sound Speed (ft/s)	Comp. Factor
60	14.7	0.11666	214.18	0.64759	0.15486	0.20119	868.44	0.99439
90	1250	43.337	124.24	0.30703	0.24495	1.199	968.38	0.2152
107.03	1937	45.925	127.09	0.30703	0.22628	0.73409	1237.9	0.30521
120.36	2625	47.731	129.81	0.30703	0.22101	0.60257	1418.5	0.38884
131.62	3313	49.162	132.43	0.30703	0.21833	0.53762	1565.7	0.46739
141.51	4000	50.362	134.99	0.30703	0.21699	0.49816	1690.8	0.5418
100	1250	30.834	145.56	0.34539	0.28846	1.2636	650.31	0.29705
133.12	1937	35.898	149.35	0.34539	0.23388	0.96937	928.83	0.37329
155.9	2625	38.933	152.75	0.34539	0.22297	0.67934	1123.1	0.44918
173.78	3313	41.141	155.92	0.34539	0.21828	0.56997	1279.5	0.52133
188.7	4000	42.9	158.95	0.34539	0.21649			
110	1250	19.497	170.42	0.38949	0.24858			
162.44	1937	25.098	176.1	0.38949	0.22516			
198.69	2625	28.985	180.8	0.38949	0.21795			
226.25	3313	31.909	184.98	0.38949	0.21594			
248.53	4000	34.238	188.83	0.38949	0.2152			
115	1250	17.682	176.08	0.3994	0.23714			
171.04	1937	23.108	182.31	0.3994	0.22105			
210.01	2625	27.016	187.38	0.3994	0.21641			
239.68	3313	30.01	191.85	0.3994	0.21514			
263.63	4000	32.415	195.92	0.3994	0.21478			

A bit more nitrogen or hydrogen in the gas stream will measurably affect discharge temperature and density

CO₂ Applications – Thermodynamics

- If suction temperature is over 100°F (38°C), sp.gr. is low and sp. heat (Cp) is low. That means it will take much more head (and many more stages or rpm) to achieve dP.
- With low specific heat, temperature rise due to pump inefficiency will be greater (not a major issue but lowers average sp.gr. slightly).
- For pump applications, results from many applications tell us to cool to 80 to 90°F (27 to 32°C) if at all practical to maximize density, reduce # of stages, reduce heat of compression, and Cp

dP

2750

90 deg. F, 1250 psia suction
 avg. Cp Avg. Density Avg. sp.gr.
 0.714 47.303 0.759

100 deg. F, 1250 psia suction
 avg. Cp Avg. Density Avg. sp.gr.
 0.799 37.941 0.609

110 deg. F, 1250 psia suction
 avg. Cp Avg. Density Avg. sp.gr.
 0.739 27.945 0.449

NOTE: Cp for 1250 psia at 100F too close to Tc/Pc; Averaged CP from 90F and 110F at 1250 psia

115 deg. F, 1250 psia suction
 avg. Cp Avg. Density Avg. sp.gr.
 0.637 26.046 0.418

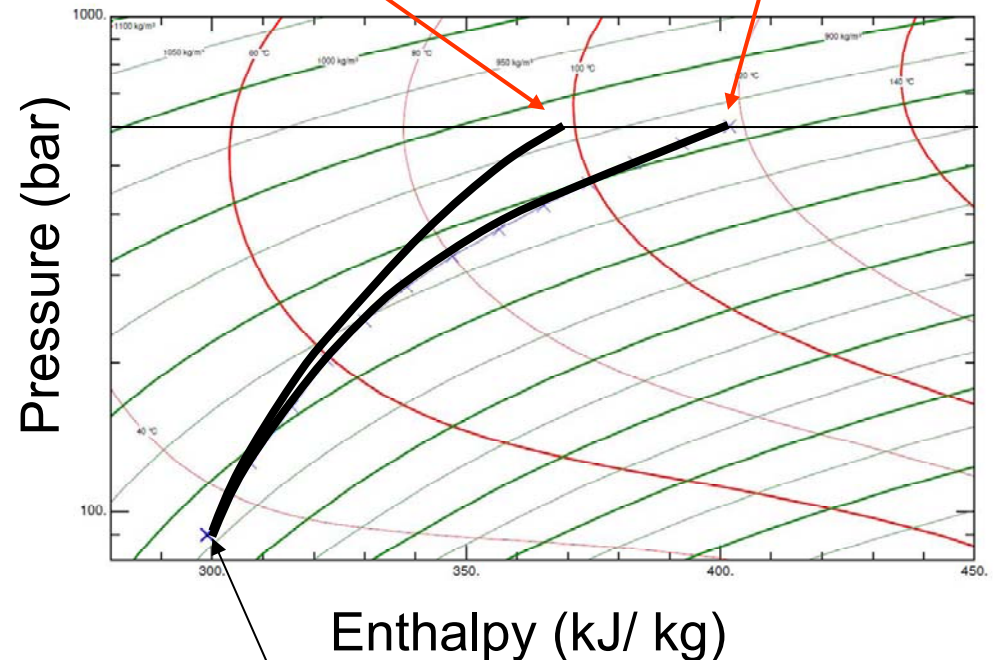
0.759 vs 0.418 = 45% fewer stages

Very High dP CO2 Pump Selection

- Isentropic fluid data at inlet and outlet provides mean density for pump selection
- pump performance curve is used for input for stage by stage polytropic analysis
- speed or impeller diameter is then corrected
- check for inlet temperature increase due to balance line return in suction – especially on lower flow / very high head pumps where efficiency is lower & temperature rise due to inefficiency is greater

Polytropic
 120°C, > 500 Bar,
 248°F, > 7300psi, SG=0.82

Isentropic
 95°C, > 500 Bar
 203°F, > 7300psi, SG=0.88



35°C, < 100 Bar
 95°F, < 1400 psi, SG=0.66

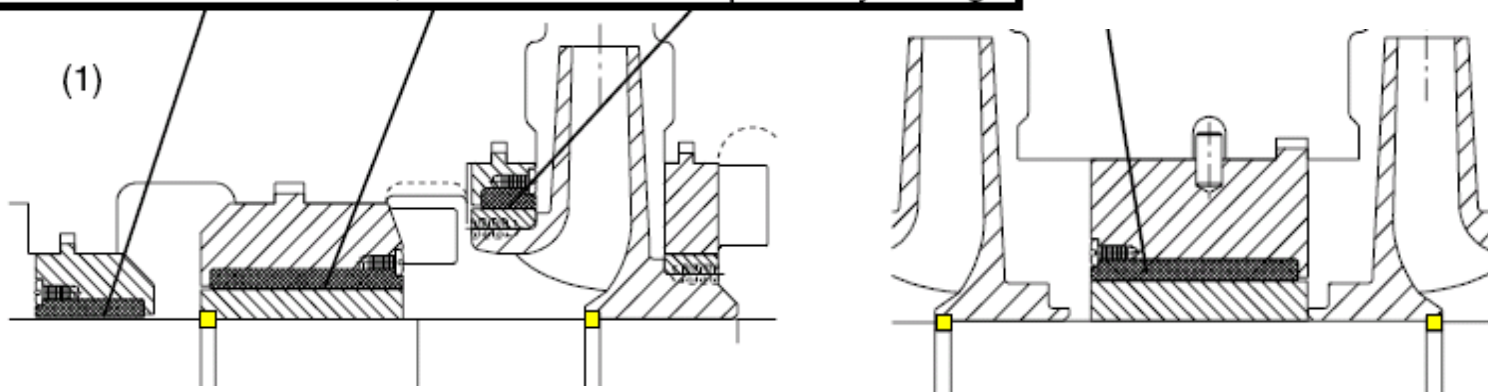
Density Change = 24%

Supercritical CO₂ Applications

– Multistage Pump Rotor Construction

- Supercritical CO₂ has the viscosity of a very light hydrocarbon, and low surface tension – it is not a good lubricant
- Design rotor to prevent galling if contact is made during operation
- If within MAWP & Max Suction Pressure limits, API 610 Type BB3 is most common multistage pump type in N. America with center bushing and throttle bushing for rotor axial balance and rotor dynamic stability.
- For higher pressures, use API 610 Type BB5 radial split barrel pumps
 - Inline rotor stack is least expensive, but check rotor dynamics with worn clearances before blindly applying inline stacked rotor. Use Back-to-Back rotor stack if there are any questions on stability with worn clearances.
- Carbon or PEEK are common non-metallic wear parts.

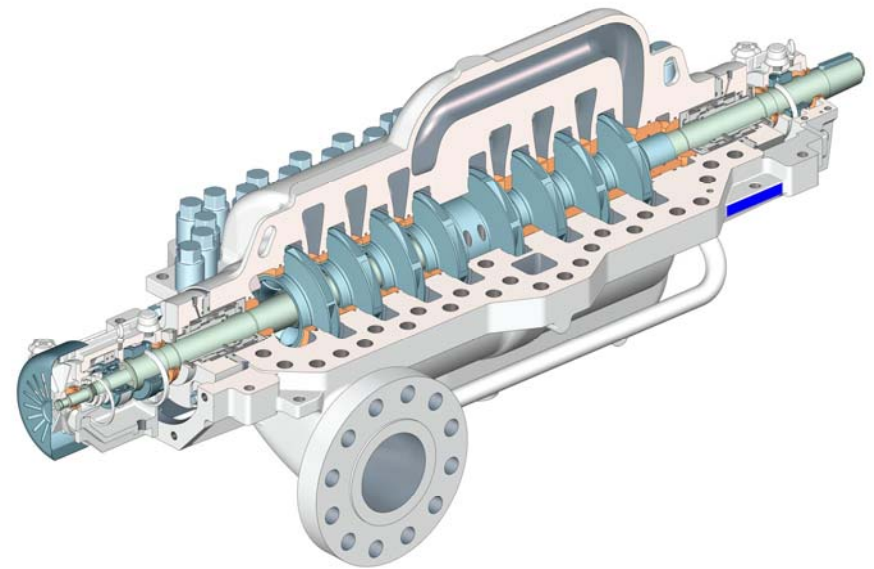
Stationary Non-Metallic Throat Bush, Throttle Bush & Impeller Eye Ring



Low Lubricity Applications - Light hydrocarbon

- There are hundreds of multistage pumps running on 0.4 to 0.55 sp. gr. (450 to 550 kg/m³) Ethane-Propane Mix and Propane pipeline applications for over 30 years. Wear parts are often non-galling metal against hardened 12% chrome
- In past 15 years we have successfully applied horizontal split multistage pumps on supercritical ethylene pipelines with 100 bar (1450 psi) suction pressure.
- Sp. Gr. is typically 0.26 to 0.3 (260 to 300 kg/m³) at ambient temperatures

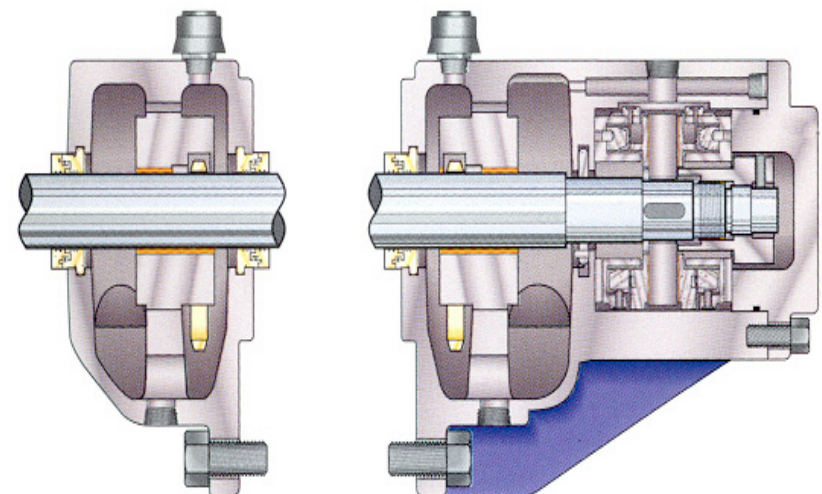
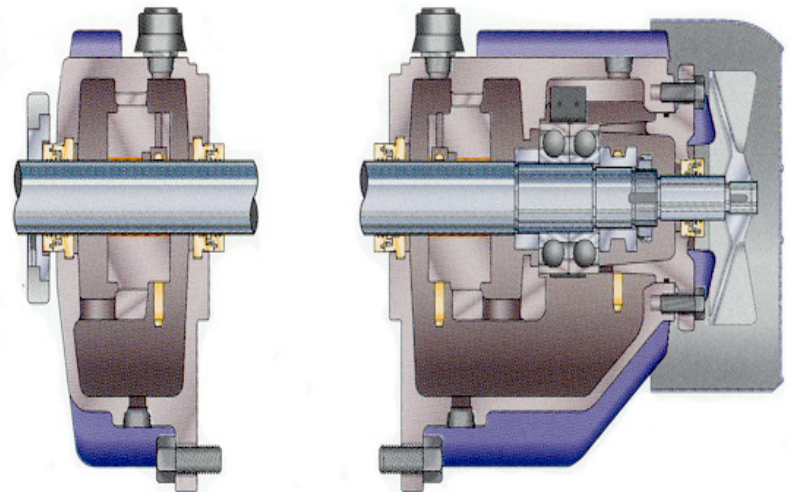
API 610 Type BB3 Axially Split Multistage



Some of our engineers refer to these as "fog" pumps due to very low specific gravity

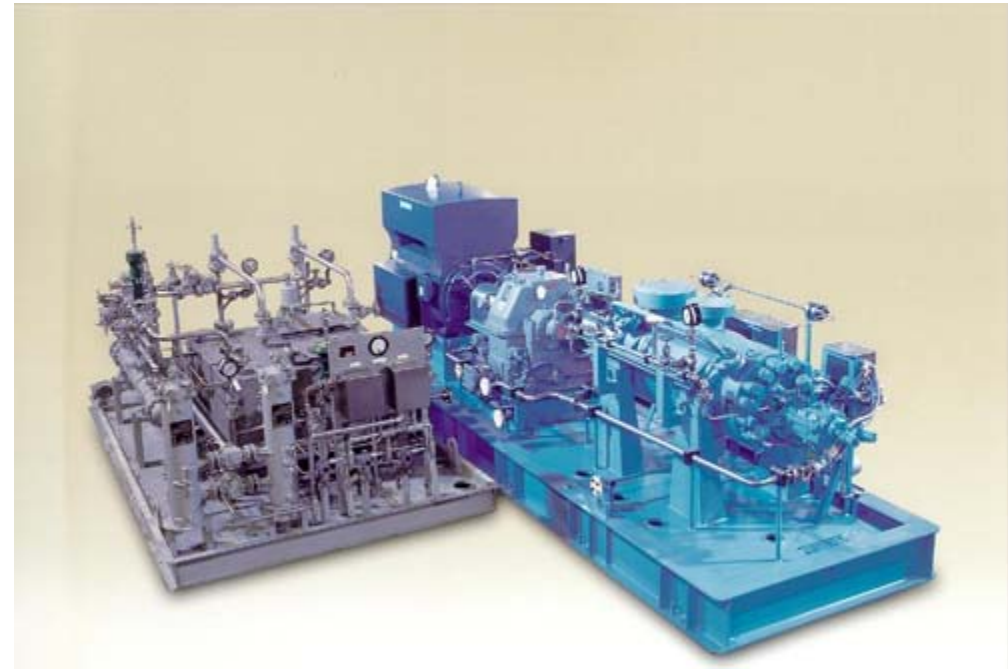
CO₂ Pumps – Bearings

- The back-to-back rotor stack in API 610 type BB3 pumps reduces axial thrust load.
- That allows a fan cooled ring oil lubricated sleeve radial / ball thrust bearings for simplicity. Pipeliners prefer not having a lube system if the power level and pump design will allow it.
- On high energy pumps or inline rotor stack BB5, there maybe no choice but to use hydrodynamic radial and thrust bearings which require a bearing lubrication system
- Sleeve/Pivot Shoe bearings, instrumentation & lube system add \$100,000 to \$200,000



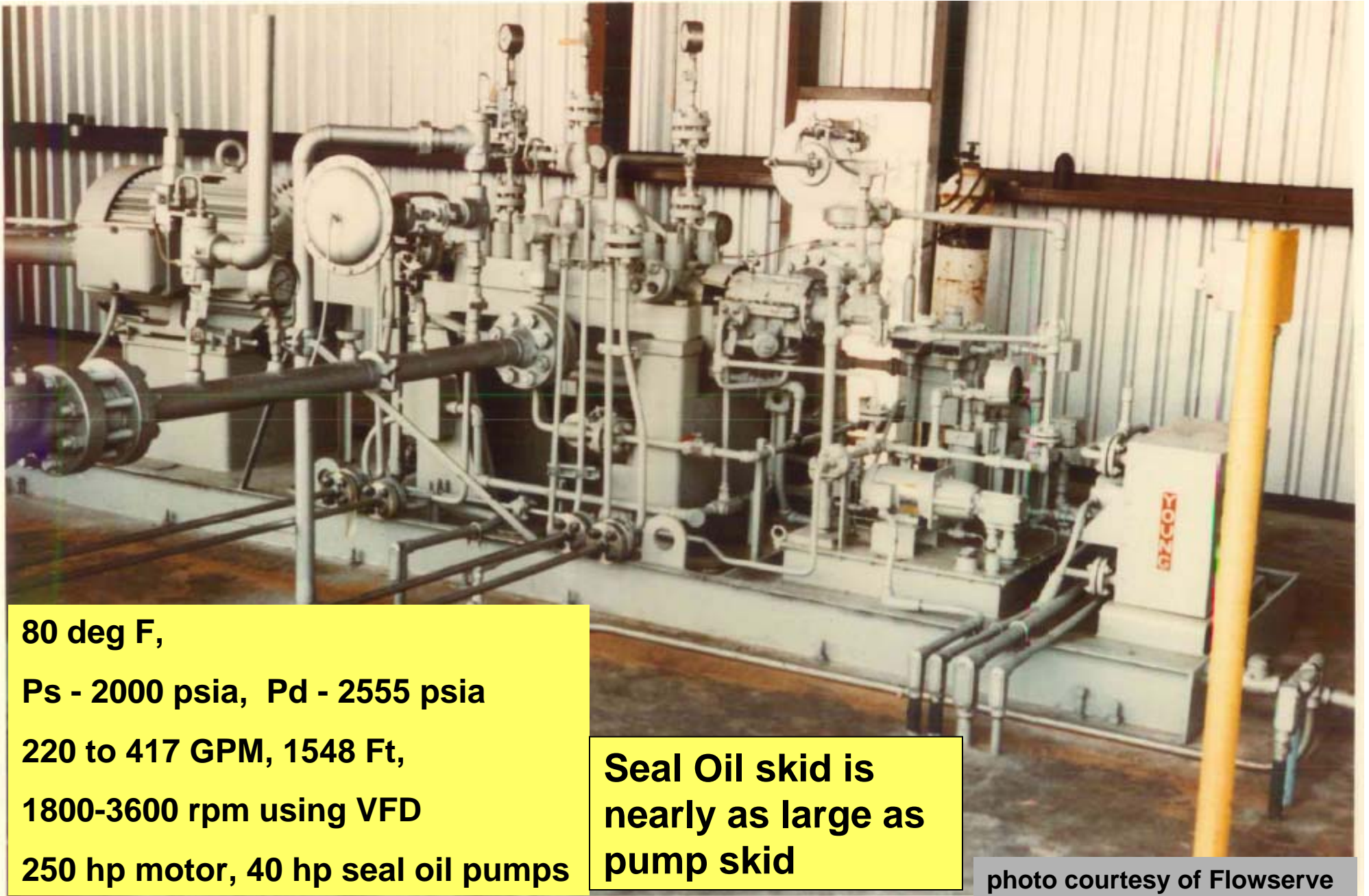
CO₂ – Mechanical Seals

- That leaves the mechanical seals. In 1983, double mechanical seals were used on supercritical CO₂ to provide oil to the seal faces (CO₂ has very low lubricity at high pressure). A large seal oil system with 30 kW (40 hp) oil pumps was needed to make the high dP and flowrate
- Oddly, the 30 kW (40 hp) oil pumps were needed on CO₂ pumps that may have only a 200 kW (250 hp) main driver
- Larger 2.2 MW (3000 hp) CO₂ pumps used 95 kW (125hp) oil pumps.



This gives a general perspective on the size of the seal oil system vs pump size. The 200 liter (50 Gal) oil tank is not shown. The larger pumps had 2280 liter (600 Gal) oil tanks.

API Type BB3 - 4 stage 1984 (seal oil system on next slide)



80 deg F,

Ps - 2000 psia, Pd - 2555 psia

220 to 417 GPM, 1548 Ft,

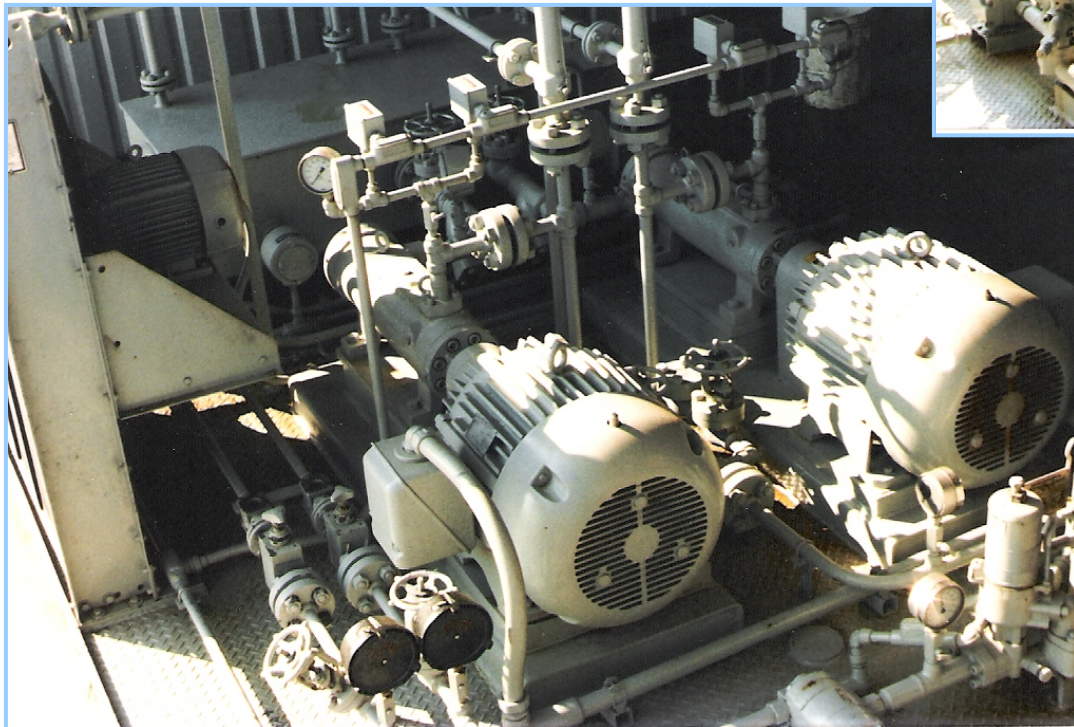
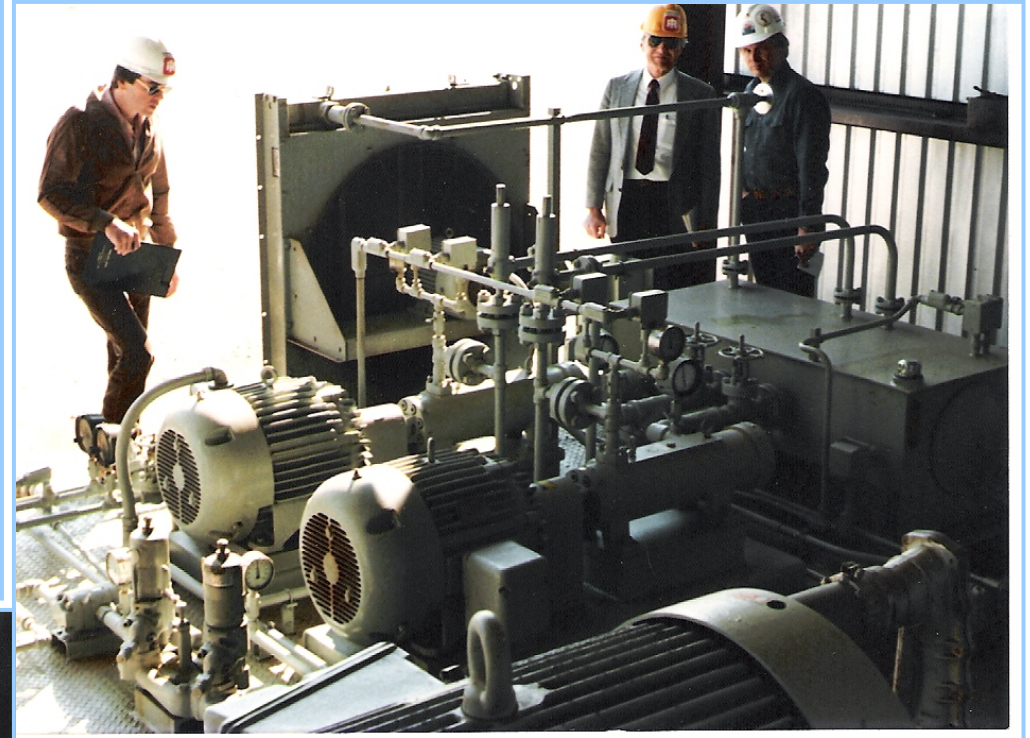
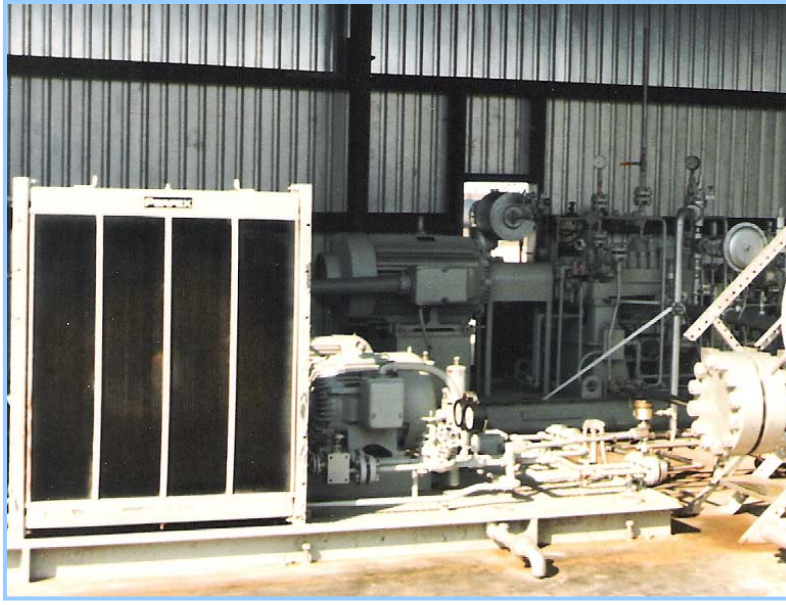
1800-3600 rpm using VFD

250 hp motor, 40 hp seal oil pumps

Seal Oil skid is nearly as large as pump skid

photo courtesy of Flowserve

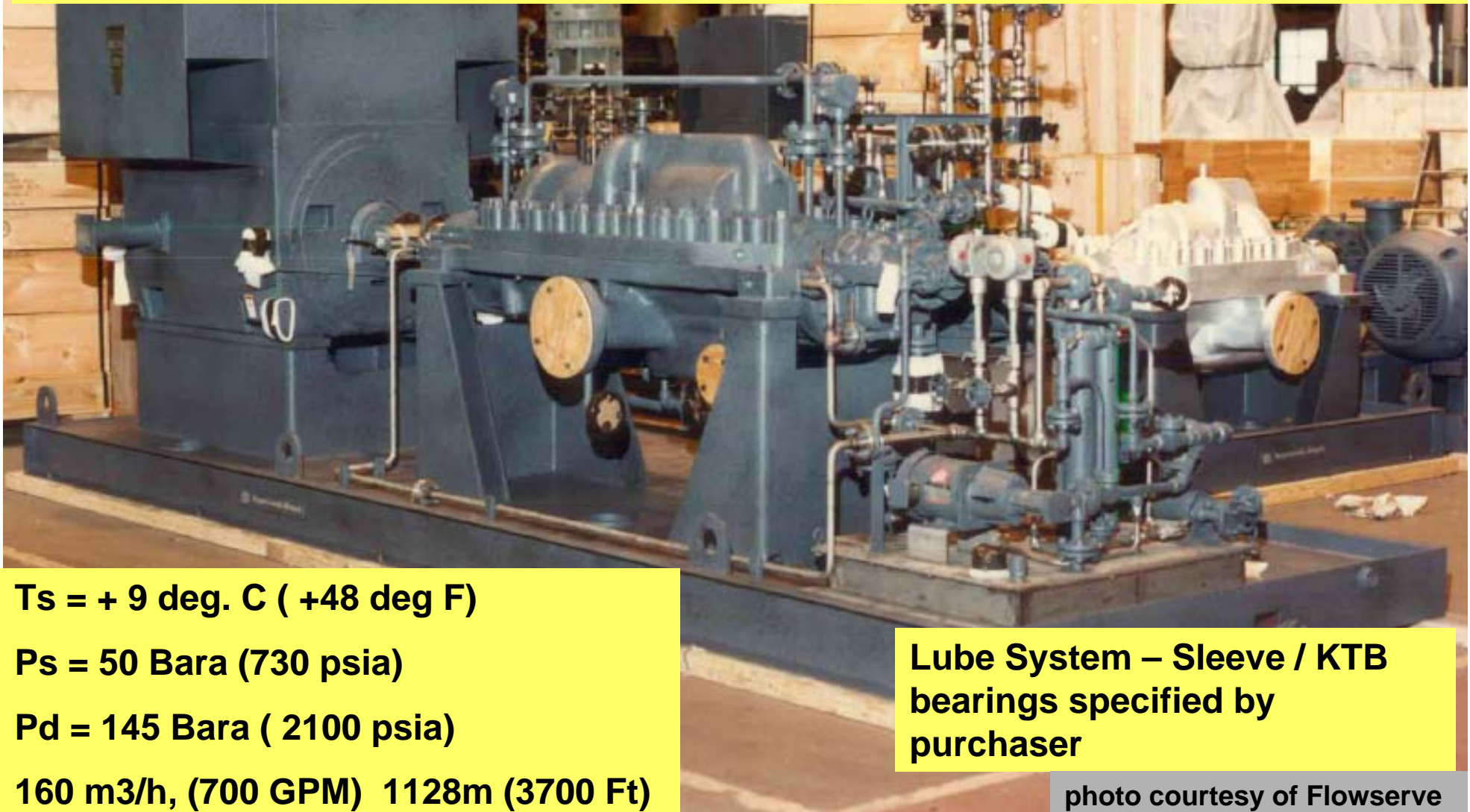
API Type BB3 - 4 stage 1984 (seal oil system)



High Suction Pressure produced high face loads and high seal oil flow rate. High Pressure CO2 mixes with the seal oil on the seal faces like it does with oil underground. It took a while to figure all that out.

API 610 Type BB3 8 stg for Wasson Field CO2 - 1983

This pump has a double suction 1st stage impeller. Would we need it if the CO2 was at 1200 psi suction pressure?



Ts = + 9 deg. C (+48 deg F)

Ps = 50 Bara (730 psia)

Pd = 145 Bara (2100 psia)

160 m³/h, (700 GPM) 1128m (3700 Ft)

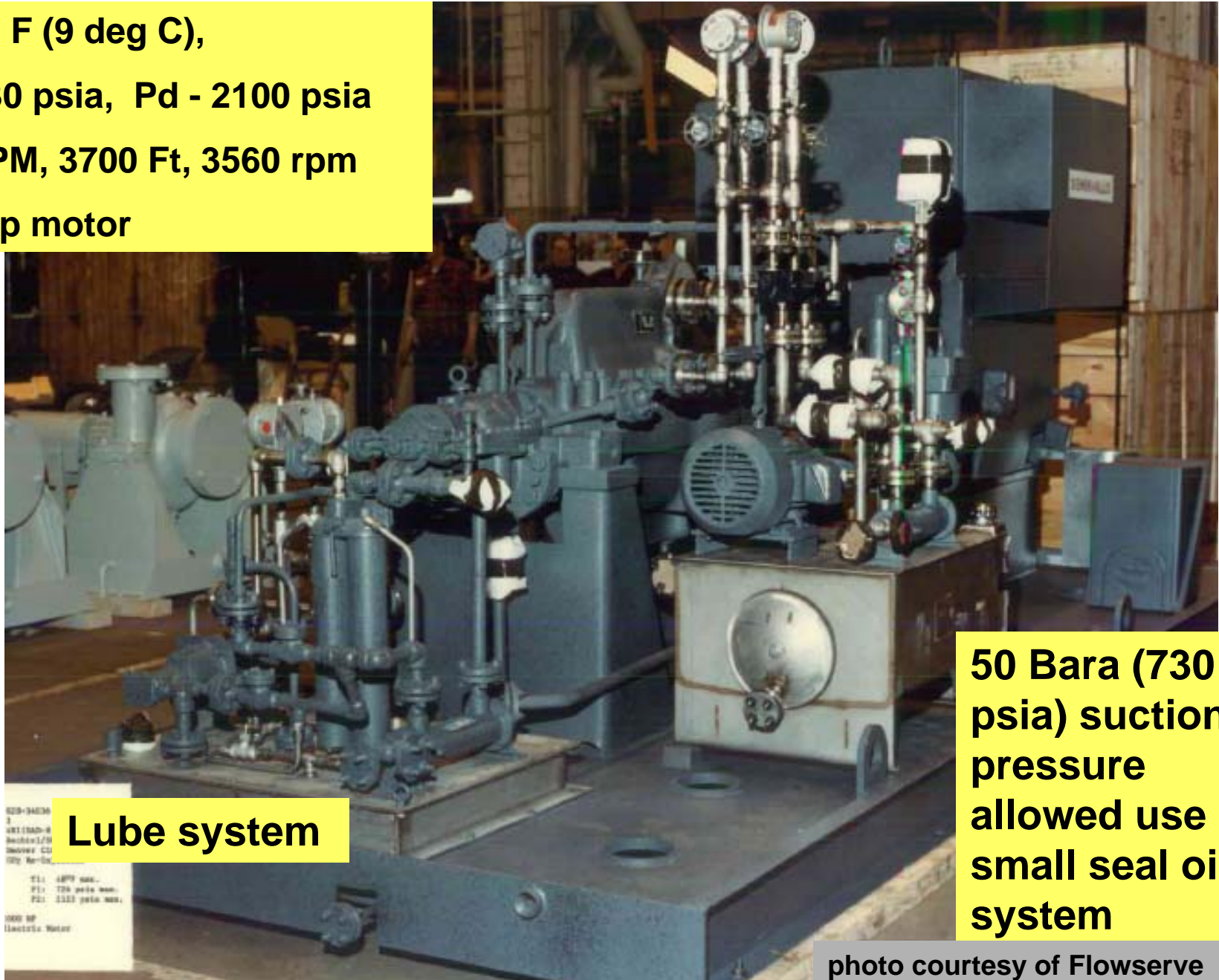
3560 rpm, 750 kW (1000 HP) motor

Lube System – Sleeve / KTB bearings specified by purchaser

photo courtesy of Flowserve

8 stg Wasson Field CO2 - 1983

48 deg F (9 deg C),
Ps - 730 psia, Pd - 2100 psia
700 GPM, 3700 Ft, 3560 rpm
1000 hp motor



820-94030
3
48115AD-8
Revised 1/83
Denver CO
City Re-Use

Lube system

TI: 4879 max.
PI: 726 psia max.
PI: 1123 psia max.

1000 HP
Electric Motor

50 Bara (730 psia) suction pressure allowed use of small seal oil system

photo courtesy of Flowserve

High Pressure CO₂ Applications

– Mechanical Seals

- The 1983 seals with the 2000 psi suction pressure didn't last and there was a steep learning curve on the seal oil system design. CO₂ Pumps at Wasson and Seminole had much better luck with lower suction temperature and suction pressure.
- Several years later another oil company bought much larger 2.2 MW supercritical CO₂ pumps for Rangely, Colorado. Those triple seals were about 460mm (18") long & weighed about 60 kg (130 lbs) each.
- In mid 1990's, API 610 Type BB3 6 stage pumps were supplied for supercritical ethylene. They had aluminum impellers and carbon wear parts. Gas seals were installed and the seal leakage rate was reportedly so low that it wouldn't keep the flare lit. There obviously was no seal oil system.

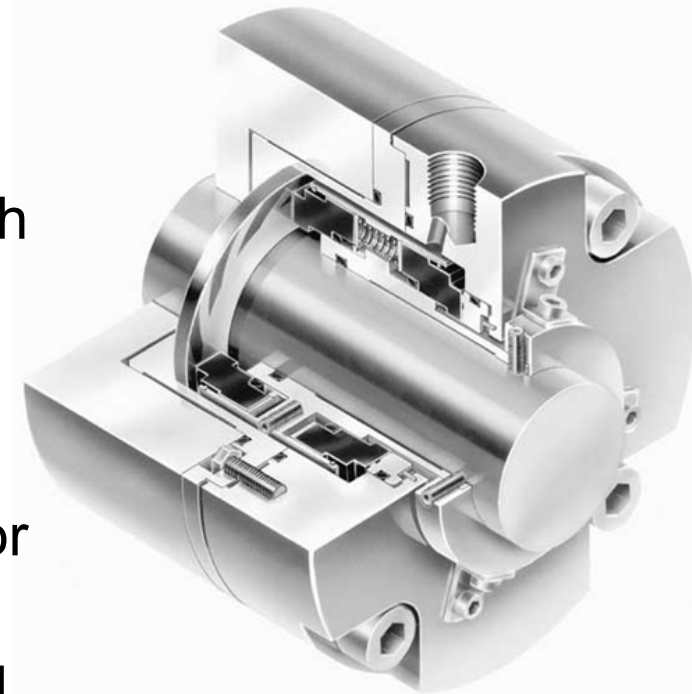


Illustration by John Crane

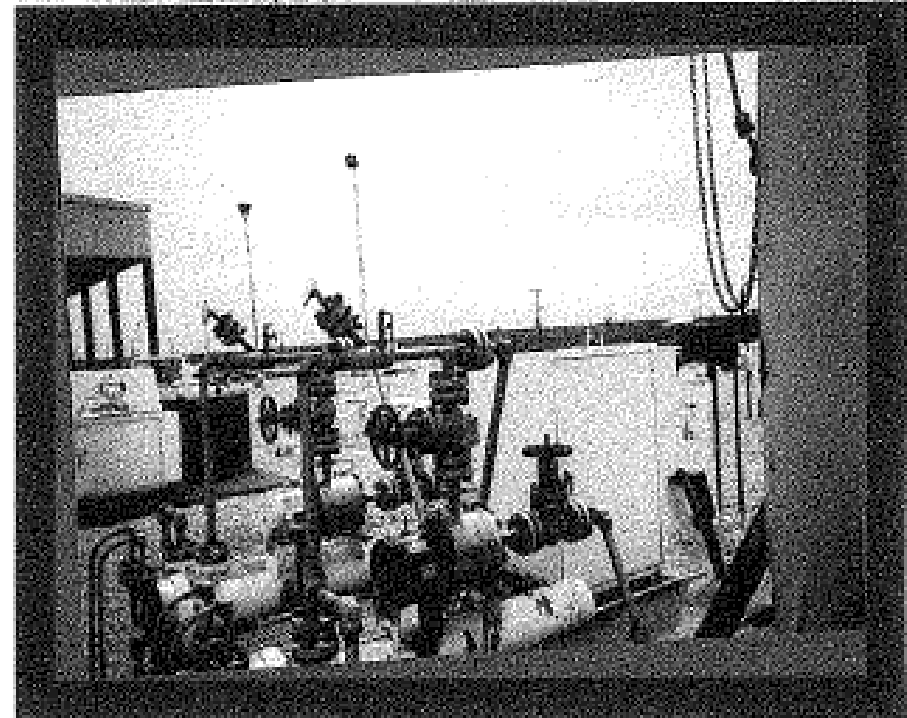
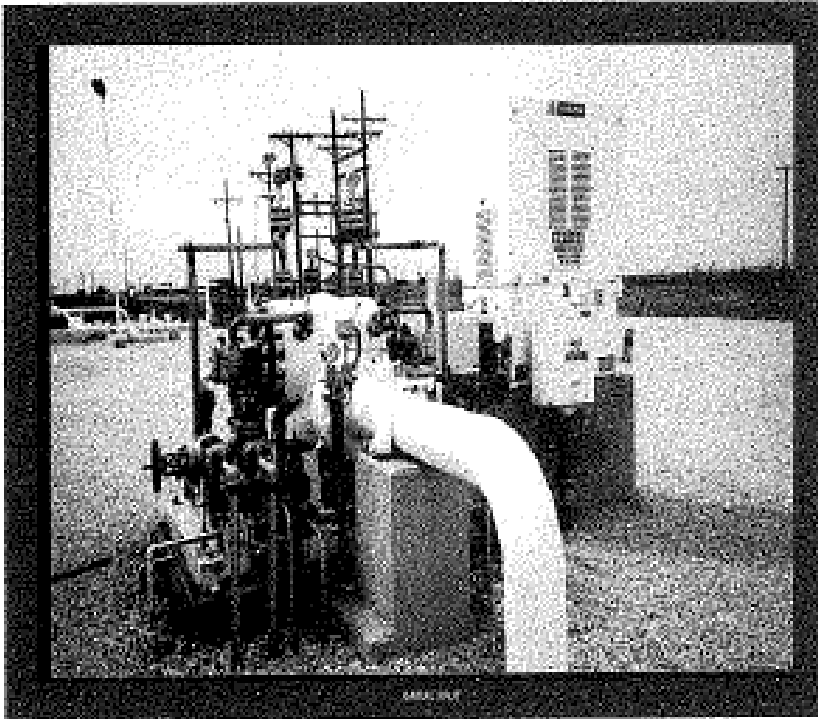
There is no oil system on gas seals so they save many kW (hp)! Be sure to add seal flush flow to 1st stage

CO₂ Applications – Mechanical Seals

- Since that time more API 610 type BB3 pump with 10 to 12 stages have been applied on supercritical ethylene. They also use gas seals and have been running for many years now.
- In 1993, Mobil converted an old API type BB3 pipeline pump to CO₂ service. The service center converted it to carbon wear parts, beefed up the flanges and installed gas seals. It is still in Sundown, Texas on supercritical CO₂
- In late 1990's we converted the dual seals in the Salt Creek 12 stage CO₂ injection pumps, to gas seals and deleted the seal oil systems. They are still in service. The oil system was eliminated and seal maintenance reduced measurably.
- Similar gas seal systems have become the norm

The old seal technology: Cortez CO2 Pipeline pumps

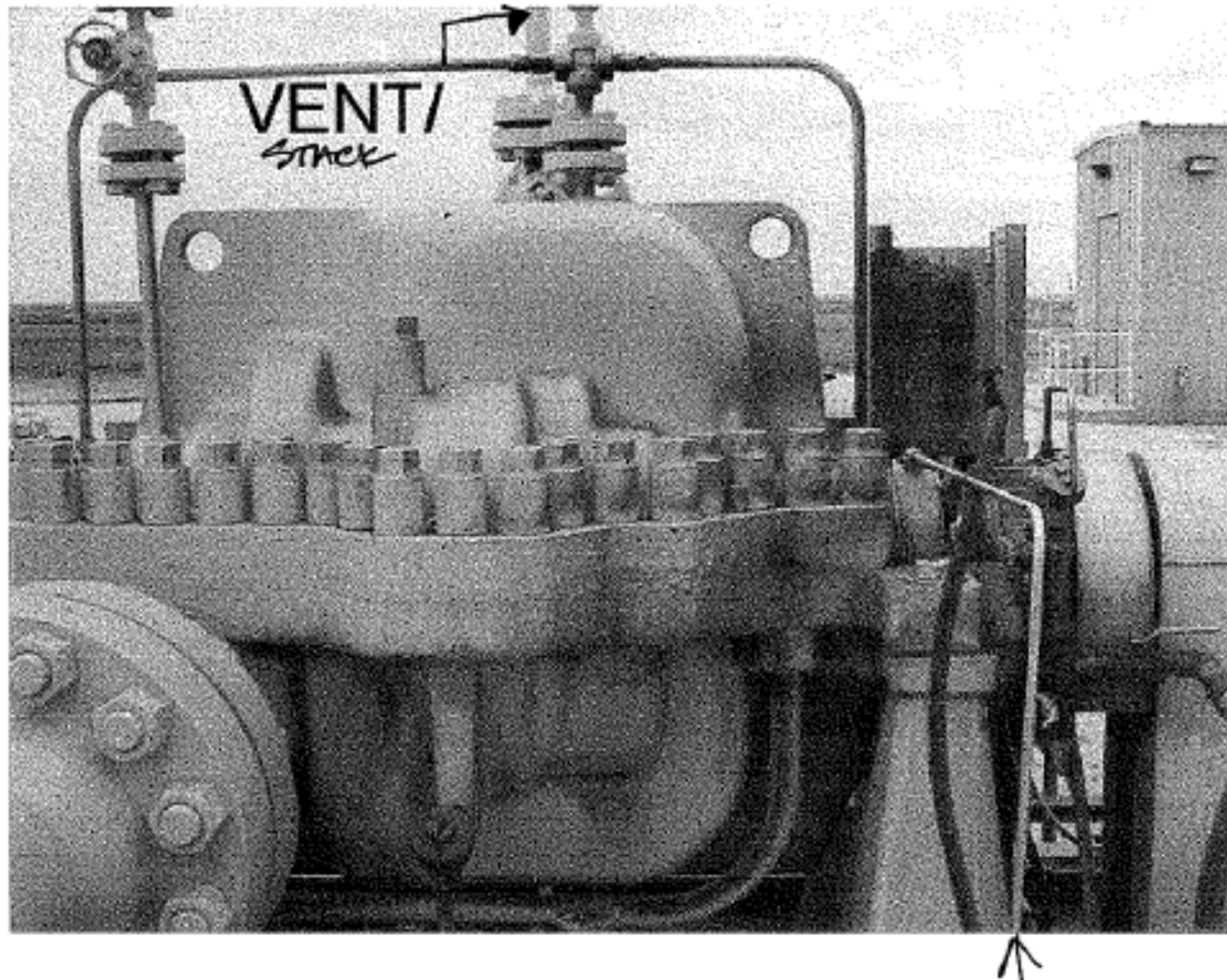
EXISTING CO2 SEAL TECHNOLOGY 1



- **RADIAL SPLIT WITH DOUBLE BACK TO BACK DESIGN**
- **HIGH PRESSURE LUBE SYSTEM**
- **BARRIER FLUID PRESSURIZED 100# ABOVE SUCTION BETWEEN THE TWO MECHANICAL SEALS**
- **BARRIER FLUID,AUXIALIARY PUMP,RESERVOIR,COOLER,FILTER,SUMP**

Picture courtesy of Champion Seals

Gas Seal CO₂ installations



Plan 11 Seal
Flush to primary
seal using
supercritical CO₂
with over 100 Bar
suction pressure.

Seal friction on
primary flashes
CO₂ to vapor and
it is vented
between primary
and secondary
seal.

Be sure to add 20 GPM x 2 = 40 GPM (9 m³/h) seal flow to rated flow on first stage. Be sure total power includes that wasted power. Adjust pump efficiency accordingly.

Not all Gas Seals are the same....

- For super critical CO₂, seals that work at temperatures less than critical temperature, may not be so successful at higher temperatures.
- Be sure to discuss the application with seal manufacturers.
- Be sure to give them the gas constituents. A little nitrogen and methane can make a big difference in pump and seal performance
- Be sure to give them the suction temperature range, the suction pressure range, rpm range, and shaft size. All can have an effect on seal selection.
- Be sure to ask them for the required seal flush flow and pressure to each seal. Since most CO₂ pumps have 2 seals, add that flow to the rated flow for number of stages needed to achieve the seal flush pressure. Correct pump power accordingly.

**New
Construction
pipeline dirt
can destroy
seal faces.**

**Invest in high
pressure dual
seal flush
filters.**

**One can be
cleaned while
the other is
running.**

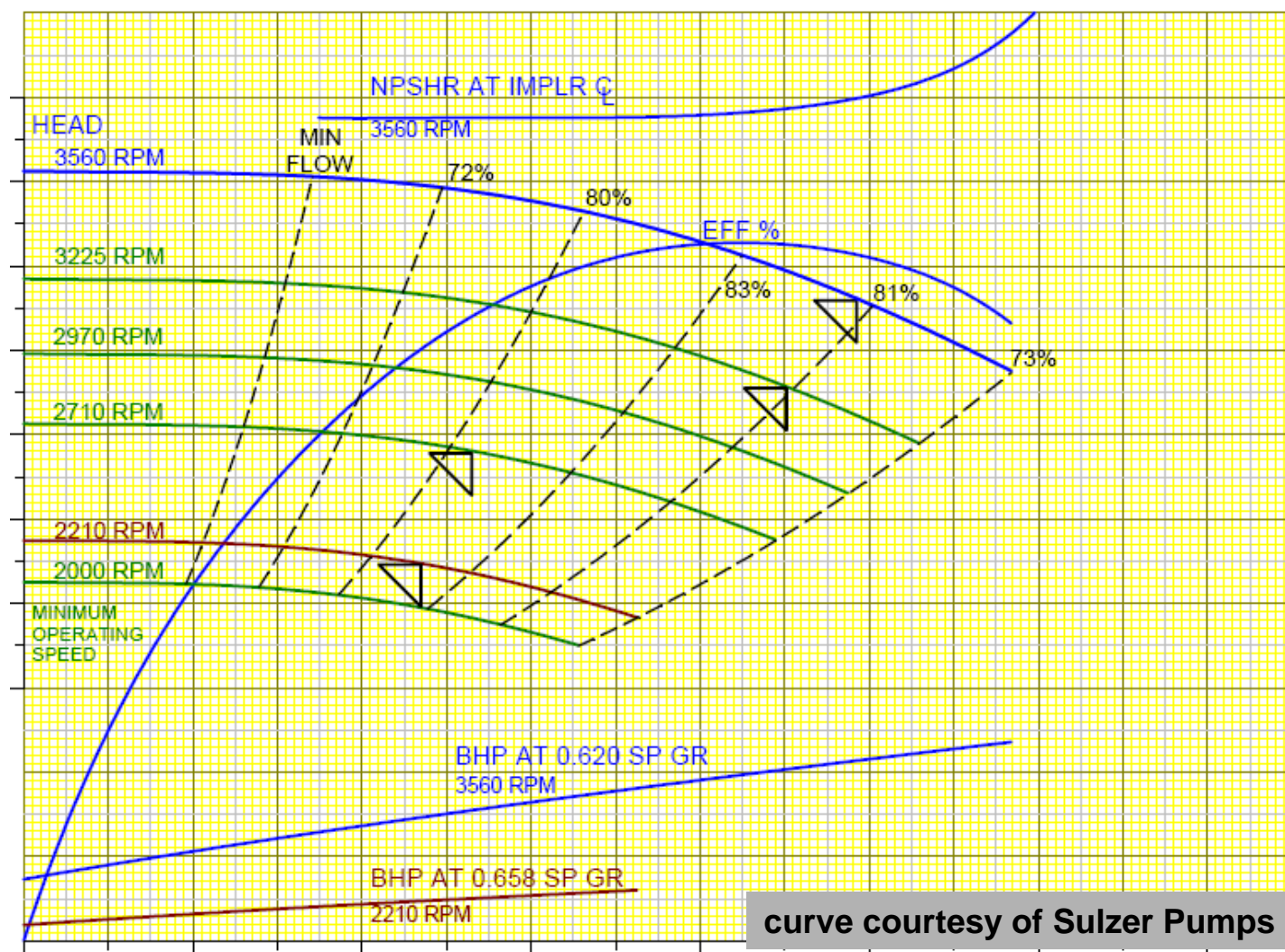
Supercritical CO₂ Applications

Summary

- Understand the Thermodynamics – Suction pressures in 86-150 Bar (1250 to 2100 psia) at 26-35C (80-90F) are common. Bubble size near critical pressure is microscopic, so Ps excursion down to about 76 Bar (1100 psi) can be tolerated. NPSH is not a consideration since cavitation is impossible above critical pressure.
- In N. America, use BB3 (Axial split Multistage) type if it will handle MAWP & MASP. Otherwise, use radially split Type BB5. On high energy pumps, they may be direct drive, or high speed, BB5 with bearing lube system
- Due to low lubricity pay attention to Rotor Construction – Avoid lots of stages on inline rotor stack. Specify non-galling metals, Carbon, or PEEK, vs hardened 12% chrome wear parts. 12% Chrome vs 12% Chrome will not work.
- Check rotor dynamics with 2 x clearances and check for acoustic resonances at all speed, temperature and pressure combinations
- Use liquid or gas seals with a track record. Do not use gas seals with N₂ injection on cold /subcritical pressure services as gas will affect NPSH

Where are we today (2010 – 2011) ?

These large 5 stage API 610 Type BB3 pumps were started in Sept 2010 on supercritical CO₂ with suction pressure varying between 100 Bar (1450 psi) and 150 Bar (2100 psi). Pump MAWP is > 210 Bar (3000 psi). Suction temperature is from about 10 to 38 C (50 to 100 F) with associated change in density



**Driver is
1670 kW
(2250 HP)
and is VFD
Gas Seals**

**Curve drawing
software
included NPSHr
curve which is
not applicable**

Recent CO2 pumps - 2010

Photo courtesy of Sulzer Pumps



W. Texas 2010: 8x10x13 API 610 Type BB3 - 5 stage. 2250 hp, 3600 RPM VFD motor, Quasi Gas seals with plan 11 and secondary vent. SFP filters added after startup – pipeline construction dirt wiped the seals.

Recent CO2 pumps - 2010

Photo courtesy of Sulzer Pumps



Fan cooled Sleeve Radial / Ball Thrust bearings, Bearing RTD's, Motor Winding RTD's.

Ultra-high pressure CO2 Pumps

Photo courtesy of GE Oil & Gas

CO2 with up to 23 molar %
of hydrocarbons

Ps = 300 Bar (4350 psi)

Pd = 540 Bar (7830 psi)

dP = 240 Bar (3480 psi)

Ts = 15 to 40°C

(60 to 104°F)

2.2 MW (2950 HP)

7600 RPM

VFD utilized for varying
density



Offshore CO2 reinjection in Brazil, 2010

For pilot project, 4 pumps had to be run in series for low flow of 10 kg/s (79,200 lb/hr) with dP as shown above. For pilot, total train only consumes about 800 kW (1100 hp) at 3600 RPM. At rated flow each pump will consume 2.2 MW at 7600 rpm. Above from Bergamini / Vescovo / Milone paper which will be presented here at 8:30 AM tomorrow

Final Exam

- Can we use gas seals with N₂ injection on cold CO₂ below critical pressure?
- Do we use a pump, or a compressor, on 60F CO₂ at 30 psig?
- What do we use to move CO₂ at -70 F at 14.7 psia?
- What is the surface tension of CO₂ compared to propane?
- How does one always avoid seal problems on startup?
- No, use a seal isolation system. Gas will kill the NPSHa
- A compressor as we are on the right side of the dome
- A truck – its dry ice
- 10% of the surface tension of propane. Hydrotest with surfactant and air test at low pressure
- One gets transferred before startup

Thank you for your attention.

Questions??